

جامعة بابل
كلية الهندسة
قسم الهندسة المدنية



جمهورية العراق
وزارة التعليم العالي
والبحث العلمي

تأثير استخدام مادة البورسلنايت على أداء معالجة المياه ومياه المجاري

أطروحة
مقدمة إلى كلية الهندسة في جامعة بابل كجزء
من متطلبات نيل درجة ماجستير علوم في
الهندسة المدنية

أعدت من قبل المهندسة:
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أيلول 2008

رمضان 1429

**Republic of Iraq
Ministry of Higher
Education and Scientific
Research**



**University of Babylon
College of Engineering
Dept. Of Civil
Engineering**

Effect of Using of Porcelanite on the Performance of Water and Wastewater Treatment

**A Thesis
Submitted to the College of Engineering
of the University of Babylon in Partial
Fulfillment of the Requirements
for the Degree of Master
of Science in Civil
Engineering**

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Ramadhan 1429

September 2008

سُورَةُ التَّوْبَةِ

[وَقُلْ يَا حَسْبُنَا اللَّهُ وَنِعْمَ الْوَكِيلُ]

[وَأَسْأَلُكَ اللَّهُمَّ بِكَرَمِكَ]

وَأَسْأَلُكَ اللَّهُمَّ بِكَرَمِكَ

Abstract

In this study the local materials (porcelanite) was tested as coagulant aid with alum, and used as a dual filter media with sand to evaluate efficiency of this material. This was done through experimental works.

This work required installing of a pilot plant system, the experimental work included tests for both water and wastewater.

The pilot plant consists of two stages: the first stage deals with coagulation, flocculation and sedimentation processes by using different dosages of alum and porcelanite material over turbidity values range between (10-200 NTU) .

The second stage was concerned with filtration process by using two types of filters. The first filter with a sand bed of (single media) of height of 40 cm. While the second was a dual media (sand bed of 30 cm in height and 10 cm of porcelanite height).

The results indicate that the porcelanite material more efficient in the removal of turbidity for all levels of turbidity.

The efficiency of turbidity removal with the initial turbidity of (10 and 50 NTU) were (72.8 and 84 %) when adding alum only in the coagulation process. This percentage was increased to a value of (79 and 93 %) after adding alum with coagulant aid of porcelanite material in the same process.

The efficiency removal of turbidity of the initial turbidities (100 , 150 and 200 NTU) was approximately (90.5 %) when adding alum only in the coagulation process. While when adding the porcelanite material as coagulant aid with alum the efficiency removal was increased to a value of (95 %) in the same process.

Also, the results of the present study referred that the dual media by using porcelanite rocks with sand was more efficient in removal turbidity when

using sand only in the filtration process . Therefore, the percent of turbidity removal by using the dual media was about (86%), while the removal efficiency by using single media was about (74%)when using alum only in the coagulation process. The efficiency was increased to about (93%) and (80%) in dual media and single media respectively when using porcelanite material with alum in the coagulation process .

It is found that the using of porcelanite with alum was better than the using of alum only in the removal of organic content (biochemical oxygen demand , (BOD₅)). Therefore , the local alum give the removal efficiency of BOD₅ of about (46%) ,while when using porcelanite with alum, the removal efficiency increased to a value of about (60%).

It was concluded that the dual media was more efficient in the reduction of organic content (BOD₅) than when using of single media filter. Therefore, the removal efficiency of BOD₅ by using dual media was more than that by using single media by about of (19%) when using alum only in the coagulation process. When using the porcelanite material with alum in the coagulation process, the removal efficiency after filtration process by using dual media was more than that by using single media about (25%).

After the results from each run were tabulated and graphed, they were analyzed statistically by using a statistical program (DATA FIT) to simulate the experimental work .

Acknowledgment

Praise be to “**God**” and to his prophet “**Mohammed**”. This research has been completed under their benediction.

I acknowledge with thanks and gratitude the valuable advice, assistance, cooperation, and encouragement of **Assis. Prof Dr. Jabbar H. Al-Baidhani** and **Assis. Prof Dr. Mohammed A. Moslem Al-Tufaily** and throughout the course of preparing my thesis. They devoted much of their spare time in going through every detail, which enabled me to reach this achievement.

I wish to express my sincere thanks and deep gratitude to the head of Civil Engineering Department and to all the staff of the department, College of Engineering for all the facilities they rendered me.

I would like to express my sincere gratitude and respect to **Assis. Prof Dr. Riyadh H. Al-Anbari** in the Environmental Department in University of Technology , **Assis. Prof Dr. Dakhel Nasir Taha** in the Chemistry Department in the Babylon University and **Assis. Prof Dr. Majid Mohhy** in the Material Department in the Babylon University for their assistance throughout this work.

I am grateful to Babylon Sewage Office, especially the head of environmental laboratory in the Al-Muamera project **Mr. Mohammed Al-Meiyalli** and to all laboratory and project staff members for their assistance throughout this work.

I would like to express my sincere thank to **Mr. Mohammed kadhun** and all the staff of water treatment plant in the Babylon University

I would also like to thank my closest friends **Zainab Ali** and **Huda Mohammad** .

I wish to express my sincere thanks to Miss **Afrah Abood**, **Amal Al-Mamori** ,**Intidhar Jaber** and **Israa Saady** for their encouragement during the entire period of this research.

I record my sincere gratitude to my family, my dear father, my affectionate mother, and my dear sisters and brother who always offer their patience and prayers and for their encouragement and support during the period of preparing this work.

Many others are not mentioned explicitly here, their efforts are equally appreciated, and I wish to thank all those who have helped by one way or another during this research.





Appendices

Appendix A

Table (A-1): Summery of Experimental Data Before and After Coagulation Process of Water

Coagulant name	Turb. NTU	Dose mg/L	Experimental tests							
			Before coagulation				After coagulation			
			TDS mg/L	Cond. μ S/cm	pH	Temp. $^{\circ}$ C	TDS mg/L	Cond. μ S/cm	pH	Temp. $^{\circ}$ C
Alum	10	10	460	886	7.6	11.5	461	853	7.53	12
	10	20	456	788	7.52	12	453	798	7.4	12.5
	10	30	456	885	7.65	12.5	457	865	7.33	13
	10	40	461	863	7.55	12.5	462	887	7.12	13
	10	50	460	867	7.6	13	455	855	7.2	13.2
Alum+Porceanite	10	10	460	812	7.7	14	459	805	7.5	10
	10	20	460	819	7.63	13.6	460	820	7.3	10.5
	10	30	462	850	7.51	14.5	461	846	7.33	11
	10	40	460	845	7.45	13	457	836	7.2	10.5
	10	50	458	802	7.61	12.4	457	793	7.26	10
Alum	50	10	460	964	7.7	14.5	459	887	7.35	15.4
	50	20	455	898	7.74	12	454	868	7.32	12.6
	50	30	456	881	7.52	12.2	452	863	7.12	13.2
	50	40	460	930	7.8	11.6	460	875	7.4	12.5
	50	50	457	858	7.3	13	456	888	7.05	14
Alum+Porceanite	50	10	460	890	7.87	13	462	970	7.68	13.5
	50	20	461	876	7.79	12.6	459	910	7.58	13.2
	50	30	464	872	7.88	13	455	870	7.61	13.7
	50	40	451	878	7.9	14	461	923	7.75	14.5
	50	50	450	889	7.72	12.3	456	855	7.5	13
Alum	100	10	460	762	7.81	11.5	461	775	7.51	13.5
	100	20	459	868	7.65	12.6	457	868	7.42	12.5
	100	30	450	775	7.57	12.5	454	798	7.26	13
	100	40	461	849	7.68	11.5	463	888	7.14	14
	100	50	457	786	7.98	11.6	455	778	7.05	13.2
Alum+Porceanite	100	10	451	849	7.84	13	454	850	7.73	13
	100	20	463	875	7.7	12.3	465	867	7.64	13.5
	100	30	453	789	7.64	12.4	453	787	7.52	12.5
	100	40	458	811	7.65	12.5	457	798	7.41	12.6
	100	50	460	825	7.68	12.6	460	818	7.3	13
Alum	150	10	460	763	7.2	11.5	460	761	7.17	11.6
	150	20	456	779	7.55	12	457	772	7.16	10.5
	150	30	450	754	7.56	13	453	768	7.22	12
	150	40	460	795	7.57	13.2	462	805	7.12	12.5
	150	50	460	787	7.43	12	461	798	7.07	13
Alum+Porceanite	150	10	455	786	7.22	13	455	783	7.11	12.5
	150	20	455	775	7.12	11.2	453	760	7.04	13
	150	30	460	775	7.3	12.5	460	777	7.12	14
	150	40	464	825	7.4	13.2	462	812	7.15	13.5
	150	50	460	787	7.45	13	457	768	7.09	12.5
Alum	200	10	460	971	7.65	12	457	962	7.55	13.5
	200	20	461	975	7.6	12.2	460	966	7.5	13
	200	30	452	887	7.58	12	455	899	7.41	14
	200	40	459	897	7.5	13.6	459	898	7.28	14.5
	200	50	458	902	7.51	14	461	912	7.2	15
Alum+Porceanite	200	10	458	950	7.52	13	454	945	7.29	16
	200	20	461	968	7.5	13.2	460	955	7.14	15.5
	200	30	453	897	7.45	14	453	902	7.22	14
	200	40	463	905	7.3	13	462	898	7.12	14.5
	200	50	451	869	7.32	14	451	879	7.25	14

Appendix A

**Table (A-2) :Average Values of Experimental Tests Before and After
Filtration Process for Water**

Coagulant name	Filter bed type	Dose mg/L	Experimental tests							
			Before filtration				After filtration			
			TDS mg/L	Cond . μ S/cm	pH	Temp $^{\circ}$ C	TDS mg/L	Cond. μ S/cm	pH	Temp $^{\circ}$ C
Alum	Single media	10	461	853	7.53	12.1	575	1058	7.2	11.8
		20	453	798	7.4	12.5	565	965	7.5	12.2
		30	457	865	7.33	13	577	1012	7.4	12.5
		40	462	887	7.12	12.7	586	1130	7.3	12.2
		50	455	855	7.2	13.2	563	1030	7.35	13
Alum	Dual media	10	450	833	7.46	12.6	585	1046	7.55	12.5
		20	452	845	7.2	13	598	1052	7.41	12.5
		30	460	868	7.16	12.7	599	1116	7.32	12.2
		40	445	797	7.3	13.3	556	985	7.5	13
		50	453	835	7.18	13.1	592	996	7.4	12.8
Alum+Porceanite	Single media	10	459	805	7.5	10	577	976	7.68	9
		20	460	820	7.3	10.5	586	998	7.4	10
		30	461	846	7.33	11	590	1031	7.5	10.5
		40	457	836	7.2	10.3	566	997	7.4	10
		50	457	793	7.16	9.8	562	963	7.55	9.2
Alum+Porceanite	Dual media	10	461	763	7.57	15.2	506	983	7.63	15
		20	452	866	7.55	14.3	516	1066	7.64	14
		30	456	896	7.3	15	586	1162	7.5	15.2
		40	464	887	7.12	13.5	588	1102	7.4	13.2
		50	466	829	7.3	13	595	1050	7.53	12.7

Appendix A

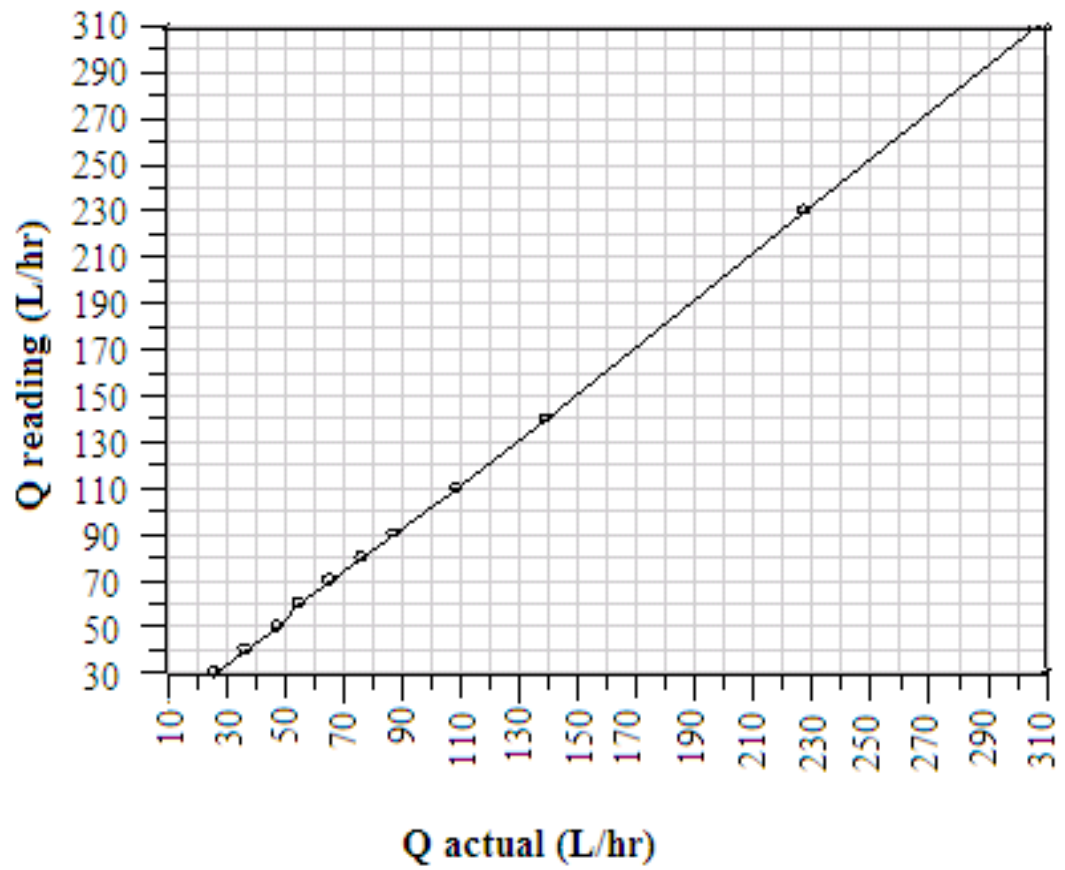
Table (A-3): Experimental Tests Before and After Coagulation

Process for Wastewater

Coagulant name	Dose mg/L	Experimental tests							
		Before coagulation				After coagulation			
		TDS mg/L	Cond. μ S/cm	pH	Temp $^{\circ}$ C	TDS mg/L	Cond. μ S/cm	pH	Temp. $^{\circ}$ C
Alum	10	1660	3.49	7.87	17.5	1665	3.56	7.86	18
	20	1549	3.47	7.71	19.5	1539	3.4	7.69	19.3
	30	1522	3.17	7.82	18.5	1525	3.2	7.78	19
	40	1488	3.1	7.77	17.5	1492	3.12	7.69	18
	50	1551	3.4	7.69	17.8	1555	3.39	7.54	18
Alum+Porceanite	10	1482	3.14	7.86	17.5	1486	3.20	7.8	18.2
	20	1539	3.29	7.96	18	1554	3.37	7.87	18.5
	30	1800	3.7	7.89	16	1793	3.5	7.73	16.5
	40	1568	3.47	7.85	19	1573	3.47	7.69	19.5
	50	1408	3.07	7.75	19	1410	3.07	7.6	19

Table (A-4):Experimental Tests for Wastewater in Filtration Process

Coagulant name	Filter bed type	Dose mg/L	Experimental tests							
			Before filtration				After filtration			
			TDS mg/L	Cond. μ S/cm	pH	Temp $^{\circ}$ C	TDS mg/L	Cond. μ S/cm	pH	Temp. $^{\circ}$ C
Alum	Single media	10	1571	3.47	7.83	19	1566	3.36	7.82	18
		20	1665	3.56	7.83	17.6	1561	3.14	7.92	16.4
		30	1526	3.27	7.67	19	1576	3.3	7.84	18
		40	1533	3.35	7.79	18.2	1556	3.4	7.98	17
		50	1565	3.35	7.7	18	1710	3.58	8.05	17.5
Alum	Dual media	10	1521	3.04	7.45	18.5	1331	2.78	7.85	18
		20	1539	3.4	7.69	19.3	1366	2.98	7.81	19
		30	1488	3.2	7.7	18.5	1335	2.94	7.88	18
		40	1512	3.32	7.56	19	1385	2.89	7.7	18.5
		50	1555	3.09	7.54	18.5	1455	3.39	7.97	18
Alum+Porceanite	Single media	10	1486	3.2	7.8	18	1648	3.46	7.87	17
		20	1554	3.37	7.87	18.5	1412	2.96	7.75	17
		30	1793	2.3	7.73	18.5	1810	2.58	7.5	17.5
		40	1573	3.47	7.76	19.2	1627	3.59	7.61	19.2
		50	1410	3.07	7.6	18.5	1527	3.28	7.85	18
Alum+Porceanite	Dual media	10	1113	2.39	7.38	18	1066	2.11	7.56	18
		20	1281	2.81	7.41	19	1230	2.96	7.63	19
		30	1355	3.02	7.35	18	1301	3.15	7.6	18
		40	1476	3.22	7.22	19	1465	3.19	7.5	19
		50	1468	3.2	7.48	18.7	1459	3.18	7.66	18.8



Calibration curve for flow- meter used

CERTIFICATION

We certify that we have read this thesis, titled “Effect of using of porcelanite on the performance of water and wastewater treatment”, and as examining committee examined the student “ **Rasha Ali Taha**” in its contents and in what is connected with it, and that in our opinion it meets the standard of a thesis for the degree of Master of Science in Civil Engineering.

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CHAPTER ONE

Introduction

1.1 General

Treatment of raw water loaded with suspended matters, such as most surface waters in Iraq, requires principally the separation of the solid and colloids particles that cause turbidity from the raw water. Production of portable water, that is free from turbidity and diseases causing organisms, and production of wastewater with less organic matter is the major objective of conventional water and wastewater treatment.

Turbidity itself is not harmful and does not cause illness. It is used to indicate whether other more dangerous contaminants such as bacteria or parasites might be present in the water. (W.D.P.W, 1999).

The removal of suspended particles from water in a conventional treatment process can be performed by two different and related processes:

- 1- by clarification or settling, this is made by using the size and specific weight of the suspended particles and by accelerating such settling process.
- 2- by filtration process through which the remaining unsettled particles by the clarification process are removed by the filters.

The two stages mentioned above are complementary to each other, and consequently the design

One of the essential processes of a water treatment involves the addition of a chemical coagulant. Such a process is a key step in the overall system. It removes turbidity-producing substances (colloidal solids, clay particles, organics, bacteria, and algae) and color in surface water, which result from decaying vegetation or industrial wastes. (Viessman and Hammer, 1985).

1.2 Scope of the problem

The source of water supply for the most of public water supply projects is surface water. This water is turbid and contains many suspended impurities. It also possesses color which may be due to colloidal matter and dissolved organic material in water. The turbidity is mainly due to the presence of very fine particles of clay, silt and organic matter. Qasim.S.(1999).

Wastewater is any water that has been adversely affected in quality. It comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentrations. Stensel, H .D. (2003).

The purpose of coagulation is thus to make particles of bigger size by adding certain chemicals known as the "coagulants" to the water. The coagulants react with the impurities in water and convert them in settleable size. Filtration is another ancient and widely used technology that removes particles and at least some microbes from water. The effect of these filtration methods in reducing microbes also varies widely, depending on the type of microbe and the type and quality of the filtration medium or system. Qasim.S.(1999).

1.3 Objectives of the study:

The main objectives of this study are:

1. Evaluating the performance of local material (porcelanite) as coagulant aid with alum to treat water and wastewater by using a pilot plant system consist of coagulation, flocculation, sedimentation and filtration.
2. Comparison between the efficiency of porcelanite material as coagulant aid with alum and alum only in removing the turbidity from water and removing organic matter from wastewater.
3. Evaluating the performance of porcelanite material as a dual filter media with sand.

4. Developing a statistical model which describes the treatment process.

1.4 Thesis layout

This thesis comprises six chapters:

1. Chapter one consist of the introduction of this study, the scope of the problem ,the objectives of the study and thesis layout.
2. Chapter two gives a presentation of the recent and relevant studies on the types of coagulants, aluminum sulfate (alum), uses, and performance, as well as natural coagulant- aid (porcelanite).
3. Chapter three gives a presentation on the basic colloidal chemistry, theories of stability, and instability. In addition, mechanisms of destabilization and mechanisms of coagulation with alum are presented too, flocculation, chemical and mineralogical analysis of Iraqi porcelanite and mechanisms of filtration test.
4. Chapter four described materials used in this study and their chemical analysis, laboratory experiments, and the setup of tests, the apparatus employed are illustrated as well.
5. Chapter five includes the results of the different experiments and the relevant discussions
6. Finally, conclusions and recommendations for future studies are present in chapter six.

CHAPTER TWO

Literature Review

2.1. Introduction

Many impurities in water are present as colloidal dispersions, i.e., they occur in particulate form with an approximate size range of (1 nm) to (100 nm). Examples of this type of suspension are clays, bacteria, and substances of biological origin such as natural colour, proteins, carbohydrates, and their natural or industrial derivatives. Turbidity particles are mostly clays and microscopic organisms occurring in widely varying sizes. Coarser particles can be removed by simple sedimentation. finer particles, however, are too small for effective removal by gravitational settling alone. Efficient removal of these fine particles can be obtained by their aggregation into large settleable particles through the coagulation and flocculation processes.

Casey, (1997) showed that the destruction of colloidal stability or coagulation may be effected in four major ways, namely, boiling, freezing, mutual flocculation by addition of a colloid of opposite charge, and the addition of electrolytes. Of these, only the latter is of major significance in water engineering practice.

Tebbutt, (1998) showed that invariable suspensions of this kind possess an inherent stability or resistance to particle aggregation. They are not amenable to clarification by the sedimentation process due to their negligible settling velocity nor can ordinary filtration processes clarify them.

2.2.Coagulation process

Braul and Leade , (2004) claimed that the coagulation process is the addition of certain chemicals into the raw water causes particles to destabilize and allows agglomeration and floc formation to occur .

Coagulation is a safe and effective method of treating water which improves its quality by reducing levels of organic compounds , dissolved phosphorus ,color , and suspended particles

2.2.1 Variables of Coagulation process

Dentel and Kingery, (1989) showed that the analysis and design of water treatment processes rarely take into account the variabilities in quality of the raw water to be treated. Yet, the diurnal, seasonal, and storm-related changes in treatment conditions represent a significant challenge for the maintenance of optimal water quality at minimal cost .

Casey, (1997) showed that because of the many factors that influence coagulation and the complex reactions involved, it is not feasible to calculate directly the coagulant dosage required for coagulation of particular water. An experimental jar test procedure is normally used for this purpose.

As pointed out by Zahiruddin and Leon, (2006) the coagulation of turbid water may be affected by many variables, including: (1) The type, amount, and size distribution of turbidity; (2) The specific ions present; (3) pH value ; (4) Coagulant type and dosage; and (5) Alkalinity.

2.2.2 Aluminum sulphate (Alum)

According to the AWWA,(1999), Aluminum sulfate, also known as (alum), is one of the most common local coagulants used. It has been used in water treatment for many years. The United States has been using alum in water treatment systems since the late 1800s.

The chemical formula for alum is $[Al_2(SO_4)_3 \cdot 16H_2O]$. It is a hydrolyzing metal salt (HMS) coagulant. This means that the way in which alum

destabilizes the particles in water is through hydrolysis. The aluminum ions form strong bonds with the surrounding oxygen of the water molecules. This weakens the atomic structure of the water molecules and positive hydrogen ions are released into the solution

According to the HDR Engineering Inc., (2001)the absorption of these hydrogen ions by the negatively charged particles results in destabilization of the particles as the charge is neutralized. An overdose of alum will produce what is called sweep floc. The alum that precipitates out of solution will settle to the bottom of a sedimentation basin, entrapping particles on its way down removing them from the effluent.

Davis and Cornwell, (1998) showed that the alum is usually purchased in a liquid form that contains about 48.8% alum. The rest of the solution that makes up the liquid alum in water. Alum is usually bought in this liquid form because dry alum cost 1.5 times as much for the same amount. Very few customers purchase dry alum except in small doses because of the difference in price, they showed that every coagulant has an optimal pH range in which it works the best. Alum is most effective when working in a pH range between 5.5 and 6.5. The reaction between alum and water however, uses up alkalinity. If a sufficient amount of alkalinity is not present when the reaction takes place, sulfuric acid will be produced. This reduces the pH of the solution and a pH adjuster will have to be added to bring the solution back to its optimum pH condition.

The primacy of alum as coagulants is due to Berberich, (1998):

- 1- Its effectiveness in destabilizing the predominantly negatively charged colloids found in natural waters.
- 2- Its relatively low cost.
- 3- Its low solubility levels in the pH range of normal use. The achievement of a low residual metal ion concentration is particularly important in the production of drinking water.

4- Its availability.

2.3 Coagulant aids

Intidhar , (2002) stated that the function of the coagulant aids is either to control the coagulation process or to increase the efficiency of the coagulation of relatively clear water (low turbid water). Such coagulant aid involve adsorbent-weighting agents.

2.3.1 Adsorbent-weighting agents

(Reihl et. al ,1976) stated that in coagulating clear water it is sometimes helpful to add artificial turbidity. Bentonite and other clays have been effectively used. When these clays are suspended in water, nuclei are provided for floc formation.

Bentonite is a type of clay used as a weighting agent in water high in color and low in turbidity and mineral content. This type of water usually would not form floc large enough to settle out of the water. The bentonite joins with the small floc, making the floc heavier and thus making it settle more quickly.

Semmens and Field , (1980) studied the influence of added bentonite to river water having a low turbidity and dissolved organic carbon concentrations ranging (10-16 mg/l), they concluded that the addition of bentonite as a coagulant aid with alum reduces the organics removal, especially at low coagulant doses and (pH>5.5) in comparison with the removal observed in the low turbidity control.

Negulescu , (1985) stated that a dose of (5-20 mg/l) of bentonite clay, which is a natural mineral form of coagulant aid, when added to raw water or wastewater, especially that containing diluted colloidal suspensions, it increases the critical mass of the colloidal suspensions. This increases the effectiveness of the metal coagulants as particle kinetics and particle

coagulant probability of contact increase. It can also increase the density of the coagulated particles, and promote a more rapid settling.

Schulz and Okun , (1992) stated that bentonite clay, fuller's earth, and other adsorption clays are used to assist in the coagulation of waters containing high color or low turbidity. Some clays swell when added to water and can produce a floc when used alone or with limited dosage of alum. Practical experience has shown that doses of clay ranging from about (10-50 mg/l) result in good floc formation and a broadening of the pH range for effective coagulation. For low turbidity raw waters, the addition of adsorptive clays may often reduce the dosage of alum required.

2.3.1.1 Local Material (Porcelanite)

Abed-Ohn, (2003)^{Arabic} showed that the high efficiency of porcelanite to extract ions of heavy metals (Fe, Zn, Cr, Cu, Ni, Co, Cd, Pb, Mn) from water as coagulant, and lowering their concentrations to less than the environmental limits. This was achieved when using porcelanite of granular size (0.15 to 0.25 mm). The adsorption capacity of porcelanite is due to the large surface area within the composition of cristobalite and tridymite.

Al-Anbari,(1997) selected suitable and durable locally filter media. He tested lightweight materials like [porcelanite rocks (PR) and burnt kaolinite (BK)], and a heavy weight media like [geothite rocks (GR)]. For single media filter, porcelanite (PR) and kaolinite (BK) gave better results in turbidity removal efficiency (TRE %) and net water product (NWP) value (m³/run) than sand medium. This was because of their higher porosity and angular grain surface textures. The performance of the mixed media filter gave better results than the conventional single media, and sometimes superior to that of dual media.

Al-Ansary , (1998), evaluated the performance of locally porcelanite rocks as a filter media in the treatment of water supplies. He studied the performance of dual media filter composed of porcelanite and sand. The

results showed that the PR filter is more effective in turbidity removal, more length in filter run, and less head loss during filtration nearly by (40%).

Al-Marshidi , (2000) stated that the porcelanite as well as bentonite are effective in removing turbidity of raw water with turbidity level of (50 NTU) and less. Furthermore, he found that porcelanite or bentonite must be added to water and should be dispersed throughout the water body for at least (45 seconds) before the addition of the primary coagulant (alum).

Al-Auraji,(2003) made a research to improve the performance of the filters of Al-Daura water treatment plant by using locally materials such as porcelanite rocks (PR) and burnt kaolinite (BK) as well as anthracite. The results showed that dual media filter gave better water quality, lower head losses, and longer filter run time than single sand filters.

Al-Bayaty ,(2006) tested the dual filter to improve the performance of the filtration process in water treatment plants. She used porcelanite rocks to get dual media with sand in her experimental work.

The pilot filtration consists of three plastic column filters, working parallel and simultaneously. The first column contains 70 cm sand, the second and third were dual filters (porcelanite with sand) of different depths and sizes. She showed that the dual media had no significant effects on the pH, conductivity and TDS of the treated water like sand, but was efficient in turbidity and bacterial removal. The removal bacterial efficiency of the treated water was 16 % more than in sand filters.

2.4. Factors Effecting Coagulation Process:

2.4.1 Coagulant Solution Concentration:

Griffith and Williams (1972) showed that improved turbidity removal could be obtained by dilution to as low as (1.5%) solution.

Kawamura (1973) showed that the optimum economical alum dosage should be selected on the basis of the most efficient alum concentrations for turbidity removal rather than in accordance with the simple correlation of alum dosage versus turbidity removal.

Jeffcoat and Singley (1975) found that flocculation with alum was not impaired by dilution to as low as (0.1%).

2.4.2. Sequence of Chemicals Application:

Kawamura (1973) stated that in many cases coagulant aids, such as lime, polyelectrolyte, activated silica, and carbon, were fed with alum at the same application time. From the chemical viewpoint, especially the colloid-chemical viewpoint, however, there is frequent disagreement on such chemical additions. For instance, lime should not be added to raw water before or with alum because calcium ions, as well as hydroxide or carbonate ions, could be adsorbed on the micelle structure of colloidal particles and the colloids could become more stabilized. Whereas, bentonite, which is one type of montmorillonite, is better to be added to raw water before alum application, because its main function is seeding or adjustment of particle-size distribution.

Hudson (1981) reported that chemical theory and practical experience often suggest certain sequences of addition of reactant chemicals. Cases have been seen where the addition of polymer prior to coagulant dosage proved beneficial.

Al-Marshidi,(2000) studied the effective sequence of alum and weighting agents. He studied three cases, namely, alum before, with, and

after weighting agents were added. He stated that the best sequence is to add alum after the addition of bentonite or porcelanite (weighting agents).

2.4.3. pH Value :

The pH value is one of the most important variables of those that have to be considered for effective flocculation. The metal coagulants (aluminum and iron salts) have been shown to precipitate and coagulant most rapidly and with minimum solubility in a certain pH range, depending upon the coagulant used.

Tekippe and Ham (1970) found that the region of alum concentration (pH 7 and 10mg/l of alum) was located at considerably higher alum concentration than the optimum region (pH 7.2 and 2.5mg/l of alum) for membrane and granular bed filtration.

Kawamura (1976) stated that in practice, in the presence of ions and turbidity normally present in natural waters, the optimum pH range is generally (6-7.8) for alum flocculation and (4-8) for iron hydroxide flocculation. Therefore, alum coagulation and flocculation should be carried out within the optimum pH zone for the particular water being treated.

Kawamura (1991) stated that the pH of raw water ranging between (7.6-8.8) was not affected by the treatment with plant materials (natural coagulants) but only by alum.

2.4.4 Mixing Intensity (Rapid and Slow)

2.4.4.1 Rapid Mixing:

The function of rapid mixing is to ensure a homogeneous coagulation caused by a completely uniform dispersion of the coagulant throughout the water. The intent is for the coagulant to make contact with the maximum number of colloidal particles before hydrolysis and adsorption or bridging action takes place.

Hudson and Wolfner (1967) reported that distribution of the coagulant throughout the water prior to the completion of hydrolysis was estimated to be in the order of a fraction of a second after addition of the coagulant. It was suggested that, in the absence of sufficient mixing, the same portions of the water might receive concentrations of coagulant high enough to cause restabilization of particles whereas other portions may have concentrations too low to initiate coagulation.

Moffett (1968) pointed out the importance of speed mixing. From jar test, he found that for constant reaction pH "twenty seven percent more alum is required to obtain zero zeta potential when the coagulant was introduced on the surface of water rather than at the agitator paddles level".

Stumm and O'Melia (1968) pointed out that for Al (III) in the pH range of (5-8) destabilization might occur by two different mechanisms (adsorption or entrapment). The effects of rapid mixing are possible different for these different cases. However, Vrale and Jorden (1971) emphasized that non-uniform mixing of metal ion coagulants will be accepted if sweep-floc precipitation is desired. The regions of high chemical concentration produced by back-mixing apparently stimulate formation of the hydroxide flocs are necessary for this mode of destabilization. However, non-uniform mixing will be quite undesirable if destabilization by adsorption is desired. Destabilization will be poor in areas of low chemical concentration because of insufficient adsorption and low chemical potential. Destabilization may also be poor in areas of high chemical concentration because of over-adsorption and charge reversal. When charge reversal occurs, continued mixing will not improve the situation because the adsorption process is essentially irreversible.

Letterman and Gemmell (1973) showed that the rapid mix operation (also known as flash or initial mixing) is often the initial step in the flocculation process. During the rapid mix period the flocculating agent or

coagulant – commonly a hydrolyzing salt such as aluminum sulfate – is dispersed by turbulent motion throughout the water to be treated . the rapid mix operation is normally followed by a period of less intense agitation (a slow mix or flocculation period) in order to promote the agglomeration of particles into flocs of size suitable for effective removal by sedimentation and filtration .

Hudson (1973) observed that rapid mixing during coagulant addition prior to slow mixing was important for effective flocculation when low velocity gradients are used during the slow – mix operation

2.4.4.2 Flocculation Studies (Slow Mixing):

Degremont, (1991) showed that the flocculation is the agglomeration of destabilized particles into microfloc, and later into bulky floccules, which can be settled, called floc. Flocculation usually consists of a two-or three-stage process, and begins when the particulates start sticking together more visibly.

Letterman and Gemmell(1973)showed that the flocculation process is an important step in the removal of dissolved, colloidal, and suspended material from water . Flocculation has been used by the water – treatment industry for almost a century as preparatory step for phase separation process such as sedimentation and filtration.

Mohtadi and Raw (1973) found that decreasing water temperature required an increase in alum dosage to achieve the same degree of flocculation.

Cole (1976) stated that temperature changes often have a dramatic effect on increasing flocculation efficiency with aluminum.

Smethurst (1997) showed that the optimum velocity gradient values for flocculation is in the range (20-50 sec.⁻¹).

Al-Marshidi (2000) stated that the period of flocculation is inversely proportional to raw water turbidity and that the velocity gradient increases with the decrease of initial turbidity and vice versa.

Zane Satterfield, (2006) stated that this process still uses the motorized paddles, but at a slower rate than during the flash mix. Stage one of flocculation is fastest, with the second and third stages working more slowly and sometimes with the paddles moving in the opposite direction in some plants. A slow speed is important so as not to break up the particles. This allows the particles to get heavier and helped them settle to the bottom in the next part of the process, sedimentation. Again, it would not be a bad idea to take daily turbidity readings at the end of the flocculation process.

2.5 Effect Of Coagulation and Flocculation Processes on the Wastewater

Asia, and Akporhonor, (2007) suggested that the wastewater contains ions and so physicochemical method of coagulation and flocculation may be a good alternative for the treatment of this wastewater. Physicochemical treatment of this wastewater yielded substantial reduction in the solid concentration, BOD and COD, nitrate, phosphorus, and bacteria counts and so the treated effluent could be discharged safely into the environment without the fear of pollution. They determined the optimum dosage of coagulant needed for wastewater treatment from the rubber factory by using the mixer as shown in Fig. (2-2).

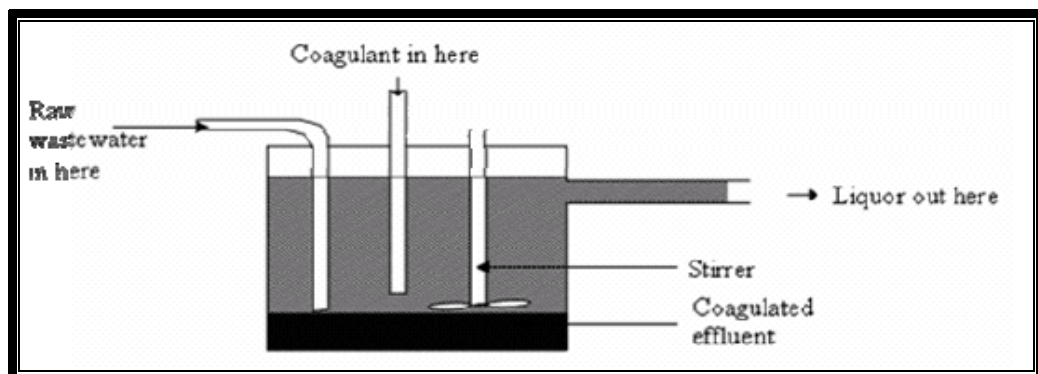


Fig.(2-2): The wastewater treatment (Asia, and Akporhonor, 2007)

Muhammad Saleem (2007) performed a physicochemical study for the treatment of pharmaceutical wastewater. He studied the removal of color, Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), turbidity and phenol and brings them up to the allowable limits for reuse purposes. He determined the efficiency of coagulation, flocculation, sedimentation, sand filtration followed by activated carbon adsorption. He found that alum was more effective among tested coagulants and reduce TSS, BOD, COD and turbidity 79.6%, 34.8, 48.6% and 69.2% respectively. Sand filtration further reduced the studied parameters 97.7%, 95.7%, 93.9% and 76.9% respectively.

(Song, et al., 2003) developed a treatment system that can effectively reduce the concentration of pollutants in tannery wastewater to environmentally acceptable levels and that can greatly reduce the cost of discharging the effluents. Aluminium sulphate and ferric chloride were used as a coagulant in the process. They studied coagulation process and conditions optimized corresponding to the best removal of organic matters, suspended solids as well as chromium. The COD and chromium were removed mainly through coagulation: 38–46% removal of suspended solids, 30–37% removal of total COD from settled tannery wastewaters and 74–99% removal of chromium.

2.6 Sedimentation Process:

Tchobanoglous and Schroeder (1985), defined sedimentation as the unit operation in which suspended materials are removed from the liquid phase by gravity settling, the common application of sedimentation in water treatment include :

1. Pretreatment of surface waters prior to conventional water treatment .
2. Settling of coagulated and flocculated waters prior to filtration .
3. Settling of coagulated flocculated waters in chemical water softening .
4. Settling of waters treated for iron and manganese removal .

Kiely (1997) stated that settlement of flocculent particles in a dilute suspension may arise after chemical coagulation and flocculation where the non-discrete particles are chemically assisted to coagulate . Flocculent particles are those particles that are chemically assisted to come together and produce large particles , and thus settle . While the particles are settling , they are also flocculating and so increase in size and mass during the settling process .

2.7 Filtration process

Degremont, (1991)stated that the filtration is a separation process that consists in passing a solid-liquid mixture through a porous material (filter), which retains the solids and allows the liquid (filtrate) to pass through,

Kiely (1997) stated that filtration has been in use since the nineteenth century when the process of slow sand filtration was generally the only water treatment process , slow sand filtration is credited with improving the aesthetic quality of water and also with the removal of pathogens .

This process is based on the theory of adsorption, where particles adsorb to sand grains because of the electrostatic attraction between opposite charges. A sand grain has a negative charge and it produces around itself a double layer by adsorbing cations from the solution, Folkman & Wachs, (1970). Ives, (1964) showed that These cations reduce the repulsion potential of the grain surface (zeta potential) and enable adsorption of particles with negative charge . The greater the concentration of cation on the sand surface, and the higher its valency, the better is the ability of the sand to adsorb negatively charged particles. Also, sand containing high percentages of ferric and aluminum ions are efficient for algal and bacterial removal, Folkman & Wachs, (1970).

Kawamura, (1999) showed that when designing a filtration system, the design engineer has to specify certain parameters: type and number of filters; size, type, and thickness of the filter bed; filtration rate and filter control system; filter washing system; type of filter under drain system; available head loss; filtered water to waste after washing; and the potential for future conversion,

(Salvato et al, 2003) stated the performance of rapid sand filter is controlled by two important accessories: the head gauge and the rate controller. The loss of head shows the frictional resistance of the flowing water through the sand, laterals, and orifices. The rate controller is constructed to automatically maintain a uniform predetermined rate of filtration through the filter.

2.7.1. Filtration Process Variables

2.7.1.1 Influent characteristics

Tuepker & Buescher, (1968) Some precipitation of calcium carbonate usually occurs on the filter media in the plants, which use lime softening, therefore efforts are exerted to stabilize the water prior to filtration.

Steel & McGhee, (1984) stated that Pretreatment is required prior to filtration and thus coagulation, flocculation, and filtration cannot properly be considered as separate unit processes. Conventional rapid filtration using sand as a medium requires low influent turbidity and has typically employed coagulation with alum or lime.

(Lechevallier et al., 1984) Settled water before filtration should have a turbidity of less than (10 NTU), if water with high turbidity reaches the filter, it will cause high filter head losses and shorter filter runs, (WSO, 2003). Water with turbidity (10 NTU) consists of bacteria eight times more than in water with turbidity (1 NTU).

Cleasby et al., (1992) showed that the combined coagulation using ferric chloride plus cationic polymer was superior to alum plus cationic polymer coagulation in producing longer filter cycles (about 50 percent longer) and substantially lower ferric dosage than alum dosage, but both coagulants produced the same filtrate quality.

2.7.1.2 Filter Media

Davis & Borchardt, (1966) showed that decreasing removal efficiency could be associated with increasing the size of the media at any flow rate. In addition, a numerical reduction in percentage removal of organisms at an increasing rate of filtration was also indicated. Finer sand exhibited greater removal efficiency of algal suspensions than did coarser sand.

Robeck et al., (1964) and Letterman, (1999) observed that the head loss of the dual media filter was less than half that of the sand filter, but the effluent turbidity was almost the same.

Tuepker & Buescher, (1968) showed that the dual media filters offer the advantage of less head losses, a greater capacity for retaining suspended solids, and less emphasis head be placed on settle ability of suspended matter, but greater emphasis on coagulation is required than for rapid sand filters to obtain the same filtered water quality.

In multi-media filters, a modification must be made by using an equivalent grain size that can be approximated as follows:

$$d_{eq} = X_1 d_1 + X_2 d_2 + X_3 d_3 \dots\dots\dots(2-1)$$

d_1, d_2, d_3 = mean size of individual media.

X_1, X_2, X_3 = percentage by volume of individual media respectively, Conley & Hsiung, (1969).

Eunpu, (1970) compared between ilmenite and garnet as filter materials, he showed that ilmenite is more efficient than garnet due to its availability, although the characteristics of both materials are similar.

Harris, (1970) showed from his experimental work that garnet is a fine heavy hazard of its downward migration into the supporting gravel. Also, unless the wash water rise is uniform, the garnet tends to mound when localized high flows lift the heavy fines and deposits nearby are formed by resulting fountain effect.

(Camp et al.,1971) showed that removal by filtration is increased by increasing bed depth or by decreasing grain size, a choice must be made in design between more depth or smaller grain size, within the limitations that the grains that are too large require excessive wash rates for suspension.

Westerhoff, (1971) showed that the mixed media (coal-sand) filter consistently produced lower filtered water turbidity than the sand media, and the microscopic quality of water was equal to, or better. Because of the very low turbidity values, it ordinarily is difficult to detect breakthrough using this parameter.

Kirchman & Jones, (1972) and Viessman et al.,(1985) showed that the filter media is usually specified in terms of “effective size” (in mm) and “uniformity coefficient”. Effective size (d_e) is 10 % by weight of the filter media is less than this diameter. Uniformity coefficient (UC) is the ratio of the 60 % size to 10 %. Common ranges of d_e and UC for sand are (0.4-0.55) mm and (1.3-1.7) respectively.

Chin & Chen, (1978) used different materials for filtration such as sand, wood shave, lallang, coconut husk, and sponge. All filter media were packed to a depth of 60 cm, and the sand had ($d_e = 0.51$ mm, UC = 1.4). The filtration runs were kept continuously for at least six hours over the range of (0.2 to 8 m/hr). Single media systems showed that the sand filter was the most efficient in suspended solids (SS), BOD, and coliform organisms removal for (6 hr) filtration run. Multi- media systems showed excellent removal efficiency when sand was added to lallang as the filter medium.

Trussell et al., (1980) showed that the affects of the bulk porosity of the bed, which is strongly related to the increase in head loss that results from the deposits in the filter. It can be seen that using angular media results in an improved performance of the filter, such as the time limiting head loss may be increased by (30 to 40 %),.

Al-Ani & Al-Baldawi, (1986) conducted several tests on the Tigris River water utilizing a pilot plant built similar to a full-scale water treatment plant. A comparison between single and dual media filters subjected to identical conditions revealed the superiority of dual filters over the single conventional filter. The results demonstrated lower head losses, longer filter runs and doubling the production of filtered water.

Al- Rawi, (1987) showed that a dual media filter consisting of 20 cm of anthracite ($d_e = 0.91$ mm) with 40 cm of sand ($d_e = 0.69$ mm) was found to show superiority in turbidity removal among other filters tested with different depth and size of dual media. This filter achieved an efficiency of (90 to 98 %) in turbidity removal over (83 hours) service time at filtration rate (8.8 m/hr).

Mohammed, (1989) showed that dual filter with anthracite of ($d_e = 0.74$ mm) and sand of ($d_e = 0.478$ mm) can be operated at high filtration rates (12 m/hr), achieved significant turbidity removal efficiency more than (91%), slower rate of head loss build up, and longer filter runs compared to sand filters under the same circumstances.

Denver, (1989) referred that at (12.2 m/hr) and after the proper chemical treatment, up to (96 %) turbidity removal was achieved with different mixed media beds. These beds consisted of: 419 mm depth of anthracite with $d_e = 1.1$ mm, 229 mm depth of garnet with $d_e = 0.35$ mm, and 76 mm depth of garnet with (1-2) mm grain size.

Latif, (1990) used granular activated carbon (GAC) as a filter medium and an adsorbent material at the same time, in water treatment plants which

received water with turbidity less than (5 NTU). He emphasized that the effluent quality from the GAC filter was better than from sand filters, less head losses, and less backwashing water requirement.

(Cleasby et al., 1992) showed from their experimental work that tri-media is considered superior to dual-media in the filtered water quality under stressful filtration conditions (e.g., high rates and sudden rate increases). Unit filter run volumes (UFRV) for the tri-media filters were higher than those for the dual-media filters.

Yohe & Getting (1993) made a study on filters with 20 cm of (0.35-0.45) mm sand ($UC \leq 1.5$) and 50 cm of (0.9-1) mm anthracite with different uniformity coefficients (1.3, 1.4, 1.5, and 1.6). They observed that the lower the anthracite uniformity coefficient, the longer run times (up to 50 % longer), the fewer the back washes (33 % less), and the better water quality (up to 88 %).

Kawamura, (1999) showed that smaller uniformity coefficient (UC) values result in slightly better filtrate quality and longer filter run lengths,

Masters, (1991) and Drain, (2001) showed that the perfect quality of the filter media should have pore openings large enough to retain large quantities of flocculants, to process large volumes of water without clogging, but small enough to prevent the passage of suspended solids. The ideal filter media would also be light in weight, enough to allow sufficient depth for long filter runs, and be graded to allow effective backwash cleaning.

Degremont, (1991) stated that the same filtered water quality was obtained when using an angular material whose effective size was smaller than that of a round grain material.

Cleasby et al., (1992) performed experiments on filters with angular sand porosity of 41 % and smooth sand of 38 % porosity. It was found that the filter performance of (1.5 m) of angular sand was approximately equivalent to (2.4 m) of similarly sized smooth sand, Moreover,

According to the Unit Standard 18452,(2002),the range of useful media is limited by the need for significant density differences together with the cost and durability of the material.

To ensure that two types of filter media grains have the same settling velocity the following relationship should exist:

$$\frac{d_1}{d_2} = \left[\frac{\rho_2 - \rho}{\rho_1 - \rho} \right]^{0.667} \dots\dots\dots (2-2)$$

d_1 and d_2 = diameter of two media with specific gravity ρ_1 and ρ_2 , and ρ is the density of water with a specific gravity of 1.

To minimize intermixing of the two or three layers, the size of each successive layer, from top to bottom, should be (5-7) % larger than the size calculated by this equation, Kawamura, (1999).

Al-Auraji, (2003) showed that the sand filter media with ($d_e = 0.635$ mm) gave a better effluent quality, higher head losses, and lower filter run time than a sand filter media with ($d_e = 1$ mm).

2.7.1.3.Depth of Filtering Material

The depth of the filter could be selected from the relationships suggested by Kawamura,(1991) and Letterman, (1999). These relationships are in the form (L/d_e) where L = depth of the filter bed in mm,

d_e =effective size of the media in mm.

Kawamura, (1999) and Kawamura, (2000)stated that some typical values for L/d_e for common bed configurations are as follows:

$L/d_e \geq 1000$ for ordinary monosand and standard dual media filters.

$L/d_e \geq 1250$ for regular multimedia and trimedia (coal, sand, and garnet).

$L/d_e \geq 1250$ to 1500 for most coarse deep monomedium beds in which
($1.2 \text{ mm} < d_e < 1.4 \text{ mm}$).

$L/de \geq 1500$ to 2000 for very coarse deep monomedium beds in which
($1.5 < d_e < 2$ mm),

Byeseda & Sylvester, (1979) showed that deep bed filtration is most effectively applied to dilute suspensions (less than 50 ppm) consisting of nonvolatile discrete solids smaller than about (50 μ m) in diameter. The operative mechanisms in a deep bed filter are complex and dynamic.

Al-Auraji, (2003) showed that increasing the depth of sand filter media from 85 cm to 100 cm had a slight effect on both turbidity removal and filter running time, with the condition of constant effective size and filtration rate.

CHAPTER THREE

Theoretical Background

3.1 Introduction

The separation of suspended solids from river water has been the subject of many investigators over the past years. It is usually achieved by conventional treatment through coagulation – flocculation, sedimentation and filtration units. In all of these operations, the removal efficiency is greatly dependant on particles size, and can usually be enhanced by aggregation of the fine particles in the coagulation flocculation sequence. Al Mamori.A,(2001)

The suspensions must therefore be converted by artificial means. Such conversion is the out –come of two separate processes; Degremont, (1991)

3.1.1 Coagulation : is also called destabilization . It is usually achieved by the addition of chemical reagents which by bonding or adsorption mechanism nullify the repulsive forces or act on the hydrophily of the colloidal particles, ie .it is a chemical addition process, Degremont, (1991).

3.1.2 Flocculation : flocculation is the agglomeration of the neutralized colloids. This is the result of various forces of attraction acting between the particles brought into contact with each other initially by (Brownian movement), Degremont, (1991).

Until they acquire a size of about 0.1 micron and then by "outside mechanical agitation" to bring the floc to the required size it is purely a physical process of mixing. After adequate flocculation, most of the aggregates will settle out during sedimentation process. It is thus the conditioning of water to form flocs that can be readily removed by settling or filtration, Hofkes, (1983).

Chemicals can be used to create changes in pollutants that increase the removal of these new forms by physical processes. Simple chemicals such as alum, lime or iron salts can be added to wastewater to cause certain pollutants, such as phosphorus, to floc or bunch together into large, heavier masses which can be removed faster through physical processes. (EPA 2004)

3.2 Characteristics of Colloids

The colloidal particles are not limited to any particular group of substances but are defined by size. The colloidal size-range is generally regarded to extend from (1nm) to (1 μ m) although some authors consider the colloidal range to extend up to a size of (10 μ m). The size relationships are shown in Fig.(3-1) (Benefield et al., 1982).

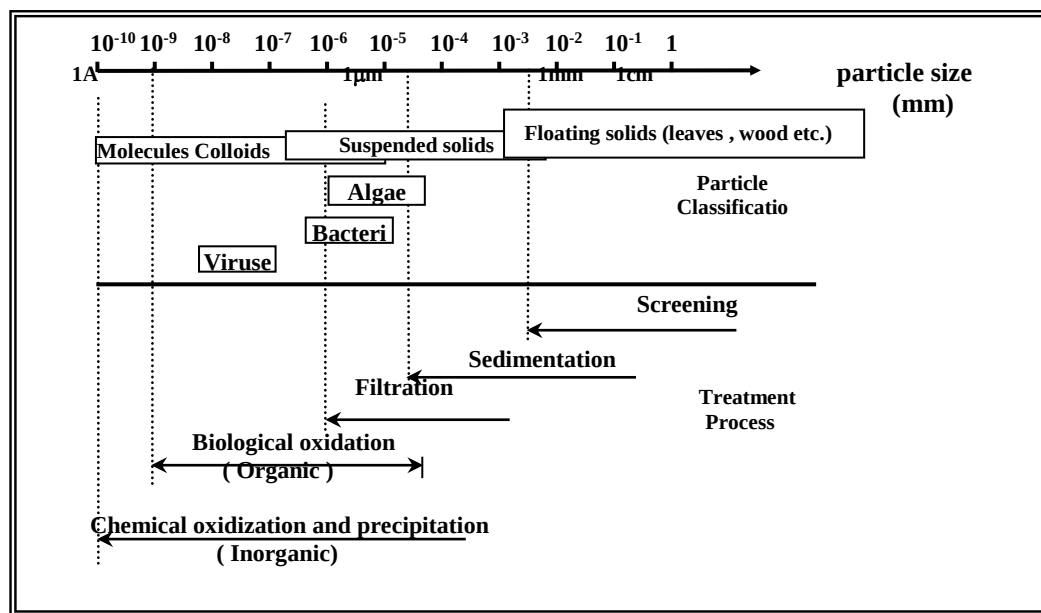


**Fig. (3-1): Particle size and treatment processes,
[After (Benefield et al., 1982)].**

Colloids were formerly classed as substance which apparently go into solution but, in fact, remain dispersed as discrete particles, and their size ranges from (10^{-3} to 0.1) μm . in water and wastewater engineering , there are some features of colloidal suspension as follows : (Barnes, et al., 1981)

- a- It cannot be removed from suspension by ordinary filtration.

- b- Colloidal particles are not visible under an ordinary microscope, but they can be seen as specks of light with an ultra microscope when a beam of light is passed through the suspension.
 - c- Brownian motion prevents the settlement of particles under gravity.
 - d- There is a natural tendency for colloids to coagulate and precipitate. Sometimes this tendency is encountered either by mutual repulsion of the particles and the medium in which they are dispersed. If these effects are strong and coagulation does not occur, the suspension is said to be "stable".
- particles found within this size range are (1) inorganic particles, such as asbestos fibers, clays, and silts, (2) coagulant precipitates, and (3) organic particles, such as humic substances, viruses, bacteria, and plankton. Colloidal dispersions have light-scattering properties. The property of scattering light is generally measured in turbidity units. Colloidal solutions may be classified, by their affinity for the dispersing medium (water), as either *hydrophobic* or *hydrophilic*. Colloidal particles are hydrophobic (water-hating) when a weak affinity for water exists and hydrophilic (water-loving) when there is a strong affinity for water. Qasim, S, (1999)
- Hydrophilic colloids may become absorbed on hydrophobic colloidal particles such as clays, thereby imparting hydrophilic properties to the latter. Colloidal suspensions of this kind are called "protective colloids" and may be difficult to coagulate. Casey, (1997).

Colloids mostly have a large surface area per unit volume, and surface electrical charge. This surface charge attracts ions carrying opposite charge, and thus creating a cloud of counter-ions in which the concentration decreases as the distance from the particle increases. The overall situation is complex. The colloids which carry similar charges will repel each other but, the presence of counter-ions complicates the law relating the degree of repulsion, causing a more rapid fall-off in repulsive force as distance increases, Zajic, (1972)

The principle phenomena controlling the behavior of colloids are: **electrostatic forces, Van der Waals forces, and Brownian motion.**

Qasim, S; (1999)

Electrostatic force is the principal force contributing to the stability of the colloidal suspensions. Most colloids are electrically charged, the nature of this charge varies depending on the nature of the colloid. Metallic oxides are generally positively charged, while nonmetallic oxides and metallic sulfides are generally negatively charged. The result of this electrical charge is that colloids of similar charge will repel each other. Typically, negatively charged colloids predominate in natural waters.

The surface charge on the colloids attracts ions of opposite charge, known as counter ions. These ions, which include hydrogen and other cations, form a dense layer adjacent to the particle known as stern layer .The fixed layer or stern layer is the tight compact layer of counter ions that surrounds the particle. Qasim, S; (1999)

Water molecules are also attracted to the colloidal particle. The attraction of water is due to the asymmetric electrical charge of water molecules. A second layer of ions, known as the diffusion layer, is also attracted to the colloid. The diffuse layer is a loose layer of ions surrounding the fixed layer. In this layer, ions of both electrical charges are attracted, but counter ions predominate. The two layers together are often referred to as the double layer. A colloidal particle and its double layer are illustrated in Fig. (3-2) ; Ravina, (1985).

In the diffusion layer, the molecules of water are sufficiently bound to create a shear surface. The water molecules inside this shear surface will behave as if attached to the colloid; water molecules outside the shear surface will behave as if independent of the colloid. In between the fixed and diffuse layers is the plane of shear. The zeta potential (ZP) is the electrostatic potential (ESP) at the plane of shear. Lowering the ZP makes the ESP of the

particle less. Lower repulsion forces between particles allow them to come together and form flocs , HDR Engineering, Inc., (2001).

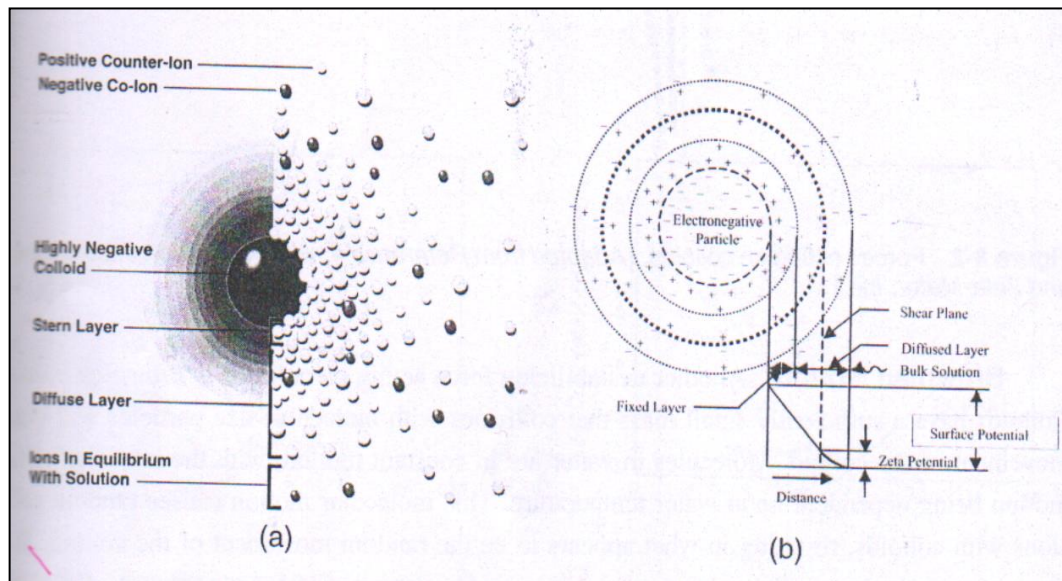


Fig. (3-2) :A colloidal particle and double layer (a) A negative colloidal particle with its electrostatic field. (b) Distribution of electrostatic potential, shear plane, and zeta potential (Ravina .L,1985).

The zeta potential is often measured in water treatment to give an indication of the stability of the colloidal system or of the effectiveness of the coagulation process.

This latter is called the Zeta potential (ζ) and is related to the particle charge and the double layer thickness as follows:

$$\zeta = \frac{4\pi q t}{D} \dots\dots\dots [3-1]$$

where: ζ = zeta potential (volts) ; q=charge difference between the particle and the medium (colump) ; t= thickness of the layer around the particle through which the charge difference is effective (cm) ; D=dielectric constant of the medium. Qasim, S; (1999)

The action of flocculating salt can only be explained by the adsorption of counter – ions and consequent reduction of " ZP " , Gregory, (1993) . In

such cases full destabilization can be achieved at low ionic strength, provided that the "ZP" has been reduced to some critical value. Once the zeta potential is lowered by the coagulant, particles are able to attach to one another and aggregate. A metal salt is added slowly and as the amount added increases the destabilization occurs.

If the additive level is increased, the "ZP" can be reversed and the particles become stable again (a process normally known as restabilization)

The zeta potential is determined experimentally in an externally applied electric field. The ordinary range of the zeta potential is (10 to 200 mV). For effective coagulation it is necessary to reduce the zeta potential to within (0.5 mV) of the isoelectric point (Fair et al., 1968).

Van der Waals forces a force of attraction exists between any two masses. The magnitude of this attraction is a function of the mass of the two bodies and the distance between them. This attraction is known as the van der Waals forces . As indicated in Fig. (3-3), the force of repulsion due to the electrical charge will normally repel the colloids before they can move close enough for van der Waals forces to become significant ; Reynolds and Richards ,(1996). If the magnitude of the electrostatic forces could be reduced, the particles would move close enough for van der Waals forces to predominate.

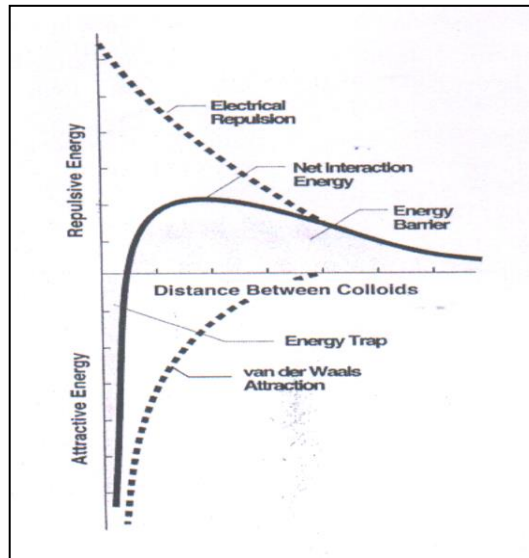


Fig. (3-3): Forces Acting on Colloids (Ravina .L, 1985).

Brownian motion another destabilizing force acting on colloids is Brownian motion .Colloids have a sufficiently small mass that collisions with molecular – size particles will cause movement of the colloid. Molecules in water are in constant motion, with the intensity of this motion being dependent upon water temperature. This molecular motion causes random movement of the colloid. This phenomena is known as Brownian motion , Montgomery ; (1985)

In some instances, Brownian motion can cause two colloids to move sufficiently close for van der Waals forces to predominate over electrostatic repulsion. If this occurs, the particles could agglomerate .such instances rarely occur, and destabilizing influence of Brownian motion is insignificant.

3.3 Stability and instability factors

In the field of colloid science, two different approaches have been advanced historically to explain the basic mechanisms and stoichiometry of coagulation. These conditions are described by the terms “Stability” and Instability ”of colloidal suspension. **Stability** refers to the inherent property of colloidal particle to remain dispersed despite passage of time, whereas **instability** describes the tendency of particles to coalesce whenever particle

– to particle contact is made. The reason due to instability suspension (coagulation) is that the kinetic energy for particle translocation is obtained from Brownian movement for smaller particles, but more importantly from the energy introduced into colloidal suspension in the form of mixing which greatly increases the probability of particle collisions if the forces of the repulsion are sufficiently reduced. Black ,(1960). Historically, two broad theories have been proposed to explain the mechanisms involved C. R., (1971):

- 1-The newer, **physical theory** or double – layer theory emphasizes the importance of the electrical double layers surrounding the colloidal particles in the solutions and the effect of counter – ion adsorption and zeta – potential reduction in the destabilization of colloidal systems.
- 2-The older, **chemical theory** assumes that colloids acquire electrical charges on their surface by ionization by chemical groups presented at the surface and that coagulation is accomplished by chemical interactions between colloidal particles and coagulant.

3.4 Destabilization of colloidal dispersions

Colloidal, or suspended, particles have a negative charge on their surfaces known as the zeta potential. Natural colloids tend to acquire this charge in one of two ways: ionization of their surface groups where they will accept or donate protons or adsorption of negatively charged organic molecules. HDR Engineering ,Inc.,(2001).A polymeric coagulant aggregates the particles in another way called bridging. The polymer consists of long molecular chains and the reactive groups on the chain absorb one or several particles in different places. This makes the particles large enough to be removed through sedimentation and/or filtration. Examples of how a polymer bridges can be seen in Fig.(3-4), AWWA,(1999).

To induce colloidal particles to aggregate, two distinct steps must occur Stumm and O'Melia, (1968):

- 1-The repulsion forces must be reduced (i.e., the particles must be destabilized).
- 2-Particle transport must be achieved to provide contacts between the destabilized particle

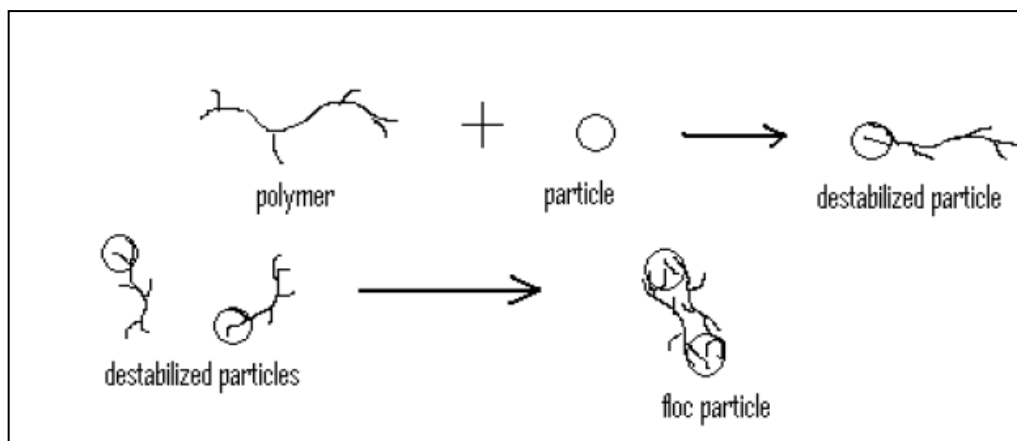


Fig.(3-4): Examples of Coagulation and Flocculation by Bridging (HDR Engineering Inc., 2001)

3.5 Mechanisms of destabilization

There are several mechanisms for explaining particle destabilization by aluminum salts in coagulation. Dentel and Gossett (1988) reported four major coagulation mechanisms:

- 1-Double – layer compression (neutralization of surface charge).
- 2-Adsorption of soluble polymeric metal-hydroxide species.
- 3-Precipitation of a metal – hydroxide.
- 4-Enmeshment in a precipitate (sweep coagulation).

3.5.1 Double – layer Compression

When a colloidal particle is immersed in a solution, electrical charges will develop at the particle – water interface. The origin of these charges may be due to the dissociation of the ionizable groups of the colloide itself or to the adsorption of low – molecular – weight ions onto its surface. As a result of this charge development, a charge balance must be established in the vicinity of the colloidal particle to fulfill the requirement of electro neutrality. Helmholtz considered the picture of the charge balance as two surface charges separated by a constant distance as a simple condenser in solution. The charges on the particle surface formed either the positive or negative portion, whereas the opposite charges (counter ions) in solution comprised the other portion .C. R., (1971).

The effect of this compression is to change the distribution of double – layer repulsion forces in the vicinity of the colloid and cause a reduction in surface potential with increasing electrolyte concentration, while allows the Van der Waals attractive forces to be more dominant, thus enhancing particle aggregation, as shown in Fig. (3-5), (Benefield et al. 1982)

Two interesting aspects of double – layer compression are (Benefield et al., 1982):

- 1-The amount of electrolyte required to achieve coagulation is practically independent of the concentration of colloids in the dispersion.
- 2-It is not possible to cause a charge reversal on a colloid, regardless of how much electrolyte is added.

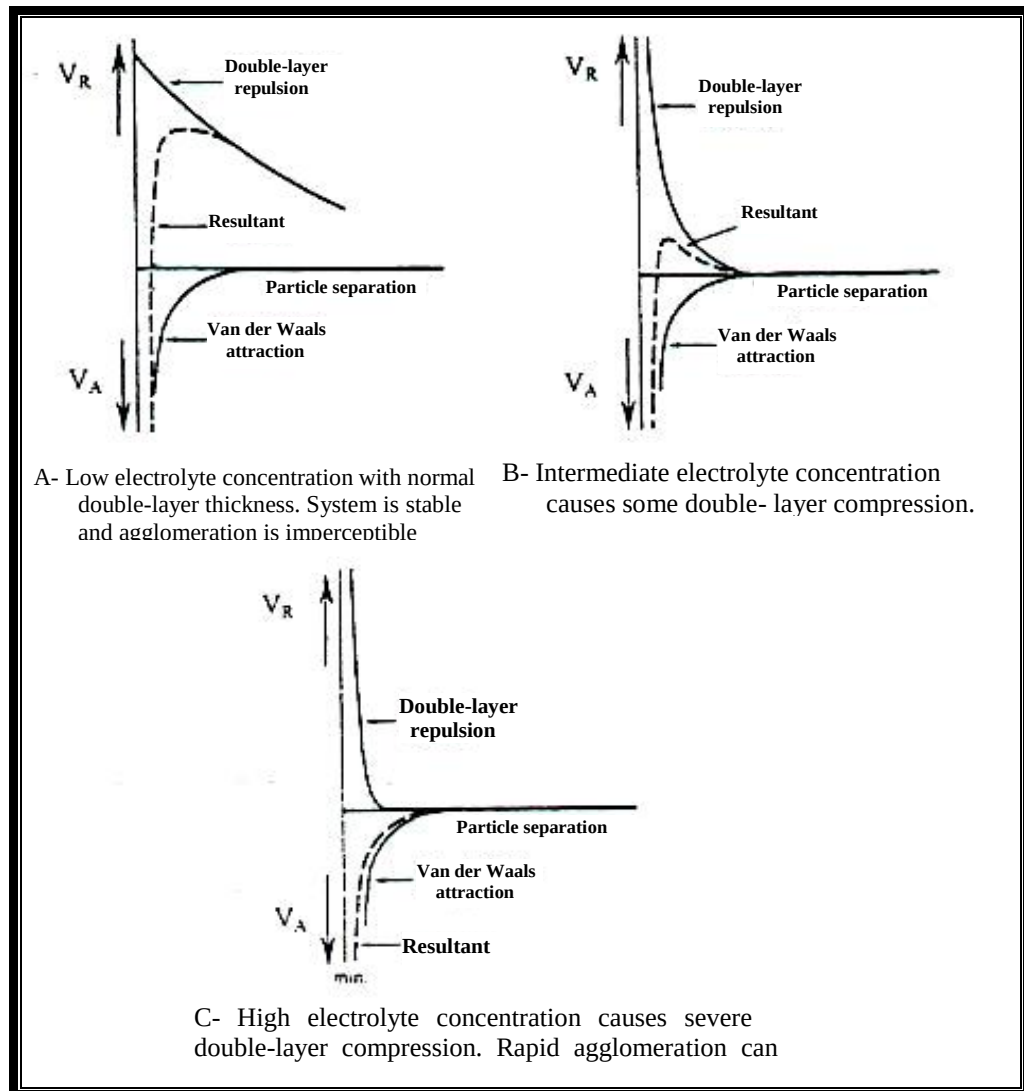


Figure (3-5): Effect of electrolyte concentration on double layer-compression, [After (Benefield et al., 1982).

3.5.2 Adsorption of soluble polymeric metal hydroxide species

Some chemical species are capable of being adsorbed at the surface of colloidal particles. If the adsorbed species carry a charge opposite to that of the colloids, such adsorption causes a reduction of surface potential and result in destabilization of the colloidal particles.

Destabilization by adsorption differs from destabilization by double-layer compression in three very important ways. **Firstly**, sorbable species are capable of destabilizing colloids at much lower dosages than nonsorbable,

"double – layer compressing " ions. **Secondly**, destabilization by adsorption is stoichiometric. Thus, the required dosage of coagulant increases as the concentration of colloids (more specifically, the total surface area of colloids)increases, while the amount of electrolyte required to achieve coagulation by double – layer compression is not stoichiometric and is practically independent of colloid concentration. **Thirdly**, it is possible to overdose a system with an adsorbable species and cause restabilization as a result of a reversal of charge on the colloidal particle .Weber, (1972).

3.5.3 Precipitation of a metal – hydroxide

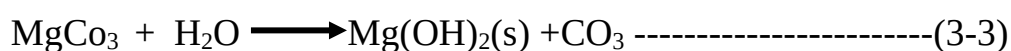
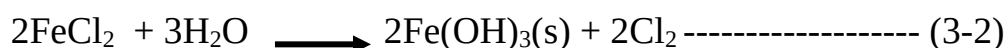
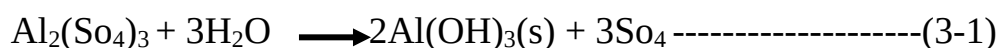
Because the metal hydroxide precipitates are positively charged in the pH range common to water treatment, it has been hypothesized that charge neutralization is achieved due to precipitate deposition on the surfaces of particles. This differs from the " adsorption–sweep floc " concept of coagulation in that precipitation precedes charge neutralization Dentel and Gossett, (1987).

The assumptions that describe this mechanism presume that coagulation involves three steps Dentel, (1987):

- 1- Coagulation comes about after the operational solubility limit for aluminum hydroxide has been exceeded. Much less alum is needed to initiate this process at intermediate pH values than at higher or lower pH levels.
- 2- Aluminum hydroxide species then are deposited onto the colloidal surface.
- 3- Under typical conditions, the metal hydroxide is positively charged, while the original colloidal material or particles are negatively charged. The deposition process therefore can lead to charge neutralization or charge reversal at certain doses.

3.5.4 Enmeshment in a Precipitate (Sweep Coagulation)

If certain metal salts are added to water in sufficient amounts, rapid formation of precipitates will occur. Colloids may serve as condensation nuclei for these precipitates or may become enmeshed as the precipitates settle. Coagulants, such as $[\text{Al}_2(\text{SO}_4)_3]$, $[\text{FeCl}_2]$, $[\text{MgCO}_3]$, and $[\text{Ca}(\text{OH})_2]$ can induce coagulation through the formation of insoluble $[\text{Al}(\text{OH})_3(\text{s})]$, $[\text{Fe}(\text{OH})_3(\text{s})]$, $[\text{Mg}(\text{OH})_2(\text{s})]$, and $[\text{CaCO}_3(\text{s})]$. Removal of colloids in this manner is frequently referred to as sweep-floc coagulation, (Benefield et al., 1982).



(Ching et al. 1994) showed that in the experimental conducted at pH (7.8) is induced by precipitation of aluminum hydroxide from solution at high alum dosage, and possibly, by precipitation of aluminum hydroxide onto the surface of clay particles at lower alum dosage. At high alum dosage, effective coagulation is accomplished by precipitation of an $[\text{Al}(\text{OH})_3(\text{s})]$. The colloidal particles can serve as nuclei for the formation of the precipitation, so that the rate of the precipitation increases with increasing concentration of the colloidal particles to be removed. This can result in an inverse relationship between the optimum coagulant dosage and the concentration of material to be removed.

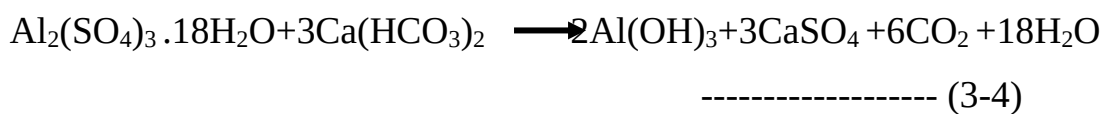
Another noteworthy fact with respect to coagulation is that the $[\text{Al}(\text{OH})_3(\text{s})]$ formed is weakly negative when (pH > 8) but is strongly positively charged at values of (pH < 7) Amirtharajah and Mills, (1982). This implies that in the range of pH (7-8) the precipitate is positively charged, and the enmeshing or the sweep mechanism of $[\text{Al}(\text{OH})_3(\text{s})]$

precipitation is enhanced by the possibility of mutual or hetero-coagulation between the negatively charged solution and the positively charged $[\text{Al}(\text{OH})_3(\text{s})]$. Jorden, (1972).

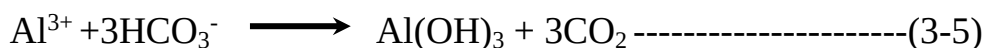
3.6 Chemistry of Coagulation with Alum

Coagulant such as alum and iron salt reacts with the alkalinity of water, and hydrolyzes in it. Alum reacts to form aluminum hydroxide floc, $\text{Al}(\text{OH})_3$; a gelatinous precipitate. This intermediate product, not only provides the charge needed to neutralize the colloids but, according to some writers Degremont, (1991) , Reshi , (1993) and (Valade ,et al., 1996) is capable of polymerization , (ie. of forming bridges between the colloids and thereby initiating the flocculation process.

When alum is added to water in the presence of alkalinity, the overall reaction is as follows:



Omitting the non – reacting species, this reaction may be written as:

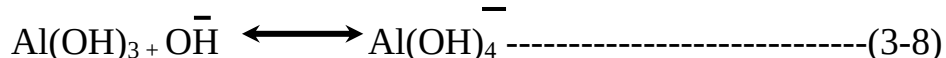
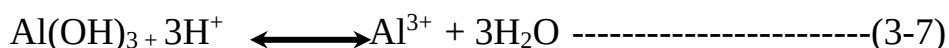


The presence of alkalinity acts as a buffer against excessive lowering of pH.

The aluminum hydroxide precipitate formed might be more correctly called a hydrated aluminum oxide precipitate.



It is amphoteric, in that it can react with H^+ or OH^- ions, depending on the pH:



Free trivalent aluminum ion is released in a solution. However, under coagulation conditions only relatively small concentrations of (Al^{3+}) is

present in solution and hence its influence on coagulation may not be as great as is sometimes suggested Casey, (1997).

The metal ion undergoes stepwise of hydrolysis reactions as exemplified in Table (3-1). It is important to note that the pH of the solution is depressed by these hydrolytic reactions.

**Table (3-1): Reactions for hydrolysis of Al(III),
[After (Dentel and Gossett, 1987)].**

Species	Reaction	
Al^{3+}	$\text{Al}(\text{OH})_3 + 3\text{H}^+$	$\text{Al}^{3+} + 3\text{H}_2\text{O}$
$\text{Al}(\text{OH})^{2+}$	$\text{Al}^{3+} + 1\text{H}_2\text{O}$	$\text{Al}(\text{OH})^{2+} + 1\text{H}^+$
$\text{Al}(\text{OH})_2^+$	$\text{Al}^{3+} + 2\text{H}_2\text{O}$	$\text{Al}(\text{OH})_2^+ + 2\text{H}^+$
$\text{Al}(\text{OH})_3^0$	$\text{Al}^{3+} + 3\text{H}_2\text{O}$	$\text{Al}(\text{OH})_3^0 + 3\text{H}^+$
$\text{Al}(\text{OH})_4^-$	$\text{Al}^{3+} + 4\text{H}_2\text{O}$	$\text{Al}(\text{OH})_4^- + 4\text{H}^+$
$\text{Al}_2(\text{OH})_2^{4+}$	$2\text{Al}^{3+} + 2\text{H}_2\text{O}$	$\text{Al}_2(\text{OH})_2^{4+} + 2\text{H}^+$
$\text{Al}_3(\text{OH})_4^{5+}$	$3\text{Al}^{3+} + 4\text{H}_2\text{O}$	$\text{Al}_3(\text{OH})_4^{5+} + 4\text{H}^+$
$\text{Al}_7(\text{OH})_{17}^{4+}$	$7\text{Al}^{3+} + 17\text{H}_2\text{O}$	$\text{Al}_7(\text{OH})_{17}^{4+} + 17\text{H}^+$
$\text{Al}_{13}(\text{OH})_{32}^{7+}$	$13\text{Al}^{3+} + 32\text{H}_2\text{O}$	$\text{Al}_{13}(\text{OH})_{32}^{7+} + 32\text{H}^+$

The hydrolysis products play a more important role in particle destabilization Dentel, (1991). Further hydrolytic reactions yielding higher hydroxide complexes, are leading to the formation of positively charged colloidal polymers and ultimately to hydroxide precipitates.

Both the positively charged complex ions and the colloidal hydroxo polymers are considered to play an important role in the overall mechanisms of coagulation. The anions of the trivalent salts also play a part in completing the coagulation process by promoting the coagulation of any excess of positively charged metal hydroxo colloids formed Casey, (1997).

There is a general agreement that under equilibrium conditions aluminum exists primarily as the insoluble solids $\text{Al}(\text{OH})_3$ as shown in Fig. (3-6)

C. R., (1971). Aluminum hydroxide is the desired end product. It is insoluble, floc forming, heavier than water, and it carries the positive electric charge necessary to neutralize the negative charges of the colloidal particles Smethurst, (1997).

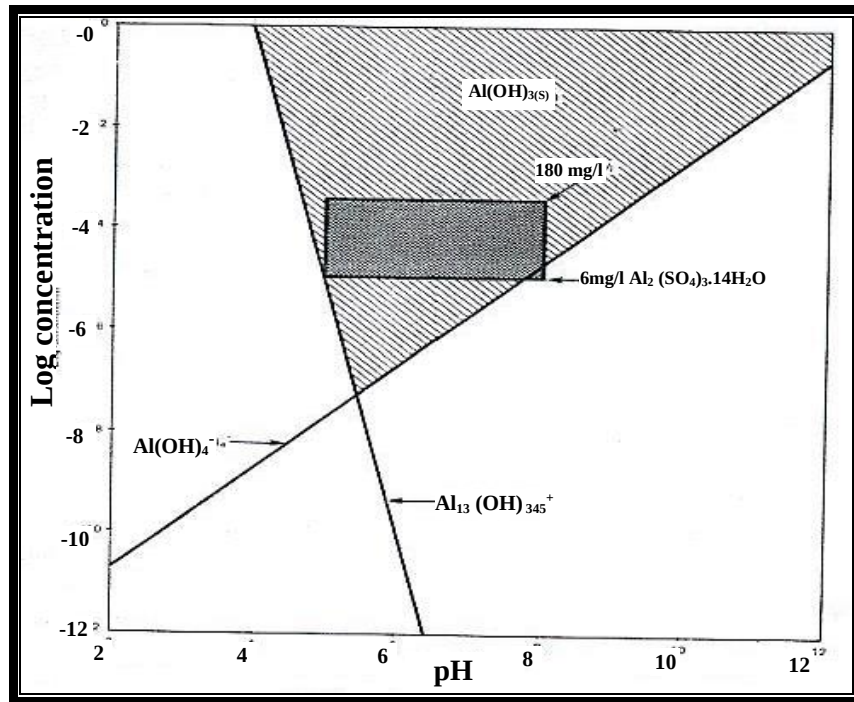


Fig. (3-6): Equilibrium solubility domain of aluminum hydroxide in water , [After (C. R., 1971)].

Sullivan and Singley have shown that, under the nonequilibrium conditions existing in water treatment plant coagulation, the predominate species may not be the simple insoluble trihydroxide, but they found that the predominant species was (Al^{3+}) up to pH (4.5), $[Al(OH)_3]$ from pH (4.5 to 8), and $[Al(OH)_4^-]$ above pH (8). Sullivan and Singley, (1968).

McGhee (1991) stated that although other techniques are possible for coagulation, the coagulation of water generally involves the addition of chemicals – either hydrolyzing electrolytes or polymers. The action of metallic coagulants is complex, involving the dissolution of the salt (which may reduce the Zeta potential by altering the ionic concentration in the bound layer) the formation of complex hydroxyl – oxides of the metal which may be

highly charged, and the entrapment of individual particles is the chemical precipitate formed.

If water contains insufficient alkalinity, the addition of a coagulant may depress the pH below the range in which the particular salt is effective. In such a circumstance an alkaline salt must be added to increase the buffer capacity of the solution. The adequacy of the natural alkalinity may be estimated from the following equation. Which represent the approximate overall reactions involved Aluminum Sulphate (alum).

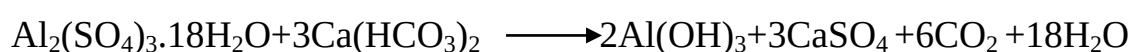


Table (3.2) indicates the advantages of using proper alum dosage for coagulation

Table (3.2) :Effects of alum – dosage on treatment criteria (Schulz and Okun, 1984)

Treatment Criteria	Under dose	Proper dose	Over dose
Turbidity removal	Poor	Good	Fair
Color removal	Poor	Good	Fair
Algae removal	Poor	Good	Fair
Length of filter run	Mediam	Long	Short
Cost value	Wasted	Good	Poor
Residual Al ⁻³	High	Low	High

3.7. Local (Porcelanite) Material

Porcelanite raw is compound of sedimentary conditions and from big quantities from live creatures rich with silica . The decay and dissolved of silica that take the place of carbonates metals also transitional process related to the compound of (opal CT) , it's a rock , which consists of two metals

(cristobillite and tridimite) which were distinguishes with opened crystallize structure that allowed to enter a lot of ions that made it have coagulation and filtration important . Abd- Al –Hussein, (1995).

Porcelanite rocks in Iraq, is from an industrial bed of (0.5 to 1.3 m) thickness in the Safra, and Trafawi site of the Jeed formation in Al-Rutba region, western of Iraq. Rocks of these deposits are composed of medium ordered crypto and microcrystalline opal-CT, associated with authigenic quartz, carbonates, clay minerals, halite, and apatite. Porcelanite rocks are largely composed of sponge spicules (pores) and some other siliceous micro fossils (diatoms and radiolarian) as well as silicified forminifera and nannoplankton, (Mohammed, 1993 ^{Arabic}).Fig.(3-7)show the location of porcelanite sample sites in Iraq .

Korkess, (1993) specified porcelanite from Traifawi site H₃ area with high percents of cristobalite, tridymite, and quartz.

The adsorption capacity of porcelanite is due to the large surface area within the composition of cristobalite and tridymite .Abed- Ohn, (2003 ^{Arabic})

Adsorption capacity for porcelanite made it important for getting rid the environment from the different pollution . Al-Wetaify ; (2005)

3.7.1 Chemical analysis of Iraqi porcelanite :

Porcelanite is a semi-vitrified clay or shale (i.e. clay or shale partially converted to glass). Two porcelanite samples are found in Iraq . They have been analyzed by method used in (GEGSM).Table (3-3) indicates some differences between the porcelanite samples of Traifawi site H₃ and Al-Safra member. Silica contents are of 83% and 72% respectively. Calcium and magnesium – oxide contents at Safra are higher than traifawi. The high calcium and magnesium content of Al- Safra member indicates the presence of dolomite [CaMg (CO₃)₂]. This was also noticed through the mineral optical studies. Al-Ansary , (1999).

Table (3-3) :Chemical analysis for local porcelanite samples.

Constituent	Safra (s)%	Traifawi T-H ₃ %
Silica(SiO ₂)	72.65	83.57
Alumina(Al ₂ O ₃)	0.80	0.62
Iron oxide(Fe ₂ O ₃)	4.71	4.45
Titanium oxide (TiO ₂)	0.10	0.01
Phosphate(P ₂ O ₅)	5.72	1.82
Lime(CaO)	6.52	1.46
Magnesia(MgO)	0.40	0.50
Sodium (Na ₂ O)	0.14	0.16
Potassium (K ₂ O)	1.18	0.22
Ignition loss(L.O.I)	6.7	5.9
Total	98.92	98.71

3.7. 2 Mineralogical Analysis of Porcelanite in Iraq

This analysis includes the identification of the type of minerals in the Iraqi porcelanite rocks, by using x-ray diffraction technique – Philips pw, 1130. This instrument present in the department of Geology – University of Baghdad.

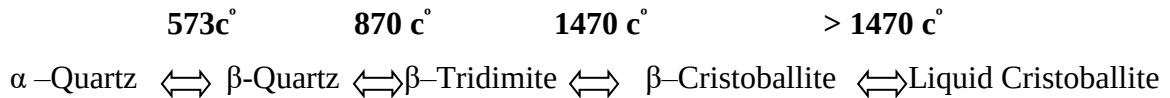
The sample from Al-Safra member contain high percent of dolomite [CaMg (CO₃)₂]. Al-Ansary , (1999).

The silica content (cristobalite, tridymite, and quartz) is slightly lower in percent when compard with the porcelanite sample from Traifawi member – H₃ area. Sample from Traifawi member –H₃ area showed high percent in the mineral of cristobalite, tridymite, and quartz. **Tridymite** is a high-temperature polymorph of quartz and usually occurs as minute tabular white or colorless crystals, or scales, in cavities in acidic volcanic rocks. Tridymite is stable between 870 and 1470 degrees centigrade of cristobalite. **cristobalite** is a high-temperature polymorph of quartz and tridymite. It occurs as white octahedra in acidic volcanic rocks. Cristobalite is stable only

above 1470 degrees centigrade . (American Geological Institute Dictionary of Geological Terms).

The transformation of the types of mineral in porcelanite rocks.

Singer, (1963)



These minerals are belonging to the silica minerals family. Traifawi samples also contains very low percentage in dolomite [$\text{CaMg}(\text{CO}_3)_2$], and apatite ($\text{Ca}_5(\text{PO}_4)_3$) with traces of polygorskite (hydrous Mg- silicate).

The reason for the higher percentage of silica minerals in the porcelanite samples from traifawi member – H₃ area when compard to Al-Safra member is that the latter contain high percentage in calcium – magnesium carbonate (dolomite $\text{CaMg}(\text{CO}_3)_2$) and low percentage in silica (SiO_2) (about 70%).

(Al-Bassam et. al, 1993)

The sample from Traifawi member – H₃ area contains high silica percent (about 80%) and very low percent in calcium magnesium carbonate (dolomite). This mean that silica content is inversely proportional to the calcium magnesium carbonate in the porcelanite rocks.

3.8. Mechanisms of Filtration

The solid removal efficiency is inversely proportional to sand grain size, filtration rate, and to the square of water viscosity, Masters, (1991). Viscosity is the ability of a liquid to resist various movements, both internal and overall, such as flow. It is the basic of head loss and therefore plays an important part in water treatment. It increases with higher content of dissolved salts and pressure. It diminishes when temperature increases, Degremont, (1991).

Most municipal water treatment systems filter their water through a deep granular bed of porous media. The most commonly used filtration

process is rapid sand filtration. The particle removal experienced in this type of filtration is known as rapid depth filtration. In rapid depth filtration, there are several mechanisms responsible for the removal of particles from water. The simplest of these mechanisms takes place with larger particles and is known as screening. Screening takes place when a particle which is to be filtered out is larger than the smallest pore through which the water must pass. Screening usually takes place near the surface of the filter, and is responsible for removing only the largest particles from the water being treated (AWWA, 1999).

3.8.1 Transport mechanism:

This is simply a process of bringing particles from the bulk of the fluid within the interstices close to the surface of the grains. Transport mechanisms may include mechanical straining, gravitational settling, interception, inertia, hydrodynamics, and Brownian diffusion as shown in Fig. (2-4) . These mechanisms are affected by physical characteristics such as size and shape of the filter grains, filtration rate, fluid temperature and the density, size, and shape of the suspended particles, Letterman, (1999).

Straining removes particles that are large enough to get caught in the pores. It is considered the most important mechanism that takes place almost in the top few centimeters of the filter medium. Gravitational settling proposes that each pore in the filter medium is a tiny sedimentation basin. Gravitation forces tend to cause particles of density higher than water to move across streamlines in the force direction.

Interception occurs when particles flowing in streamlines through the filters pass the medium within the particle radius, then they will tend to be in contact with the medium. A particle's inertia can cause it to leave the streamline and make contact with the grain when a medium grain causes the divergence of flow around it. Hydrodynamic action occurs when the flow

through the filter is laminar, the velocity gradient across the streamline can cause the particles to spin and this in turn causes them to veer across the streamline, Jago, (1977).

Interception works only with relatively large particles as smaller particles would not tend to contact the filter media when traveling along laminar flow lines .Eurofiltec, (2002).

The final transport mechanism responsible for the removal of particles from water is known as diffusional or Brownian interception. This type of interception takes place with small particles that have a density close to that of water. Particles being transported by this mechanism exhibit seemingly random motion known as Brownian motion ,Henke, (2002).

Diffusion results from random Brownian motion by bombardment of the particle by molecules of water. This became increasingly important for particles ($<1\ \mu\text{m}$) in size, i.e., as they approach the size of water molecules, Amirtharajah, (1988). Brownian motion is the result of continuous collisions between the particle and the surrounding fluid. The main driving force behind Brownian motion is the thermal energy present in the fluid (HDR Engineering, Inc., 2001).

The pore openings of the sand media are often larger than the flocculent particles to be removed, so in rapid filter systems there are a combination of techniques for the removal of suspended solids and particulate matter from the influent. These techniques include: simple straining, adsorption, and sedimentation, Drain, (2001). As shown in Fig.(3-8)

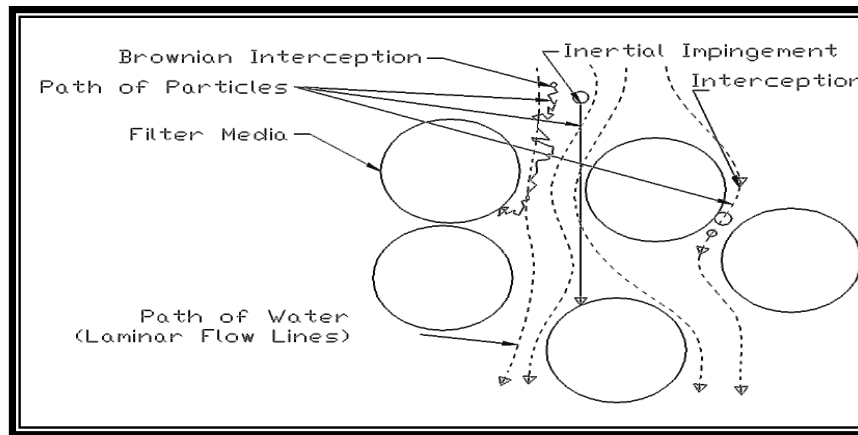


Fig. (3-8): Transportation Mechanisms in Rapid Depth Filtration

3.8.2 Attachment mechanism:

The mechanism of attachment of suspended particles to the surface of the filtering material is known as adsorption. It is physical in nature as it has opposition to chemical adsorption a reversible characteristic, which permits the regeneration of the adsorbent, it may include mainly Van der waals forces, electrostatic repulsive forces, and surface tension, Leclerc & Vu, (1972).

After a particle comes in contact with the filter media, it must attach to the media and stay attached. For attachment to occur a particle must be sufficiently destabilized so that a net attractive force is present between the particle and the filter media. Particles are destabilized by the various destabilization mechanisms of coagulants. Attachment of particles to filter media is similar to the aggregation of destabilized particles during flocculation (HDR Engineering, Inc., 2001).

Particle removal in granular filters is not an irreversible process and detachment of particles may occur when forces shearing the particles away from the media grain are greater than the adhesive forces holding the particle, (Crittenden, et al, 2005).

Van der waals forces are well known as attractive forces between molecules and theoretically they apply to nearly all materials in water but

their range is usually limited to minute distances of less than 0.05 μm , (Twort et al., 2000).

Electrostatic repulsive forces attract particles to the media. This occurs to a limited extent in rapid sand filters, (Unit Standard 18452, 2002).

3.8.3 Detachment mechanism:

As a result of the previous mechanisms, the space between the walls of the material covered with particles that have been already deposited will decrease. Consequently, the velocity of flow increases. The retained deposits may become partially detached and be driven deeper into the filter material or even be carried off in the filtrate, Degremont, (1991).

Surface tension is defined as a tensile force and which tends to reduce the area of this surface to the greatest possible extent. The addition of dissolved salts generally increases surface tension, Degremont, (1991).

3.9. Parameters Effecting the Coagulation and Filtration Processes

The following parameters are to be considered in evaluating the performance of conventional water and wastewater treatment plants.

3.9.1 Temperature

The water and wastewater temperature is of importance because it affects many parameters that impact engineering designs. These parameters include density, viscosity, vapor pressure, surface tension, solubility, the saturation value of gases dissolved in water and the rates of chemical, biochemical and biological activity. Cold water generally requires more chemicals for efficient coagulation and flocculation to take place (Crittenden, et al, 2005).

According to (WSO, 2003), Water with higher temperatures may result in a higher chlorine demand because of increased reactivity and also because there is usually an increased level of organic matter such as algae and bacteria in the raw water.

The effect of water temperature on the backwash rate is significant, when the temperature increases the backwash rate also increases, Kawamura, (2000)

3.9.2 pH

This parameter controls many chemical reactions including coagulation, disinfection, water softening, corrosion, biochemical reactions and ammonia removal. It also indicates the designer, what construction materials to use, (WSO, 2003). The chlorination is less effective to kill bacteria at high pH values, (WHO, 1989).

In a limited number of cases, a pretreatment and filtration at pH (5.7) achieved better pathogen removal than a pretreatment and filtration at pH (7), (Harrington et al, 2003)

3.9.3 Turbidity

This property is caused by suspended particles in water. These particles cause light rays to be scattered rather than to be transmitted in straight lines making a matter appear cloudy.

Suspended particles in water and wastewater causing turbidity include organic and inorganic matter and plankton.

3.9.4 Conductivity

Conductivity is the ability of an aqueous solution to carry an electric current. Solutions of most inorganic compounds are relatively good conductors conversely; molecules of organic compounds that do not dissociate in aqueous solution conduct a current very poorly. Conductivity evaluates variations in the concentration of dissolved minerals in water sources, (WSO, 2003).

3.9.5 Total Dissolved Solids (TDS)

The presence of harmful dissolved compounds or ions (such as arsenic and mercury) can be dangerous in water even where the total solids concentrations are relatively low, (WSO, 2003).

Dissolved solids in drinking water tend to change the water's physical and chemical nature.

It refers to the total filterable residue in natural water consisting mainly carbonates, bicarbonates, chloride, sulfate, calcium, magnesium, sodium, and potassium. Dissolved metals, dissolved organic and other substances also account as a portion of the dissolved residue in water.

3.9.6 Biochemical Oxygen Demand

Biochemical Oxygen Demand is the amount of oxygen required in the oxidation of organic matter by biological action under specific standard test conditions. This is widely used to measure the amount of organic pollution in wastewater and streams. BOD is used to measure how well a sewage treatment plant is working. If the effluent, the treated wastewater produced by a treatment plant, has a high content of organic pollutants or ammonia, it will demand more oxygen from the water and leave the water with less oxygen to support fish and other aquatic life.

Biochemical Oxygen Demand (BOD) is a chemical procedure for determining how fast biological organisms use up oxygen in a body of water. It is used in water quality management and assessment, ecology and environmental science. BOD is not an accurate quantitative test, although it could be considered as an indication of the quality of a water source.

Organic matter and ammonia are “oxygen-demanding” substances. Oxygen-demanding substances are contributed by domestic sewage and agricultural and industrial wastes of both plant and animal origin, such as those from food processing, paper mills, tanning, and other manufacturing processes. These substances are usually destroyed or converted to other compounds by bacteria if there is sufficient oxygen present in the water, but the dissolved oxygen needed to sustain fish life is used up in this break down process. (EPA 2004)

Biochemical Oxygen Demand (BOD₅) is the most commonly used parameter to express the strength of municipal and industrial wastewaters. The BOD₅ test is important for the design of biological treatment facilities, determining organic loadings to treatment plants, and evaluating the efficiency of treatment systems. The BOD of wastewater is not a single point, but rather a time– dependent variable. A 5 d incubation has become a standard practice. It takes approximately 20 d to stabilize all biodegradable organic matter and nitrogen contained in a wastewater sample (Qasim , S,1999).

CHAPTER FOUR

Experimental Work

4-1 Introduction

This chapter presents the experimental work of the present study. A pilot plant as shown in a schematic diagram in Fig. (4.1) was constructed to perform the processes of coagulation, flocculation, sedimentation and filtration. During this study two hundreds runs were conducted in the Laboratory of Al-Muamera wastewater treatment plant of Hilla city.

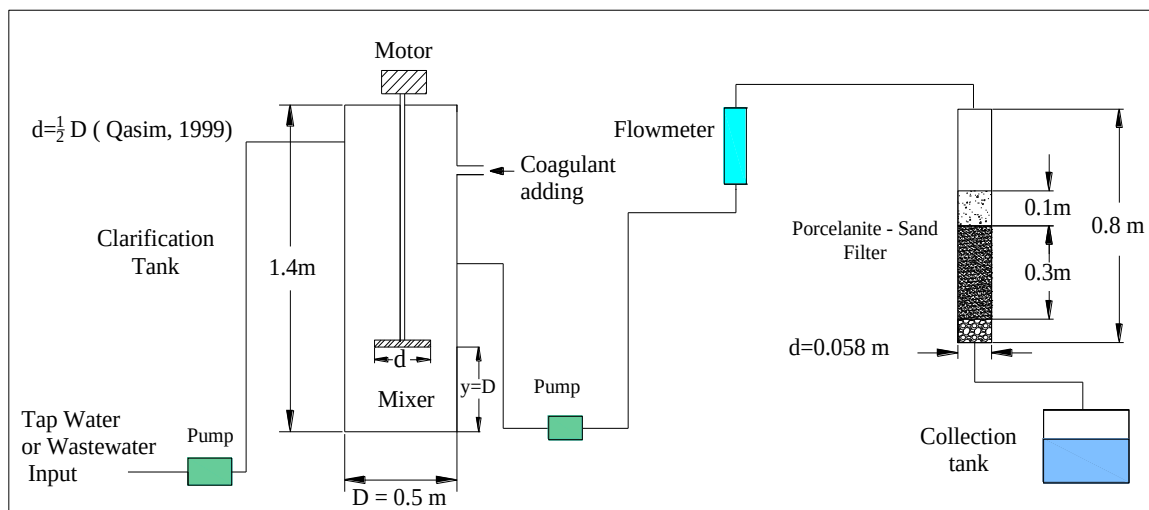


**Fig.(4-1):A Schematic Diagram of the Pilot Plant Used in the Study
for Treatment of Water and Wastewater**

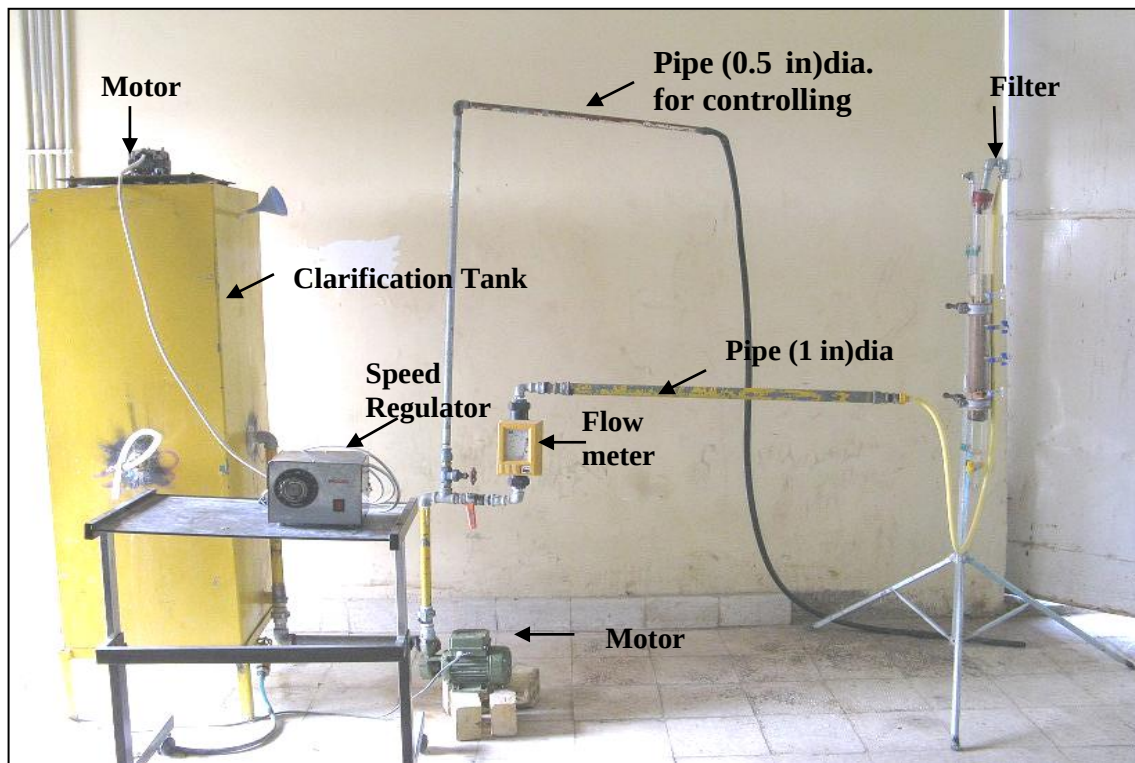


Fig. (4-2): The Pilot Plant Used

The description of each device and other apparatuses used are presented as follow :

4.2 The Pilot Plant Units

4.2.1 The Tank Used in the Experimental Work:

The tank used in this study has a capacity of (350 ℓ), and it has dimension of (1.4m x 0.5m x 0.5m). A stainless steel paddle mixer was connected to the tank for two purposes: firstly for preparing synthetic raw water and secondly to mix the coagulants with raw water .The mixer was driven by a motor , which was connected to a speed regulator . mixing of water and wastewater was done continuously. Three processes(coagulation, flocculation and sedimentation) were conducted in this tank.(Qasim , S,1999).

4.2.2 Rapid Mixer:-

In this process destabilization of colloids was achieved by using different types of coagulants and electrically driven stirring propeller, to disperse these coagulants(Qasim , S,1999).The stirrer has a constant rotation speed equal to (250 rpm) with mixing time of (1min).(A specification of jar test).

4.2.3 Flocculation process :-

Flocculation process is the formation of bigger flocs by agglomeration of small ones. This process obtained after a destabilization of colloids occurred in rapid mixing process.

The value of speed was maintained constant at a value of (60 rpm).The mixing time was equal to a value of (15-20 min).(A specification of jar test).

4.2.4 The Pumps Used

In this study two pumps were used , the first one is to supply water and wastewater to the tank. The second pump was used to deliver settled water or wastewater from the tank to the filter. The pumps were of specification of :

Type: Italy - SAER

Power=0.5 HP= 0.37 KW

Speed= 2850 rpm

H=50 , A= 2.3

Volt = 220 V

4.2.5 Flow-Meter

To measure the water flow rate, a standard flow meter was used. The filtration rate was kept constant at a value of (5ℓ /hr). The flow meter consisted of a plastic-metering tube with a stainless steel float, and was fixed vertically. The calibration process was carried before using. The calibration curve is shown in appendix (B).

4.2.6 Filter Used :-

In this study a vertical pyrex glass filter column was used. It has a dimension of (5.8 cm diameter) and length of (80 cm). There are two types of filters used. The first filter has a sand bed of (single media) of height 40 cm, while the type of second filter is a dual media of sand bed of 30 cm in height and 10 cm of porcelanite height. Kawamura, (1999).

4-3 Apparatus

4.3.1 Turbidimeter:-

Turbidity is a measure of the ability of water to scatter light and it depends upon the shape, size, number and the refractive index of the suspended particles. The turbid meter is an instrument used to measure turbidity of water by balancing the scattered and transmitted light intensities for a defined condition for illumination using closed glasses containing formalize polymers as standard suspensions. (A Hach model 2100-A), was used for measuring the turbidity .

4.3.2 Standard Sieves :-

An American (US) sieve series of (4, 10, 16, 40,100,200) with a standard shaker were used in the sieving analysis of different media samples in order to determine, effective size (E.S) and uniformity coefficient (U.C).

4.3.3 Balances:-

Two balances were used in the experimental work. The first one was used to measure the weight of the required amounts of coagulants and kaolinite clay (colloidal suspension). This balance was of model (ADAM AAA) with an accuracy of 1×10^{-4} grams. The second balance was used to measure the weight of sieves during sieving and the weights of the required amounts of filter media. The second one was of model of (Sartorius 1204 M_P) with an accuracy of 1×10^{-2} grams.



Fig.(4-3):The First Balance

4.3.4 Conductivity meter :-

The ability of water to conduct an electric current is known as conductivity or specific conductance and it depends on the concentration of ions in solution. Conductivity is measured in millisiemens per metre ($1 \text{ mS/ m} = 10 \mu\text{S /cm} = 10 \mu \text{ mhos /cm}$).

Conductivity were measured by a conductivity meter of type [JENWAY, 4510].

4.3.5 pH meter :-

The pH and temperature values were measured by using the pH meter of type named (Schott). The temperature of water and wastewater in this study was being from (9-20) °C



Fig.(4-4):pH meter

4.3.6 DO meter:-

The DO meter is used to measure the dissolved oxygen and this measuring helps to determine the Biochemical Oxygen Demand

(BOD₅) value. The dissolved oxygen is determined in the diluted sample initially and after incubation at 20°C for 5 d. The DO meter used in this study is of (HACH /LDO) type.



Fig.(4-5):DO meter

4.4 Turbidity Material :-

The turbidity material used in the experimental work is from kaolinite (which passed through sieve No 200). The kaolinite has a particle size distribution as shown in Fig.(4.6). Table (4-1) presents the chemical analysis of kaolinite used in this study

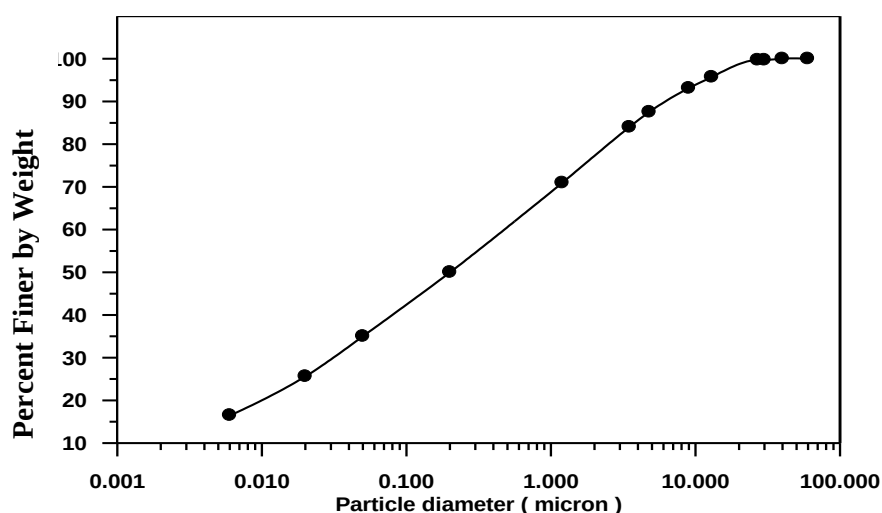


Fig. (4.6): Particle Size Distribution of Kaolinite

Table (4-1) :Chemical Analysis of Kaolinite Used

CaO %	TiO ₂ %	Fe ₂ O ₃ %	SiO ₂ %	Al ₂ O ₃ %
0.3-1.1	0.35-1.65	0.5-1.36	45-58.5	28.4-37.9

4.5 The Coagulants Used

4.5.1 Alum:-

The Iraqi alum or (local alum) is used in this study. The aluminum sulfate used in these experiments as coagulant has the chemical formula of $[\text{Al}_2(\text{SO}_4)_3 \cdot 16\text{H}_2\text{O}]$ which is always used in the water treatment plants. The chemical analysis of Iraqi alum was done by the laboratory of the General Corporation of Water and Sewage in the year of (2002). The results are presented in Table (4-2) below.

Table (4-2): Chemical Analysis of Iraqi Alum (after Intidhar,2002)

Acidity %	Basicity %	Total alumina%	Insoluble matter	pH
NIL	0.08	14	14.45	3.08

The Alkalinity concentration of tap water used is sufficient for alum reaction with water without of pH - adjustment.

4.5.2 Coagulant aid (Porcelanite Powder):-

Local material of porcelanite was used as coagulant aid. The particle size is between (0.07 – 0.1) mm, with effective size of (0.085 mm) and the value of uniformity coefficient was (3.18). The porcelanite was supplied from the General Establishment for Geological Survey and Mineralogy-Ministry of Industry and Minerals (GEGSM). The chemical and physical analysis of the porcelanite is shown in Table (4-3). The particle size distribution is shown in Fig. (4.7)

**Table (4-3) :Chemical and Physical Analysis of Porcelanite
Used in this Study, (GEGSM)**

Chemical Composition %	SiO ₃	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	Na ₂ O	K ₂ O	L.O.I
	83.57	0.62	4.45	0.01	1.82	1.46	0.5	0.16	0.22	5.9
Specific gravity (SG)		Range for 5 Sample			Average (SG)			Recommendation		
		1.5-1.61			1.554			Ok		
Porosity		0.52								

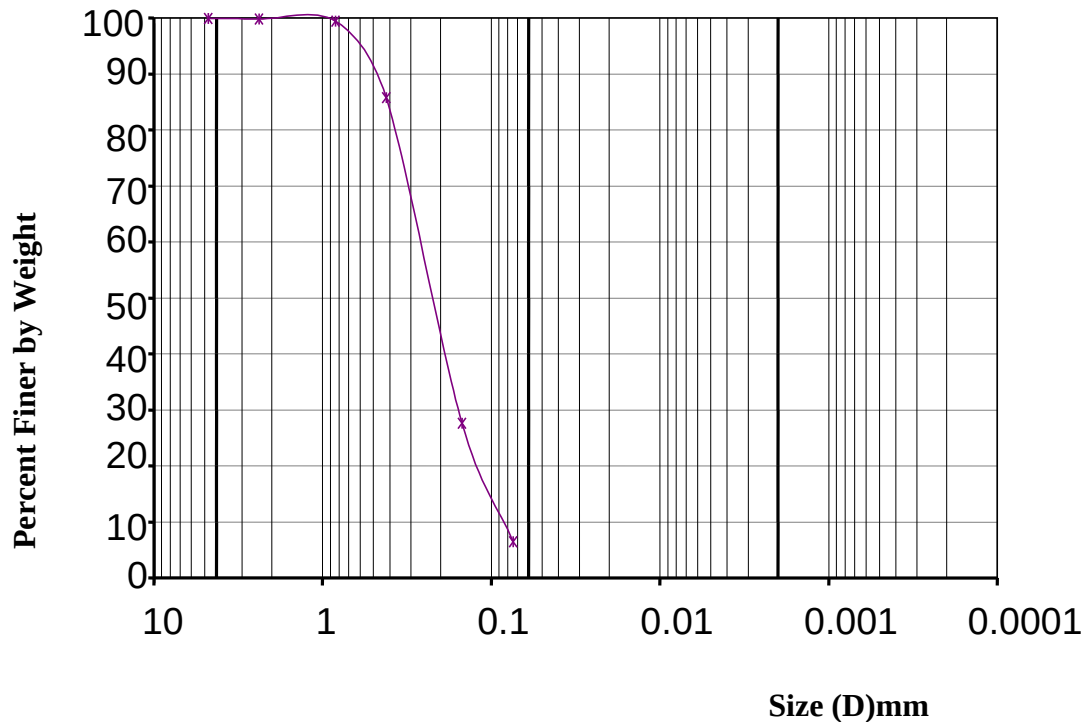


Fig. (4-7): Particle Size Distribution of Powder Porcelanite Used

4.6 Filter media

4.6.1 Sand:-

The properties of the sand media was used with all filters of the water treatment plants in Iraq are durable, hard, spherical form, and it has density of 2500 to 2670 kg/m³. The sand used in this study hasn't organic material content, the sulfate does not exceed 1 % [Iraqi specification No. (1555)]. A sample of sand was sieved by the set of American US standard sieves to determine the effective size (E.S) and uniformity coefficient (U.C).

In this study The effective size of sand particles is of 0.45 mm , while the uniformity coefficient is of a value equal to 1.71. Fig. (4.8) shows the particle size distribution of sand material

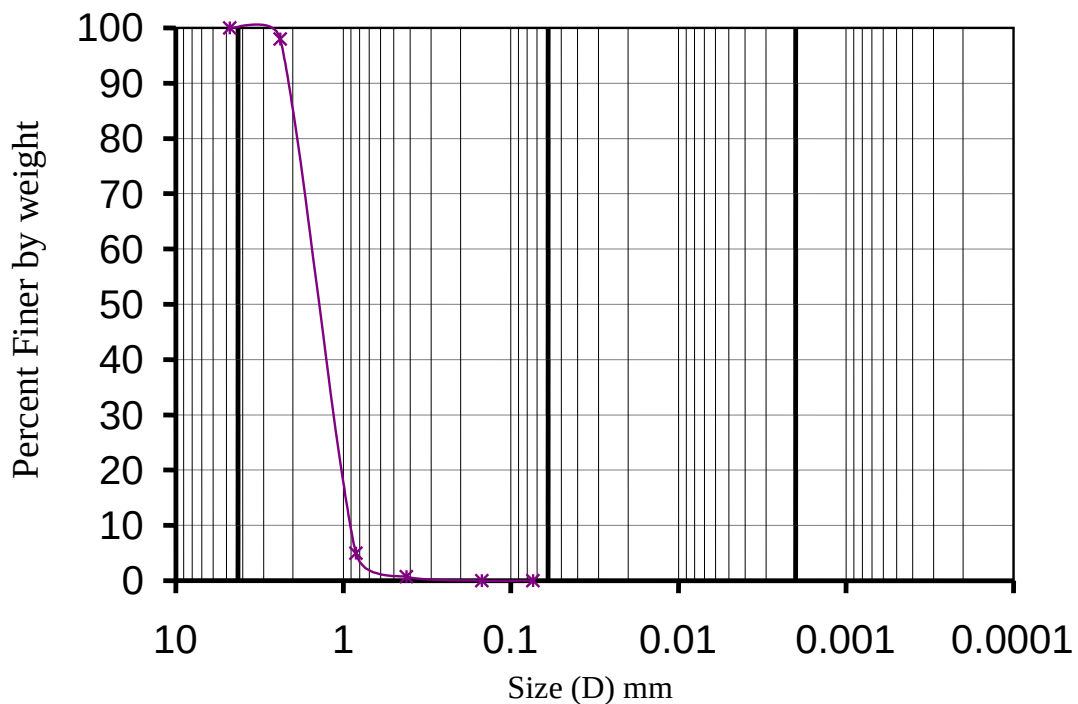


Fig. (4-8): Particle Size Distribution of Sand material

4.6.2 Local Porcelanite Rocks

In this study a sample of porcelanite rocks was sieved by a set of US standard sieves to determine the E.S and U.C .The effective size of porcelanite particles is 0.9 mm , while the uniformity coefficient is of a value equal to 1.74. After sieving process the porcelanite was washed with tap water for several times to remove dust and fine particles. The porcelanite media has a particle size distribution as shown in Fig. (4.9).

Al-Ansary used narrow range of porcelanite particles passing through a 0.85 mm standard sieve and retained on 0.6 mm sieve to give average diameter of 0.725 mm .

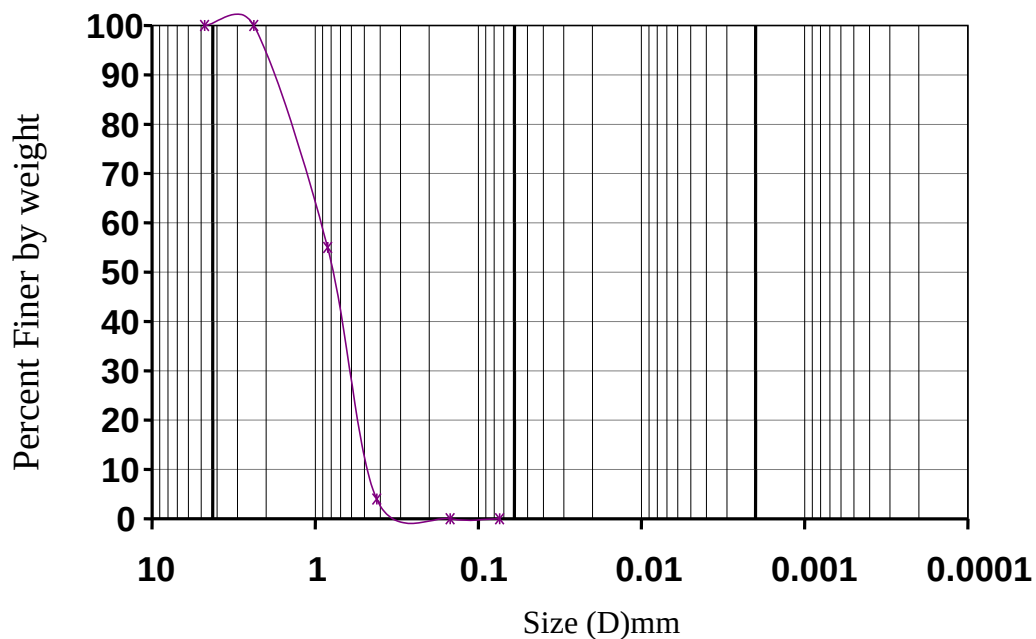


**Fig.(4.9) :Particle Size Distribution of Porcelanite Rocks Samples
Used in this Stud**

4.6.3 Supporting Gravel Layer :-

The drainage system of the filter was constructed of gravel-supporting layer. The size of gravel layer is between (2.38 to 6.5 mm). The thickness of gravel layer is of (10 cm). The gravel used was sieved, washed and then packed into the column.

4.7 Experimental Procedure

4.7.1 Synthetic Turbid Water :-

In this study the synthetic turbid water was used in the experimental work is made by mixing koalinite material with tap water to achieve the desired values of initial turbidity of (10, 50, 100,150,200)NTU.

4.7.2 Determination of Coagulant Dosage :-

The tank used in this study was filled with the capacity of (200 ℓ) with tap water or wastewater. Different dosages of aluminum sulphate , aluminum sulphate and porcelanite were added to the water in the tank .

The tank contents was stirred rapidly for (1min), with rotating speed (250 rpm) ,then the contents were mixed slowly for (15-20 min)with rotating speed of (60 rpm) .The sedimentation time flocs were allowed to settle (30min), then it was possible to determine the optimum dosage of coagulant . In this study alum and alum with porcelanite were added with different dosages of (10, 20,30,40,50) mg /ℓ .

4.7.3 Determination of the Best Percentage of Coagulant and Coagulant Aid :-

The alum used with coagulant aid (porcelanite) material with the different percentage is shown in table (4-4) .These percentages were used for all dosages added in this study.

Table (4-4) :Percentages of Alum with Porcelanite

Run No.	Alum percentage %	Porcelanite percentage %
1	100	0
2	50	50
3	60	40
4	75	25

4.7.4 Measurement of Organic Contents (Biochemical Oxygen Demand BOD5) :-

In this study the BOD₅ test is conducted by placing a measured amount of wastewater in a 300-ml standard BOD bottle and filling the bottle with dilution water that contains the essential nutrients and is saturated with dissolved oxygen. Well- acclimated microbial seed may be supplied if sufficient microorganisms are not already present in the wastewater sample.

The dissolved oxygen is determined in the diluted sample initially and after incubation at 20°C for 5 d. Fig.(4-10) shows samples of BOD₅ inside the incubator used in this study.

In this study three samples of BOD₅ were measured for each run :

- (1) Initial BOD₅(before adding the coagulant)
- (2) Before filtration process (after adding the coagulant)
- (3) After filtration process



Fig.(4-10) :Samples of BOD₅ Inside the Incubator

CHAPTER FIVE

Results and Discussion

5-1 Introduction

In this chapter the results of all the experimental work are presented and discussed. The following discussion deals with the performance of the pilot plant used according to the tests performed on the influent and effluent of the water flow system. Results obtained, using alum with local material such as (porcelanite) , were used in evaluating the effect of this material on the residual turbidity and organic matter concentration of water and wastewater in coagulation and filtration processes . three studies were conducted in this research , in study No.1 different ratios of alum to porcelanite were tested while studies No.2 and No.3 consist of all the experiments on the water and wastewater respectively.

5.2 Study No. 1 :

This study includes the selecting of the best percentage of (A/P), where A is mean alum and P is mean porcelanite. Initially different ratio of A/P were done and discussed, and then minimum residual turbidity ratio was indicated and selected as the optimum ratio and used for all experiments.

Table (5-1) presents four sets of run; each set contains five different dosages of alum with different dosage of porcelanite in order to obtain the best dosages of alum and porcelanite.

Fig. (5-1) shows the relationship between the dosages of coagulants (alum, alum +porcelanite) in mg/l and the efficiency of turbidity removal in percent, with a different percentage of alum and porcelanite.

Blank-Beaker were carried out without adding the coagulant under same condition of time and speed of mixing and sedimentation for checking the effect of mixing and other condition on the residual turbidity.

Table (5-1) Summery of Experiments of Study No.1

Set No.	Dosage of coagulant mg/ℓ	Percentage of alum %	Dosage of alum mg/ℓ	Percentage of Porcelanite %	Dosage of porcelanite mg/ℓ
1	10	100	10	0	0
	20	100	20	0	0
	30	100	30	0	0
	40	100	40	0	0
	50	100	50	0	0
2	10	50	5	50	5
	20	50	10	50	10
	30	50	15	50	15
	40	50	20	50	20
	50	50	25	50	25
3	10	60	6	40	4
	20	60	12	40	8
	30	60	18	40	12
	40	60	24	40	16
	50	60	30	40	20
4	10	75	7.5	25	2.5
	20	75	15	25	5
	30	75	23	25	7
	40	75	30	25	10
	50	75	38	25	12

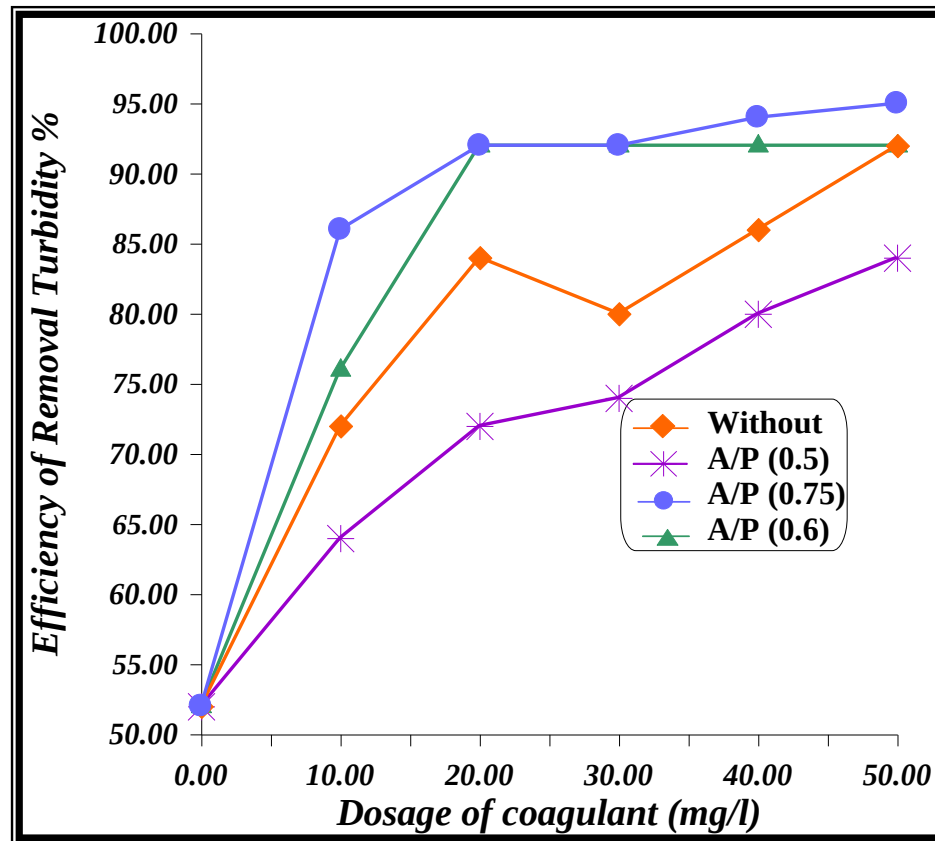


Fig. (5-1) :Variation of Efficiency of Removal Turbidity and Dosage of Alum with Different Dosages of Porcelanite

The results indicated that the percentage of 75% of alum and 25% of porcelanite can be considered as the best percentage to obtain minimum residual turbidity and for different levels of initial turbidity used in this study.

5.3 Study No.(2):

This study includes all the experimental work in coagulation and filtration processes of the water as follow:

5.3.1 Clarification Process

This study includes five different initial values of water turbidity namely 10, 50, 100, 150, and 200 NTU.

1. Initial turbidity of $T_0=10$ NTU

Fig. (5-2) shows the relation of dosage of alum and (alum with Porcelanite) versus efficiency of removal turbidity with initial water turbidity of 10 NTU .

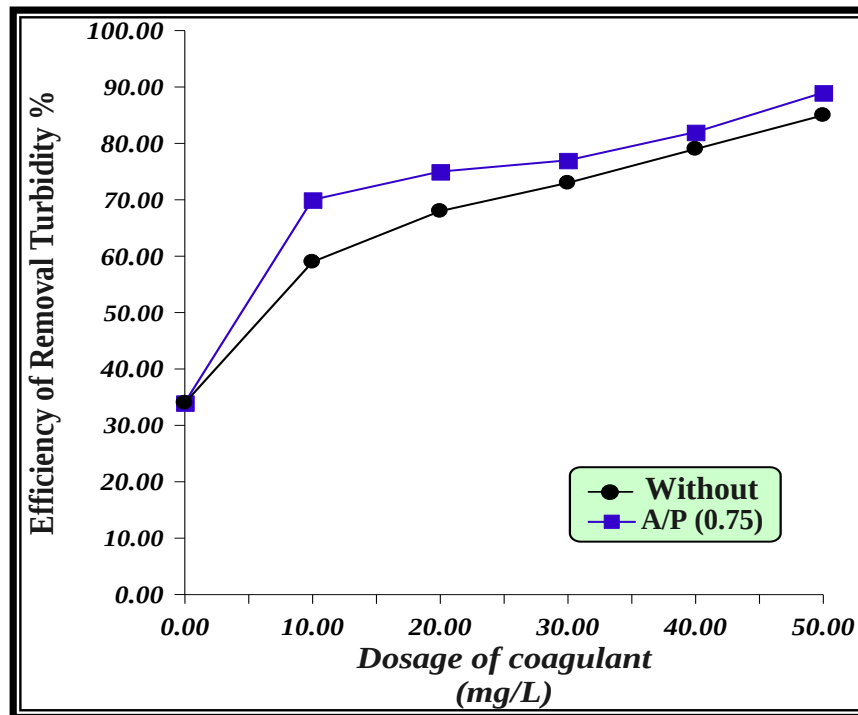


Fig. (5-2) : Turbidity Removal Versus Different Dosage of A/P under Initial Turbidity of (10 NTU)

It can be concluded that the best values of removal efficiency are obtained by adding dosages of alum with coagulant aid porcelanite .These values are better than those obtain by adding alum only.

2. Initial turbidity of $T_0=50$ NTU

Fig.(5-3) presents the variation of dosage of A/P percent with efficiency of removal turbidity under initial turbidity of (50 NTU).

One can be seen that any increase in the coagulant dosage leads to increase of the removal efficiency of water for five dosages of values between (10-50) mg/l.

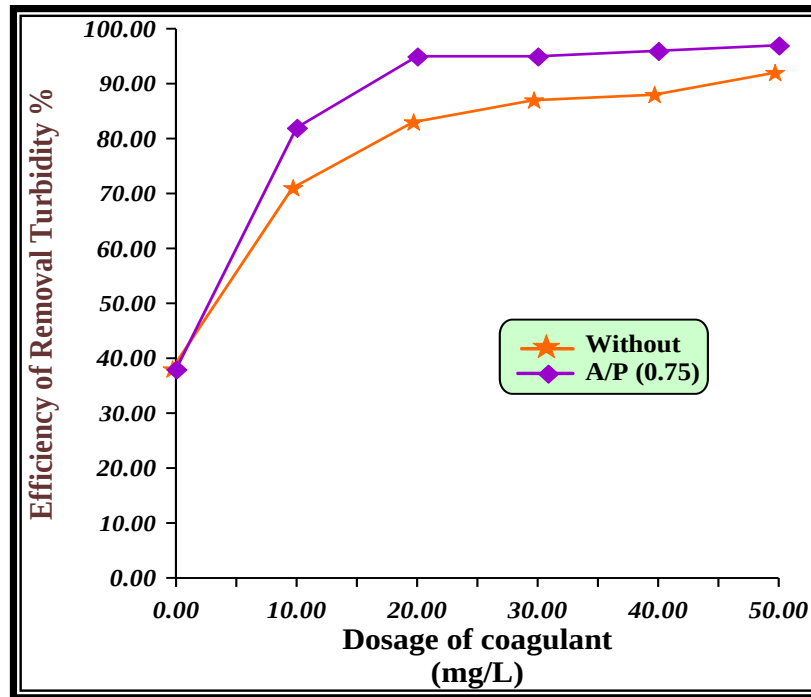


Fig. (5-3): Turbidity Removal Versus Different Dosage of (A/P) at the Initial Turbidity of (50 NTU)

In this figure the best values of removal efficiency are obtained by adding dosages of alum with coagulant aid porcelanite which is better than values obtained by adding alum only.

3. Initial turbidity of $T_0=100$ NTU

Fig.(5-4) indicated the relation of dosage of alum and alum with porcelanite versus the efficiency of removal turbidity under initial value of turbidity of (100 NTU).

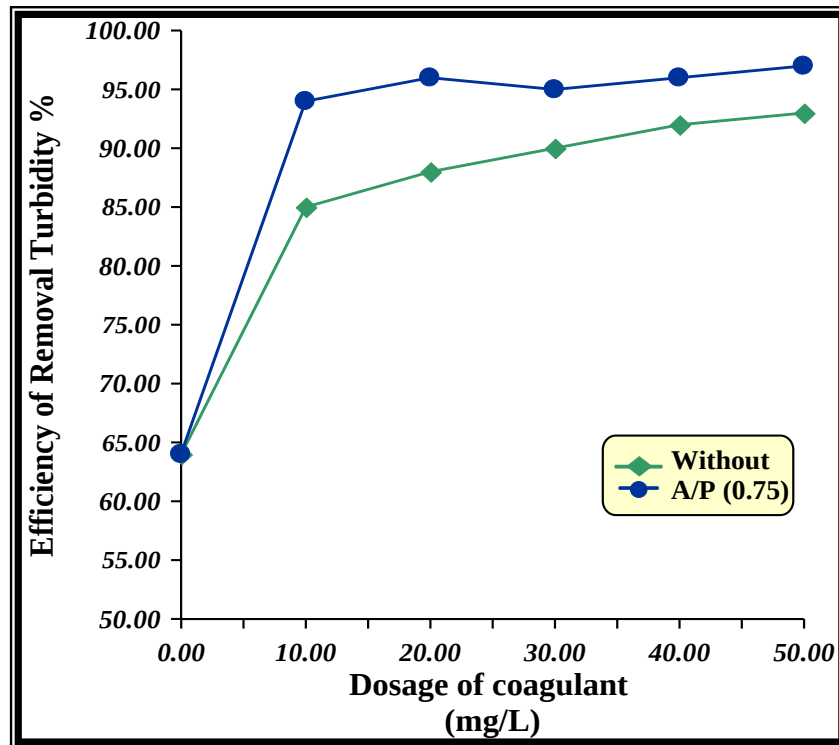


Fig. (5-4): Turbidity Removal Versus Different Dosage of (A/P)
at the Initial Turbidity of (100 NTU)

It can be noted that the using of porcelanite as coagulant aid with alum was better than using of alum only for the five dosages that namely 10,20,30,40,and 50mg/ℓ

4. Initial turbidity of $T_0=150$ NTU

Fig.(5-5) explain the variation of dosage of Alum and Alum with porcelanite and the efficiency of removal turbidity under initial value of turbidity of(150 NTU).

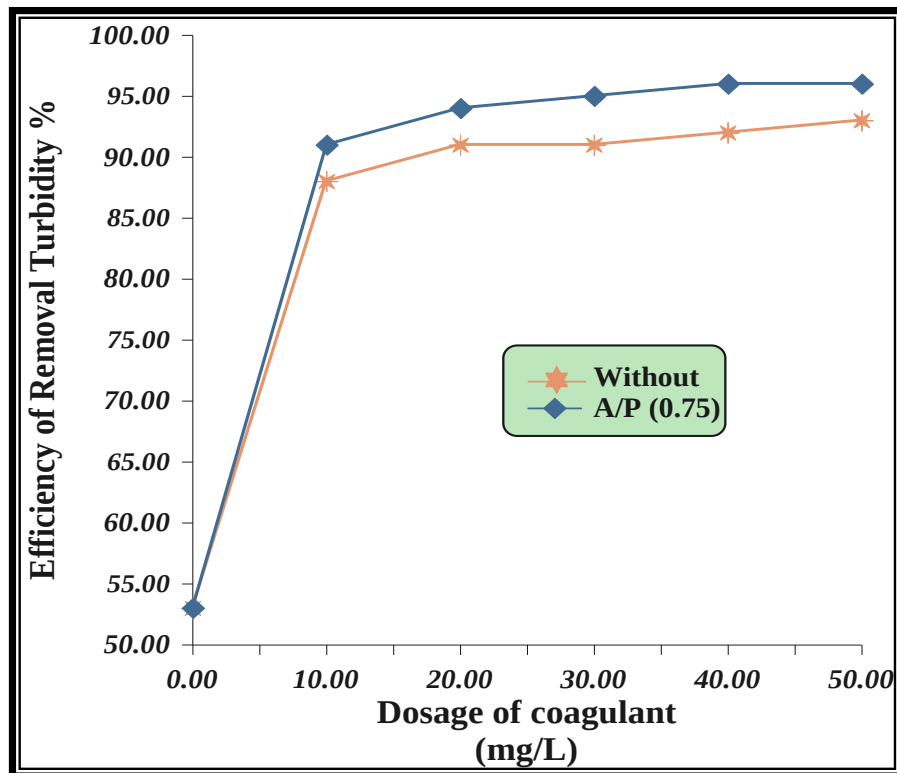


Fig. (5-5) : Turbidity Removal Versus Different Dosage of (A/P) at the Initial Turbidity of (150 NTU)

In this figure it can be noted that the increasing of dosages of alum or alum with coagulant aid porcelanite leads to increase of the value of removal efficiency .

From the analysis of results of this figure one can be concluded that the using of alum with coagulant aid porcelanite was better than using of alum only for the limited dosages between(10-50)mg/ℓ

5. Initial turbidity of $T_0=200\text{NTU}$

Fig.(5-6) presented the relationship between dosages of alum and alum with porcelanite and the efficiency of removal turbidity under initial value of (200 NTU).

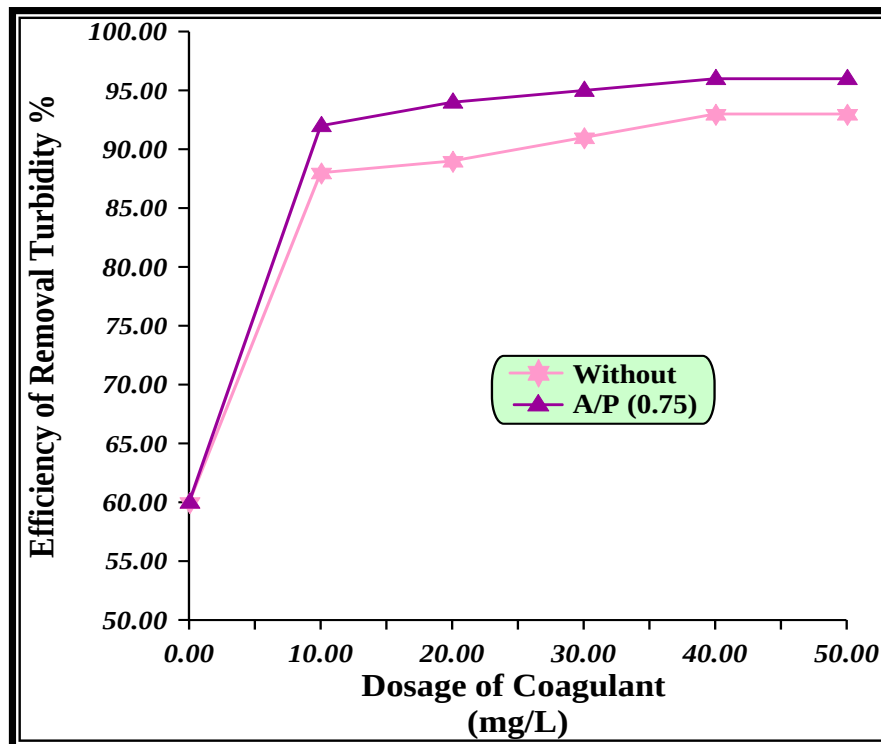


Fig. (5-6): Turbidity Removal Versus Different Dosage of (A/P)
at the Initial Turbidity of (200 NTU)

This figure shows that any increasing of dosages of alum or alum with coagulant aid porcelanite leads to increase the value of removal efficiency of the dosage in range of (10-50)mg/l.

The using of alum with coagulant aid porcelanite is giving better performance than that using of alum only .

5.3.2 Filtration process of Water

1. Initial turbidity of $T_0=10\text{NTU}$

Table (5-2) shows the efficiency of single media filter and the efficiency of dual media filter of removal turbidity under the initial turbidity of (10 NTU).

Table (5-2) :Efficiency of Filter Before and After Filtration Process for the Initial Turbidity (10 NTU)

Run No.	Coagulant type	Dose mg/ℓ	Filter type	Residual Turbidity		Efficiency %
				Before filtration	After filtration	
1	Alum	10	Single media	4.12	2.04	50.5
2		20		3.25	0.95	71
3		30		2.66	0.86	68
4		40		2.06	0.62	70
5		50		1.52	0.44	71
6	Alum	10	Dual media	4.75	1.35	72
7		20		3.54	0.54	85
8		30		2.86	0.41	86
9		40		2.08	0.25	88
10		50		1.77	0.2	89
11	Alum+Porcelanite	10	Single media	3.04	0.9	70
12		20		1.66	0.38	77
13		30		2.56	0.75	71
14		40		1.86	0.56	70
15		50		1.44	0.4	72
16	Alum+Porcelanite	10	Dual media	4.33	0.2	95
17		20		1.76	0.22	88
18		30		1.53	0.15	90
19		40		1.42	0.12	92
20		50		1.38	0.04	97

Fig. (5-7 and 5-8) explain the efficiency of filter of the removal turbidity after adding alum and alum with coagulant aid (porcelanite) respectively .

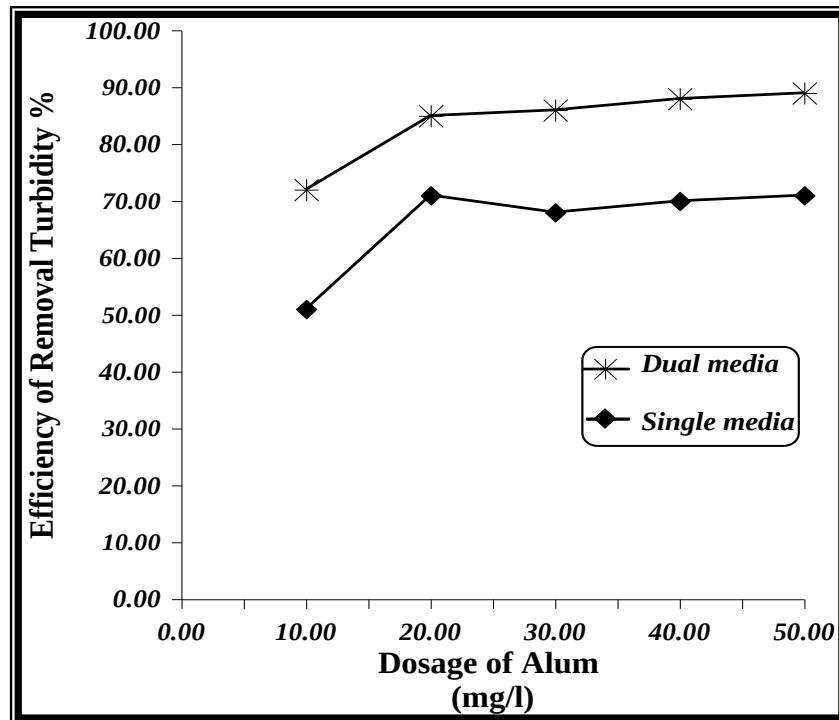


Fig. (5-7): Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media Filter

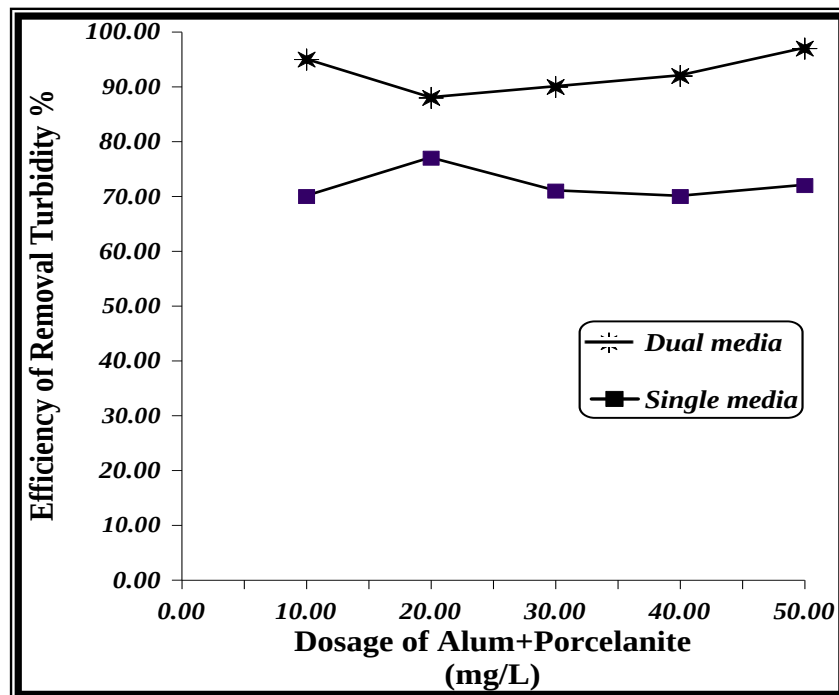


Fig. (5-8): Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

The results indicate that the dual media filter is better than that of single media filter in turbidity removal by approximately of 20% .

2. Initial turbidity of $T_0=50\text{NTU}$

Table (5-3) presents the efficiency of single media filter and the efficiency of dual media filter turbidity removal under the initial turbidity of (50 NTU).

Table (5-3): Efficiency of Filter Before and After Filtration Process under the Initial Turbidity (50 NTU)

Run No.	Coagulant type	Dose mg/l	Filter type	Residual Turbidity		Efficiency %
				Before filtration	After filtration	
1	Alum	10	Single media	10.56	3.04	71
2		20		5.5	1.2	78
3		30		4.2	1	76
4		40		2.95	0.85	71
5		50		2.52	0.8	68
6	Alum	10	Dual media	14.36	2.88	80
7		20		8.43	1.35	84
8		30		6.5	1	85
9		40		5.8	0.75	87
10		50		3.85	0.61	84
11	Alum+Porcelanite	10	Single media	8.92	2.21	75
12		20		2.93	0.34	88
13		30		2.65	0.54	80
14		40		2.25	0.44	80
15		50		1.52	0.35	77
16	Alum+Porcelanite	10	Dual media	8.91	1.02	89
17		20		5.42	0.33	94
18		30		3.88	0.4	90
19		40		2.28	0.25	89
20		50		1.69	0.2	88

Fig. (5-9 and 5-10) explain the efficiency of single media filter and dual media filter of turbidity removal ,by using alum and alum with coagulant aid porcelanite respectively .

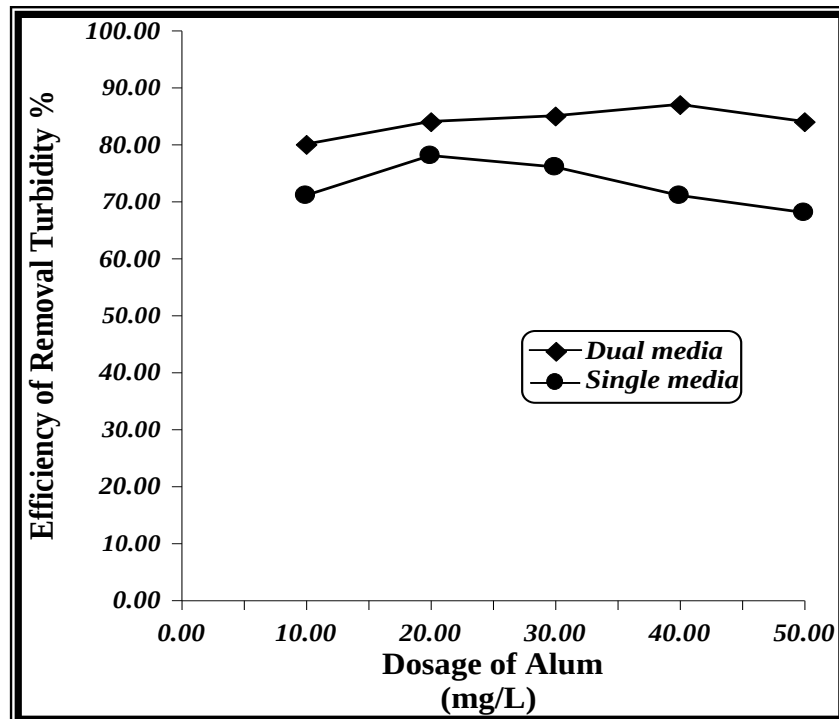


Fig. (5-9): Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media filter

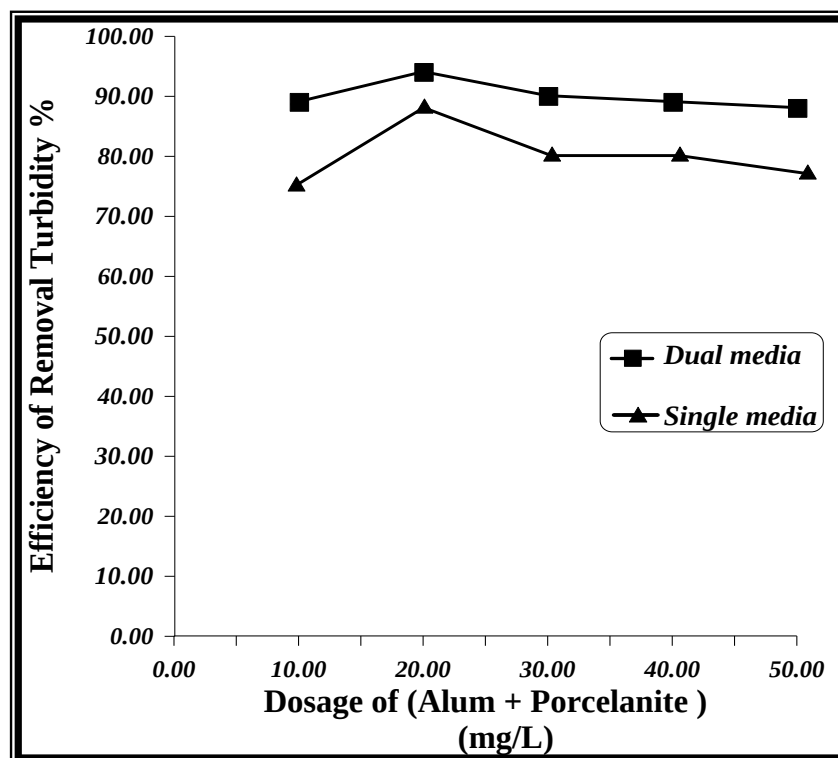


Fig. (5-10) : Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

The analysis of results refers to conclude that the dual media filter shows the better performance than that of single media filter in removing turbidity especially after adding alum with coagulant aid of porcelanite material.

The increasing of efficiency is of about 10% more than that obtained by using alum only.

3. Initial turbidity of $T_0=100\text{NTU}$

Table (5-4) present the data obtained of residual turbidity by using two types of filter media under the initial turbidity of 100 NTU.

Fig. (5-11 and 5-12) show the efficiency of single media filter and dual media filter of turbidity removal ,after adding alum and alum with coagulant aid of porcelanite respectively .

Table (5-4): Efficiency of Filter Before and After Filtration Process under the Initial Turbidity of (100 NTU)

Run No.	Coagulant type	Dose mg/l	Filter type	Residual Turbidity		Efficiency %
				Before filtration	After filtration	
1	Alum	10	Single media	15	3.98	73.5
2		20		12.3	2.76	78
3		30		9.05	2.25	75
4		40		8.16	1.75	79
5		50		6.68	1.32	80
6	Alum	10	Dual media	14.2	2.56	82
7		20		11.66	1.21	90
8		30		9.3	1	89
9		40		7.22	0.85	88
10		50		6.56	0.64	90
11	Alum+Porcelanite	10	Single media	6.1	1.42	77
12		20		4.23	0.75	82
13		30		5.5	1.2	78
14		40		3.95	0.95	76
15		50		3.44	0.67	81
16	Alum+Porcelanite	10	Dual media	5.35	0.36	93
17		20		4.12	0.22	95
18		30		4.87	0.45	91
19		40		3.56	0.25	93
20		50		3.23	0.15	95

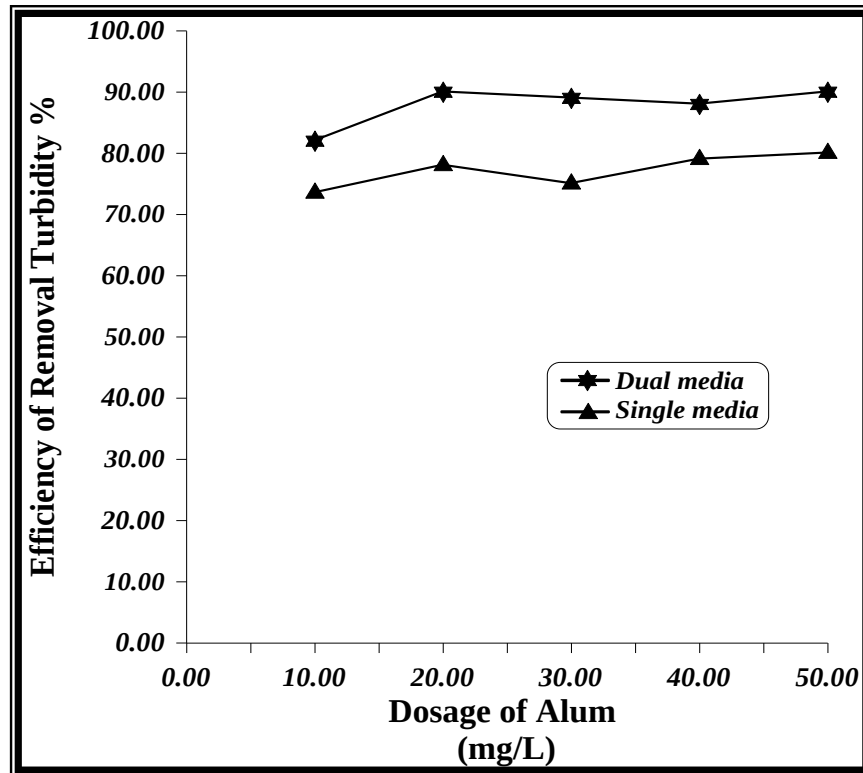


Fig. (5-11) Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media Filter

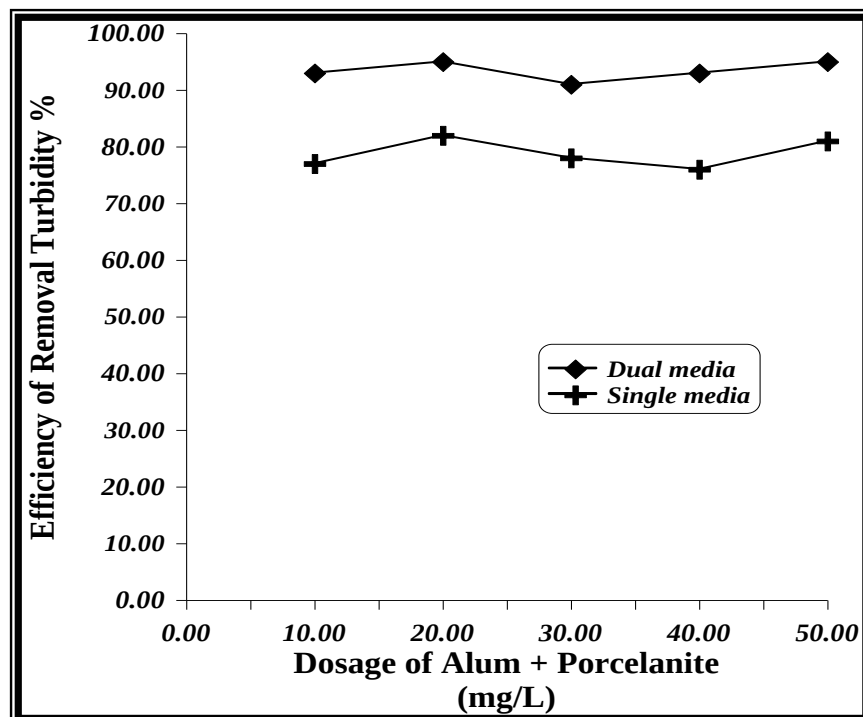


Fig. (5-12): Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

The results of the figures indicated that the using of dual media is better than that of single media by about of 10% after adding alum without coagulant aid .This percentage can be increased to a value of 15% by using alum with coagulant aid of porcelanite material.

4. Initial turbidity of $T_0=150\text{NTU}$

Table (5-5)shows the relation between dosage of coagulants(Alum , Alum with porcelanite) for two types of filter media (single media , and dual media).

Table (5-5) :Efficiency of Filter Before and After Filtration Process for the Initial Turbidity of (150 NTU)

Run No.	Coagulant type	Dose mg/l	Filter type	Residual Turbidity		Efficiency %
				Before filtration	After filtration	
1	Alum	10	Single media	18.6	4.68	75
2		20		12.5	2.95	76
3		30		9.6	2.45	74
4		40		8.5	1.85	78
5		50		7.7	1.44	81
6	Alum	10	Dual media	17.6	2.94	83
7		20		11.55	1.22	89
8		30		10.7	1.05	90
9		40		8.8	0.95	89
10		50		7.05	0.89	87
11	Alum+Porcelanite	10	Single media	14.6	3.12	79
12		20		8.86	1.62	82
13		30		8.2	1.75	79
14		40		6.7	1.46	78
15		50		6.1	1.25	80
16	Alum+Porcelanite	10	Dual media	14.5	1.14	92
17		20		8.5	0.52	94
18		30		7.8	0.56	93
19		40		6.5	0.35	95
20		50		5.86	0.45	92

Fig. (5-13 and 5-14) explain the efficiency of filter of turbidity removal with initial value of 150 NTU after adding alum ,alum with porcelanite respectively.

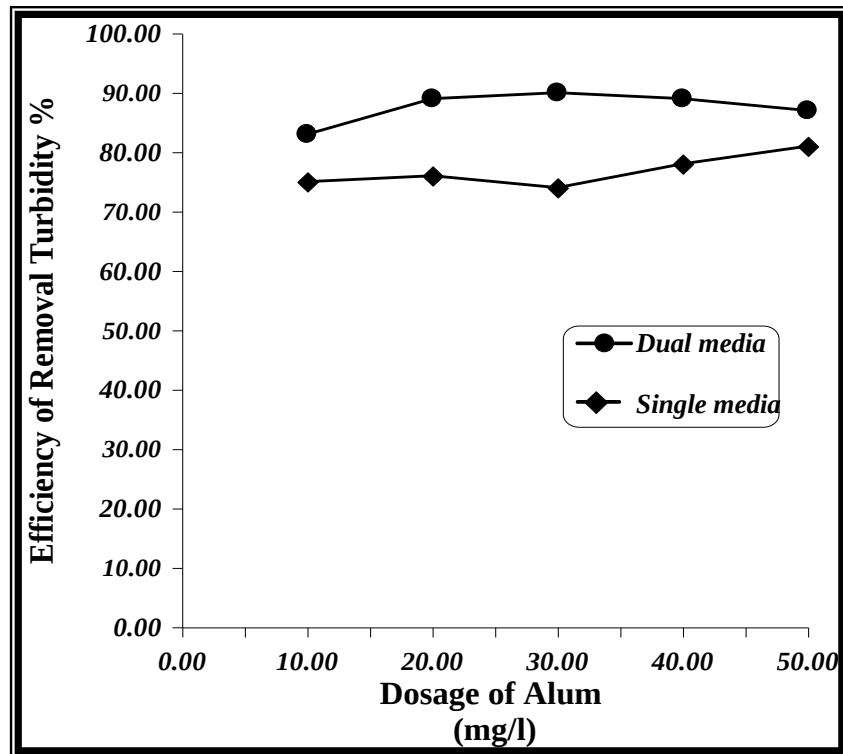


Fig. (5-13): Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media Filter

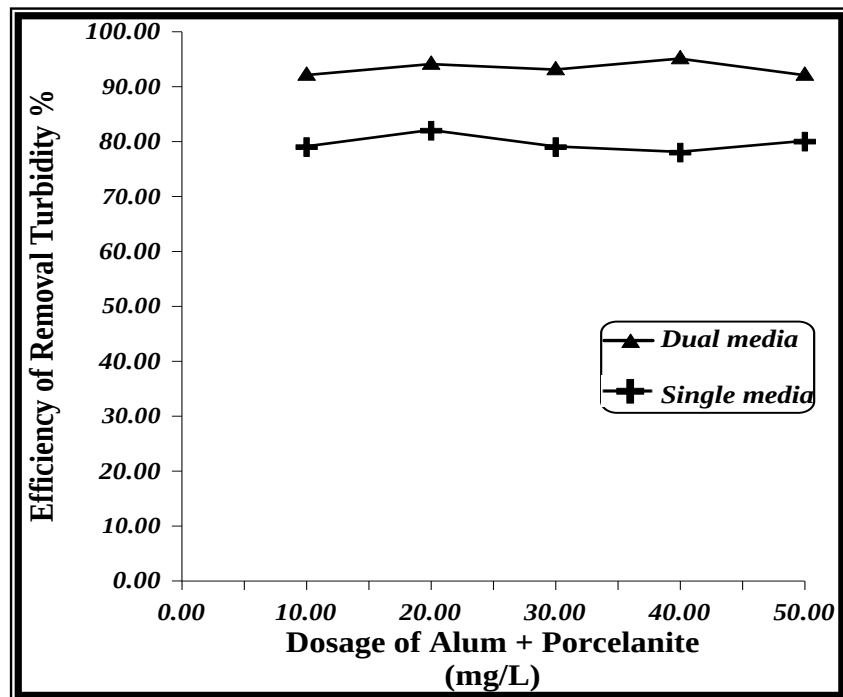


Fig. (5-14): Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

These figures indicate that the using of dual media was better than that of single media by about 11% after adding alum without coagulant aid, the

above percentage can be increased to a value of 14% after adding alum with coagulant aid porcelanite.

5. Initial turbidity of $T_0=200\text{NTU}$

Table (5-6) presents the relation between dosage of coagulants (alum, alum with porcelanite) for two types of filter media (single media , and dual media) with initial turbidity of 200 NTU.

Table (5-6): Residual Turbidity Before and After Filtration Process of the Initial Turbidity of (200 NTU)

Run No.	Coagulant type	Dose mg/l	Filter type	Residual Turbidity		Eff. %
				Before filtration	After filtration	
1	Alum	10	Single media	25	6.2	75
2		20		20	4.52	77
3		30		16.22	4.32	73
4		40		14.5	3.66	75
5		50		12.7	2.75	78
6	Alum	10	Dual media	24.2	3.8	84
7		20		21.5	2.35	89
8		30		18.25	1.85	90
9		40		14.33	1.65	88
10		50		13.02	0.98	92
11	Alum+Porcelanite	10	Single media	15.5	3.55	77
12		20		13.5	2.66	80
13		30		11	1.95	82
14		40		9.05	1.66	82
15		50		8.2	1.2	85
16	Alum+Porcelanite	10	Dual media	16.8	2.05	88
17		20		12.25	0.66	95
18		30		10.4	0.4	96
19		40		9	0.5	94
20		50		8.5	0.22	97

Fig. (5-15 and 5-16) show the efficiency of filter of turbidity removal with initial value of 200 NTU after adding alum ,alum with porcelanite respectively.

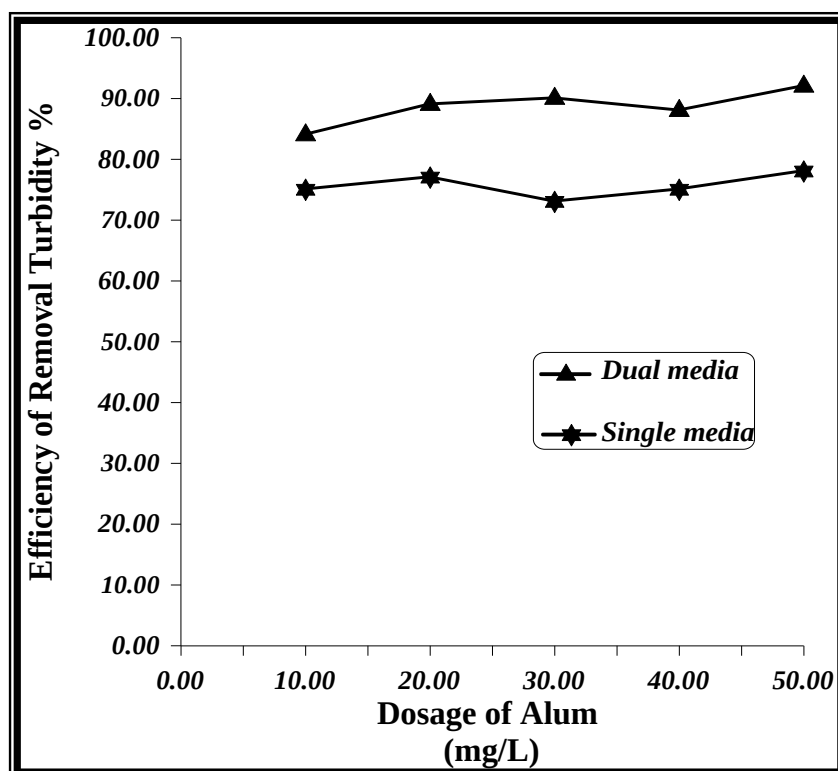


Fig. (5-15): Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media Filter

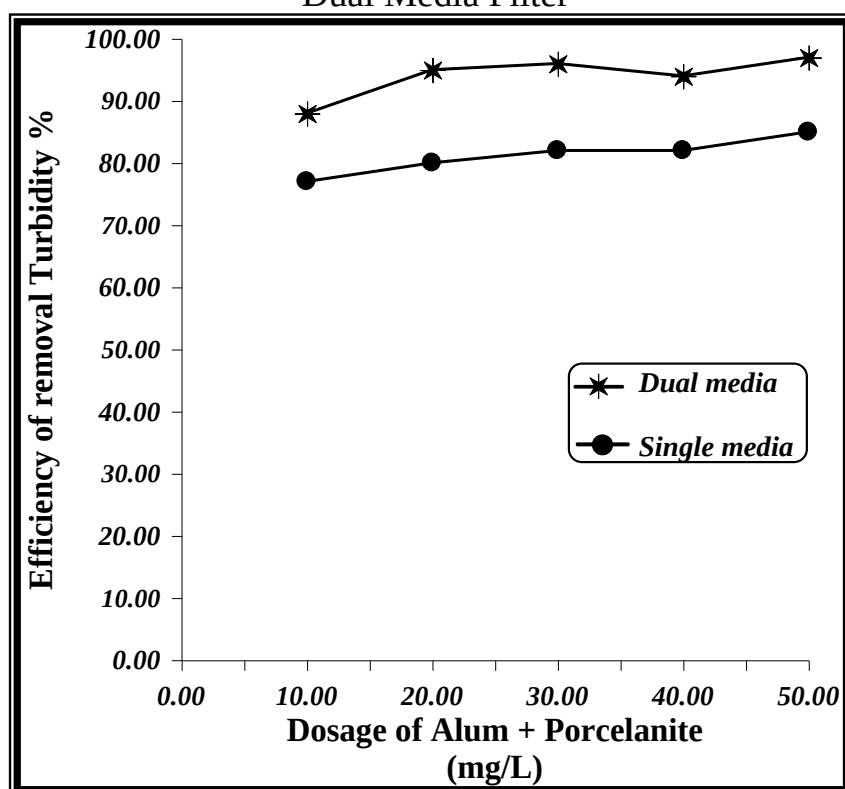


Fig. (5-16) Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

It can be concluded that the using of dual media was better than of using single media by about of 13%

5.4 Experimental Tests

Table (A-1) indicates the summery of experimental tests (pH, TDS , conductivity and temperature) before and after coagulation process of water as shown in appendix (A).

Table (A-2) presents the average results of all experimental tests before and after filtration process of water as shown in appendix (A).

5-5 Study No. 3

This study includes all the experimental work of coagulation and filtration processes of the wastewater

5.5.1 Effect of Coagulation Process on the Organic Matter of Wastewater:

In order to give inclusive evaluation of performance of coagulation process in treating pollutants of water and wastewater , the present study deals with the removal of organic matters from wastewater by using this process of treatment .

Fig. (5-17) shows the efficiency of coagulants in removal of the biochemical oxygen demand (BOD₅), the BOD₅ is considered as a measurement of organic matter. The experiments were done by adding different dosages of (alum)and (alum with porcelanite).

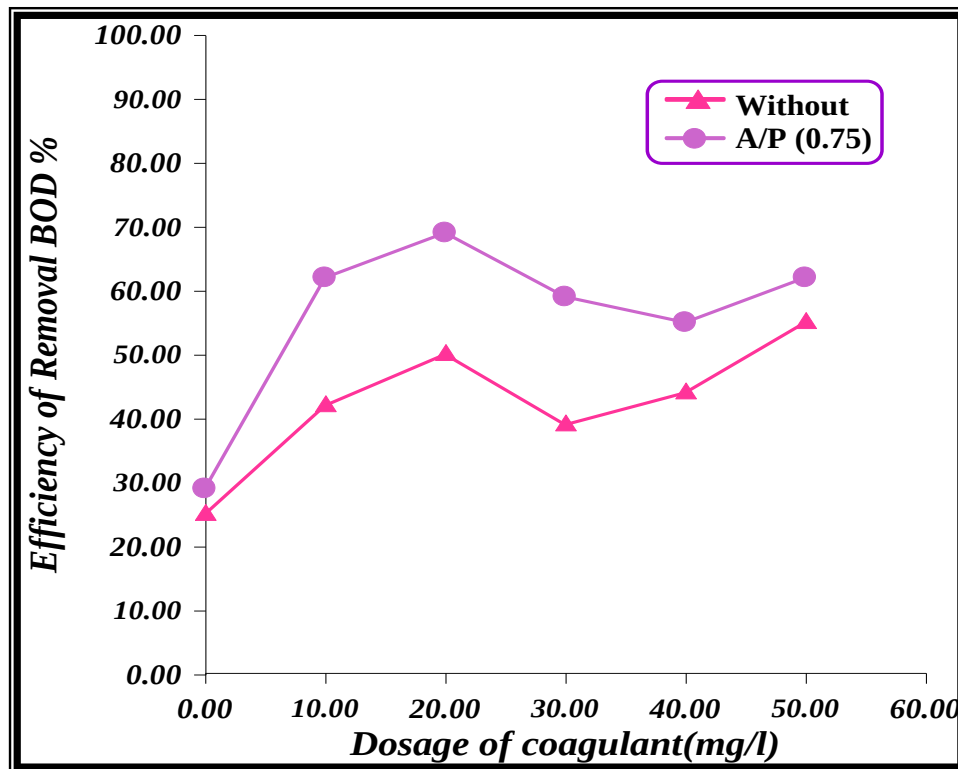


Fig. (5-17): Removal Efficiency of BOD₅ Versus Dosages of Coagulant

The efficiency of alum with coagulant aid of porcelanite material in removal of BOD₅ was better than that the efficiency of removal BOD₅ obtained by using alum only.

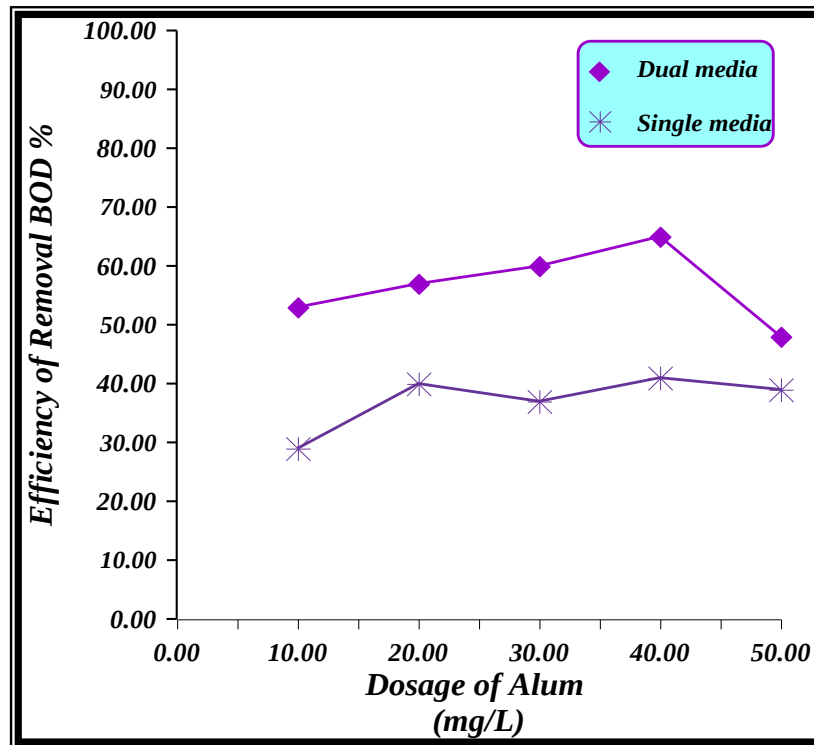
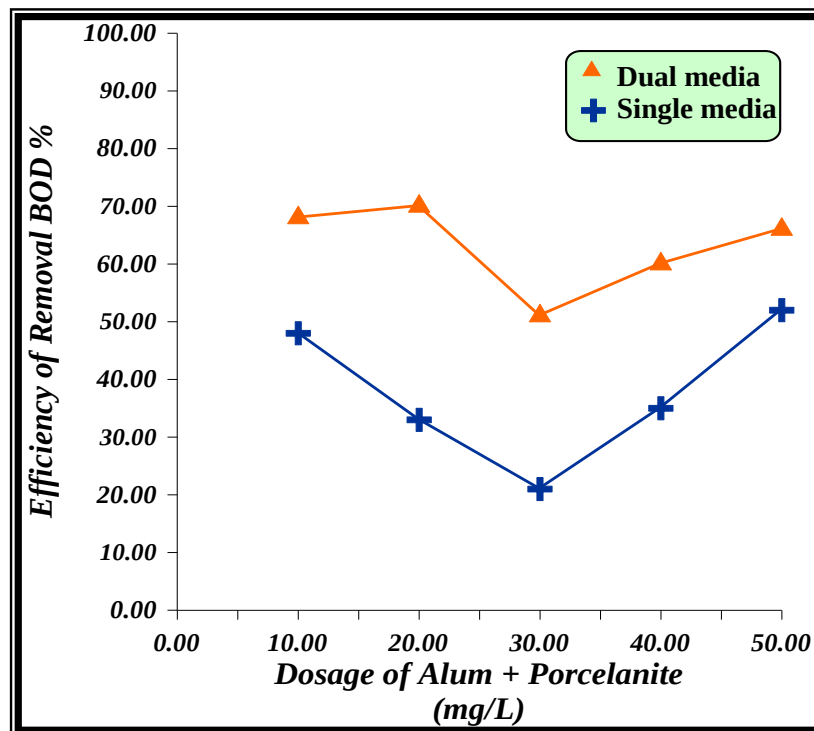
5.5.2 Effect of Filtration on The Biochemical Oxygen Demand (BOD₅)

Table (5-7) presents the results of the BOD₅ before and after filtration process. These results are obtained by adding different dosages of coagulant and coagulant aid with the coagulation process, and also by using two types of filter media with the filtration process.

Table (5-7): Efficiency of Removal BOD₅ in the Filtration Process

Coagulant type	Dose mg/ℓ	Filter type	Residual BOD		Efficiency %
			Before filtration	After filtration	
Alum	10	Single media	52	37	29
	20		67	40	40
	30		89	56	37
	40		85	50	41
	50		61	37	39
Alum	10	Dual media	60	28	53
	20		74	32	57
	30		82	33	60
	40		51	18	65
	50		78	40.5	48
Alum+Porcelanite	10	Single media	77	40	48
	20		60	40	33
	30		48	38	21
	40		49	32	35
	50		104	50	52
Alum+Porcelanite	10	Dual media	75	24	68
	20		56	17	70
	30		78	38	51
	40		77	31	60
	50		88	30	66

Fig. (5-18) and (5-19) indicate that the efficiency of removal of BOD₅ by using (alum)and (alum with porcelanite)respectively, for both single and dual filter media.

Fig. (5-18): BOD₅ Removal Efficiency by Filtration ProcessFig. (5-19): BOD₅ Removal Efficiency by Filtration Process

It was noted that the efficiency of BOD₅ removal by using alum with coagulant aid of porcelanite material in the coagulation process and when using of porcelanite material with sand as a dual media in filtration process

was being better than the efficiency obtained by using alum only with single media filter.

Analysis of results refers that the efficiency by using alum only with dual media was better than the efficiency by using single media by about of (19%) .

Fig. (5-19) presents that the efficiency by using alum with coagulant aid porcelanite by using dual media was better than that of efficiency obtained by using single media by about of (25 %)

5.6 Experimental Tests

Table (A-3and A-4) present summery of experimental tests (pH, TDS , conductivity and temperature) before and after coagulation and filtration processes of wastewater as shown in appendix (A).

Regression Analysis Technique

In this chapter, data of water and wastewater are arranged in four studies (Efficiency of removal turbidity and BOD₅, with coagulation and filtration processes). The data are analyzed to achieve the main objective of this research. Along with data of factors (independent variables) that are assumed to have a reliable impact on efficiency of removal (initial concentration , pH, temperature , dosage of coagulant, alum to porcelanite ratio ,and sand to the porcelanite ratio) are also analyzed to assess their effects.

5.7 Statistical Descriptive of Independent Variables

The most predominant independent variables were investigated in this study are shown in Table (5-10).

Table (5-10): Description of Independent Variables

Independent Variables	Description
X_1	Initial concentration (I.C)
X_2	pH
X_3	Temperature
X_4	alum to porcelanite ratio (A/P)
X_5	dosage of coagulant in (mg/L)
X_6	sand to the porcelanite ratio (S/P)

5.8 Regression Models

Stepwise multiple linear regression models in three forms of transformation were used for each one of studies (turbidity, BOD₅, in coagulation and filtration processes) to investigate which form gives the best fitting of data (i.e. appropriate model).

It is very important to explain that the method of transformation are being used to reduce complex models to linear ones and use a regression model of simple form in the transformation variables, rather than a more complicated one in the original variables. Transforms are used to force all variables to normal distribution and to correct a positive skew distribution. Therefore, it should be noted that there are nonlinear models that are intrinsically linear (i.e. they seemed nonlinear only in their appearance, but they are intrinsically linear). Then, the nonlinear models can be divided into

two types which can be called intrinsically linear and intrinsically nonlinear models. If a model is intrinsically linear it can be expressed by suitable transformation of the variables in the standard linear model form of Eq. (5.2). If a nonlinear model cannot be expressed in this form then it is intrinsically nonlinear .

One very general form for the linear model would be:

$$Y = f(x_1, x_2, \dots, x_q, D) \quad \dots (5.1)$$

Where f is unknown function, D is a dummy variable (if needed).

The following models were proposed and investigated:

$$1. Y = g + a * x_1 + b * x_2 + \dots + f * x_6 \quad \dots (5.2)$$

$$2. Y = a * x_1 + b * x_2 + \dots + f * x_6 \quad \dots (5.3)$$

$$3. \ln Y = g + a * x_1 + b * x_2 + \dots + f * x_6 \quad \dots (5.4)$$

Where Y = efficiency of removal (turbidity, BOD₅, in coagulation , and filtration processes)in percent ; $x_1, x_2, \dots, x_6$ = the independent variables (as mentioned before in Section 5-1).

5.9 Results of Study No.1:

The findings of the present study are based on the results of the linear regression analysis summarized in Table (5-11A and B) to choose the appropriate model.

Table (5-11A) :Testing Models

Model No.	Model formula
A	$a * x_1 + b * x_2 + c * x_3 + d * x_4 + e * x_5$
B	$a * x_1 + b * x_2 + c * x_3 + d * x_4 + e * x_5 + f$
C	$\exp(a * x_1 + b * x_2 + c * x_3 + d * x_4 + e * x_5 + f)$

Table (5-11B) Models Summery

Rank	Model	Std. Error	R ²
1	B	5.183	0.565
2	A	5.206	0.551
3	C	5.292	0.546

Model (B) was found to be the most suitable model to express the efficiency of removal turbidity in the coagulation process.

The predicted model was as :

$$Y = a \cdot x_1 + b \cdot x_2 + c \cdot x_3 + d \cdot x_4 + e \cdot x_5 + f \dots \dots \dots (5-5)$$

Where:

Y= efficiency of removal turbidity.

In this model, five out of all independent variables assumed to have a reliable impact on efficiency: initial concentration(X_1), pH (X_2), temperature (X_3), alum to porcelanite ratio(X_4) and dosage of coagulant (X_5), are the most significant variables.

The best fitting of data gives the best model which has the higher value of R^2 , the smaller value of the standard error of the estimate .Then, the model gives a coefficient of determination of ($R^2=0.565$) to show that 0.565 of the variation in dependent variable was explained by all independent variables appeared in regression equation, and the standard error of the estimate of (5.183). Table (5-12) displays the coefficient of this model .

Table (5-12) :Model Coefficient

Model	a	b	c	d	e	f
$Y = a \cdot x_1 + b \cdot x_2 + c \cdot x_3 + d \cdot x_4 + e \cdot x_5 + f$	8.15E-04	0.108	-1.197	-0.257	2.444	3.897

There is a correlation matrix between the dependent variable and the five independent variables as shown in table (5-13).

Table (5-13): Correlation Matrix

	X1	X2	X3	X4	X5	Y
X1	1	-0.413	0.014	0	0	0.529
X2	-0.413	1	-0.037	0.072	-0.078	-0.087
X3	0.014	-0.037	1	-0.377	0.108	0.059
X4	0	0.072	-0.377	1	0	-0.312
X5	0	-0.078	0.108	0	1	0.365
Y	0.529	-0.087	0.059	-0.312	0.365	1

The adequacy of this model can be seen from Figure (5-20), which presents the variation of the estimated and observed values of the efficiency of removal turbidity in coagulation process.

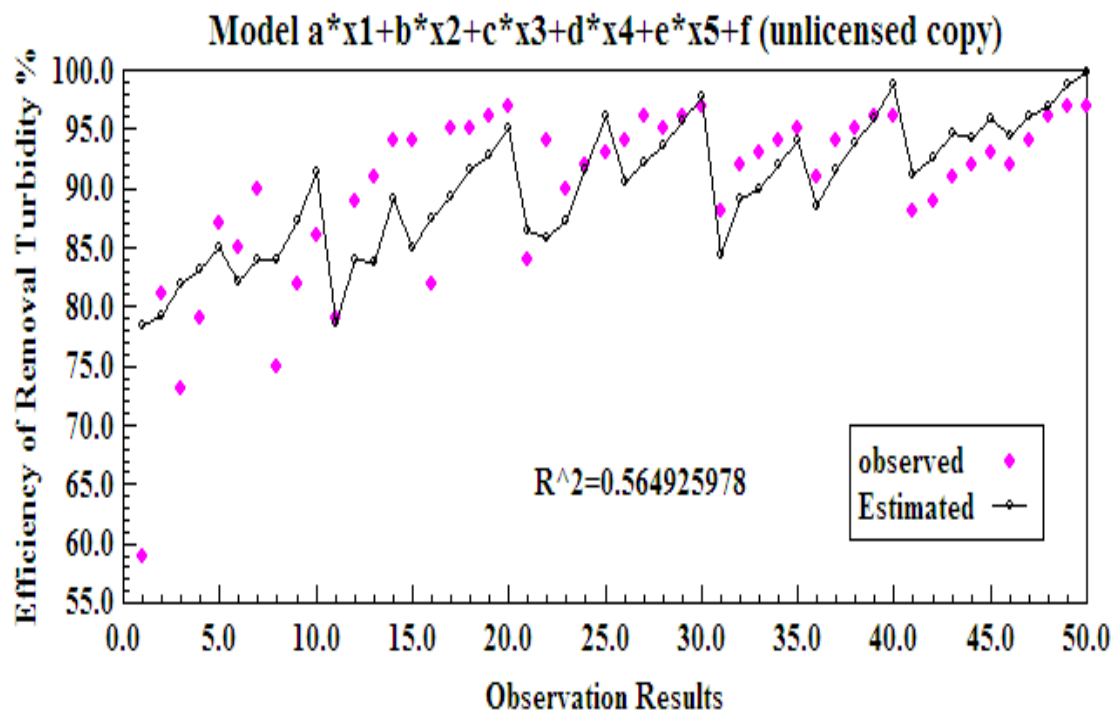


Fig. (5-20) :The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model

5.10 Results of Study No.2:

The findings of the present study are based on the results of the linear regression analysis summarized in Table (5-14 A and B) to choose the appropriate model.

Table (5-14A): Testing Models

Model No.	Model formula
A	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6$
B	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g$
C	$\text{Exp}(a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g)$

Table (5-14B) :Models Summery

Rank	Model	StdError	R ²
1	B	3.971	0.80
2	A	4.655	0.7195
3	C	81.704	0

Table (5-14B) shows that model (B) was found to be the most suitable to represent the efficiency of removal turbidity in the filtration process.

The model was predicted as:

$$Y = a*x_1 + b*x_2 + c*x_3 + d*x_4 + e*x_5 + f*x_6 + g \dots\dots\dots(5-6)$$

where Y = efficiency of removal turbidity in the filtration process

In this model, six out of all independent variables assumed to have a reliable impact on efficiency: initial concentration (X_1), pH (X_2), temperature (X_3), alum to porcelanite ratio (X_4) dosage of coagulant (X_5), and sand to porcelanite ratio (X_6) are the most significant variables.

When the data was fitted very well, then the explanatory power of the model is measured by coefficient of multiple determination $R^2=0.80$ and the standard error of estimate was 3.971; Table (5-15) displays details of the coefficient.

Table (5-15) :Model Coefficient

Model	a	b	c	d	e	f	g
$Y=a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g$	0.357	1.839	0.486	-26.400	0.157	-52.154	124.165

There is a correlation matrix between the dependent variable and the four independent variables.

Table (5-16) Correlation Matrix

	X1	X2	X3	X4	X5	X6	Y
X1	1	0.073	0.104	0.353	-0.406	-0.01	0.0097
X2	0.073	1	-0.065	-0.133	-0.508	0.0005	-0.028
X3	0.104	-0.065	1	-0.107	0.023	-0.332	0.398
X4	0.353	-0.133	-0.107	1	0	0	-0.318
X5	-0.406	-0.508	0.023	0	1	0	0.146
X6	-0.01	0.0005	-0.332	0	0	1	-0.792
Y	0.0097	-0.028	0.398	-0.318	0.146	-0.792	1

The adequacy of this model can be seen from Figure (5-21), which shows the variation of the estimated and observed values of the efficiency of removal turbidity in filtration process.

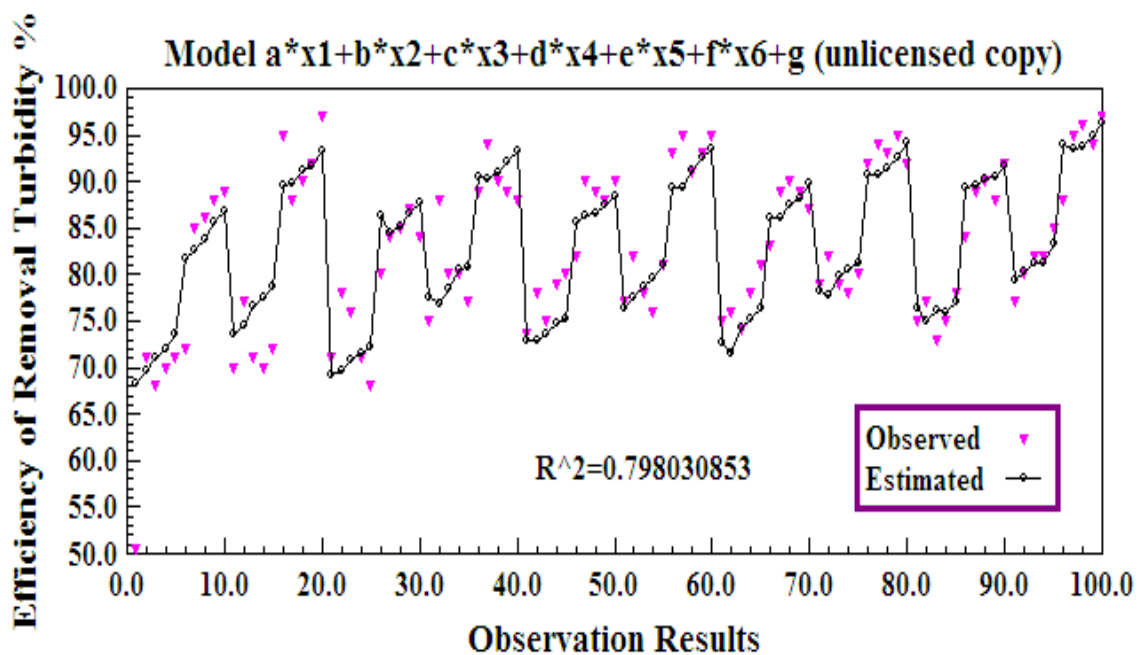


Fig. (5-21) :The Variation of the Estimated and Observed values of the Efficiency by Using the Linear Model

5.11 Results of Study No.3:

The findings of the present study are based on the results of the linear regression analysis summarized in Table (5-17 A and B) to choose the appropriate model.

Table (5-17-A) :Testing Models

Model No.	Model formula
A	$a \cdot x_1 + b \cdot x_2 + c \cdot x_3 + d \cdot x_4 + e \cdot x_5$
B	$a \cdot x_1 + b \cdot x_2 + c \cdot x_3 + d \cdot x_4 + e \cdot x_5 + f$
C	$\text{Exp}(a \cdot x_1 + b \cdot x_2 + c \cdot x_3 + d \cdot x_4 + e \cdot x_5 + f)$

Table(5-17-B) Model Summery

Rank	Model	StdError	R ²
1	B	3.681	0.908
2	C	4.108	0.886
3	A	5.145	0.776

Table (5-17-B) shows that model (B) was found to be the most suitable to represent the efficiency of removal BOD₅ in the coagulation process.

The model was predicted as:

$$Y = a \cdot x_1 + b \cdot x_2 + c \cdot x_3 + d \cdot x_4 + e \cdot x_5 + f \dots \dots \dots (5-7)$$

where Y = efficiency of removal Biochemical Oxygen Demand (BOD₅) from wastewater in coagulation process.

In this model, five out of all independent variables assumed to have a reliable impact on efficiency: initial concentration (X_1), pH (X_2), temperature (X_3), alum to porcelanite ratio (X_4) and dosage of coagulant (X_5), are the most significant variables.

When the data was fitted very well, then the explanatory power of the model is measured by coefficient of multiple determination $R^2 = 0.908$ and the standard error of estimate was 3.681; Table (5-18) displays details of the coefficient.

Table (5-18) :Model Coefficient

Model	a	b	c	d	e	f
$y=a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f$	0.106	-51.168	-2.993	-48.283	-9.8334	535.216

There is a correlation matrix between the dependent variable and the five independent variables as shown in table (5-19).

Table (5-19) Correlation Matrix

	X1	X2	X3	X4	X5	Y
X1	1	0.179	0.257	-0.621	0.0043	0.749
X2	0.179	1	-0.433	-0.555	-0.549	0.239
X3	0.257	-0.433	1	0.135	0.191	-0.164
X4	-0.621	-0.555	0.135	1	0	-0.819
X5	0.0043	-0.549	0.191	0	1	0.046
Y	0.7493	0.239	-0.164	-0.819	0.046	1

The adequacy of this model can be seen from Figure (5-22), which shows the variation of the estimated and observed values of the efficiency of removal BOD₅ in coagulation process.

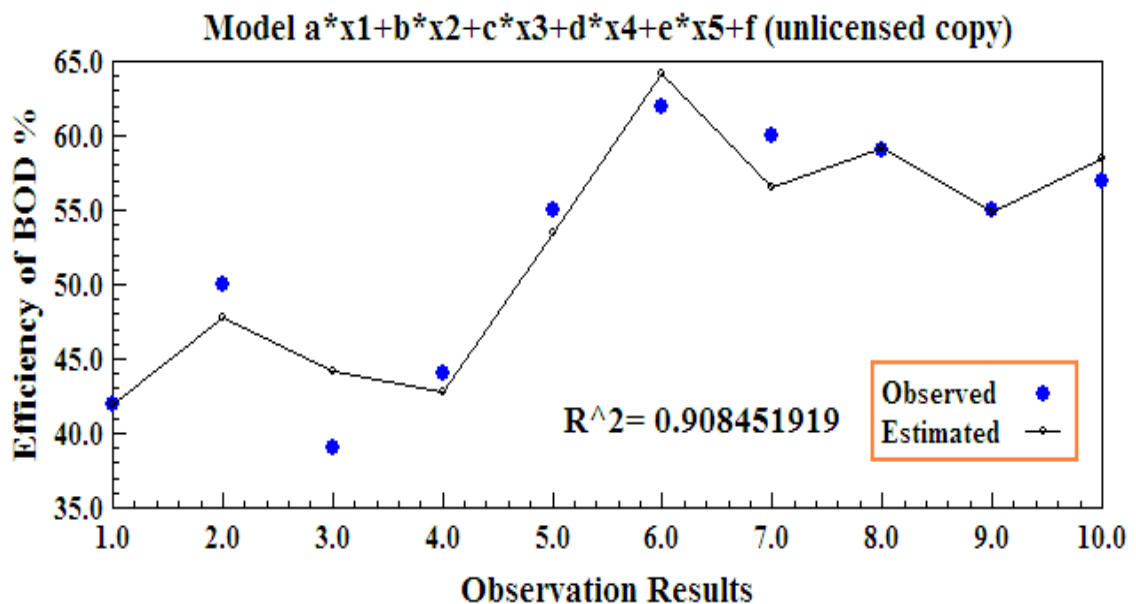


Fig. (5-22) :The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model

5.12 Results of Study No.4:

The findings of the present study are based on the results of the linear regression analysis summarized in Table (5-20 A and B) to choose the appropriate model.

Table (5-20-A) :Testing Models

Model No.	Model formula
A	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6$
B	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g$
C	$\text{Exp}(a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g)$

Table (5-20-B) :Model Summery

Rank	Model	Std .Error	R ²
1	B	8.904	0.718
2	A	9.008	0.6896
3	C	58.504	0

Table (5-20-B) shows that model (B) was found to be the most suitable to represent the efficiency of removal BOD₅ in the filtration process.

The model was predicted as:

$$Y=a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g \dots\dots\dots(5-8)$$

where Y = efficiency of removal turbidity in the filtration process

In this model, six out of all independent variables assumed to have a reliable impact on efficiency: initial concentration(X_1), pH (X_2), temperature (X_3), alum to porcelanite ratio(X_4) dosage of coagulant (X_5), and sand to porcelanite ratio (X_6) are the most significant variables.

When the data was fitted very well, then the explanatory power of the model is measured by coefficient of multiple determination $R^2=0.718$

and the standard error of estimate was 8.904; Table (5-21) displays details of the coefficient.

Table (5-21) :Model Coefficient

Model	a	b	c	d	e	f	g
$Y=a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g$	0.248	-9.996	-0.269	-7.327	-8.045	-74.819	187.105

There is a correlation matrix between the dependent variable and the five independent variables as shown in table (5-22).

Table (5-22) :Correlation Matrix

	X1	X2	X3	X4	X5	X6	Y
X1	1	-0.118	-0.311	0.054	0.224	0.007	0.261
X2	-0.118	1	-0.115	0.3199	-0.146	0.772	-0.708
X3	-0.311	-0.115	1	0.022	0.107	-0.216	0.0616
X4	0.054	0.3199	0.022	1	0	0	-0.096
X5	0.224	-0.146	0.107	0	1	0	-0.005
X6	0.007	0.772	-0.216	0	0	1	-0.791
Y	0.261	-0.708	0.0616	-0.096	-0.005	-0.791	1

The adequacy of this model can be seen from Figure (5-23), which shows the variation of the estimated and observed values of the efficiency of removal BOD₅ in filtration process.

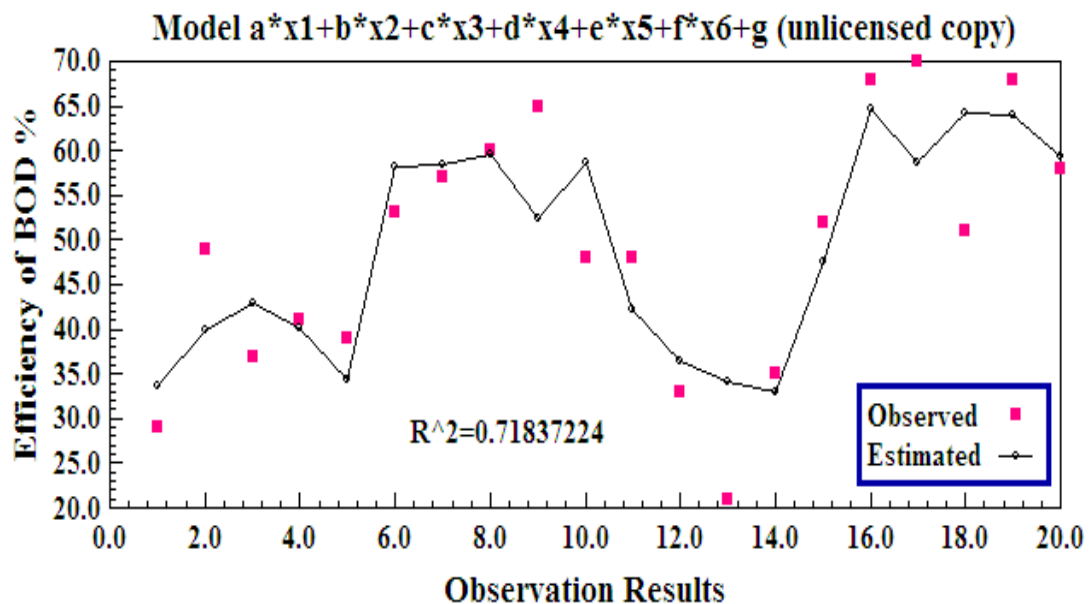


Fig. (5-23): The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model

CHAPTER SIX

Conclusions and Recommendations

6-1 Conclusions

- 1- The best percentage of alum with coagulant aid of porcelanite material was 75 % of alum and 25% of porcelanite material. This percentage was appeared for all dosages used in this study. The porcelanite gives better efficiency when using with alum to remove turbidity more than efficiency obtained when using alum only and for the different levels of turbidity used in this study.
- 2- It can be obtained high level of BOD removal efficiency after coagulation process by about (14%) when adding alum with coagulant aid of porcelanite material more than when adding alum only .
- 3- It can be concluded that the using of dual filter composed of porcelanite and sand gives a better performance than that of single media filter of sand material only .
- 4- The dual filter was efficient in turbidity removal better than of single filter. In which the turbidity of the treated water was less than (3.8 NTU). The maximum turbidity removal efficiency for the single filter was (85 %) and for dual filters was (97 %) when using porcelanite as coagulant aid with alum. The maximum turbidity removal efficiency for the single filter was (81%) and for dual filters was (92%) when using alum without coagulant aid.
- 5- The BOD removal efficiency for dual filter was greater than that of single filter by about (19 %) when adding alum in coagulation process, and about (25 %) when adding porcelanite with alum in coagulation process.

6- A statistical analysis is as shown in table (6-1):

Table (6-1): A Statistical Analysis of Data

Study No.	Predicted model	R²	standard error
1	$Y = 3.897 + 8.15E-04 X_1 + 0.108 X_2 - 1.197 X_3 - 0.257 X_4 + 2.444 X_5$	0.565	5.183
2	$Y = 124.165 + 0.357 X_1 + 1.839 X_2 + 0.486 X_3 - 26.400 X_4 + 0.157 X_5 - 52.154 X_6$	0.80	3.97
3	$Y = 535.216 + 0.106 X_1 - 51.168 X_2 - 2.993 X_3 - 48.283 X_4 - 9.8334 X_5$	0.91	3.68
4	$Y = 187.105 + 0.248 X_1 - 9.996 X_2 - 0.269 X_3 - 7.327 X_4 - 8.045 X_5 - 74.819 X_6$	0.72	8.904

6.2 Recommendations for Future Studies :

- 1- Future study will be needed to show the effect of porcelanite material as coagulant aid with alum on the heavy metal removal and evaluating the adsorption capacity of porcelanite rocks in heavy metal removal .

- 2-The selecting of the best effective size and the best thickness of porcelanite rocks as a dual filter media with different design parameters (filtration rate, backwashing process and depth of filter)were recommended in future study.

List of Contents

Subject

Page

Acknowledgement	I
Abstract	II
List of content	IV
Table of symbols and abbreviations.....	VIII
Table of figures.....	IX
Table of tables.....	XII

Chapter One: Introduction

1-1 General	1
1-2 Scope of the problem.....	2
1-3 Objectives of the study.....	2
1-4 Thesis layout.....	3

Chapter Two : Literature Review

2-1 Introduction.....	4
2-2 Coagulation process.....	5
2-2-1 Variables of coagulation process.....	5
2-2-2 Aluminum sulphate (Alum).....	5
2-3 Coagulant aids.....	7
2-3-1 Adsorbent-weighting agents	7
2-3-1-1 Local material (Porcelanite).....	8
2-4 Factors Effecting coagulation process.....	10
2-4-1 Coagulant solution concentration.....	10
2-4-2 Sequence of chemicals application.....	10
2-4-3 pH value.....	11
2-4-4 Mixing intensity (rapid and slow).....	11
2-4-4-1 Rapid mixing.....	11
2-4-4-2 Flocculation studies(slow mixing).....	13
2-5 Effect of coagulation and flocculation processes on the wastewater	14
2-6 Sedimentation process.....	15
2-7 Filtration process.....	16
2-7-1 Filtration process Variables.....	17

2-7-1-1	Influent characteristics	17
2-7-1-2	Filter media.....	18
2-7-1-3	Depth of filtering material.....	22

Chapter Three: Theoretical Background

3-1	Introduction	24
3-1-1	Coagulation.....	24
3-1-2	Flocculation	24
3-2	Characteristics of colloids	25
3-3	Stability and instability factors.....	30
3-4	Destabilization of colloidal dispersions.....	31
3-5	Mechanisms of destabilization	32
3-5-1	Double – layer compression.....	33
3-5-2	Adsorption of soluble polymeric metal hydroxide species	34
3-5-3	Precipitation of a metal – hydroxide.....	35
3-5-4	Enmeshment in a Precipitate (Sweep Coagulation).....	36
3-6	Chemistry of Coagulation With Alum.....	37
3-7	Local (Porcelanite) Material	40
3-7-1	Chemical analysis of Iraqi porcelanite.....	41
3-7-2	Mineralogical Analysis of Porcelanite in Iraq.....	43
3-8	Mechanisms of Filtration	44
3-8-1	Transport mechanism.....	45
3-8-2	Attachment mechanism.....	47
3-8-3	Detachment mechanism.....	48
3-9	Parameters Effecting the Coagulation and Filtration Processes...	48
3-9-1	Temperature.....	48
3-9-2	pH.....	49
3-9-3	Turbidity.....	49
3-9-4	Conductivity.....	49
3-9-5	Total Dissolved Solids (TDS).....	49

3-9-6 Biochemical Oxygen Demand.....	50
--------------------------------------	----

Chapter Four : Experimental Work

4-1 Introduction.....	52
4-2 The Pilot plant units	53
4-2-1 The tank used in the experimental work	53
4-2-2 Rapid mixing.....	54
4-2-3 Flocculation process.....	54
4-2-4 The pumps used.....	54
4-2-5 Flow-meter.....	54
4-2-6 The filter used.....	55
4-3 Apparatuses	55
4-3-1 Turbidimeter.....	55
4-3-2 Standard sieves.....	55
4-3-3 Balances.....	55
4-3-4 Conductivity meter.....	56
4-3-5 pH meter.....	56
4-3-6 DO meter.....	56
4-4 Turbidity material.....	58
4-5 The coagulants used.....	57
4-5-1 Alum.....	58
4-5-2 Coagulant aid (powder porcelanite).....	58
4-6 Filter media.....	59
4-6-1 Sand.....	59
4-6-2 Local porcelanite rocks.....	60
4-6-3 Supporting gravel layer.....	61
4-7 Experimental procedure.....	61
4-7-1 Synthetic turbid water	61
4-7-2 Determination of coagulant dosage	61
4-7-3 Determination of the best percentage of coagulant And Coagulant Aid	62
4-7-4 Measurement of Organic Contents (Biochemical Oxygen Demand BOD5)	62

Chapter Five: Results and Discussion

5-1	Introduction	64
5-2	Study No.1	64
5-3	Study No. (2).....	66
5-3-1	Clarification Process of Water.....	66
	1. Initial turbidity $T_0=10$ NTU.....	67
	2. Initial turbidity $T_0=50$ NTU	67
	3. Initial turbidity $T_0=100$ NTU.....	68
	4. Initial turbidity $T_0=150$ NTU	69
	5. Initial turbidity $T_0=200$ NTU	70
5-3-2	Filtration process of water.....	71
	1. Initial turbidity $T_0=10$ NTU	71
	2. Initial turbidity $T_0=50$ NTU.....	74
	3. Initial turbidity $T_0=100$ NTU.....	76
	4. Initial turbidity $T_0=150$ NTU.....	78
	5. Initial turbidity $T_0=200$ NTU.....	80
5-4	Experimental tests.....	82
5-5	Study No. 3.....	82
5-5-1	Effect of coagulation process on the organic matter of wastewater:.....	82
5-5-2	Effect of filtration process on the biochemical oxygen demand (BOD_5).....	83
5-6	Experimental tests.....	86
	Regression Analysis Technique	86
5-7	Statistical description of independent variables.....	87
5-8	Regression Models.....	87
5-9	Results of Study No.1.....	88
5-10	Results of Study No.2.....	91
5-11	Results of Study No.3.....	93
5-12	Results of Study No.4.....	95

Chapter Six: Conclusions and Recommendations

6-1	Conclusions.....	97
6-2	Recommendations for future study.....	99
	Appendix A	A-1
	Appendix B	B-1

Table of Symbols and Abbreviation

Symbol or Abbreviation	Description
A/P	Alum to Porcelanite ratio
a,b,c,...,g	Model Coefficient
BOD ₅	Biochemical Oxygen Demand
D.O	Dissolved Oxygen
E.S	Effective size
L/hr	Liter per hour
NTU	Nephelometric Turbidity Unit
R ²	Coefficient of multiple determination
r.p.m	Rounded per minute
TDS	Total Dissolved Solid
T ₀	Initial Turbidity
U.C	Uniformity coefficient
X ₁ , X ₂ ,..., X ₆	Independent variables
X ₁	Initial concentration I.C
X ₂	pH
X ₃	Temperature
X ₄	Alum to porcelanite ratio A/P
X ₅	Dosage of coagulant in mg/L
X ₆	Sand to the porcelanite ratio S/P

Table of Figures

No.of Figure	Title	Page
Figure(2-1)	The wastewater treatment (Asia, and Akporhonor, 2007)	14
Figure(3-1)	Particle size and treatment processes, [After (Benefield et al., 1982)].	25
Figure(3-2)	A colloidal particle and double layer (a) A negative colloidal particle with its electrostatic field (b) Distribution of electrostatic potential, shear plane, and zeta potential (Ravina .L,1985).	28
Figure(3-3)	Forces Acting on Colloids (Ravina .L, 1985)	30
Figure(3-4)	Examples of Coagulation and Flocculation by Bridging (HDR Engineering Inc., 2001)	32
Figure(3-5)	Effect of electrolyte concentration on double layer compression, [After (Benefield et al., 1982).	34
Figure(3-6)	Equilibrium solubility domain of aluminum hydroxide in water , [After (C. R., 1971)].	39
Figure(3-7)	Map showing the location of porcelanite sample sites	42
Figure(3-8)	Transportation Mechanisms in Rapid Depth Filtration	47
Figure(4-1)	A Schematic Diagram of the pilot plant used in the study for treatment of water and wastewater	52
Figure(4-2)	The pilot plant used	53
Figure(4-3)	The first balance	56
Figure(4-4)	pH meter	56
Figure(4-5)	D.O meter	57

Figure(4-6)	Particle Size Distribution of Kaolinite	58
Figure(4-7)	Particle Size Distribution of powder Porcelanite Used	59
Figure(4-8)	Particle Size Distribution of Sand material	60
Figure(4-9)	Particle Size Distribution of Porcelanite Rocks Samples Used in this Study	61
Figure(4-10)	Samples of BOD ₅ Inside the Incubator	63
Figure(5-1)	Variation of Efficiency of removal Turbidity and Dosage of Coagulant with Different Dosages of Porcelanite	66
Figure(5-2)	Turbidity Removal Versus Different Dosage of A /P under the Initial Turbidity of (10 NTU)	67
Figure(5-3)	Turbidity Removal Versus Different Dosage of A /P at the Initial Turbidity of (50 NTU)	68
Figure(5-4)	Turbidity Removal Versus Different Dosage of A /P at the InitialTurbidity of (100 NTU)	69
Figure(5-5)	Turbidity Removal Versus Different Dosage of A /P at the InitialTurbidity of (150 NTU)	70
Figure(5-6)	Turbidity Removal Versus Different Dosage of A /P at the InitialTurbidity of (200 NTU)	71
Figure(5-7)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	73
Figure(5-8)	Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual	73
Figure(5-9)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	75
Figure (5-10)	Turbidity Removal Versus Dosage of Alum with	75

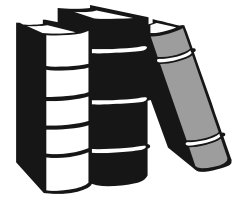
	Coagulant Aid Porcelanite of Both Single and Dual	
Figure(5-11)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	77
Figure(5-12)	Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Filters	77
Figure(5-13)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	79
Figure(5-14)	Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Filter	79
Figure(5-15)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	81
Figure(5-16)	Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual	81
Figure(5-17)	Removal Efficiency of BOD ₅ Versus Dosages of coag.	83
Figure(5-18)	BOD ₅ Removal Efficiency by Filtration Process	85
Figure(5-19)	BOD ₅ Removal Efficiency by Filtration Process	85
Figure(5-20)	The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model	90
Figure(5-21)	The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model	92
Figure(5-22)	The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model	94
Figure(5-23)	The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model	96

Table of Tables

No.of Table	Title	Page
Table(3-1)	Reactions for hydrolysis of Al(III),[After (Dentel and Gossett, 1987)].	38
Table(3-2)	Effects of alum – dosage on treatment criteria (Schulz and Okun, 1984)	40
Table(3-3)	Chemical analysis of local porcelanite samples	43
Table(4-1)	Chemical analysis of Kaolinite Used	57
Table(4-2)	Chemical analysis of Iraqi Alum	58
Table(4-3)	Chemical and physical analysis of porcelanite used in this study	58
Table(4-4)	Percentages of Alum with Porcelanite	62
Table(5-1)	Summery of Experiments of Study No.1	65
Table(5-2)	Efficiency of Filter Before and After Filtration Process for the Initial Turbidity (10 NTU)	72
Table(5-3)	Efficiency of Filter Before and After Filtration Process under the Initial Turbidity (50 NTU)	74
Table(5-4)	Efficiency of Filter Before and After Filtration Process of the Initial Turbidity of (100 NTU)	76
Table(5-5)	Efficiency of Filter Before and After Filtration Process for the Initial Turbidity of (150 NTU)	78
Table(5-6)	Residual Turbidity Before and After Filtration Process of the Initial Turbidity of (200 NTU)	80
Table(5-7)	Efficiency of Removal BOD ₅ in the Filtration Process	84

Table(5-10)	Description of Independent Variables	87
Table(5-11-A)	Testing Models	88
Table(5-11-B)	Models Summery	89
Table(5-12)	Model Coefficient	89
Table(5-13)	Correlation Matrix	90
Table(5-14-A)	Testing Models	91
Table(5-14-B)	Models Summery	91
Table(5-15)	Model Coefficient	92
Table(5-16)	Correlation Matrix	92
Table(5-17-A)	Testing Models	93
Table(5-17-B)	Models Summery	93
Table(5-18)	Model Coefficient	94
Table(5-19)	Correlation Matrix	94
Table(5-20-A)	Testing Models	95
Table(5-20-B)	Models Summery	95
Table(5-21)	Model Coefficient	96
Table(5-22)	Correlation Matrix	96
Table(A-1)	Summery of Experimental Data Before and After Coagulation Process of Water	A-1
Table(A-2)	Average Values of Experimental Tests Before and After Filtration Process for Water	A-2
Table(A-3)	Experimental Tests Before and After Coagulation Process for Wastewater	A-3
Table(A-4)	Experimental Tests for Wastewater in Filtration Process	A-3

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الخلاصة

في هذه الدراسة تم اختيار مادة البورسلنايت كمادة مساعدة للتخثير مع الشب وكذلك استخدامها كمرشح ثنائي مع الرمل لتقييم كفاءة هذه المادة وذلك من خلال التجارب العملية.

ولقد تطلب العمل إنشاء منظومة معالجة مختبرية. العمل التجريبي تضمن فحوصات لكل من المياه ومياه المجاري

وتتضمن المنظومة المختبرية مرحلتين : المرحلة الأولى تتعلق بكل من عمليات التخثير والتلييد والترسيب باستخدام جرعة مختلفة من الشب ومادة البورسلنايت وقيم عكورة تراوحت بين (10- 200 NTU) .

والمرحلة الثانية تتعلق بعملية الترشيح باستخدام نوعين من المرشحات ، المرشح الاول يحتوي على طبقة مفردة من الرمل بارتفاع 40 سم بينما النوع الثاني هو مرشح ثنائي باستخدام طبقة من الرمل بارتفاع 30 سم مع طبقة من صخور البورسلنايت بارتفاع 10 سم.

وقد أظهرت النتائج بان مادة البورسلنايت أكثر كفاءة عند استخدامها مع الشب في إزالة العكورة ولجميع مستويات الكدرة .

فقد وجد ان كفاءة إزالة العكورة عند مستوى عكورة ابتدائية (10 و 50 NTU) كانت بحدود (72.8 و 84%) عند اضافة الشب فقط في عملية التخثير وهذه النسبة تزداد لتصبح (79 و 93%) بعد إضافة الشب مع مادة البورسلنايت .

وكانت كفاءة إزالة العكورة عند مستويات الكدرة (100،150،200 NTU) هي (90.5 %) عند إضافة الشب فقط في عملية التخثير بينما عند إضافة مادة البورسلنايت مع الشب فان كفاءة الإزالة تزداد لتصبح (95%).

وقد بينت النتائج في هذه الدراسة بان المرشح الثنائي باستخدام صخور البورسلنايت مع الرمل أكثر كفاءة في إزالة العكورة من استخدام الرمل فقط في عملية الترشيح ,حيث ان نسبة ازالة العكورة باستخدام المرشح الثنائي كانت بحدود (86%) بينما نسبة الازالة باستخدام مرشح الرمل كانت (74 %) عند استخدام الشب فقط في عملية التخثير. وهذه الكفاءة تزداد لتصل (93 %) و (80 %) باستخدام المرشح الثنائي ومرشح الرمل على التوالي عند استخدام مادة البورسلنايت مع الشب في عملية التخثير

وكذلك وجد بان استخدام البورسلنايت مع الشب افضل من استخدام الشب فقط في ازالة المحتوى العضوي (طلب الاوكسجين البايوكيميائي BOD) حيث أعطى الشب المحلي كفاءة إزالة (BOD) بحدود

(46%) بينما عند استخدام البورسلنايت مع الشب فان كفاءة إزالة (BOD) تزداد لتصبح بحدود (60%) .

من الملاحظ من النتائج بان المرشح الثنائي أكثر كفاءة من الرمل في تقليل المحتوى العضوي (BOD)، حيث ان كفاءة ازالة ال BOD باستخدام المرشح الثنائي أفضل من استخدام مرشح الرمل بحدود (19 %) عند استخدام الشب فقط في عملية التخثير، بينما عند استخدام الشب مع البورسلنايت في عملية التخثير، فان كفاءة إزالة ال BOD بعد عملية الترشيح باستخدام المرشح الثنائي أفضل من مرشح الرمل بحدود (25 %).

وبعد رسم النتائج تم تحليلها إحصائيا باستخدام البرنامج الإحصائي (Data fit) .

جامعة بابل
كلية الهندسة
قسم الهندسة المدنية



جمهورية العراق
وزارة التعليم العالي
والبحث العلمي

تأثير استخدام مادة البورسلنايت على أداء معالجة المياه ومياه المجاري

أطروحة
مقدمة إلى كلية الهندسة في جامعة بابل كجزء
من متطلبات نيل درجة ماجستير علوم في
الهندسة المدنية

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أيلول 2008

رمضان 1429

**Republic of Iraq
Ministry of Higher
Education and Scientific
Research**



**University of Babylon
College of Engineering
Dept. Of Civil
Engineering**

Effect of Using of Porcelanite on the Performance of Water and Wastewater Treatment

**A Thesis
Submitted to the College of Engineering
of the University of Babylon in Partial
Fulfillment of the Requirements
for the Degree of Master
of Science in Civil
Engineering**

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Ramadhan 1429

September 2008

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

[وَقُلْ أَجِبُوا دُعَاءَ رَبِّكُمْ إِلَهُكُمْ جَمِيعًا
يَسْتَجِيبُ لَكُمْ فِي الْأُمُورِ]

[وَأَسْأَلُكُمْ وَاللَّهُ يَسْأَلُكُمْ فِي الْأُمُورِ...]

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Abstract

In this study the local materials (porcelanite) was tested as coagulant aid with alum, and used as a dual filter media with sand to evaluate efficiency of this material. This was done through experimental works.

This work required installing of a pilot plant system, the experimental work included tests for both water and wastewater.

The pilot plant consists of two stages: the first stage deals with coagulation, flocculation and sedimentation processes by using different dosages of alum and porcelanite material over turbidity values range between (10-200 NTU) .

The second stage was concerned with filtration process by using two types of filters. The first filter with a sand bed of (single media) of height of 40 cm. While the second was a dual media (sand bed of 30 cm in height and 10 cm of porcelanite height).

The results indicate that the porcelanite material more efficient in the removal of turbidity for all levels of turbidity.

The efficiency of turbidity removal with the initial turbidity of (10 and 50 NTU) were (72.8 and 84 %) when adding alum only in the coagulation process. This percentage was increased to a value of (79 and 93 %) after adding alum with coagulant aid of porcelanite material in the same process.

The efficiency removal of turbidity of the initial turbidities (100 , 150 and 200 NTU) was approximately (90.5 %) when adding alum only in the coagulation process. While when adding the porcelanite material as coagulant aid with alum the efficiency removal was increased to a value of (95 %) in the same process.

Also, the results of the present study referred that the dual media by using porcelanite rocks with sand was more efficient in removal turbidity when

using sand only in the filtration process . Therefore, the percent of turbidity removal by using the dual media was about (86%), while the removal efficiency by using single media was about (74%)when using alum only in the coagulation process. The efficiency was increased to about (93%) and (80%) in dual media and single media respectively when using porcelanite material with alum in the coagulation process .

It is found that the using of porcelanite with alum was better than the using of alum only in the removal of organic content (biochemical oxygen demand , (BOD_5)). Therefore , the local alum give the removal efficiency of BOD_5 of about (46%) ,while when using porcelanite with alum, the removal efficiency increased to a value of about (60%).

It was concluded that the dual media was more efficient in the reduction of organic content (BOD_5) than when using of single media filter. Therefore, the removal efficiency of BOD_5 by using dual media was more than that by using single media by about of (19%) when using alum only in the coagulation process. When using the porcelanite material with alum in the coagulation process, the removal efficiency after filtration process by using dual media was more than that by using single media about (25%).

After the results from each run were tabulated and graphed, they were analyzed statistically by using a statistical program (DATA FIT) to simulate the experimental work .

Acknowledgment

Praise be to “**God**” and to his prophet “**Mohammed**”. This research has been completed under their benediction.

I acknowledge with thanks and gratitude the valuable advice, assistance, cooperation, and encouragement of **Assis. Prof Dr. Jabbar H. Al-Baidhani** and **Assis. Prof Dr. Mohammed A. Moslem Al-Tufaily** and throughout the course of preparing my thesis. They devoted much of their spare time in going through every detail, which enabled me to reach this achievement.

I wish to express my sincere thanks and deep gratitude to the head of Civil Engineering Department and to all the staff of the department, College of Engineering for all the facilities they rendered me.

I would like to express my sincere gratitude and respect to **Assis. Prof Dr. Riyadh H. Al-Anbari** in the Environmental Department in University of Technology , **Assis. Prof Dr. Dakhel Nasir Taha** in the Chemistry Department in the Babylon University and **Assis. Prof Dr. Majid Mohhy** in the Material Department in the Babylon University for their assistance throughout this work.

I am grateful to Babylon Sewage Office, especially the head of environmental laboratory in the Al-Muamera project **Mr. Mohammed Al-Meiyalli** and to all laboratory and project staff members for their assistance throughout this work.

I would like to express my sincere thank to **Mr. Mohammed kadhun** and all the staff of water treatment plant in the Babylon University

I would also like to thank my closest friends **Zainab Ali** and **Huda Mohammad** .

I wish to express my sincere thanks to Miss **Afrah Abood**, **Amal Al-Mamori** ,**Intidhar Jaber** and **Israa Saady** for their encouragement during the entire period of this research.

I record my sincere gratitude to my family, my dear father, my affectionate mother, and my dear sisters and brother who always offer their patience and prayers and for their encouragement and support during the period of preparing this work.

Many others are not mentioned explicitly here, their efforts are equally appreciated, and I wish to thank all those who have helped by one way or another during this research.





Appendices

Appendix A

Table (A-1): Summery of Experimental Data Before and After Coagulation Process of Water

Coagulant name	Turb. NTU	Dose mg/L	Experimental tests							
			Before coagulation				After coagulation			
			TDS mg/L	Cond. μ S/cm	pH	Temp. $^{\circ}$ C	TDS mg/L	Cond. μ S/cm	pH	Temp. $^{\circ}$ C
Alum	10	10	460	886	7.6	11.5	461	853	7.53	12
	10	20	456	788	7.52	12	453	798	7.4	12.5
	10	30	456	885	7.65	12.5	457	865	7.33	13
	10	40	461	863	7.55	12.5	462	887	7.12	13
	10	50	460	867	7.6	13	455	855	7.2	13.2
Alum+Porceanite	10	10	460	812	7.7	14	459	805	7.5	10
	10	20	460	819	7.63	13.6	460	820	7.3	10.5
	10	30	462	850	7.51	14.5	461	846	7.33	11
	10	40	460	845	7.45	13	457	836	7.2	10.5
	10	50	458	802	7.61	12.4	457	793	7.26	10
Alum	50	10	460	964	7.7	14.5	459	887	7.35	15.4
	50	20	455	898	7.74	12	454	868	7.32	12.6
	50	30	456	881	7.52	12.2	452	863	7.12	13.2
	50	40	460	930	7.8	11.6	460	875	7.4	12.5
	50	50	457	858	7.3	13	456	888	7.05	14
Alum+Porceanite	50	10	460	890	7.87	13	462	970	7.68	13.5
	50	20	461	876	7.79	12.6	459	910	7.58	13.2
	50	30	464	872	7.88	13	455	870	7.61	13.7
	50	40	451	878	7.9	14	461	923	7.75	14.5
	50	50	450	889	7.72	12.3	456	855	7.5	13
Alum	100	10	460	762	7.81	11.5	461	775	7.51	13.5
	100	20	459	868	7.65	12.6	457	868	7.42	12.5
	100	30	450	775	7.57	12.5	454	798	7.26	13
	100	40	461	849	7.68	11.5	463	888	7.14	14
	100	50	457	786	7.98	11.6	455	778	7.05	13.2
Alum+Porceanite	100	10	451	849	7.84	13	454	850	7.73	13
	100	20	463	875	7.7	12.3	465	867	7.64	13.5
	100	30	453	789	7.64	12.4	453	787	7.52	12.5
	100	40	458	811	7.65	12.5	457	798	7.41	12.6
	100	50	460	825	7.68	12.6	460	818	7.3	13
Alum	150	10	460	763	7.2	11.5	460	761	7.17	11.6
	150	20	456	779	7.55	12	457	772	7.16	10.5
	150	30	450	754	7.56	13	453	768	7.22	12
	150	40	460	795	7.57	13.2	462	805	7.12	12.5
	150	50	460	787	7.43	12	461	798	7.07	13
Alum+Porceanite	150	10	455	786	7.22	13	455	783	7.11	12.5
	150	20	455	775	7.12	11.2	453	760	7.04	13
	150	30	460	775	7.3	12.5	460	777	7.12	14
	150	40	464	825	7.4	13.2	462	812	7.15	13.5
	150	50	460	787	7.45	13	457	768	7.09	12.5
Alum	200	10	460	971	7.65	12	457	962	7.55	13.5
	200	20	461	975	7.6	12.2	460	966	7.5	13
	200	30	452	887	7.58	12	455	899	7.41	14
	200	40	459	897	7.5	13.6	459	898	7.28	14.5
	200	50	458	902	7.51	14	461	912	7.2	15
Alum+Porceanite	200	10	458	950	7.52	13	454	945	7.29	16
	200	20	461	968	7.5	13.2	460	955	7.14	15.5
	200	30	453	897	7.45	14	453	902	7.22	14
	200	40	463	905	7.3	13	462	898	7.12	14.5
	200	50	451	869	7.32	14	451	879	7.25	14

Appendix A

**Table (A-2) :Average Values of Experimental Tests Before and After
Filtration Process for Water**

Coagulant name	Filter bed type	Dose mg/L	Experimental tests							
			Before filtration				After filtration			
			TDS mg/L	Cond . μ S/cm	pH	Temp $^{\circ}$ C	TDS mg/L	Cond. μ S/cm	pH	Temp $^{\circ}$ C
Alum	Single media	10	461	853	7.53	12.1	575	1058	7.2	11.8
		20	453	798	7.4	12.5	565	965	7.5	12.2
		30	457	865	7.33	13	577	1012	7.4	12.5
		40	462	887	7.12	12.7	586	1130	7.3	12.2
		50	455	855	7.2	13.2	563	1030	7.35	13
Alum	Dual media	10	450	833	7.46	12.6	585	1046	7.55	12.5
		20	452	845	7.2	13	598	1052	7.41	12.5
		30	460	868	7.16	12.7	599	1116	7.32	12.2
		40	445	797	7.3	13.3	556	985	7.5	13
		50	453	835	7.18	13.1	592	996	7.4	12.8
Alum+Porceanite	Single media	10	459	805	7.5	10	577	976	7.68	9
		20	460	820	7.3	10.5	586	998	7.4	10
		30	461	846	7.33	11	590	1031	7.5	10.5
		40	457	836	7.2	10.3	566	997	7.4	10
		50	457	793	7.16	9.8	562	963	7.55	9.2
Alum+Porceanite	Dual media	10	461	763	7.57	15.2	506	983	7.63	15
		20	452	866	7.55	14.3	516	1066	7.64	14
		30	456	896	7.3	15	586	1162	7.5	15.2
		40	464	887	7.12	13.5	588	1102	7.4	13.2
		50	466	829	7.3	13	595	1050	7.53	12.7

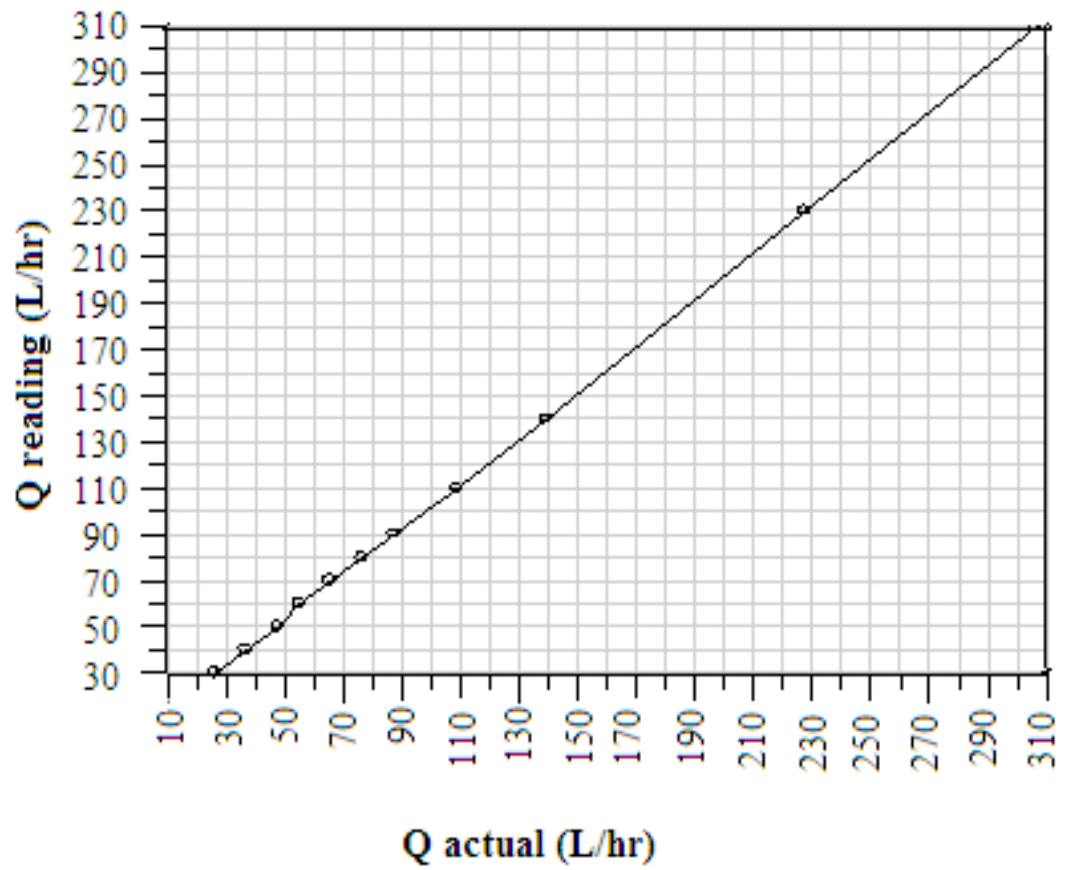
Appendix A

**Table (A-3): Experimental Tests Before and After Coagulation
Process for Wastewater**

Coagulant name	Dose mg/L	Experimental tests							
		Before coagulation				After coagulation			
		TDS mg/L	Cond. μ S/cm	pH	Temp $^{\circ}$ C	TDS mg/L	Cond. μ S/cm	pH	Temp. $^{\circ}$ C
Alum	10	1660	3.49	7.87	17.5	1665	3.56	7.86	18
	20	1549	3.47	7.71	19.5	1539	3.4	7.69	19.3
	30	1522	3.17	7.82	18.5	1525	3.2	7.78	19
	40	1488	3.1	7.77	17.5	1492	3.12	7.69	18
	50	1551	3.4	7.69	17.8	1555	3.39	7.54	18
Alum+Porceanite	10	1482	3.14	7.86	17.5	1486	3.20	7.8	18.2
	20	1539	3.29	7.96	18	1554	3.37	7.87	18.5
	30	1800	3.7	7.89	16	1793	3.5	7.73	16.5
	40	1568	3.47	7.85	19	1573	3.47	7.69	19.5
	50	1408	3.07	7.75	19	1410	3.07	7.6	19

**Table (A-4):Experimental Tests for Wastewater in Filtration
Process**

Coagulant name	Filter bed type	Dose mg/L	Experimental tests							
			Before filtration				After filtration			
			TDS mg/L	Cond. μ S/cm	pH	Temp $^{\circ}$ C	TDS mg/L	Cond. μ S/cm	pH	Temp. $^{\circ}$ C
Alum	Single media	10	1571	3.47	7.83	19	1566	3.36	7.82	18
		20	1665	3.56	7.83	17.6	1561	3.14	7.92	16.4
		30	1526	3.27	7.67	19	1576	3.3	7.84	18
		40	1533	3.35	7.79	18.2	1556	3.4	7.98	17
		50	1565	3.35	7.7	18	1710	3.58	8.05	17.5
Alum	Dual media	10	1521	3.04	7.45	18.5	1331	2.78	7.85	18
		20	1539	3.4	7.69	19.3	1366	2.98	7.81	19
		30	1488	3.2	7.7	18.5	1335	2.94	7.88	18
		40	1512	3.32	7.56	19	1385	2.89	7.7	18.5
		50	1555	3.09	7.54	18.5	1455	3.39	7.97	18
Alum+Porceanite	Single media	10	1486	3.2	7.8	18	1648	3.46	7.87	17
		20	1554	3.37	7.87	18.5	1412	2.96	7.75	17
		30	1793	2.3	7.73	18.5	1810	2.58	7.5	17.5
		40	1573	3.47	7.76	19.2	1627	3.59	7.61	19.2
		50	1410	3.07	7.6	18.5	1527	3.28	7.85	18
Alum+Porceanite	Dual media	10	1113	2.39	7.38	18	1066	2.11	7.56	18
		20	1281	2.81	7.41	19	1230	2.96	7.63	19
		30	1355	3.02	7.35	18	1301	3.15	7.6	18
		40	1476	3.22	7.22	19	1465	3.19	7.5	19
		50	1468	3.2	7.48	18.7	1459	3.18	7.66	18.8



Calibration curve for flow- meter used

CERTIFICATION

We certify that we have read this thesis, titled “Effect of using of porcelanite on the performance of water and wastewater treatment”, and as examining committee examined the student “ **Rasha Ali Taha**” in its contents and in what is connected with it, and that in our opinion it meets the standard of a thesis for the degree of Master of Science in Civil Engineering.

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CHAPTER ONE

Introduction

1.1 General

Treatment of raw water loaded with suspended matters, such as most surface waters in Iraq, requires principally the separation of the solid and colloids particles that cause turbidity from the raw water. Production of portable water, that is free from turbidity and diseases causing organisms, and production of wastewater with less organic matter is the major objective of conventional water and wastewater treatment.

Turbidity itself is not harmful and does not cause illness. It is used to indicate whether other more dangerous contaminants such as bacteria or parasites might be present in the water. (W.D.P.W, 1999).

The removal of suspended particles from water in a conventional treatment process can be performed by two different and related processes:

- 1- by clarification or settling, this is made by using the size and specific weight of the suspended particles and by accelerating such settling process.
- 2- by filtration process through which the remaining unsettled particles by the clarification process are removed by the filters.

The two stages mentioned above are complementary to each other, and consequently the design

One of the essential processes of a water treatment involves the addition of a chemical coagulant. Such a process is a key step in the overall system. It removes turbidity-producing substances (colloidal solids, clay particles, organics, bacteria, and algae) and color in surface water, which result from decaying vegetation or industrial wastes. (Viessman and Hammer, 1985).

1.2 Scope of the problem

The source of water supply for the most of public water supply projects is surface water. This water is turbid and contains many suspended impurities. It also possesses color which may be due to colloidal matter and dissolved organic material in water. The turbidity is mainly due to the presence of very fine particles of clay, silt and organic matter. Qasim.S.(1999).

Wastewater is any water that has been adversely affected in quality. It comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentrations. Stensel, H .D. (2003).

The purpose of coagulation is thus to make particles of bigger size by adding certain chemicals known as the "coagulants" to the water. The coagulants react with the impurities in water and convert them in settleable size. Filtration is another ancient and widely used technology that removes particles and at least some microbes from water. The effect of these filtration methods in reducing microbes also varies widely, depending on the type of microbe and the type and quality of the filtration medium or system. Qasim.S.(1999).

1.3 Objectives of the study:

The main objectives of this study are:

1. Evaluating the performance of local material (porcelanite) as coagulant aid with alum to treat water and wastewater by using a pilot plant system consist of coagulation, flocculation, sedimentation and filtration.
2. Comparison between the efficiency of porcelanite material as coagulant aid with alum and alum only in removing the turbidity from water and removing organic matter from wastewater.
3. Evaluating the performance of porcelanite material as a dual filter media with sand.

4. Developing a statistical model which describes the treatment process.

1.4 Thesis layout

This thesis comprises six chapters:

1. Chapter one consist of the introduction of this study, the scope of the problem ,the objectives of the study and thesis layout.
2. Chapter two gives a presentation of the recent and relevant studies on the types of coagulants, aluminum sulfate (alum), uses, and performance, as well as natural coagulant- aid (porcelanite).
3. Chapter three gives a presentation on the basic colloidal chemistry, theories of stability, and instability. In addition, mechanisms of destabilization and mechanisms of coagulation with alum are presented too, flocculation, chemical and mineralogical analysis of Iraqi porcelanite and mechanisms of filtration test.
4. Chapter four described materials used in this study and their chemical analysis, laboratory experiments, and the setup of tests, the apparatus employed are illustrated as well.
5. Chapter five includes the results of the different experiments and the relevant discussions
6. Finally, conclusions and recommendations for future studies are present in chapter six.

CHAPTER TWO

Literature Review

2.1. Introduction

Many impurities in water are present as colloidal dispersions, i.e., they occur in particulate form with an approximate size range of (1 nm) to (100 nm). Examples of this type of suspension are clays, bacteria, and substances of biological origin such as natural colour, proteins, carbohydrates, and their natural or industrial derivatives. Turbidity particles are mostly clays and microscopic organisms occurring in widely varying sizes. Coarser particles can be removed by simple sedimentation. finer particles, however, are too small for effective removal by gravitational settling alone. Efficient removal of these fine particles can be obtained by their aggregation into large settleable particles through the coagulation and flocculation processes.

Casey, (1997) showed that the destruction of colloidal stability or coagulation may be effected in four major ways, namely, boiling, freezing, mutual flocculation by addition of a colloid of opposite charge, and the addition of electrolytes. Of these, only the latter is of major significance in water engineering practice.

Tebbutt, (1998) showed that invariable suspensions of this kind possess an inherent stability or resistance to particle aggregation. They are not amenable to clarification by the sedimentation process due to their negligible settling velocity nor can ordinary filtration processes clarify them.

2.2.Coagulation process

Braul and Leade , (2004) claimed that the coagulation process is the addition of certain chemicals into the raw water causes particles to destabilize and allows agglomeration and floc formation to occur .

Coagulation is a safe and effective method of treating water which improves its quality by reducing levels of organic compounds , dissolved phosphorus ,color , and suspended particles

2.2.1 Variables of Coagulation process

Dentel and Kingery, (1989) showed that the analysis and design of water treatment processes rarely take into account the variabilities in quality of the raw water to be treated. Yet, the diurnal, seasonal, and storm-related changes in treatment conditions represent a significant challenge for the maintenance of optimal water quality at minimal cost .

Casey, (1997) showed that because of the many factors that influence coagulation and the complex reactions involved, it is not feasible to calculate directly the coagulant dosage required for coagulation of particular water. An experimental jar test procedure is normally used for this purpose.

As pointed out by Zahiruddin and Leon, (2006) the coagulation of turbid water may be affected by many variables, including: (1) The type, amount, and size distribution of turbidity; (2) The specific ions present; (3) pH value ; (4) Coagulant type and dosage; and (5) Alkalinity.

2.2.2 Aluminum sulphate (Alum)

According to the AWWA,(1999), Aluminum sulfate, also known as (alum), is one of the most common local coagulants used. It has been used in water treatment for many years. The United States has been using alum in water treatment systems since the late 1800s.

The chemical formula for alum is $[\text{Al}_2(\text{SO}_4)_3 \cdot 16\text{H}_2\text{O}]$. It is a hydrolyzing metal salt (HMS) coagulant. This means that the way in which alum

destabilizes the particles in water is through hydrolysis. The aluminum ions form strong bonds with the surrounding oxygen of the water molecules. This weakens the atomic structure of the water molecules and positive hydrogen ions are released into the solution

According to the HDR Engineering Inc., (2001)the absorption of these hydrogen ions by the negatively charged particles results in destabilization of the particles as the charge is neutralized. An overdose of alum will produce what is called sweep floc. The alum that precipitates out of solution will settle to the bottom of a sedimentation basin, entrapping particles on its way down removing them from the effluent.

Davis and Cornwell, (1998) showed that the alum is usually purchased in a liquid form that contains about 48.8% alum. The rest of the solution that makes up the liquid alum in water. Alum is usually bought in this liquid form because dry alum cost 1.5 times as much for the same amount. Very few customers purchase dry alum except in small doses because of the difference in price, they showed that every coagulant has an optimal pH range in which it works the best. Alum is most effective when working in a pH range between 5.5 and 6.5. The reaction between alum and water however, uses up alkalinity. If a sufficient amount of alkalinity is not present when the reaction takes place, sulfuric acid will be produced. This reduces the pH of the solution and a pH adjuster will have to be added to bring the solution back to its optimum pH condition.

The primacy of alum as coagulants is due to Berberich, (1998):

- 1- Its effectiveness in destabilizing the predominantly negatively charged colloids found in natural waters.
- 2- Its relatively low cost.
- 3- Its low solubility levels in the pH range of normal use. The achievement of a low residual metal ion concentration is particularly important in the production of drinking water.

4- Its availability.

2.3 Coagulant aids

Intidhar , (2002) stated that the function of the coagulant aids is either to control the coagulation process or to increase the efficiency of the coagulation of relatively clear water (low turbid water). Such coagulant aid involve adsorbent-weighting agents.

2.3.1 Adsorbent-weighting agents

(Reihl et. al ,1976) stated that in coagulating clear water it is sometimes helpful to add artificial turbidity. Bentonite and other clays have been effectively used. When these clays are suspended in water, nuclei are provided for floc formation.

Bentonite is a type of clay used as a weighting agent in water high in color and low in turbidity and mineral content. This type of water usually would not form floc large enough to settle out of the water. The bentonite joins with the small floc, making the floc heavier and thus making it settle more quickly.

Semmens and Field , (1980) studied the influence of added bentonite to river water having a low turbidity and dissolved organic carbon concentrations ranging (10-16 mg/l), they concluded that the addition of bentonite as a coagulant aid with alum reduces the organics removal, especially at low coagulant doses and (pH>5.5) in comparison with the removal observed in the low turbidity control.

Negulescu , (1985) stated that a dose of (5-20 mg/l) of bentonite clay, which is a natural mineral form of coagulant aid, when added to raw water or wastewater, especially that containing diluted colloidal suspensions, it increases the critical mass of the colloidal suspensions. This increases the effectiveness of the metal coagulants as particle kinetics and particle

coagulant probability of contact increase. It can also increase the density of the coagulated particles, and promote a more rapid settling.

Schulz and Okun , (1992) stated that bentonite clay, fuller's earth, and other adsorption clays are used to assist in the coagulation of waters containing high color or low turbidity. Some clays swell when added to water and can produce a floc when used alone or with limited dosage of alum. Practical experience has shown that doses of clay ranging from about (10-50 mg/l) result in good floc formation and a broadening of the pH range for effective coagulation. For low turbidity raw waters, the addition of adsorptive clays may often reduce the dosage of alum required.

2.3.1.1 Local Material (Porcelanite)

Abed-Ohn, (2003)^{Arabic} showed that the high efficiency of porcelanite to extract ions of heavy metals (Fe, Zn, Cr, Cu, Ni, Co, Cd, Pb, Mn) from water as coagulant, and lowering their concentrations to less than the environmental limits. This was achieved when using porcelanite of granular size (0.15 to 0.25 mm). The adsorption capacity of porcelanite is due to the large surface area within the composition of cristobalite and tridymite.

Al-Anbari,(1997) selected suitable and durable locally filter media. He tested lightweight materials like [porcelanite rocks (PR) and burnt kaolinite (BK)], and a heavy weight media like [geothite rocks (GR)]. For single media filter, porcelanite (PR) and kaolinite (BK) gave better results in turbidity removal efficiency (TRE %) and net water product (NWP) value (m³/run) than sand medium. This was because of their higher porosity and angular grain surface textures. The performance of the mixed media filter gave better results than the conventional single media, and sometimes superior to that of dual media.

Al-Ansary , (1998), evaluated the performance of locally porcelanite rocks as a filter media in the treatment of water supplies. He studied the performance of dual media filter composed of porcelanite and sand. The

results showed that the PR filter is more effective in turbidity removal, more length in filter run, and less head loss during filtration nearly by (40%).

Al-Marshidi , (2000) stated that the porcelanite as well as bentonite are effective in removing turbidity of raw water with turbidity level of (50 NTU) and less. Furthermore, he found that porcelanite or bentonite must be added to water and should be dispersed throughout the water body for at least (45 seconds) before the addition of the primary coagulant (alum).

Al-Auraji,(2003) made a research to improve the performance of the filters of Al-Daura water treatment plant by using locally materials such as porcelanite rocks (PR) and burnt kaolinite (BK) as well as anthracite. The results showed that dual media filter gave better water quality, lower head losses, and longer filter run time than single sand filters.

Al-Bayaty ,(2006) tested the dual filter to improve the performance of the filtration process in water treatment plants. She used porcelanite rocks to get dual media with sand in her experimental work.

The pilot filtration consists of three plastic column filters, working parallel and simultaneously. The first column contains 70 cm sand, the second and third were dual filters (porcelanite with sand) of different depths and sizes. She showed that the dual media had no significant effects on the pH, conductivity and TDS of the treated water like sand, but was efficient in turbidity and bacterial removal. The removal bacterial efficiency of the treated water was 16 % more than in sand filters.

2.4. Factors Effecting Coagulation Process:

2.4.1 Coagulant Solution Concentration:

Griffith and Williams (1972) showed that improved turbidity removal could be obtained by dilution to as low as (1.5%) solution.

Kawamura (1973) showed that the optimum economical alum dosage should be selected on the basis of the most efficient alum concentrations for turbidity removal rather than in accordance with the simple correlation of alum dosage versus turbidity removal.

Jeffcoat and Singley (1975) found that flocculation with alum was not impaired by dilution to as low as (0.1%).

2.4.2. Sequence of Chemicals Application:

Kawamura (1973) stated that in many cases coagulant aids, such as lime, polyelectrolyte, activated silica, and carbon, were fed with alum at the same application time. From the chemical viewpoint, especially the colloid-chemical viewpoint, however, there is frequent disagreement on such chemical additions. For instance, lime should not be added to raw water before or with alum because calcium ions, as well as hydroxide or carbonate ions, could be adsorbed on the micelle structure of colloidal particles and the colloids could become more stabilized. Whereas, bentonite, which is one type of montmorillonite, is better to be added to raw water before alum application, because its main function is seeding or adjustment of particle-size distribution.

Hudson (1981) reported that chemical theory and practical experience often suggest certain sequences of addition of reactant chemicals. Cases have been seen where the addition of polymer prior to coagulant dosage proved beneficial.

Al-Marshidi,(2000) studied the effective sequence of alum and weighting agents. He studied three cases, namely, alum before, with, and

after weighting agents were added. He stated that the best sequence is to add alum after the addition of bentonite or porcelanite (weighting agents).

2.4.3. pH Value :

The pH value is one of the most important variables of those that have to be considered for effective flocculation. The metal coagulants (aluminum and iron salts) have been shown to precipitate and coagulant most rapidly and with minimum solubility in a certain pH range, depending upon the coagulant used.

Tekippe and Ham (1970) found that the region of alum concentration (pH 7 and 10mg/l of alum) was located at considerably higher alum concentration than the optimum region (pH 7.2 and 2.5mg/l of alum) for membrane and granular bed filtration.

Kawamura (1976) stated that in practice, in the presence of ions and turbidity normally present in natural waters, the optimum pH range is generally (6-7.8) for alum flocculation and (4-8) for iron hydroxide flocculation. Therefore, alum coagulation and flocculation should be carried out within the optimum pH zone for the particular water being treated.

Kawamura (1991) stated that the pH of raw water ranging between (7.6-8.8) was not affected by the treatment with plant materials (natural coagulants) but only by alum.

2.4.4 Mixing Intensity (Rapid and Slow)

2.4.4.1 Rapid Mixing:

The function of rapid mixing is to ensure a homogeneous coagulation caused by a completely uniform dispersion of the coagulant throughout the water. The intent is for the coagulant to make contact with the maximum number of colloidal particles before hydrolysis and adsorption or bridging action takes place.

Hudson and Wolfner (1967) reported that distribution of the coagulant throughout the water prior to the completion of hydrolysis was estimated to be in the order of a fraction of a second after addition of the coagulant. It was suggested that, in the absence of sufficient mixing, the same portions of the water might receive concentrations of coagulant high enough to cause restabilization of particles whereas other portions may have concentrations too low to initiate coagulation.

Moffett (1968) pointed out the importance of speed mixing. From jar test, he found that for constant reaction pH "twenty seven percent more alum is required to obtain zero zeta potential when the coagulant was introduced on the surface of water rather than at the agitator paddles level".

Stumm and O'Melia (1968) pointed out that for Al (III) in the pH range of (5-8) destabilization might occur by two different mechanisms (adsorption or entrapment). The effects of rapid mixing are possible different for these different cases. However, Vrale and Jorden (1971) emphasized that non-uniform mixing of metal ion coagulants will be accepted if sweep-floc precipitation is desired. The regions of high chemical concentration produced by back-mixing apparently stimulate formation of the hydroxide flocs are necessary for this mode of destabilization. However, non-uniform mixing will be quite undesirable if destabilization by adsorption is desired. Destabilization will be poor in areas of low chemical concentration because of insufficient adsorption and low chemical potential. Destabilization may also be poor in areas of high chemical concentration because of over-adsorption and charge reversal. When charge reversal occurs, continued mixing will not improve the situation because the adsorption process is essentially irreversible.

Letterman and Gemmell (1973) showed that the rapid mix operation (also known as flash or initial mixing) is often the initial step in the flocculation process. During the rapid mix period the flocculating agent or

coagulant – commonly a hydrolyzing salt such as aluminum sulfate – is dispersed by turbulent motion throughout the water to be treated . the rapid mix operation is normally followed by a period of less intense agitation (a slow mix or flocculation period) in order to promote the agglomeration of particles into flocs of size suitable for effective removal by sedimentation and filtration .

Hudson (1973) observed that rapid mixing during coagulant addition prior to slow mixing was important for effective flocculation when low velocity gradients are used during the slow – mix operation

2.4.4.2 Flocculation Studies (Slow Mixing):

Degremont, (1991) showed that the flocculation is the agglomeration of destabilized particles into microfloc, and later into bulky floccules, which can be settled, called floc. Flocculation usually consists of a two-or three-stage process, and begins when the particulates start sticking together more visibly.

Letterman and Gemmell(1973)showed that the flocculation process is an important step in the removal of dissolved, colloidal, and suspended material from water . Flocculation has been used by the water – treatment industry for almost a century as preparatory step for phase separation process such as sedimentation and filtration.

Mohtadi and Raw (1973) found that decreasing water temperature required an increase in alum dosage to achieve the same degree of flocculation.

Cole (1976) stated that temperature changes often have a dramatic effect on increasing flocculation efficiency with aluminum.

Smethurst (1997) showed that the optimum velocity gradient values for flocculation is in the range (20-50 sec.⁻¹).

Al-Marshidi (2000) stated that the period of flocculation is inversely proportional to raw water turbidity and that the velocity gradient increases with the decrease of initial turbidity and vice versa.

Zane Satterfield, (2006) stated that this process still uses the motorized paddles, but at a slower rate than during the flash mix. Stage one of flocculation is fastest, with the second and third stages working more slowly and sometimes with the paddles moving in the opposite direction in some plants. A slow speed is important so as not to break up the particles. This allows the particles to get heavier and helped them settle to the bottom in the next part of the process, sedimentation. Again, it would not be a bad idea to take daily turbidity readings at the end of the flocculation process.

2.5 Effect Of Coagulation and Flocculation Processes on the Wastewater

Asia, and Akporhonor, (2007) suggested that the wastewater contains ions and so physicochemical method of coagulation and flocculation may be a good alternative for the treatment of this wastewater. Physicochemical treatment of this wastewater yielded substantial reduction in the solid concentration, BOD and COD, nitrate, phosphorus, and bacteria counts and so the treated effluent could be discharged safely into the environment without the fear of pollution. They determined the optimum dosage of coagulant needed for wastewater treatment from the rubber factory by using the mixer as shown in Fig. (2-2).

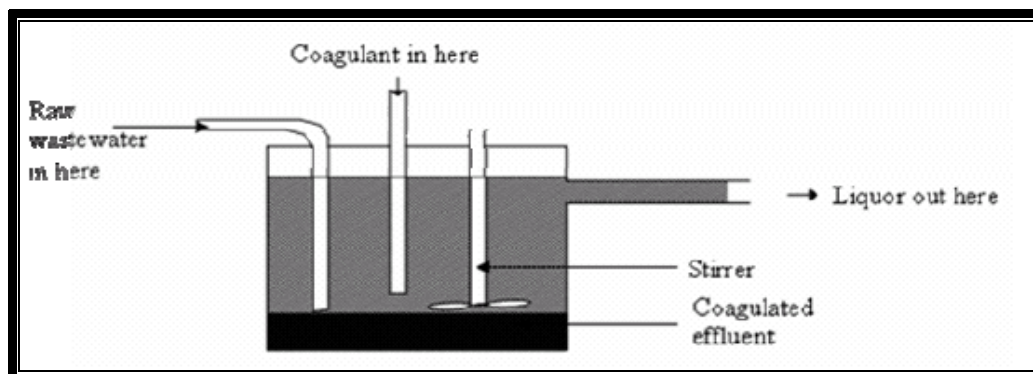


Fig.(2-2): The wastewater treatment (Asia, and Akporhonor, 2007)

Muhammad Saleem (2007) performed a physicochemical study for the treatment of pharmaceutical wastewater. He studied the removal of color, Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), turbidity and phenol and brings them up to the allowable limits for reuse purposes. He determined the efficiency of coagulation, flocculation, sedimentation, sand filtration followed by activated carbon adsorption. He found that alum was more effective among tested coagulants and reduce TSS, BOD, COD and turbidity 79.6%, 34.8, 48.6% and 69.2% respectively. Sand filtration further reduced the studied parameters 97.7%, 95.7%, 93.9% and 76.9% respectively.

(Song, et al., 2003) developed a treatment system that can effectively reduce the concentration of pollutants in tannery wastewater to environmentally acceptable levels and that can greatly reduce the cost of discharging the effluents. Aluminium sulphate and ferric chloride were used as a coagulant in the process. They studied coagulation process and conditions optimized corresponding to the best removal of organic matters, suspended solids as well as chromium. The COD and chromium were removed mainly through coagulation: 38–46% removal of suspended solids, 30–37% removal of total COD from settled tannery wastewaters and 74–99% removal of chromium.

2.6 Sedimentation Process:

Tchobanoglous and Schroeder (1985), defined sedimentation as the unit operation in which suspended materials are removed from the liquid phase by gravity settling, the common application of sedimentation in water treatment include :

1. Pretreatment of surface waters prior to conventional water treatment .
2. Settling of coagulated and flocculated waters prior to filtration .
3. Settling of coagulated flocculated waters in chemical water softening .
4. Settling of waters treated for iron and manganese removal .

Kiely (1997) stated that settlement of flocculent particles in a dilute suspension may arise after chemical coagulation and flocculation where the non-discrete particles are chemically assisted to coagulate . Flocculent particles are those particles that are chemically assisted to come together and produce large particles , and thus settle . While the particles are settling , they are also flocculating and so increase in size and mass during the settling process .

2.7 Filtration process

Degremont, (1991) stated that the filtration is a separation process that consists in passing a solid-liquid mixture through a porous material (filter), which retains the solids and allows the liquid (filtrate) to pass through,

Kiely (1997) stated that filtration has been in use since the nineteenth century when the process of slow sand filtration was generally the only water treatment process , slow sand filtration is credited with improving the aesthetic quality of water and also with the removal of pathogens .

This process is based on the theory of adsorption, where particles adsorb to sand grains because of the electrostatic attraction between opposite charges. A sand grain has a negative charge and it produces around itself a double layer by adsorbing cations from the solution, Folkman & Wachs, (1970). Ives, (1964) showed that These cations reduce the repulsion potential of the grain surface (zeta potential) and enable adsorption of particles with negative charge . The greater the concentration of cation on the sand surface, and the higher its valency, the better is the ability of the sand to adsorb negatively charged particles. Also, sand containing high percentages of ferric and aluminum ions are efficient for algal and bacterial removal, Folkman & Wachs, (1970).

Kawamura, (1999) showed that when designing a filtration system, the design engineer has to specify certain parameters: type and number of filters; size, type, and thickness of the filter bed; filtration rate and filter control system; filter washing system; type of filter under drain system; available head loss; filtered water to waste after washing; and the potential for future conversion,

(Salvato et al, 2003) stated the performance of rapid sand filter is controlled by two important accessories: the head gauge and the rate controller. The loss of head shows the frictional resistance of the flowing water through the sand, laterals, and orifices. The rate controller is constructed to automatically maintain a uniform predetermined rate of filtration through the filter.

2.7.1. Filtration Process Variables

2.7.1.1 Influent characteristics

Tuepker & Buescher, (1968) Some precipitation of calcium carbonate usually occurs on the filter media in the plants, which use lime softening, therefore efforts are exerted to stabilize the water prior to filtration.

Steel & McGhee, (1984) stated that Pretreatment is required prior to filtration and thus coagulation, flocculation, and filtration cannot properly be considered as separate unit processes. Conventional rapid filtration using sand as a medium requires low influent turbidity and has typically employed coagulation with alum or lime.

(Lechevallier et al., 1984) Settled water before filtration should have a turbidity of less than (10 NTU), if water with high turbidity reaches the filter, it will cause high filter head losses and shorter filter runs, (WSO, 2003). Water with turbidity (10 NTU) consists of bacteria eight times more than in water with turbidity (1 NTU).

Cleasby et al., (1992) showed that the combined coagulation using ferric chloride plus cationic polymer was superior to alum plus cationic polymer coagulation in producing longer filter cycles (about 50 percent longer) and substantially lower ferric dosage than alum dosage, but both coagulants produced the same filtrate quality.

2.7.1.2 Filter Media

Davis & Borchardt, (1966) showed that decreasing removal efficiency could be associated with increasing the size of the media at any flow rate. In addition, a numerical reduction in percentage removal of organisms at an increasing rate of filtration was also indicated. Finer sand exhibited greater removal efficiency of algal suspensions than did coarser sand.

Robeck et al., (1964) and Letterman, (1999) observed that the head loss of the dual media filter was less than half that of the sand filter, but the effluent turbidity was almost the same.

Tuepker & Buescher, (1968) showed that the dual media filters offer the advantage of less head losses, a greater capacity for retaining suspended solids, and less emphasis head be placed on settle ability of suspended matter, but greater emphasis on coagulation is required than for rapid sand filters to obtain the same filtered water quality.

In multi-media filters, a modification must be made by using an equivalent grain size that can be approximated as follows:

$$d_{eq} = X_1 d_1 + X_2 d_2 + X_3 d_3 \dots\dots\dots(2-1)$$

d_1, d_2, d_3 = mean size of individual media.

X_1, X_2, X_3 = percentage by volume of individual media respectively, Conley & Hsiung, (1969).

Eunpu, (1970) compared between ilmenite and garnet as filter materials, he showed that ilmenite is more efficient than garnet due to its availability, although the characteristics of both materials are similar.

Harris, (1970) showed from his experimental work that garnet is a fine heavy hazard of its downward migration into the supporting gravel. Also, unless the wash water rise is uniform, the garnet tends to mound when localized high flows lift the heavy fines and deposits nearby are formed by resulting fountain effect.

(Camp et al.,1971) showed that removal by filtration is increased by increasing bed depth or by decreasing grain size, a choice must be made in design between more depth or smaller grain size, within the limitations that the grains that are too large require excessive wash rates for suspension.

Westerhoff, (1971) showed that the mixed media (coal-sand) filter consistently produced lower filtered water turbidity than the sand media, and the microscopic quality of water was equal to, or better. Because of the very low turbidity values, it ordinarily is difficult to detect breakthrough using this parameter.

Kirchman & Jones, (1972) and Viessman et al.,(1985) showed that the filter media is usually specified in terms of “effective size” (in mm) and “uniformity coefficient”. Effective size (d_e) is 10 % by weight of the filter media is less than this diameter. Uniformity coefficient (UC) is the ratio of the 60 % size to 10 %. Common ranges of d_e and UC for sand are (0.4-0.55) mm and (1.3-1.7) respectively.

Chin & Chen, (1978) used different materials for filtration such as sand, wood shave, lallang, coconut husk, and sponge. All filter media were packed to a depth of 60 cm, and the sand had ($d_e = 0.51$ mm, UC = 1.4). The filtration runs were kept continuously for at least six hours over the range of (0.2 to 8 m/hr). Single media systems showed that the sand filter was the most efficient in suspended solids (SS), BOD, and coliform organisms removal for (6 hr) filtration run. Multi- media systems showed excellent removal efficiency when sand was added to lallang as the filter medium.

Trussell et al., (1980) showed that the affects of the bulk porosity of the bed, which is strongly related to the increase in head loss that results from the deposits in the filter. It can be seen that using angular media results in an improved performance of the filter, such as the time limiting head loss may be increased by (30 to 40 %),.

Al-Ani & Al-Baldawi, (1986) conducted several tests on the Tigris River water utilizing a pilot plant built similar to a full-scale water treatment plant. A comparison between single and dual media filters subjected to identical conditions revealed the superiority of dual filters over the single conventional filter. The results demonstrated lower head losses, longer filter runs and doubling the production of filtered water.

Al- Rawi, (1987) showed that a dual media filter consisting of 20 cm of anthracite ($d_e = 0.91$ mm) with 40 cm of sand ($d_e = 0.69$ mm) was found to show superiority in turbidity removal among other filters tested with different depth and size of dual media. This filter achieved an efficiency of (90 to 98 %) in turbidity removal over (83 hours) service time at filtration rate (8.8 m/hr).

Mohammed, (1989) showed that dual filter with anthracite of ($d_e = 0.74$ mm) and sand of ($d_e = 0.478$ mm) can be operated at high filtration rates (12 m/hr), achieved significant turbidity removal efficiency more than (91%), slower rate of head loss build up, and longer filter runs compared to sand filters under the same circumstances.

Denver, (1989) referred that at (12.2 m/hr) and after the proper chemical treatment, up to (96 %) turbidity removal was achieved with different mixed media beds. These beds consisted of: 419 mm depth of anthracite with $d_e = 1.1$ mm, 229 mm depth of garnet with $d_e = 0.35$ mm, and 76 mm depth of garnet with (1-2) mm grain size.

Latif, (1990) used granular activated carbon (GAC) as a filter medium and an adsorbent material at the same time, in water treatment plants which

received water with turbidity less than (5 NTU). He emphasized that the effluent quality from the GAC filter was better than from sand filters, less head losses, and less backwashing water requirement.

(Cleasby et al., 1992) showed from their experimental work that tri-media is considered superior to dual-media in the filtered water quality under stressful filtration conditions (e.g., high rates and sudden rate increases). Unit filter run volumes (UFRV) for the tri-media filters were higher than those for the dual-media filters.

Yohe & Getting (1993) made a study on filters with 20 cm of (0.35-0.45) mm sand ($UC \leq 1.5$) and 50 cm of (0.9-1) mm anthracite with different uniformity coefficients (1.3, 1.4, 1.5, and 1.6). They observed that the lower the anthracite uniformity coefficient, the longer run times (up to 50 % longer), the fewer the back washes (33 % less), and the better water quality (up to 88 %).

Kawamura, (1999) showed that smaller uniformity coefficient (UC) values result in slightly better filtrate quality and longer filter run lengths,

Masters, (1991) and Drain, (2001) showed that the perfect quality of the filter media should have pore openings large enough to retain large quantities of flocculants, to process large volumes of water without clogging, but small enough to prevent the passage of suspended solids. The ideal filter media would also be light in weight, enough to allow sufficient depth for long filter runs, and be graded to allow effective backwash cleaning.

Degremont, (1991) stated that the same filtered water quality was obtained when using an angular material whose effective size was smaller than that of a round grain material.

Cleasby et al., (1992) performed experiments on filters with angular sand porosity of 41 % and smooth sand of 38 % porosity. It was found that the filter performance of (1.5 m) of angular sand was approximately equivalent to (2.4 m) of similarly sized smooth sand, Moreover,

According to the Unit Standard 18452,(2002),the range of useful media is limited by the need for significant density differences together with the cost and durability of the material.

To ensure that two types of filter media grains have the same settling velocity the following relationship should exist:

$$\frac{d_1}{d_2} = \left[\frac{\rho_2 - \rho}{\rho_1 - \rho} \right]^{0.667} \dots\dots\dots (2-2)$$

d_1 and d_2 = diameter of two media with specific gravity ρ_1 and ρ_2 , and ρ is the density of water with a specific gravity of 1.

To minimize intermixing of the two or three layers, the size of each successive layer, from top to bottom, should be (5-7) % larger than the size calculated by this equation, Kawamura, (1999).

Al-Auraji, (2003) showed that the sand filter media with ($d_e = 0.635$ mm) gave a better effluent quality, higher head losses, and lower filter run time than a sand filter media with ($d_e = 1$ mm).

2.7.1.3.Depth of Filtering Material

The depth of the filter could be selected from the relationships suggested by Kawamura,(1991) and Letterman, (1999). These relationships are in the form (L/d_e) where L = depth of the filter bed in mm,

d_e =effective size of the media in mm.

Kawamura, (1999) and Kawamura, (2000)stated that some typical values for L/d_e for common bed configurations are as follows:

$L/d_e \geq 1000$ for ordinary monosand and standard dual media filters.

$L/d_e \geq 1250$ for regular multimedia and trimedia (coal, sand, and garnet).

$L/d_e \geq 1250$ to 1500 for most coarse deep monomedium beds in which
($1.2 \text{ mm} < d_e < 1.4 \text{ mm}$).

$L/d_e \geq 1500$ to 2000 for very coarse deep monomedium beds in which
($1.5 < d_e < 2$ mm),

Byeseda & Sylvester, (1979) showed that deep bed filtration is most effectively applied to dilute suspensions (less than 50 ppm) consisting of nonvolatile discrete solids smaller than about (50 μ m) in diameter. The operative mechanisms in a deep bed filter are complex and dynamic.

Al-Auraji, (2003) showed that increasing the depth of sand filter media from 85 cm to 100 cm had a slight effect on both turbidity removal and filter running time, with the condition of constant effective size and filtration rate.

CHAPTER THREE

Theoretical Background

3.1 Introduction

The separation of suspended solids from river water has been the subject of many investigators over the past years. It is usually achieved by conventional treatment through coagulation – flocculation, sedimentation and filtration units. In all of these operations, the removal efficiency is greatly dependant on particles size, and can usually be enhanced by aggregation of the fine particles in the coagulation flocculation sequence. Al Mamori.A,(2001)

The suspensions must therefore be converted by artificial means. Such conversion is the out –come of two separate processes; Degremont, (1991)

3.1.1 Coagulation : is also called destabilization . It is usually achieved by the addition of chemical reagents which by bonding or adsorption mechanism nullify the repulsive forces or act on the hydrophily of the colloidal particles, ie .it is a chemical addition process, Degremont, (1991).

3.1.2 Flocculation : flocculation is the agglomeration of the neutralized colloids. This is the result of various forces of attraction acting between the particles brought into contact with each other initially by (Brownian movement), Degremont, (1991).

Until they acquire a size of about 0.1 micron and then by "outside mechanical agitation" to bring the floc to the required size it is purely a physical process of mixing. After adequate flocculation, most of the aggregates will settle out during sedimentation process. It is thus the conditioning of water to form flocs that can be readily removed by settling or filtration, Hofkes, (1983).

Chemicals can be used to create changes in pollutants that increase the removal of these new forms by physical processes. Simple chemicals such as alum, lime or iron salts can be added to wastewater to cause certain pollutants, such as phosphorus, to floc or bunch together into large, heavier masses which can be removed faster through physical processes. (EPA 2004)

3.2 Characteristics of Colloids

The colloidal particles are not limited to any particular group of substances but are defined by size. The colloidal size-range is generally regarded to extend from (1nm) to (1 μ m) although some authors consider the colloidal range to extend up to a size of (10 μ m). The size relationships are shown in Fig.(3-1) (Benefield et al., 1982).

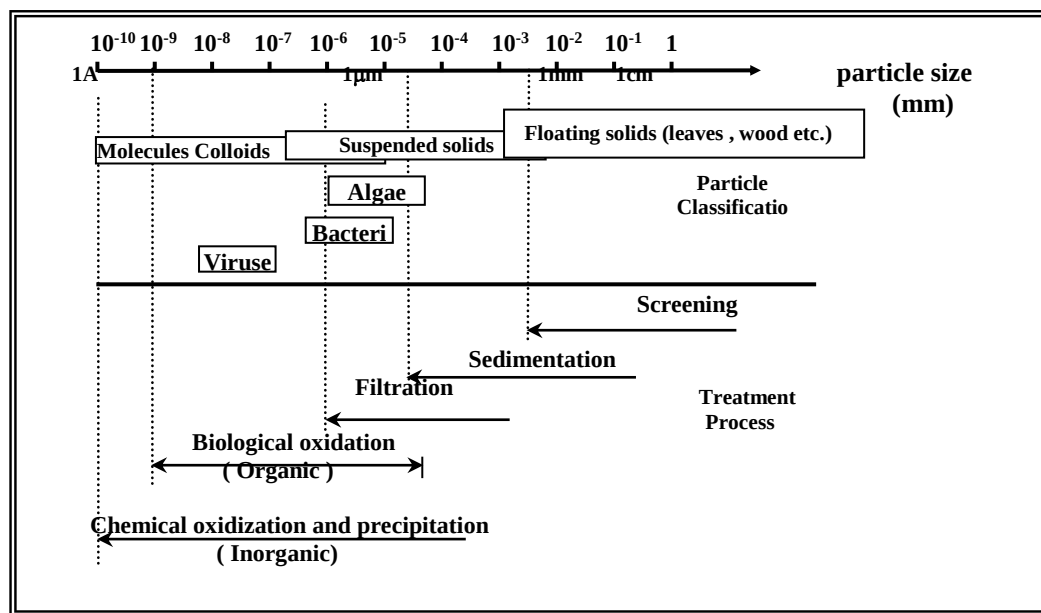


Fig. (3-1): Particle size and treatment processes,
[After (Benefield et al., 1982)].

Colloids were formerly classed as substance which apparently go into solution but, in fact, remain dispersed as discrete particles, and their size ranges from (10⁻³ to 0.1) μ m. in water and wastewater engineering , there are some features of colloidal suspension as follows : (Barnes, et al., 1981)

- a- It cannot be removed from suspension by ordinary filtration.

- b- Colloidal particles are not visible under an ordinary microscope, but they can be seen as specks of light with an ultra microscope when a beam of light is passed through the suspension.
 - c- Brownian motion prevents the settlement of particles under gravity.
 - d- There is a natural tendency for colloids to coagulate and precipitate. Sometimes this tendency is encountered either by mutual repulsion of the particles and the medium in which they are dispersed. If these effects are strong and coagulation does not occur, the suspension is said to be "stable".
- particles found within this size range are (1) inorganic particles, such as asbestos fibers, clays, and silts, (2) coagulant precipitates, and (3) organic particles, such as humic substances, viruses, bacteria, and plankton. Colloidal dispersions have light-scattering properties. The property of scattering light is generally measured in turbidity units. Colloidal solutions may be classified, by their affinity for the dispersing medium (water), as either *hydrophobic* or *hydrophilic*. Colloidal particles are hydrophobic (water-hating) when a weak affinity for water exists and hydrophilic (water-loving) when there is a strong affinity for water. Qasim, S, (1999)
- Hydrophilic colloids may become absorbed on hydrophobic colloidal particles such as clays, thereby imparting hydrophilic properties to the latter. Colloidal suspensions of this kind are called "protective colloids" and may be difficult to coagulate. Casey, (1997).

Colloids mostly have a large surface area per unit volume, and surface electrical charge. This surface charge attracts ions carrying opposite charge, and thus creating a cloud of counter-ions in which the concentration decreases as the distance from the particle increases. The overall situation is complex. The colloids which carry similar charges will repel each other but, the presence of counter-ions complicates the law relating the degree of repulsion, causing a more rapid fall-off in repulsive force as distance increases, Zajic, (1972)

The principle phenomena controlling the behavior of colloids are: **electrostatic forces, Van der Waals forces, and Brownian motion.**

Qasim, S; (1999)

Electrostatic force is the principal force contributing to the stability of the colloidal suspensions. Most colloids are electrically charged, the nature of this charge varies depending on the nature of the colloid. Metallic oxides are generally positively charged, while nonmetallic oxides and metallic sulfides are generally negatively charged. The result of this electrical charge is that colloids of similar charge will repel each other. Typically, negatively charged colloids predominate in natural waters.

The surface charge on the colloids attracts ions of opposite charge, known as counter ions. These ions, which include hydrogen and other cations, form a dense layer adjacent to the particle known as stern layer .The fixed layer or stern layer is the tight compact layer of counter ions that surrounds the particle. Qasim, S; (1999)

Water molecules are also attracted to the colloidal particle. The attraction of water is due to the asymmetric electrical charge of water molecules. A second layer of ions, known as the diffusion layer, is also attracted to the colloid. The diffuse layer is a loose layer of ions surrounding the fixed layer. In this layer, ions of both electrical charges are attracted, but counter ions predominate. The two layers together are often referred to as the double layer. A colloidal particle and its double layer are illustrated in Fig. (3-2) ; Ravina, (1985).

In the diffusion layer, the molecules of water are sufficiently bound to create a shear surface. The water molecules inside this shear surface will behave as if attached to the colloid; water molecules outside the shear surface will behave as if independent of the colloid. In between the fixed and diffuse layers is the plane of shear. The zeta potential (ZP) is the electrostatic potential (ESP) at the plane of shear. Lowering the ZP makes the ESP of the

particle less. Lower repulsion forces between particles allow them to come together and form flocs , HDR Engineering, Inc., (2001).

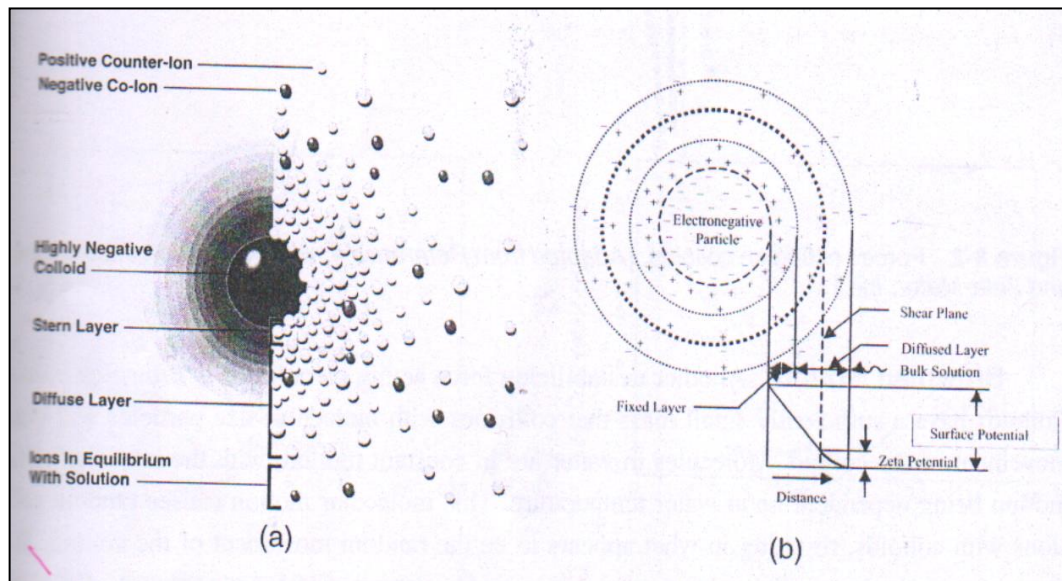


Fig. (3-2) :A colloidal particle and double layer (a) A negative colloidal particle with its electrostatic field. (b) Distribution of electrostatic potential, shear plane, and zeta potential (Ravina .L,1985).

The zeta potential is often measured in water treatment to give an indication of the stability of the colloidal system or of the effectiveness of the coagulation process.

This latter is called the Zeta potential (ζ) and is related to the particle charge and the double layer thickness as follows:

$$\zeta = \frac{4\pi q t}{D} \dots\dots\dots [3-1]$$

where: ζ = zeta potential (volts) ; q=charge difference between the particle and the medium (colump) ; t= thickness of the layer around the particle through which the charge difference is effective (cm) ; D=dielectric constant of the medium. Qasim, S; (1999)

The action of flocculating salt can only be explained by the adsorption of counter – ions and consequent reduction of " ZP " , Gregory, (1993) . In

such cases full destabilization can be achieved at low ionic strength, provided that the "ZP" has been reduced to some critical value. Once the zeta potential is lowered by the coagulant, particles are able to attach to one another and aggregate. A metal salt is added slowly and as the amount added increases the destabilization occurs.

If the additive level is increased, the "ZP" can be reversed and the particles become stable again (a process normally known as restabilization)

The zeta potential is determined experimentally in an externally applied electric field. The ordinary range of the zeta potential is (10 to 200 mV). For effective coagulation it is necessary to reduce the zeta potential to within (0.5 mV) of the isoelectric point (Fair et al., 1968).

Van der Waals forces a force of attraction exists between any two masses. The magnitude of this attraction is a function of the mass of the two bodies and the distance between them. This attraction is known as the van der Waals forces . As indicated in Fig. (3-3), the force of repulsion due to the electrical charge will normally repel the colloids before they can move close enough for van der Waals forces to become significant ; Reynolds and Richards ,(1996). If the magnitude of the electrostatic forces could be reduced, the particles would move close enough for van der Waals forces to predominate.

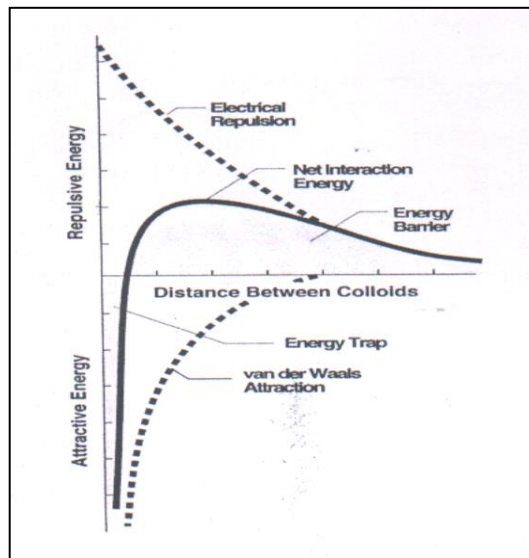


Fig. (3-3): Forces Acting on Colloids (Ravina .L, 1985).

Brownian motion another destabilizing force acting on colloids is Brownian motion .Colloids have a sufficiently small mass that collisions with molecular – size particles will cause movement of the colloid. Molecules in water are in constant motion, with the intensity of this motion being dependent upon water temperature. This molecular motion causes random movement of the colloid. This phenomena is known as Brownian motion , Montgomery ; (1985)

In some instances, Brownian motion can cause two colloids to move sufficiently close for van der Waals forces to predominate over electrostatic repulsion. If this occurs, the particles could agglomerate .such instances rarely occur, and destabilizing influence of Brownian motion is insignificant.

3.3 Stability and instability factors

In the field of colloid science, two different approaches have been advanced historically to explain the basic mechanisms and stoichiometry of coagulation. These conditions are described by the terms “Stability” and Instability ”of colloidal suspension. **Stability** refers to the inherent property of colloidal particle to remain dispersed despite passage of time, whereas **instability** describes the tendency of particles to coalesce whenever particle

– to particle contact is made. The reason due to instability suspension (coagulation) is that the kinetic energy for particle translocation is obtained from Brownian movement for smaller particles, but more importantly from the energy introduced into colloidal suspension in the form of mixing which greatly increases the probability of particle collisions if the forces of the repulsion are sufficiently reduced. Black ,(1960). Historically, two broad theories have been proposed to explain the mechanisms involved C. R., (1971):

- 1-The newer, **physical theory** or double – layer theory emphasizes the importance of the electrical double layers surrounding the colloidal particles in the solutions and the effect of counter – ion adsorption and zeta – potential reduction in the destabilization of colloidal systems.
- 2-The older, **chemical theory** assumes that colloids acquire electrical charges on their surface by ionization by chemical groups presented at the surface and that coagulation is accomplished by chemical interactions between colloidal particles and coagulant.

3.4 Destabilization of colloidal dispersions

Colloidal, or suspended, particles have a negative charge on their surfaces known as the zeta potential. Natural colloids tend to acquire this charge in one of two ways: ionization of their surface groups where they will accept or donate protons or adsorption of negatively charged organic molecules. HDR Engineering ,Inc.,(2001).A polymeric coagulant aggregates the particles in another way called bridging. The polymer consists of long molecular chains and the reactive groups on the chain absorb one or several particles in different places. This makes the particles large enough to be removed through sedimentation and/or filtration. Examples of how a polymer bridges can be seen in Fig.(3-4), AWWA,(1999).

To induce colloidal particles to aggregate, two distinct steps must occur Stumm and O'Melia, (1968):

- 1-The repulsion forces must be reduced (i.e., the particles must be destabilized).
- 2-Particle transport must be achieved to provide contacts between the destabilized particle

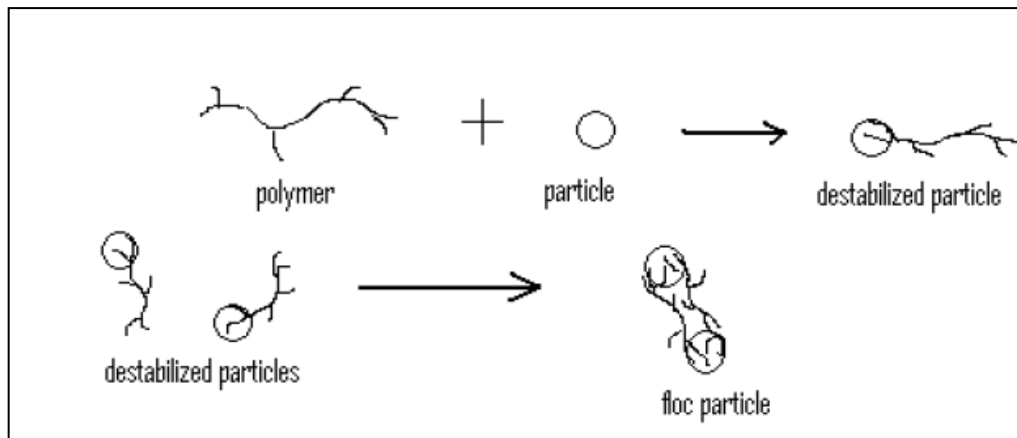


Fig.(3-4): Examples of Coagulation and Flocculation by Bridging (HDR Engineering Inc., 2001)

3.5 Mechanisms of destabilization

There are several mechanisms for explaining particle destabilization by aluminum salts in coagulation. Dentel and Gossett (1988) reported four major coagulation mechanisms:

- 1-Double – layer compression (neutralization of surface charge).
- 2-Adsorption of soluble polymeric metal-hydroxide species.
- 3-Precipitation of a metal – hydroxide.
- 4-Enmeshment in a precipitate (sweep coagulation).

3.5.1 Double – layer Compression

When a colloidal particle is immersed in a solution, electrical charges will develop at the particle – water interface. The origin of these charges may be due to the dissociation of the ionizable groups of the colloide itself or to the adsorption of low – molecular – weight ions onto its surface. As a result of this charge development, a charge balance must be established in the vicinity of the colloidal particle to fulfill the requirement of electro neutrality. Helmholtz considered the picture of the charge balance as two surface charges separated by a constant distance as a simple condenser in solution. The charges on the particle surface formed either the positive or negative portion, whereas the opposite charges (counter ions) in solution comprised the other portion .C. R., (1971).

The effect of this compression is to change the distribution of double – layer repulsion forces in the vicinity of the colloid and cause a reduction in surface potential with increasing electrolyte concentration, while allows the Van der Waals attractive forces to be more dominant, thus enhancing particle aggregation, as shown in Fig. (3-5), (Benefield et al. 1982)

Two interesting aspects of double – layer compression are (Benefield et al., 1982):

- 1-The amount of electrolyte required to achieve coagulation is practically independent of the concentration of colloids in the dispersion.
- 2-It is not possible to cause a charge reversal on a colloid, regardless of how much electrolyte is added.

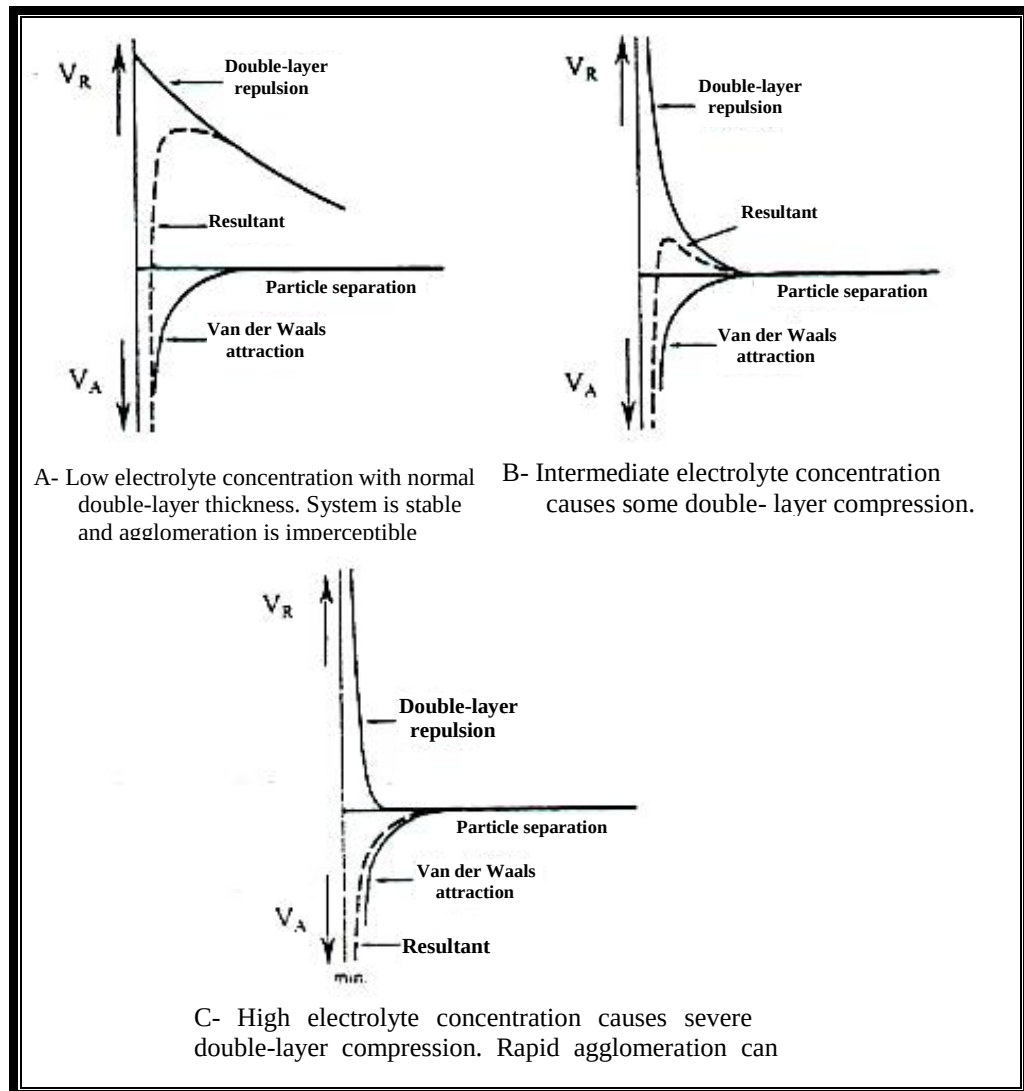


Figure (3-5): Effect of electrolyte concentration on double layer-compression, [After (Benefield et al., 1982).

3.5.2 Adsorption of soluble polymeric metal hydroxide species

Some chemical species are capable of being adsorbed at the surface of colloidal particles. If the adsorbed species carry a charge opposite to that of the colloids, such adsorption causes a reduction of surface potential and result in destabilization of the colloidal particles.

Destabilization by adsorption differs from destabilization by double-layer compression in three very important ways. **Firstly**, sorbable species are capable of destabilizing colloids at much lower dosages than nonsorbable,

"double – layer compressing " ions. **Secondly**, destabilization by adsorption is stoichiometric. Thus, the required dosage of coagulant increases as the concentration of colloids (more specifically, the total surface area of colloids)increases, while the amount of electrolyte required to achieve coagulation by double – layer compression is not stoichiometric and is practically independent of colloid concentration. **Thirdly**, it is possible to overdose a system with an adsorbable species and cause restabilization as a result of a reversal of charge on the colloidal particle .Weber, (1972).

3.5.3 Precipitation of a metal – hydroxide

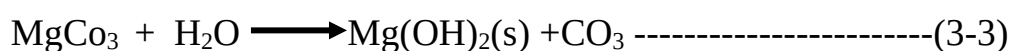
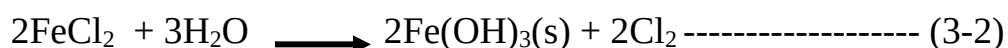
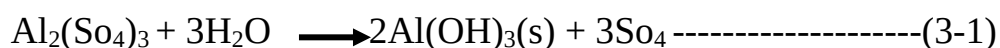
Because the metal hydroxide precipitates are positively charged in the pH range common to water treatment, it has been hypothesized that charge neutralization is achieved due to precipitate deposition on the surfaces of particles. This differs from the " adsorption–sweep floc " concept of coagulation in that precipitation precedes charge neutralization Dentel and Gossett, (1987).

The assumptions that describe this mechanism presume that coagulation involves three steps Dentel, (1987):

- 1- Coagulation comes about after the operational solubility limit for aluminum hydroxide has been exceeded. Much less alum is needed to initiate this process at intermediate pH values than at higher or lower pH levels.
- 2- Aluminum hydroxide species then are deposited onto the colloidal surface.
- 3- Under typical conditions, the metal hydroxide is positively charged, while the original colloidal material or particles are negatively charged. The deposition process therefore can lead to charge neutralization or charge reversal at certain doses.

3.5.4 Enmeshment in a Precipitate (Sweep Coagulation)

If certain metal salts are added to water in sufficient amounts, rapid formation of precipitates will occur. Colloids may serve as condensation nuclei for these precipitates or may become enmeshed as the precipitates settle. Coagulants, such as $[\text{Al}_2(\text{SO}_4)_3]$, $[\text{FeCl}_2]$, $[\text{MgCO}_3]$, and $[\text{Ca}(\text{OH})_2]$ can induce coagulation through the formation of insoluble $[\text{Al}(\text{OH})_3(\text{s})]$, $[\text{Fe}(\text{OH})_3(\text{s})]$, $[\text{Mg}(\text{OH})_2(\text{s})]$, and $[\text{CaCO}_3(\text{s})]$. Removal of colloids in this manner is frequently referred to as sweep-floc coagulation, (Benefield et al., 1982).



(Ching et al. 1994) showed that in the experimental conducted at pH (7.8) is induced by precipitation of aluminum hydroxide from solution at high alum dosage, and possibly, by precipitation of aluminum hydroxide onto the surface of clay particles at lower alum dosage. At high alum dosage, effective coagulation is accomplished by precipitation of an $[\text{Al}(\text{OH})_3(\text{s})]$. The colloidal particles can serve as nuclei for the formation of the precipitation, so that the rate of the precipitation increases with increasing concentration of the colloidal particles to be removed. This can result in an inverse relationship between the optimum coagulant dosage and the concentration of material to be removed.

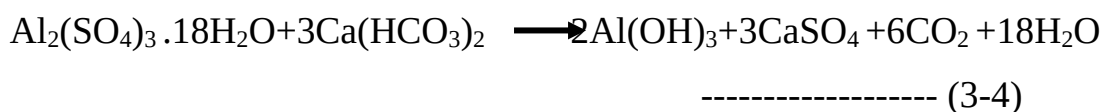
Another noteworthy fact with respect to coagulation is that the $[\text{Al}(\text{OH})_3(\text{s})]$ formed is weakly negative when (pH > 8) but is strongly positively charged at values of (pH < 7) Amirtharajah and Mills, (1982). This implies that in the range of pH (7-8) the precipitate is positively charged, and the enmeshing or the sweep mechanism of $[\text{Al}(\text{OH})_3(\text{s})]$

precipitation is enhanced by the possibility of mutual or hetero-coagulation between the negatively charged solution and the positively charged $[\text{Al}(\text{OH})_3(\text{s})]$. Jorden, (1972).

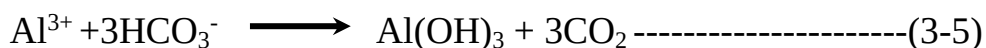
3.6 Chemistry of Coagulation with Alum

Coagulant such as alum and iron salt reacts with the alkalinity of water, and hydrolyzes in it. Alum reacts to form aluminum hydroxide floc, $\text{Al}(\text{OH})_3$; a gelatinous precipitate. This intermediate product, not only provides the charge needed to neutralize the colloids but, according to some writers Degremont, (1991) , Reshi , (1993) and (Valade ,et al., 1996) is capable of polymerization , (ie. of forming bridges between the colloids and thereby initiating the flocculation process.

When alum is added to water in the presence of alkalinity, the overall reaction is as follows:



Omitting the non – reacting species, this reaction may be written as:

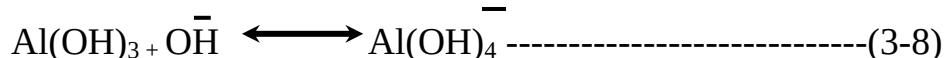
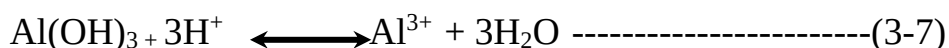


The presence of alkalinity acts as a buffer against excessive lowering of pH.

The aluminum hydroxide precipitate formed might be more correctly called a hydrated aluminum oxide precipitate.



It is amphoteric, in that it can react with H^+ or OH^- ions, depending on the pH:



Free trivalent aluminum ion is released in a solution. However, under coagulation conditions only relatively small concentrations of (Al^{3+}) is

present in solution and hence its influence on coagulation may not be as great as is sometimes suggested Casey, (1997).

The metal ion undergoes stepwise of hydrolysis reactions as exemplified in Table (3-1). It is important to note that the pH of the solution is depressed by these hydrolytic reactions.

**Table (3-1): Reactions for hydrolysis of Al(III),
[After (Dentel and Gossett, 1987)].**

Species	Reaction	
Al^{3+}	$\text{Al}(\text{OH})_3 + 3\text{H}^+$	$\text{Al}^{3+} + 3\text{H}_2\text{O}$
$\text{Al}(\text{OH})^{2+}$	$\text{Al}^{3+} + 1\text{H}_2\text{O}$	$\text{Al}(\text{OH})^{2+} + 1\text{H}^+$
$\text{Al}(\text{OH})_2^+$	$\text{Al}^{3+} + 2\text{H}_2\text{O}$	$\text{Al}(\text{OH})_2^+ + 2\text{H}^+$
$\text{Al}(\text{OH})_3^0$	$\text{Al}^{3+} + 3\text{H}_2\text{O}$	$\text{Al}(\text{OH})_3^0 + 3\text{H}^+$
$\text{Al}(\text{OH})_4^-$	$\text{Al}^{3+} + 4\text{H}_2\text{O}$	$\text{Al}(\text{OH})_4^- + 4\text{H}^+$
$\text{Al}_2(\text{OH})_2^{4+}$	$2\text{Al}^{3+} + 2\text{H}_2\text{O}$	$\text{Al}_2(\text{OH})_2^{4+} + 2\text{H}^+$
$\text{Al}_3(\text{OH})_4^{5+}$	$3\text{Al}^{3+} + 4\text{H}_2\text{O}$	$\text{Al}_3(\text{OH})_4^{5+} + 4\text{H}^+$
$\text{Al}_7(\text{OH})_{17}^{4+}$	$7\text{Al}^{3+} + 17\text{H}_2\text{O}$	$\text{Al}_7(\text{OH})_{17}^{4+} + 17\text{H}^+$
$\text{Al}_{13}(\text{OH})_{32}^{7+}$	$13\text{Al}^{3+} + 32\text{H}_2\text{O}$	$\text{Al}_{13}(\text{OH})_{32}^{7+} + 32\text{H}^+$

The hydrolysis products play a more important role in particle destabilization Dentel, (1991). Further hydrolytic reactions yielding higher hydroxide complexes, are leading to the formation of positively charged colloidal polymers and ultimately to hydroxide precipitates.

Both the positively charged complex ions and the colloidal hydroxo polymers are considered to play an important role in the overall mechanisms of coagulation. The anions of the trivalent salts also play a part in completing the coagulation process by promoting the coagulation of any excess of positively charged metal hydroxo colloids formed Casey, (1997).

There is a general agreement that under equilibrium conditions aluminum exists primarily as the insoluble solids $\text{Al}(\text{OH})_3$ as shown in Fig. (3-6)

C. R., (1971). Aluminum hydroxide is the desired end product. It is insoluble, floc forming, heavier than water, and it carries the positive electric charge necessary to neutralize the negative charges of the colloidal particles Smethurst, (1997).

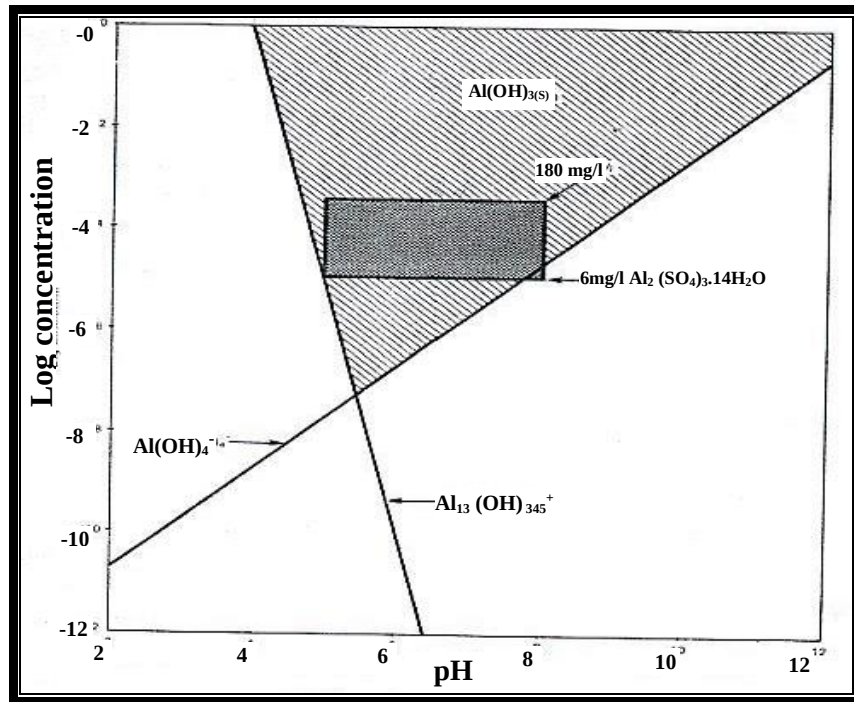


Fig. (3-6): Equilibrium solubility domain of aluminum hydroxide in water , [After (C. R., 1971)].

Sullivan and Singley have shown that, under the nonequilibrium conditions existing in water treatment plant coagulation, the predominate species may not be the simple insoluble trihydroxide, but they found that the predominant species was (Al^{3+}) up to pH (4.5), $[\text{Al(OH)}_3]$ from pH (4.5 to 8), and $[\text{Al(OH)}_4^-]$ above pH (8). Sullivan and Singley, (1968).

McGhee (1991) stated that although other techniques are possible for coagulation, the coagulation of water generally involves the addition of chemicals – either hydrolyzing electrolytes or polymers. The action of metallic coagulants is complex, involving the dissolution of the salt (which may reduce the Zeta potential by altering the ionic concentration in the bound layer) the formation of complex hydroxyl – oxides of the metal which may be

highly charged, and the entrapment of individual particles is the chemical precipitate formed.

If water contains insufficient alkalinity, the addition of a coagulant may depress the pH below the range in which the particular salt is effective. In such a circumstance an alkaline salt must be added to increase the buffer capacity of the solution. The adequacy of the natural alkalinity may be estimated from the following equation. Which represent the approximate overall reactions involved Aluminum Sulphate (alum).

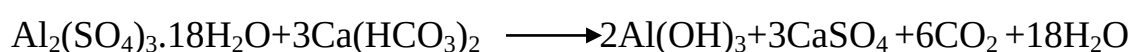


Table (3.2) indicates the advantages of using proper alum dosage for coagulation

Table (3.2) :Effects of alum – dosage on treatment criteria (Schulz and Okun, 1984)

Treatment Criteria	Under dose	Proper dose	Over dose
Turbidity removal	Poor	Good	Fair
Color removal	Poor	Good	Fair
Algae removal	Poor	Good	Fair
Length of filter run	Mediam	Long	Short
Cost value	Wasted	Good	Poor
Residual Al ⁻³	High	Low	High

3.7. Local (Porcelanite) Material

Porcelanite raw is compound of sedimentary conditions and from big quantities from live creatures rich with silica . The decay and dissolved of silica that take the place of carbonates metals also transitional process related to the compound of (opal CT) , it's a rock , which consists of two metals

(cristobillite and tridimite) which were distinguishes with opened crystallize structure that allowed to enter a lot of ions that made it have coagulation and filtration important . Abd- Al –Hussein, (1995).

Porcelanite rocks in Iraq, is from an industrial bed of (0.5 to 1.3 m) thickness in the Safra, and Trafawi site of the Jeed formation in Al-Rutba region, western of Iraq. Rocks of these deposits are composed of medium ordered crypto and microcrystalline opal-CT, associated with authigenic quartz, carbonates, clay minerals, halite, and apatite. Porcelanite rocks are largely composed of sponge spicules (pores) and some other siliceous micro fossils (diatoms and radiolarian) as well as silicified forminifera and nannoplankton, (Mohammed, 1993 ^{Arabic}).Fig.(3-7)show the location of porcelanite sample sites in Iraq .

Korkess, (1993) specified porcelanite from Traifawi site H₃ area with high percents of cristobalite, tridymite, and quartz.

The adsorption capacity of porcelanite is due to the large surface area within the composition of cristobalite and tridymite .Abed- Ohn, (2003 ^{Arabic})

Adsorption capacity for porcelanite made it important for getting rid the environment from the different pollution . Al-Wetaify ; (2005)

3.7.1 Chemical analysis of Iraqi porcelanite :

Porcelanite is a semi-vitrified clay or shale (i.e. clay or shale partially converted to glass). Two porcelanite samples are found in Iraq . They have been analyzed by method used in (GEGSM).Table (3-3) indicates some differences between the porcelanite samples of Traifawi site H₃ and Al-Safra member. Silica contents are of 83% and 72% respectively. Calcium and magnesium – oxide contents at Safra are higher than traifawi. The high calcium and magnesium content of Al- Safra member indicates the presence of dolomite [CaMg (CO₃)₂]. This was also noticed through the mineral optical studies. Al-Ansary , (1999).

Table (3-3) :Chemical analysis for local porcelanite samples.

Constituent	Safra (s)%	Traifawi T-H ₃ %
Silica(SiO ₂)	72.65	83.57
Alumina(Al ₂ O ₃)	0.80	0.62
Iron oxide(Fe ₂ O ₃)	4.71	4.45
Titanium oxide (TiO ₂)	0.10	0.01
Phosphate(P ₂ O ₅)	5.72	1.82
Lime(CaO)	6.52	1.46
Magnesia(MgO)	0.40	0.50
Sodium (Na ₂ O)	0.14	0.16
Potassium (K ₂ O)	1.18	0.22
Ignition loss(L.O.I)	6.7	5.9
Total	98.92	98.71

3.7. 2 Mineralogical Analysis of Porcelanite in Iraq

This analysis includes the identification of the type of minerals in the Iraqi porcelanite rocks, by using x-ray diffraction technique – Philips pw, 1130. This instrument present in the department of Geology – University of Baghdad.

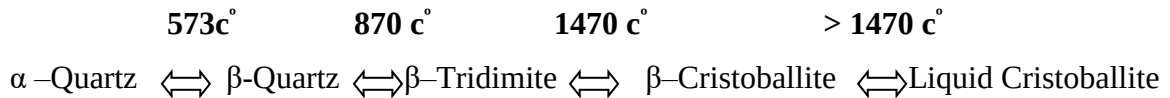
The sample from Al-Safra member contain high percent of dolomite [CaMg (CO₃)₂]. Al-Ansary , (1999).

The silica content (cristobalite, tridymite, and quartz) is slightly lower in percent when compard with the porcelanite sample from Traifawi member – H₃ area. Sample from Traifawi member –H₃ area showed high percent in the mineral of cristobalite, tridymite, and quartz. **Tridymite** is a high-temperature polymorph of quartz and usually occurs as minute tabular white or colorless crystals, or scales, in cavities in acidic volcanic rocks. Tridymite is stable between 870 and 1470 degrees centigrade of cristobalite. **cristobalite** is a high-temperature polymorph of quartz and tridymite. It occurs as white octahedra in acidic volcanic rocks. Cristobalite is stable only

above 1470 degrees centigrade . (American Geological Institute Dictionary of Geological Terms).

The transformation of the types of mineral in porcelanite rocks.

Singer, (1963)



These minerals are belonging to the silica minerals family. Traifawi samples also contains very low percentage in dolomite [$\text{CaMg}(\text{CO}_3)_2$], and apatite ($\text{Ca}_5(\text{PO}_4)_3$) with traces of polygorskite (hydrous Mg- silicate).

The reason for the higher percentage of silica minerals in the porcelanite samples from traifawi member – H₃ area when compard to Al-Safra member is that the latter contain high percentage in calcium – magnesium carbonate (dolomite $\text{CaMg}(\text{CO}_3)_2$) and low percentage in silica (SiO_2) (about 70%).

(Al-Bassam et. al, 1993)

The sample from Traifawi member – H₃ area contains high silica percent (about 80%) and very low percent in calcium magnesium carbonate (dolomite). This mean that silica content is inversely proportional to the calcium magnesium carbonate in the porcelanite rocks.

3.8. Mechanisms of Filtration

The solid removal efficiency is inversely proportional to sand grain size, filtration rate, and to the square of water viscosity, Masters, (1991). Viscosity is the ability of a liquid to resist various movements, both internal and overall, such as flow. It is the basic of head loss and therefore plays an important part in water treatment. It increases with higher content of dissolved salts and pressure. It diminishes when temperature increases, Degremont, (1991).

Most municipal water treatment systems filter their water through a deep granular bed of porous media. The most commonly used filtration

process is rapid sand filtration. The particle removal experienced in this type of filtration is known as rapid depth filtration. In rapid depth filtration, there are several mechanisms responsible for the removal of particles from water. The simplest of these mechanisms takes place with larger particles and is known as screening. Screening takes place when a particle which is to be filtered out is larger than the smallest pore through which the water must pass. Screening usually takes place near the surface of the filter, and is responsible for removing only the largest particles from the water being treated (AWWA, 1999).

3.8.1 Transport mechanism:

This is simply a process of bringing particles from the bulk of the fluid within the interstices close to the surface of the grains. Transport mechanisms may include mechanical straining, gravitational settling, interception, inertia, hydrodynamics, and Brownian diffusion as shown in Fig. (2-4) . These mechanisms are affected by physical characteristics such as size and shape of the filter grains, filtration rate, fluid temperature and the density, size, and shape of the suspended particles, Letterman, (1999).

Straining removes particles that are large enough to get caught in the pores. It is considered the most important mechanism that takes place almost in the top few centimeters of the filter medium. Gravitational settling proposes that each pore in the filter medium is a tiny sedimentation basin. Gravitation forces tend to cause particles of density higher than water to move across streamlines in the force direction.

Interception occurs when particles flowing in streamlines through the filters pass the medium within the particle radius, then they will tend to be in contact with the medium. A particle's inertia can cause it to leave the streamline and make contact with the grain when a medium grain causes the divergence of flow around it. Hydrodynamic action occurs when the flow

through the filter is laminar, the velocity gradient across the streamline can cause the particles to spin and this in turn causes them to veer across the streamline, Jago, (1977).

Interception works only with relatively large particles as smaller particles would not tend to contact the filter media when traveling along laminar flow lines .Eurofiltec, (2002).

The final transport mechanism responsible for the removal of particles from water is known as diffusional or Brownian interception. This type of interception takes place with small particles that have a density close to that of water. Particles being transported by this mechanism exhibit seemingly random motion known as Brownian motion ,Henke, (2002).

Diffusion results from random Brownian motion by bombardment of the particle by molecules of water. This became increasingly important for particles ($<1\ \mu\text{m}$) in size, i.e., as they approach the size of water molecules, Amirtharajah, (1988). Brownian motion is the result of continuous collisions between the particle and the surrounding fluid. The main driving force behind Brownian motion is the thermal energy present in the fluid (HDR Engineering, Inc., 2001).

The pore openings of the sand media are often larger than the flocculent particles to be removed, so in rapid filter systems there are a combination of techniques for the removal of suspended solids and particulate matter from the influent. These techniques include: simple straining, adsorption, and sedimentation, Drain, (2001). As shown in Fig.(3-8)

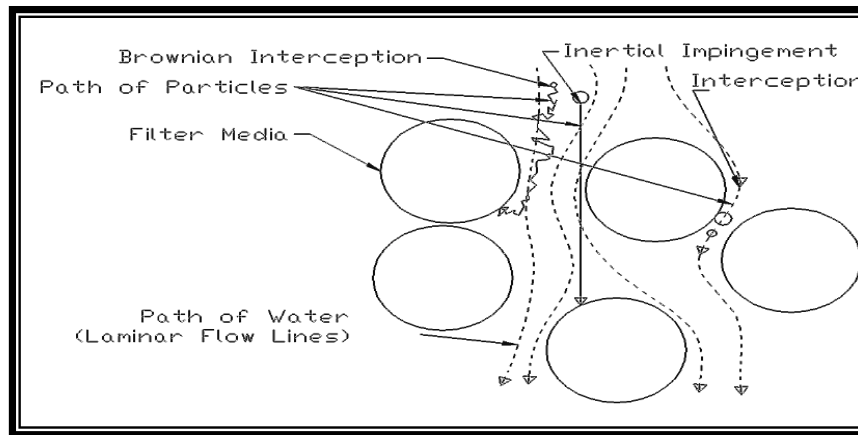


Fig. (3-8): Transportation Mechanisms in Rapid Depth Filtration

3.8.2 Attachment mechanism:

The mechanism of attachment of suspended particles to the surface of the filtering material is known as adsorption. It is physical in nature as it has opposition to chemical adsorption a reversible characteristic, which permits the regeneration of the adsorbent, it may include mainly Van der waals forces, electrostatic repulsive forces, and surface tension, Leclerc & Vu, (1972).

After a particle comes in contact with the filter media, it must attach to the media and stay attached. For attachment to occur a particle must be sufficiently destabilized so that a net attractive force is present between the particle and the filter media. Particles are destabilized by the various destabilization mechanisms of coagulants. Attachment of particles to filter media is similar to the aggregation of destabilized particles during flocculation (HDR Engineering, Inc., 2001).

Particle removal in granular filters is not an irreversible process and detachment of particles may occur when forces shearing the particles away from the media grain are greater than the adhesive forces holding the particle, (Crittenden, et al, 2005).

Van der waals forces are well known as attractive forces between molecules and theoretically they apply to nearly all materials in water but

their range is usually limited to minute distances of less than 0.05 μm , (Twort et al., 2000).

Electrostatic repulsive forces attract particles to the media. This occurs to a limited extent in rapid sand filters, (Unit Standard 18452, 2002).

3.8.3 Detachment mechanism:

As a result of the previous mechanisms, the space between the walls of the material covered with particles that have been already deposited will decrease. Consequently, the velocity of flow increases. The retained deposits may become partially detached and be driven deeper into the filter material or even be carried off in the filtrate, Degremont, (1991).

Surface tension is defined as a tensile force and which tends to reduce the area of this surface to the greatest possible extent. The addition of dissolved salts generally increases surface tension, Degremont, (1991).

3.9. Parameters Effecting the Coagulation and Filtration Processes

The following parameters are to be considered in evaluating the performance of conventional water and wastewater treatment plants.

3.9.1 Temperature

The water and wastewater temperature is of importance because it affects many parameters that impact engineering designs. These parameters include density, viscosity, vapor pressure, surface tension, solubility, the saturation value of gases dissolved in water and the rates of chemical, biochemical and biological activity. Cold water generally requires more chemicals for efficient coagulation and flocculation to take place (Crittenden, et al, 2005).

According to (WSO, 2003), Water with higher temperatures may result in a higher chlorine demand because of increased reactivity and also because there is usually an increased level of organic matter such as algae and bacteria in the raw water.

The effect of water temperature on the backwash rate is significant, when the temperature increases the backwash rate also increases, Kawamura, (2000)

3.9.2 pH

This parameter controls many chemical reactions including coagulation, disinfection, water softening, corrosion, biochemical reactions and ammonia removal. It also indicates the designer, what construction materials to use, (WSO, 2003). The chlorination is less effective to kill bacteria at high pH values, (WHO, 1989).

In a limited number of cases, a pretreatment and filtration at pH (5.7) achieved better pathogen removal than a pretreatment and filtration at pH (7), (Harrington et al, 2003)

3.9.3 Turbidity

This property is caused by suspended particles in water. These particles cause light rays to be scattered rather than to be transmitted in straight lines making a matter appear cloudy.

Suspended particles in water and wastewater causing turbidity include organic and inorganic matter and plankton.

3.9.4 Conductivity

Conductivity is the ability of an aqueous solution to carry an electric current. Solutions of most inorganic compounds are relatively good conductors conversely; molecules of organic compounds that do not dissociate in aqueous solution conduct a current very poorly. Conductivity evaluates variations in the concentration of dissolved minerals in water sources, (WSO, 2003).

3.9.5 Total Dissolved Solids (TDS)

The presence of harmful dissolved compounds or ions (such as arsenic and mercury) can be dangerous in water even where the total solids concentrations are relatively low, (WSO, 2003).

Dissolved solids in drinking water tend to change the water's physical and chemical nature.

It refers to the total filterable residue in natural water consisting mainly carbonates, bicarbonates, chloride, sulfate, calcium, magnesium, sodium, and potassium. Dissolved metals, dissolved organic and other substances also account as a portion of the dissolved residue in water.

3.9.6 Biochemical Oxygen Demand

Biochemical Oxygen Demand is the amount of oxygen required in the oxidation of organic matter by biological action under specific standard test conditions. This is widely used to measure the amount of organic pollution in wastewater and streams. BOD is used to measure how well a sewage treatment plant is working. If the effluent, the treated wastewater produced by a treatment plant, has a high content of organic pollutants or ammonia, it will demand more oxygen from the water and leave the water with less oxygen to support fish and other aquatic life.

Biochemical Oxygen Demand (BOD) is a chemical procedure for determining how fast biological organisms use up oxygen in a body of water. It is used in water quality management and assessment, ecology and environmental science. BOD is not an accurate quantitative test, although it could be considered as an indication of the quality of a water source.

Organic matter and ammonia are “oxygen-demanding” substances. Oxygen-demanding substances are contributed by domestic sewage and agricultural and industrial wastes of both plant and animal origin, such as those from food processing, paper mills, tanning, and other manufacturing processes. These substances are usually destroyed or converted to other compounds by bacteria if there is sufficient oxygen present in the water, but the dissolved oxygen needed to sustain fish life is used up in this break down process. (EPA 2004)

Biochemical Oxygen Demand (BOD₅) is the most commonly used parameter to express the strength of municipal and industrial wastewaters. The BOD₅ test is important for the design of biological treatment facilities, determining organic loadings to treatment plants, and evaluating the efficiency of treatment systems. The BOD of wastewater is not a single point, but rather a time– dependent variable. A 5 d incubation has become a standard practice. It takes approximately 20 d to stabilize all biodegradable organic matter and nitrogen contained in a wastewater sample (Qasim , S,1999).

CHAPTER FOUR

Experimental Work

4-1 Introduction

This chapter presents the experimental work of the present study. A pilot plant as shown in a schematic diagram in Fig. (4.1) was constructed to perform the processes of coagulation, flocculation, sedimentation and filtration. During this study two hundreds runs were conducted in the Laboratory of Al-Muamera wastewater treatment plant of Hilla city.

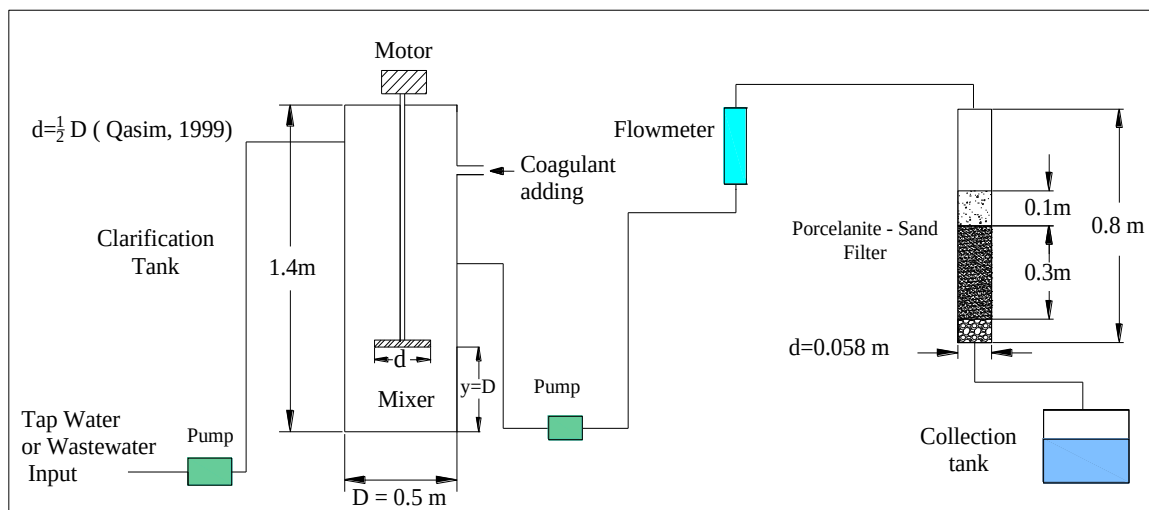


**Fig.(4-1):A Schematic Diagram of the Pilot Plant Used in the Study
for Treatment of Water and Wastewater**

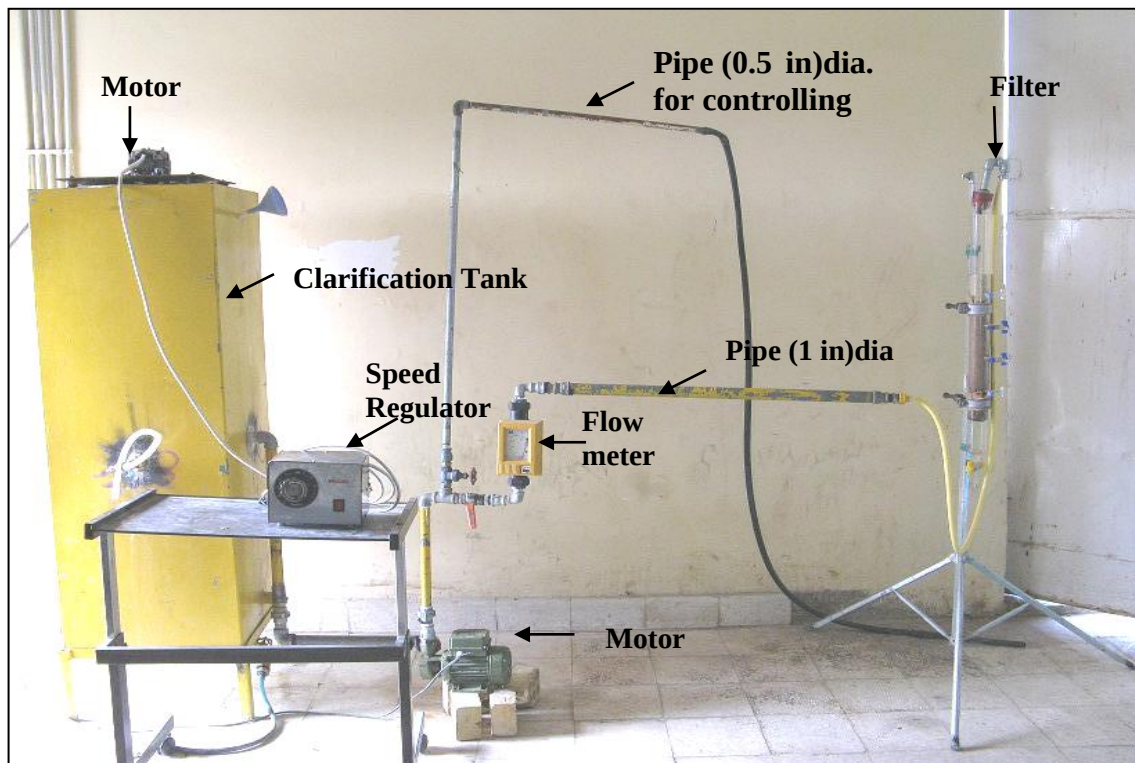


Fig. (4-2): The Pilot Plant Used

The description of each device and other apparatuses used are presented as follow :

4.2 The Pilot Plant Units

4.2.1 The Tank Used in the Experimental Work:

The tank used in this study has a capacity of (350 ℓ), and it has dimension of (1.4m x 0.5m x 0.5m). A stainless steel paddle mixer was connected to the tank for two purposes: firstly for preparing synthetic raw water and secondly to mix the coagulants with raw water .The mixer was driven by a motor , which was connected to a speed regulator . mixing of water and wastewater was done continuously. Three processes(coagulation, flocculation and sedimentation) were conducted in this tank.(Qasim , S,1999).

4.2.2 Rapid Mixer:-

In this process destabilization of colloids was achieved by using different types of coagulants and electrically driven stirring propeller, to disperse these coagulants(Qasim , S,1999).The stirrer has a constant rotation speed equal to (250 rpm) with mixing time of (1min).(A specification of jar test).

4.2.3 Flocculation process :-

Flocculation process is the formation of bigger flocs by agglomeration of small ones. This process obtained after a destabilization of colloids occurred in rapid mixing process.

The value of speed was maintained constant at a value of (60 rpm).The mixing time was equal to a value of (15-20 min).(A specification of jar test).

4.2.4 The Pumps Used

In this study two pumps were used , the first one is to supply water and wastewater to the tank. The second pump was used to deliver settled water or wastewater from the tank to the filter. The pumps were of specification of :

Type: Italy - SAER

Power=0.5 HP= 0.37 KW

Speed= 2850 rpm

H=50 , A= 2.3

Volt = 220 V

4.2.5 Flow-Meter

To measure the water flow rate, a standard flow meter was used. The filtration rate was kept constant at a value of (5ℓ /hr). The flow meter consisted of a plastic-metering tube with a stainless steel float, and was fixed vertically. The calibration process was carried before using. The calibration curve is shown in appendix (B).

4.2.6 Filter Used :-

In this study a vertical pyrex glass filter column was used. It has a dimension of (5.8 cm diameter) and length of (80 cm). There are two types of filters used. The first filter has a sand bed of (single media) of height 40 cm, while the type of second filter is a dual media of sand bed of 30 cm in height and 10 cm of porcelanite height. Kawamura, (1999).

4-3 Apparatus

4.3.1 Turbidimeter:-

Turbidity is a measure of the ability of water to scatter light and it depends upon the shape, size, number and the refractive index of the suspended particles. The turbid meter is an instrument used to measure turbidity of water by balancing the scattered and transmitted light intensities for a defined condition for illumination using closed glasses containing formalize polymers as standard suspensions. (A Hach model 2100-A), was used for measuring the turbidity .

4.3.2 Standard Sieves :-

An American (US) sieve series of (4, 10, 16, 40,100,200) with a standard shaker were used in the sieving analysis of different media samples in order to determine, effective size (E.S) and uniformity coefficient (U.C).

4.3.3 Balances:-

Two balances were used in the experimental work. The first one was used to measure the weight of the required amounts of coagulants and kaolinite clay (colloidal suspension). This balance was of model (ADAM AAA) with an accuracy of 1×10^{-4} grams. The second balance was used to measure the weight of sieves during sieving and the weights of the required amounts of filter media. The second one was of model of (Sartorius 1204 M_P) with an accuracy of 1×10^{-2} grams.



Fig.(4-3):The First Balance

4.3.4 Conductivity meter :-

The ability of water to conduct an electric current is known as conductivity or specific conductance and it depends on the concentration of ions in solution. Conductivity is measured in millisiemens per metre ($1 \text{ mS/ m} = 10 \mu\text{S /cm} = 10 \mu \text{ mhos /cm}$).

Conductivity were measured by a conductivity meter of type [JENWAY, 4510].

4.3.5 pH meter :-

The pH and temperature values were measured by using the pH meter of type named (Schott). The temperature of water and wastewater in this study was being from (9-20) °C



Fig.(4-4):pH meter

4.3.6 DO meter:-

The DO meter is used to measure the dissolved oxygen and this measuring helps to determine the Biochemical Oxygen Demand

(BOD₅) value. The dissolved oxygen is determined in the diluted sample initially and after incubation at 20°C for 5 d. The DO meter used in this study is of (HACH /LDO) type.



Fig.(4-5):DO meter

4.4 Turbidity Material :-

The turbidity material used in the experimental work is from kaolinite (which passed through sieve No 200). The kaolinite has a particle size distribution as shown in Fig.(4.6). Table (4-1) presents the chemical analysis of kaolinite used in this study

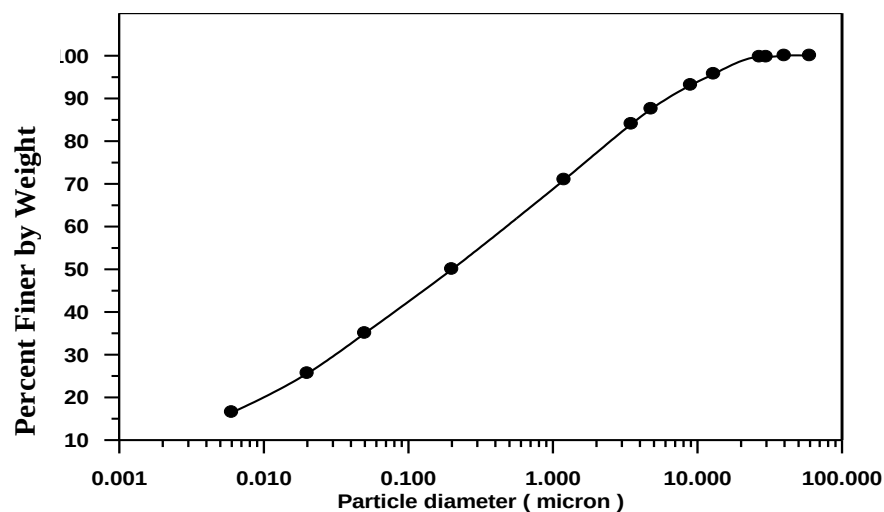


Fig. (4.6): Particle Size Distribution of Kaolinite

Table (4-1) :Chemical Analysis of Kaolinite Used

CaO %	TiO ₂ %	Fe ₂ O ₃ %	SiO ₂ %	Al ₂ O ₃ %
0.3-1.1	0.35-1.65	0.5-1.36	45-58.5	28.4-37.9

4.5 The Coagulants Used

4.5.1 Alum:-

The Iraqi alum or (local alum) is used in this study. The aluminum sulfate used in these experiments as coagulant has the chemical formula of $[\text{Al}_2(\text{SO}_4)_3 \cdot 16\text{H}_2\text{O}]$ which is always used in the water treatment plants. The chemical analysis of Iraqi alum was done by the laboratory of the General Corporation of Water and Sewage in the year of (2002). The results are presented in Table (4-2) below.

Table (4-2): Chemical Analysis of Iraqi Alum (after Intidhar,2002)

Acidity %	Basicity %	Total alumina%	Insoluble matter	pH
NIL	0.08	14	14.45	3.08

The Alkalinity concentration of tap water used is sufficient for alum reaction with water without of pH - adjustment.

4.5.2 Coagulant aid (Porcelanite Powder):-

Local material of porcelanite was used as coagulant aid. The particle size is between (0.07 – 0.1) mm, with effective size of (0.085 mm) and the value of uniformity coefficient was (3.18). The porcelanite was supplied from the General Establishment for Geological Survey and Mineralogy-Ministry of Industry and Minerals (GEGSM). The chemical and physical analysis of the porcelanite is shown in Table (4-3). The particle size distribution is shown in Fig. (4.7)

**Table (4-3) :Chemical and Physical Analysis of Porcelanite
Used in this Study, (GEGSM)**

Chemical Composition %	SiO ₃	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	Na ₂ O	K ₂ O	L.O.I
	83.57	0.62	4.45	0.01	1.82	1.46	0.5	0.16	0.22	5.9
Specific gravity (SG)		Range for 5 Sample			Average (SG)			Recommendation		
		1.5-1.61			1.554			Ok		
Porosity		0.52								

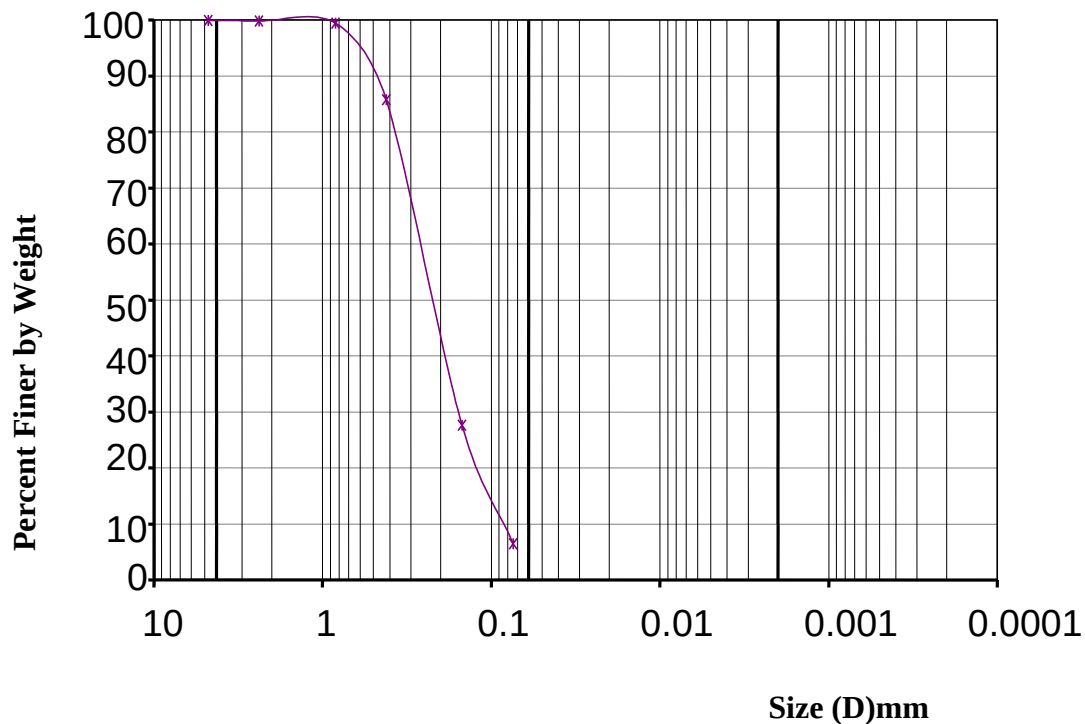


Fig. (4-7): Particle Size Distribution of Powder Porcelanite Used

4.6 Filter media

4.6.1 Sand:-

The properties of the sand media was used with all filters of the water treatment plants in Iraq are durable, hard, spherical form, and it has density of 2500 to 2670 kg/m³. The sand used in this study hasn't organic material content, the sulfate does not exceed 1 % [Iraqi specification No. (1555)]. A sample of sand was sieved by the set of American US standard sieves to determine the effective size (E.S) and uniformity coefficient (U.C).

In this study The effective size of sand particles is of 0.45 mm , while the uniformity coefficient is of a value equal to 1.71. Fig. (4.8) shows the particle size distribution of sand material

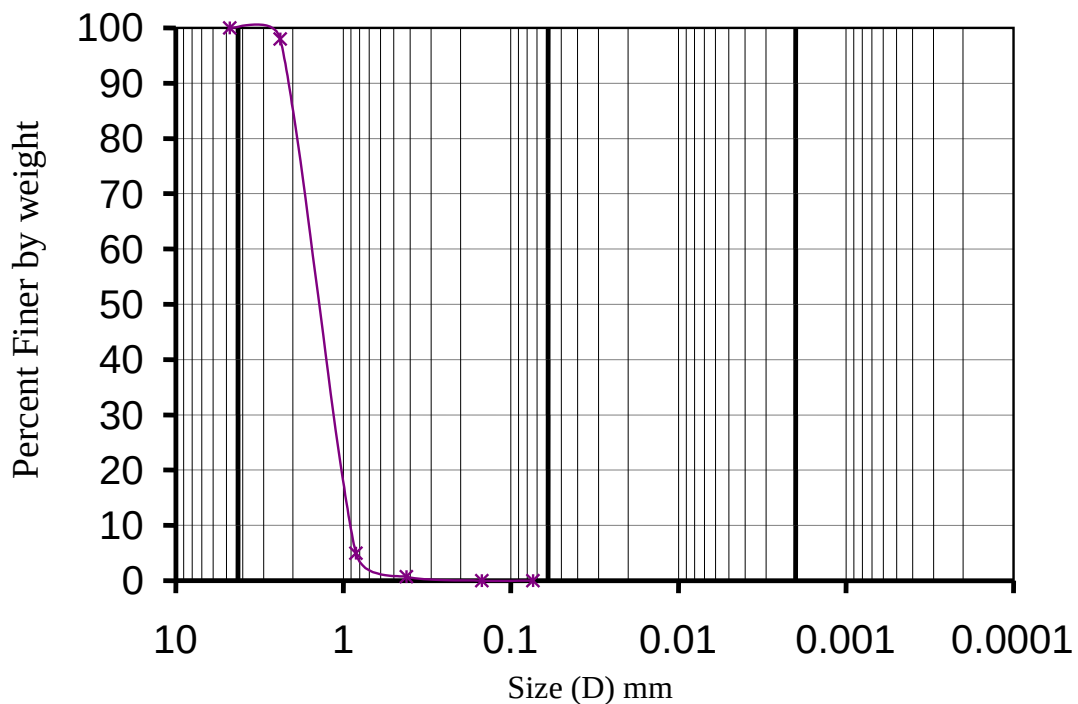


Fig. (4-8): Particle Size Distribution of Sand material

4.6.2 Local Porcelanite Rocks

In this study a sample of porcelanite rocks was sieved by a set of US standard sieves to determine the E.S and U.C .The effective size of porcelanite particles is 0.9 mm , while the uniformity coefficient is of a value equal to 1.74. After sieving process the porcelanite was washed with tap water for several times to remove dust and fine particles. The porcelanite media has a particle size distribution as shown in Fig. (4.9).

Al-Ansary used narrow range of porcelanite particles passing through a 0.85 mm standard sieve and retained on 0.6 mm sieve to give average diameter of 0.725 mm .

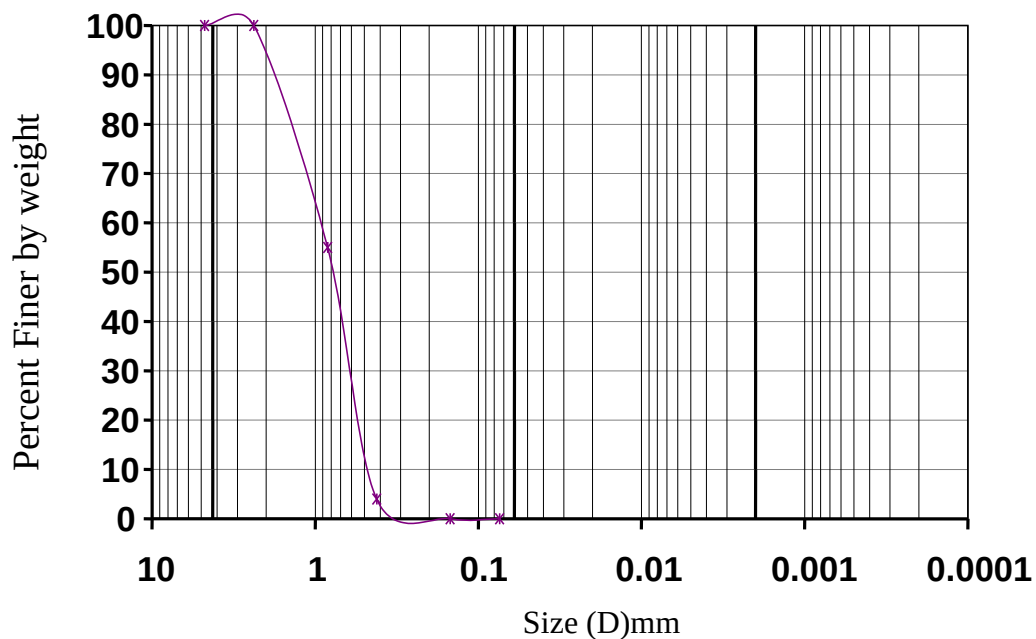


**Fig.(4.9) :Particle Size Distribution of Porcelanite Rocks Samples
Used in this Stud**

4.6.3 Supporting Gravel Layer :-

The drainage system of the filter was constructed of gravel-supporting layer. The size of gravel layer is between (2.38 to 6.5 mm). The thickness of gravel layer is of (10 cm). The gravel used was sieved, washed and then packed into the column.

4.7 Experimental Procedure

4.7.1 Synthetic Turbid Water :-

In this study the synthetic turbid water was used in the experimental work is made by mixing koalinite material with tap water to achieve the desired values of initial turbidity of (10, 50, 100,150,200)NTU.

4.7.2 Determination of Coagulant Dosage :-

The tank used in this study was filled with the capacity of (200 ℓ) with tap water or wastewater. Different dosages of aluminum sulphate , aluminum sulphate and porcelanite were added to the water in the tank .

The tank contents was stirred rapidly for (1min), with rotating speed (250 rpm) ,then the contents were mixed slowly for (15-20 min)with rotating speed of (60 rpm) .The sedimentation time flocs were allowed to settle (30min), then it was possible to determine the optimum dosage of coagulant . In this study alum and alum with porcelanite were added with different dosages of (10, 20,30,40,50) mg /ℓ .

4.7.3 Determination of the Best Percentage of Coagulant and Coagulant Aid :-

The alum used with coagulant aid (porcelanite) material with the different percentage is shown in table (4-4) .These percentages were used for all dosages added in this study.

Table (4-4) :Percentages of Alum with Porcelanite

Run No.	Alum percentage %	Porcelanite percentage %
1	100	0
2	50	50
3	60	40
4	75	25

4.7.4 Measurement of Organic Contents (Biochemical Oxygen Demand BOD5) :-

In this study the BOD₅ test is conducted by placing a measured amount of wastewater in a 300-ml standard BOD bottle and filling the bottle with dilution water that contains the essential nutrients and is saturated with dissolved oxygen. Well- acclimated microbial seed may be supplied if sufficient microorganisms are not already present in the wastewater sample.

The dissolved oxygen is determined in the diluted sample initially and after incubation at 20°C for 5 d. Fig.(4-10) shows samples of BOD₅ inside the incubator used in this study.

In this study three samples of BOD₅ were measured for each run :

- (1) Initial BOD₅(before adding the coagulant)
- (2) Before filtration process (after adding the coagulant)
- (3) After filtration process



Fig.(4-10) :Samples of BOD₅ Inside the Incubator

CHAPTER FIVE

Results and Discussion

5-1 Introduction

In this chapter the results of all the experimental work are presented and discussed. The following discussion deals with the performance of the pilot plant used according to the tests performed on the influent and effluent of the water flow system. Results obtained, using alum with local material such as (porcelanite) , were used in evaluating the effect of this material on the residual turbidity and organic matter concentration of water and wastewater in coagulation and filtration processes . three studies were conducted in this research , in study No.1 different ratios of alum to porcelanite were tested while studies No.2 and No.3 consist of all the experiments on the water and wastewater respectively.

5.2 Study No. 1 :

This study includes the selecting of the best percentage of (A/P), where A is mean alum and P is mean porcelanite. Initially different ratio of A/P were done and discussed, and then minimum residual turbidity ratio was indicated and selected as the optimum ratio and used for all experiments.

Table (5-1) presents four sets of run; each set contains five different dosages of alum with different dosage of porcelanite in order to obtain the best dosages of alum and porcelanite.

Fig. (5-1) shows the relationship between the dosages of coagulants (alum, alum +porcelanite) in mg/l and the efficiency of turbidity removal in percent, with a different percentage of alum and porcelanite.

Blank-Beaker were carried out without adding the coagulant under same condition of time and speed of mixing and sedimentation for checking the effect of mixing and other condition on the residual turbidity.

Table (5-1) Summery of Experiments of Study No.1

Set No.	Dosage of coagulant mg/ℓ	Percentage of alum %	Dosage of alum mg/ℓ	Percentage of Porcelanite %	Dosage of porcelanite mg/ℓ
1	10	100	10	0	0
	20	100	20	0	0
	30	100	30	0	0
	40	100	40	0	0
	50	100	50	0	0
2	10	50	5	50	5
	20	50	10	50	10
	30	50	15	50	15
	40	50	20	50	20
	50	50	25	50	25
3	10	60	6	40	4
	20	60	12	40	8
	30	60	18	40	12
	40	60	24	40	16
	50	60	30	40	20
4	10	75	7.5	25	2.5
	20	75	15	25	5
	30	75	23	25	7
	40	75	30	25	10
	50	75	38	25	12

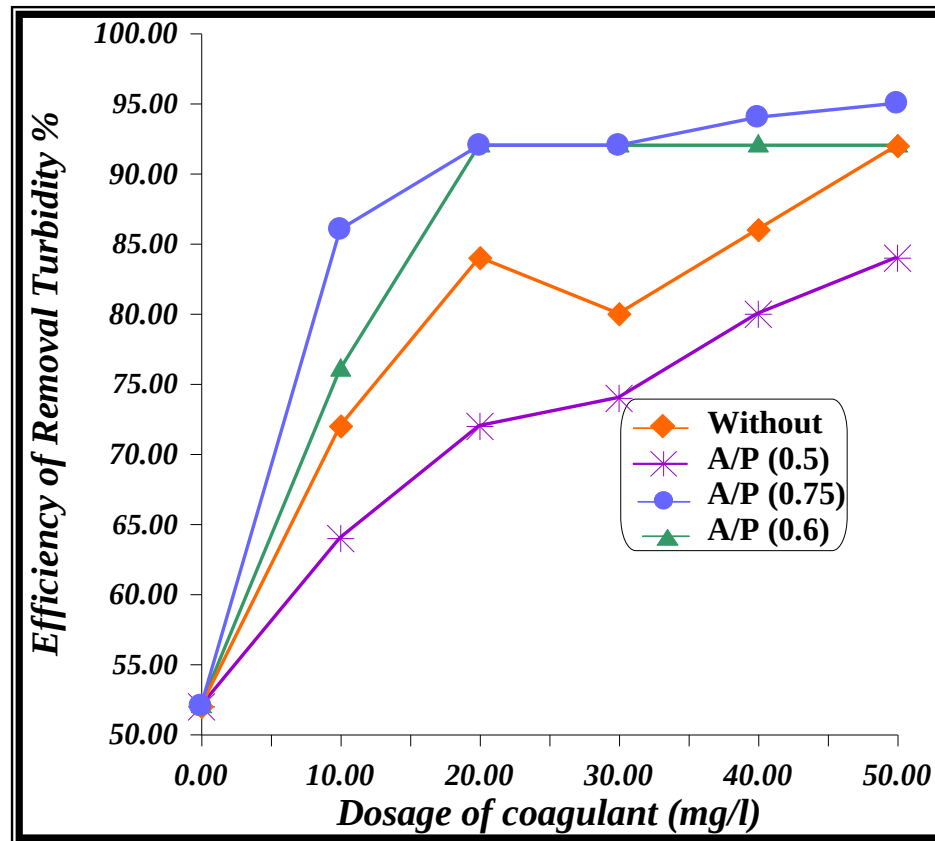


Fig. (5-1) :Variation of Efficiency of Removal Turbidity and Dosage of Alum with Different Dosages of Porcelanite

The results indicated that the percentage of 75% of alum and 25% of porcelanite can be considered as the best percentage to obtain minimum residual turbidity and for different levels of initial turbidity used in this study.

5.3 Study No.(2):

This study includes all the experimental work in coagulation and filtration processes of the water as follow:

5.3.1 Clarification Process

This study includes five different initial values of water turbidity namely 10, 50, 100, 150, and 200 NTU.

1. Initial turbidity of $T_0=10$ NTU

Fig. (5-2) shows the relation of dosage of alum and (alum with Porcelanite) versus efficiency of removal turbidity with initial water turbidity of 10 NTU .

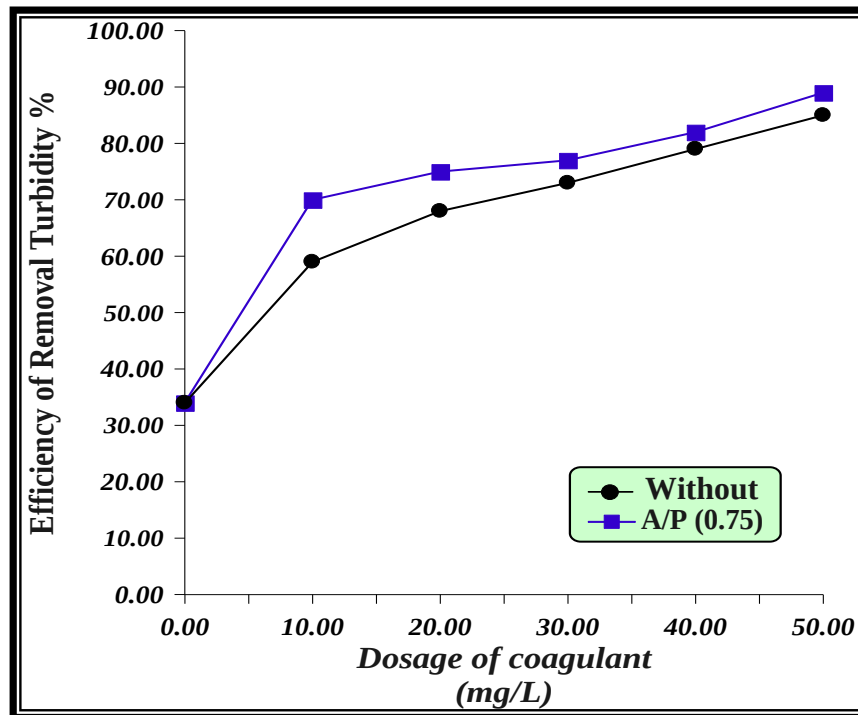


Fig. (5-2) : Turbidity Removal Versus Different Dosage of A/P under Initial Turbidity of (10 NTU)

It can be concluded that the best values of removal efficiency are obtained by adding dosages of alum with coagulant aid porcelanite .These values are better than those obtain by adding alum only.

2. Initial turbidity of $T_0=50$ NTU

Fig.(5-3) presents the variation of dosage of A/P percent with efficiency of removal turbidity under initial turbidity of (50 NTU).

One can be seen that any increase in the coagulant dosage leads to increase of the removal efficiency of water for five dosages of values between (10-50) mg/l.

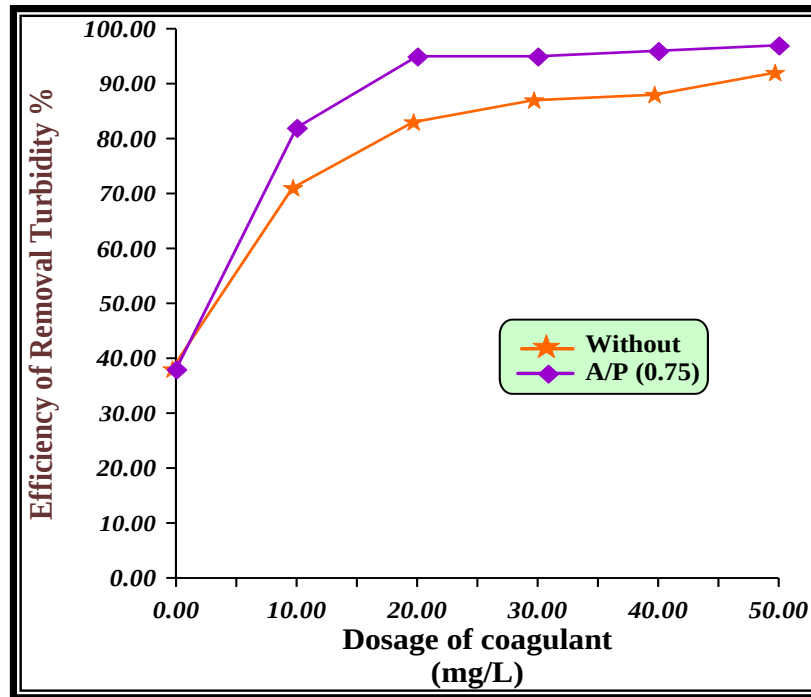


Fig. (5-3): Turbidity Removal Versus Different Dosage of (A/P) at the Initial Turbidity of (50 NTU)

In this figure the best values of removal efficiency are obtained by adding dosages of alum with coagulant aid porcelanite which is better than values obtained by adding alum only.

3. Initial turbidity of $T_0=100$ NTU

Fig.(5-4) indicated the relation of dosage of alum and alum with porcelanite versus the efficiency of removal turbidity under initial value of turbidity of (100 NTU).

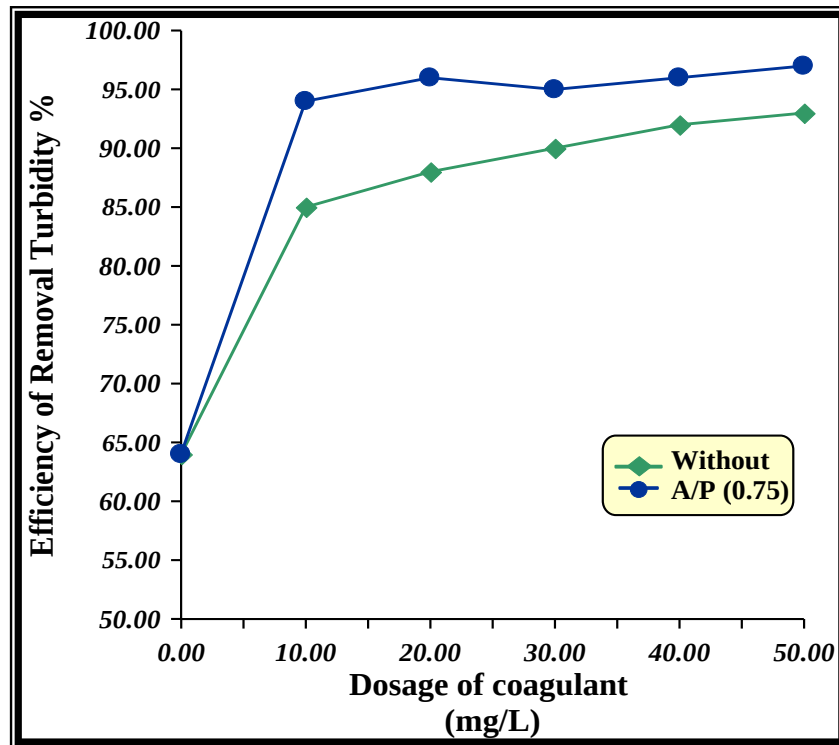


Fig. (5-4): Turbidity Removal Versus Different Dosage of (A/P)
at the Initial Turbidity of (100 NTU)

It can be noted that the using of porcelanite as coagulant aid with alum was better than using of alum only for the five dosages that namely 10,20,30,40,and 50mg/ℓ

4. Initial turbidity of $T_0=150$ NTU

Fig.(5-5) explain the variation of dosage of Alum and Alum with porcelanite and the efficiency of removal turbidity under initial value of turbidity of(150 NTU).

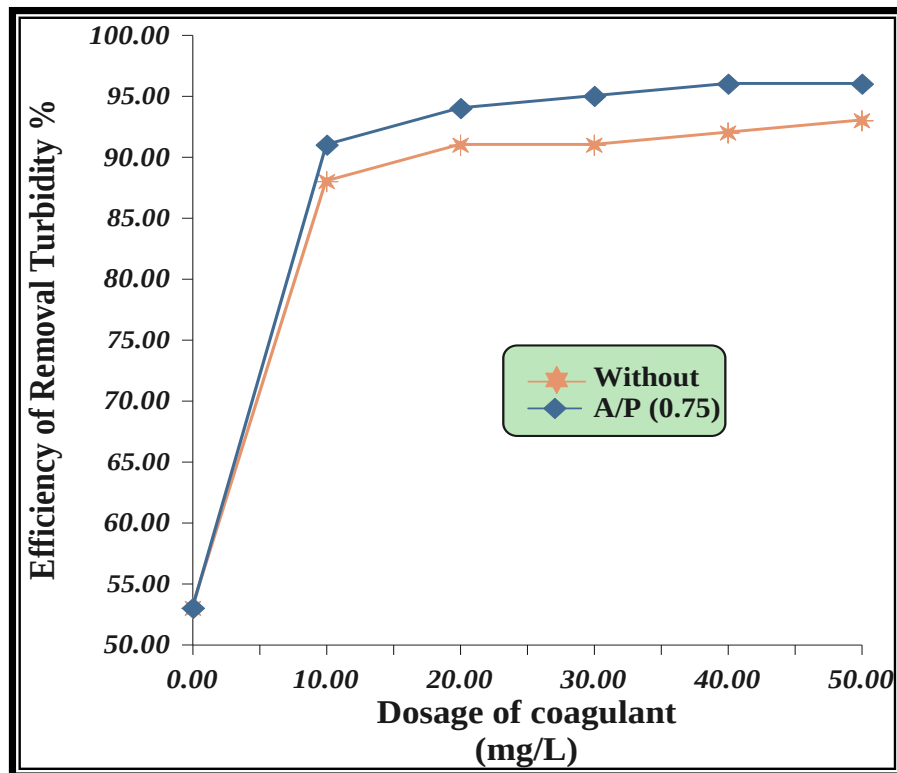


Fig. (5-5) : Turbidity Removal Versus Different Dosage of (A/P) at the Initial Turbidity of (150 NTU)

In this figure it can be noted that the increasing of dosages of alum or alum with coagulant aid porcelanite leads to increase of the value of removal efficiency .

From the analysis of results of this figure one can be concluded that the using of alum with coagulant aid porcelanite was better than using of alum only for the limited dosages between(10-50)mg/l

5. Initial turbidity of $T_0=200\text{NTU}$

Fig.(5-6) presented the relationship between dosages of alum and alum with porcelanite and the efficiency of removal turbidity under initial value of (200 NTU).

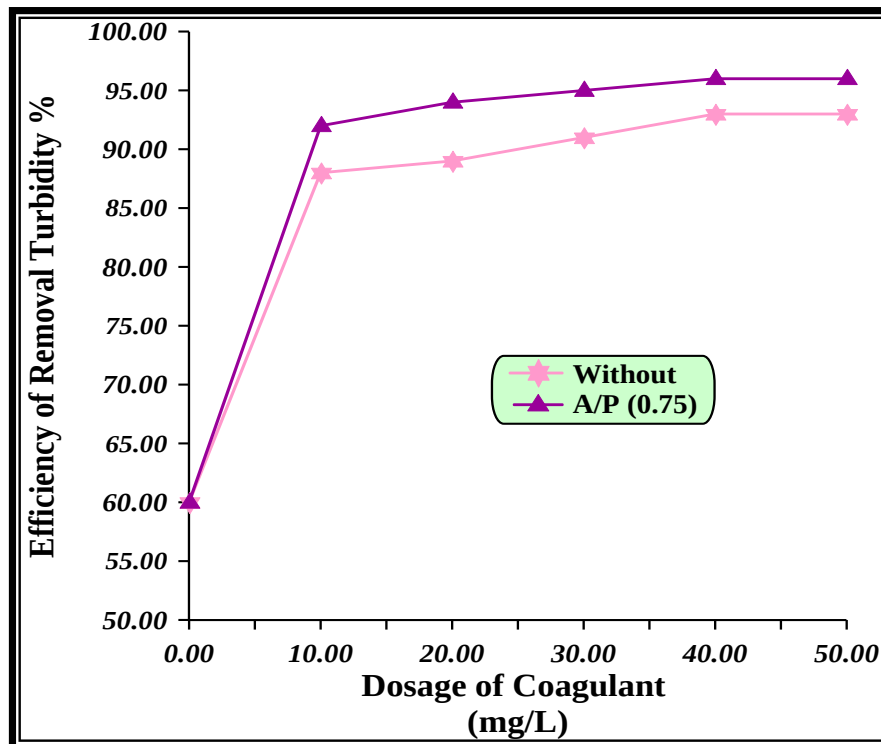


Fig. (5-6): Turbidity Removal Versus Different Dosage of (A/P)
at the Initial Turbidity of (200 NTU)

This figure shows that any increasing of dosages of alum or alum with coagulant aid porcelanite leads to increase the value of removal efficiency of the dosage in range of (10-50)mg/l.

The using of alum with coagulant aid porcelanite is giving better performance than that using of alum only .

5.3.2 Filtration process of Water

1. Initial turbidity of $T_0=10\text{NTU}$

Table (5-2) shows the efficiency of single media filter and the efficiency of dual media filter of removal turbidity under the initial turbidity of (10 NTU).

Table (5-2) :Efficiency of Filter Before and After Filtration Process for the Initial Turbidity (10 NTU)

Run No.	Coagulant type	Dose mg/ℓ	Filter type	Residual Turbidity		Efficiency %
				Before filtration	After filtration	
1	Alum	10	Single media	4.12	2.04	50.5
2		20		3.25	0.95	71
3		30		2.66	0.86	68
4		40		2.06	0.62	70
5		50		1.52	0.44	71
6	Alum	10	Dual media	4.75	1.35	72
7		20		3.54	0.54	85
8		30		2.86	0.41	86
9		40		2.08	0.25	88
10		50		1.77	0.2	89
11	Alum+Porcelanite	10	Single media	3.04	0.9	70
12		20		1.66	0.38	77
13		30		2.56	0.75	71
14		40		1.86	0.56	70
15		50		1.44	0.4	72
16	Alum+Porcelanite	10	Dual media	4.33	0.2	95
17		20		1.76	0.22	88
18		30		1.53	0.15	90
19		40		1.42	0.12	92
20		50		1.38	0.04	97

Fig. (5-7 and 5-8) explain the efficiency of filter of the removal turbidity after adding alum and alum with coagulant aid (porcelanite) respectively .

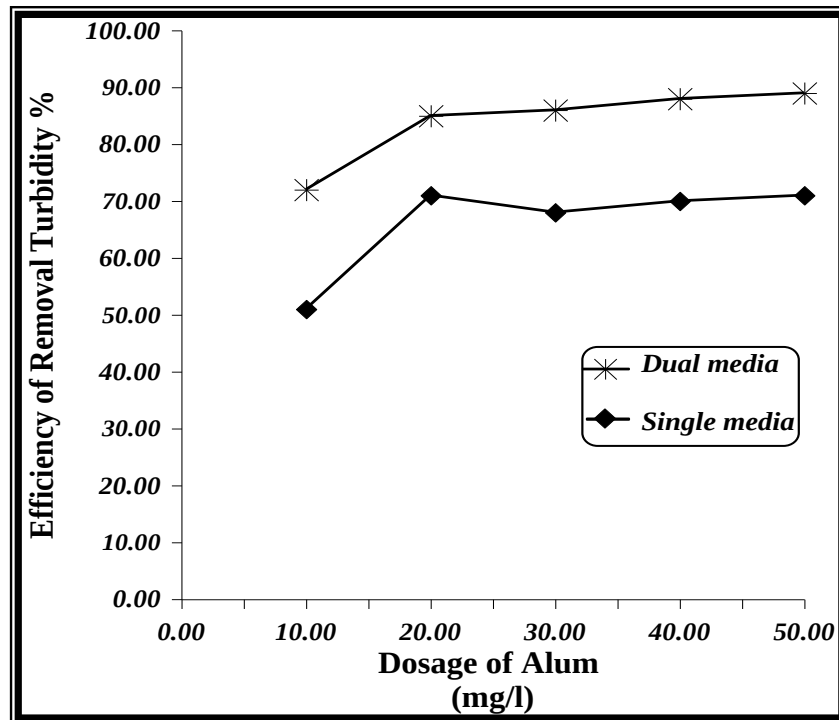


Fig. (5-7): Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media Filter

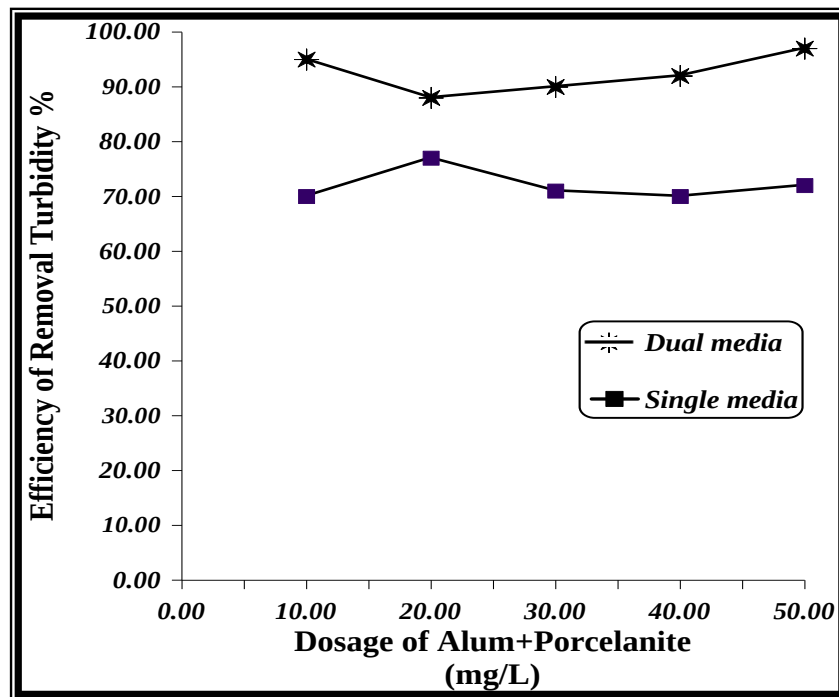


Fig. (5-8): Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

The results indicate that the dual media filter is better than that of single media filter in turbidity removal by approximately of 20% .

2. Initial turbidity of $T_0=50\text{NTU}$

Table (5-3) presents the efficiency of single media filter and the efficiency of dual media filter turbidity removal under the initial turbidity of (50 NTU).

Table (5-3): Efficiency of Filter Before and After Filtration Process under the Initial Turbidity (50 NTU)

Run No.	Coagulant type	Dose mg/l	Filter type	Residual Turbidity		Efficiency %
				Before filtration	After filtration	
1	Alum	10	Single media	10.56	3.04	71
2		20		5.5	1.2	78
3		30		4.2	1	76
4		40		2.95	0.85	71
5		50		2.52	0.8	68
6	Alum	10	Dual media	14.36	2.88	80
7		20		8.43	1.35	84
8		30		6.5	1	85
9		40		5.8	0.75	87
10		50		3.85	0.61	84
11	Alum+Porcelanite	10	Single media	8.92	2.21	75
12		20		2.93	0.34	88
13		30		2.65	0.54	80
14		40		2.25	0.44	80
15		50		1.52	0.35	77
16	Alum+Porcelanite	10	Dual media	8.91	1.02	89
17		20		5.42	0.33	94
18		30		3.88	0.4	90
19		40		2.28	0.25	89
20		50		1.69	0.2	88

Fig. (5-9 and 5-10) explain the efficiency of single media filter and dual media filter of turbidity removal ,by using alum and alum with coagulant aid porcelanite respectively .

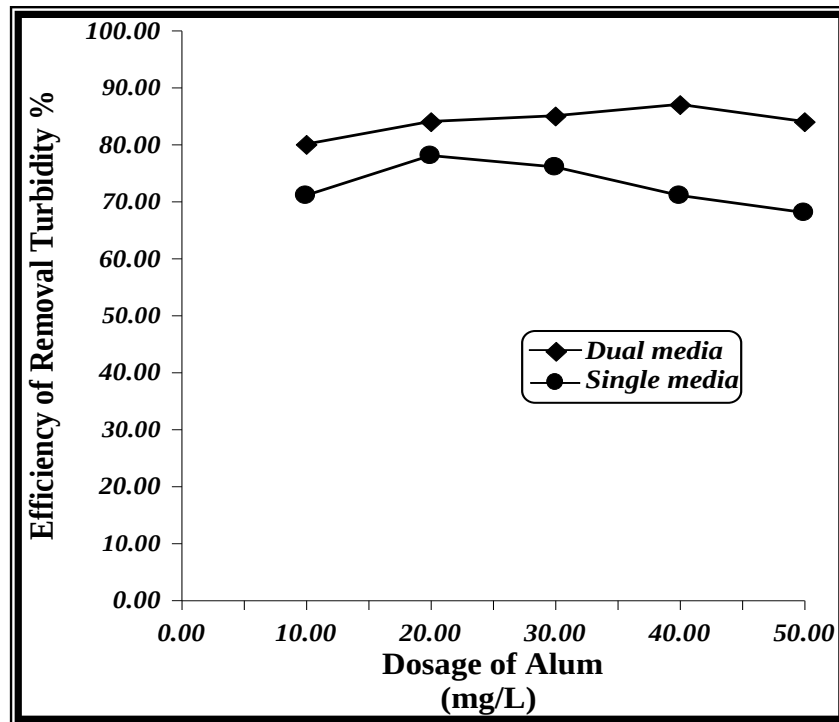


Fig. (5-9): Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media filter

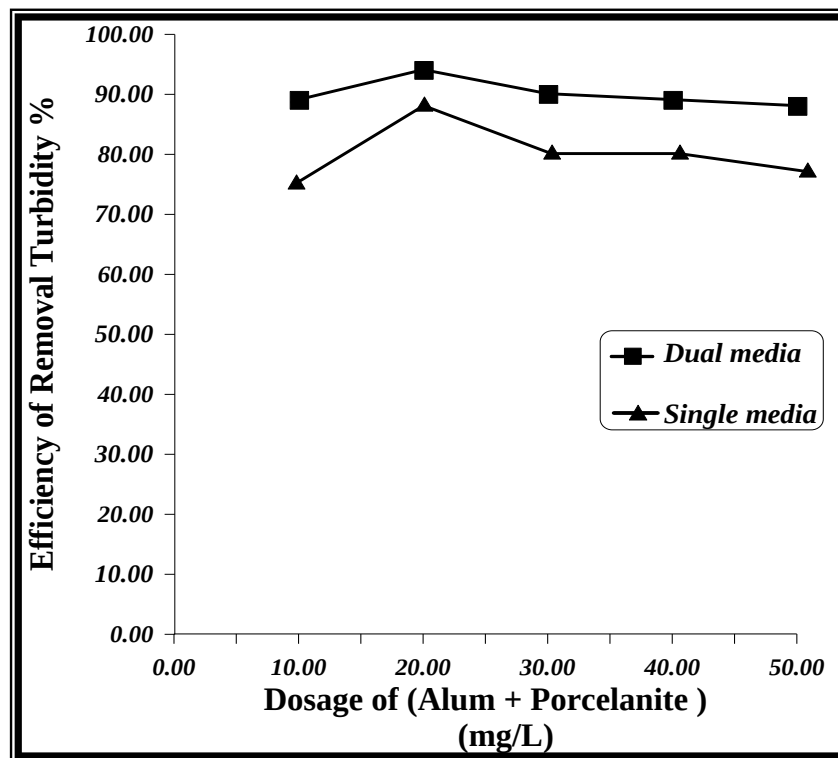


Fig. (5-10) : Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

The analysis of results refers to conclude that the dual media filter shows the better performance than that of single media filter in removing turbidity especially after adding alum with coagulant aid of porcelanite material.

The increasing of efficiency is of about 10% more than that obtained by using alum only.

3. Initial turbidity of $T_0=100\text{NTU}$

Table (5-4) present the data obtained of residual turbidity by using two types of filter media under the initial turbidity of 100 NTU.

Fig. (5-11 and 5-12) show the efficiency of single media filter and dual media filter of turbidity removal ,after adding alum and alum with coagulant aid of porcelanite respectively .

Table (5-4): Efficiency of Filter Before and After Filtration Process under the Initial Turbidity of (100 NTU)

Run No.	Coagulant type	Dose mg/l	Filter type	Residual Turbidity		Efficiency %
				Before filtration	After filtration	
1	Alum	10	Single media	15	3.98	73.5
2		20		12.3	2.76	78
3		30		9.05	2.25	75
4		40		8.16	1.75	79
5		50		6.68	1.32	80
6	Alum	10	Dual media	14.2	2.56	82
7		20		11.66	1.21	90
8		30		9.3	1	89
9		40		7.22	0.85	88
10		50		6.56	0.64	90
11	Alum+Porcelanite	10	Single media	6.1	1.42	77
12		20		4.23	0.75	82
13		30		5.5	1.2	78
14		40		3.95	0.95	76
15		50		3.44	0.67	81
16	Alum+Porcelanite	10	Dual media	5.35	0.36	93
17		20		4.12	0.22	95
18		30		4.87	0.45	91
19		40		3.56	0.25	93
20		50		3.23	0.15	95

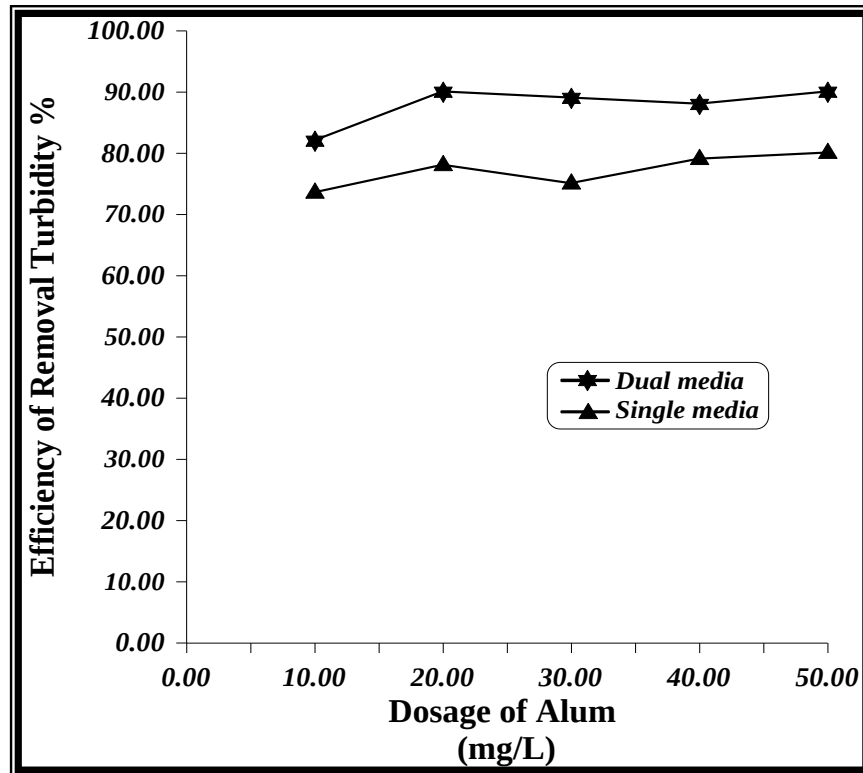


Fig. (5-11) Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media Filter

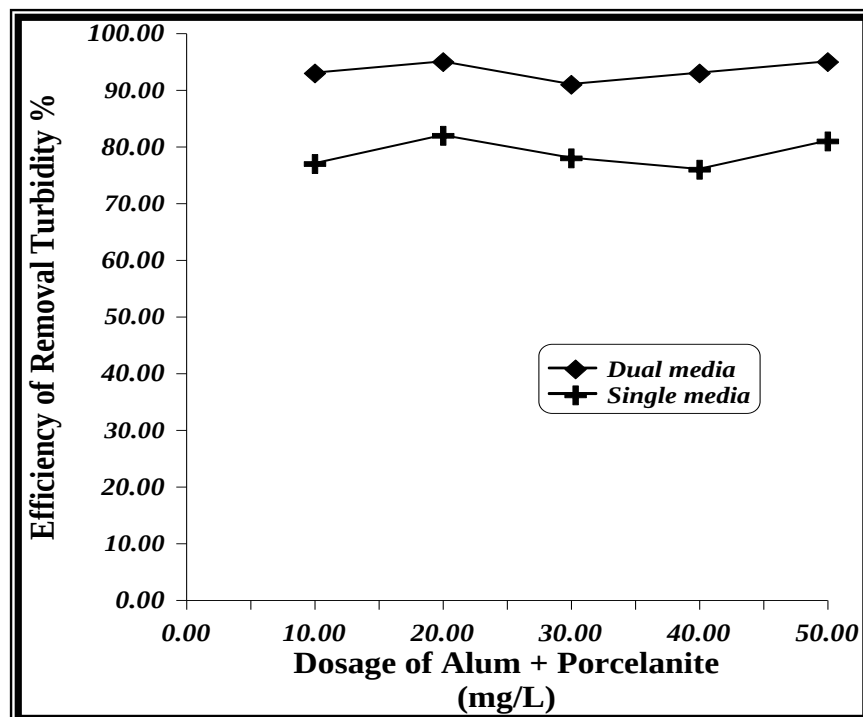


Fig. (5-12): Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

The results of the figures indicated that the using of dual media is better than that of single media by about of 10% after adding alum without coagulant aid .This percentage can be increased to a value of 15% by using alum with coagulant aid of porcelanite material.

4. Initial turbidity of $T_0=150\text{NTU}$

Table (5-5)shows the relation between dosage of coagulants(Alum , Alum with porcelanite) for two types of filter media (single media , and dual media).

Table (5-5) :Efficiency of Filter Before and After Filtration Process for the Initial Turbidity of (150 NTU)

Run No.	Coagulant type	Dose mg/l	Filter type	Residual Turbidity		Efficiency %
				Before filtration	After filtration	
1	Alum	10	Single media	18.6	4.68	75
2		20		12.5	2.95	76
3		30		9.6	2.45	74
4		40		8.5	1.85	78
5		50		7.7	1.44	81
6	Alum	10	Dual media	17.6	2.94	83
7		20		11.55	1.22	89
8		30		10.7	1.05	90
9		40		8.8	0.95	89
10		50		7.05	0.89	87
11	Alum+Porcelanite	10	Single media	14.6	3.12	79
12		20		8.86	1.62	82
13		30		8.2	1.75	79
14		40		6.7	1.46	78
15		50		6.1	1.25	80
16	Alum+Porcelanite	10	Dual media	14.5	1.14	92
17		20		8.5	0.52	94
18		30		7.8	0.56	93
19		40		6.5	0.35	95
20		50		5.86	0.45	92

Fig. (5-13 and 5-14) explain the efficiency of filter of turbidity removal with initial value of 150 NTU after adding alum ,alum with porcelanite respectively.

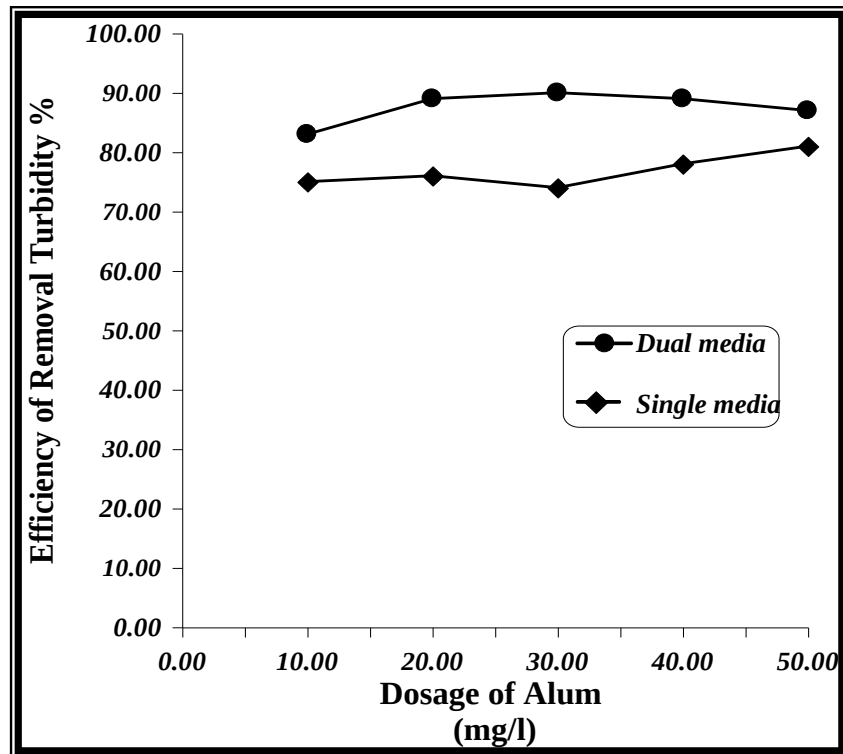


Fig. (5-13): Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media Filter

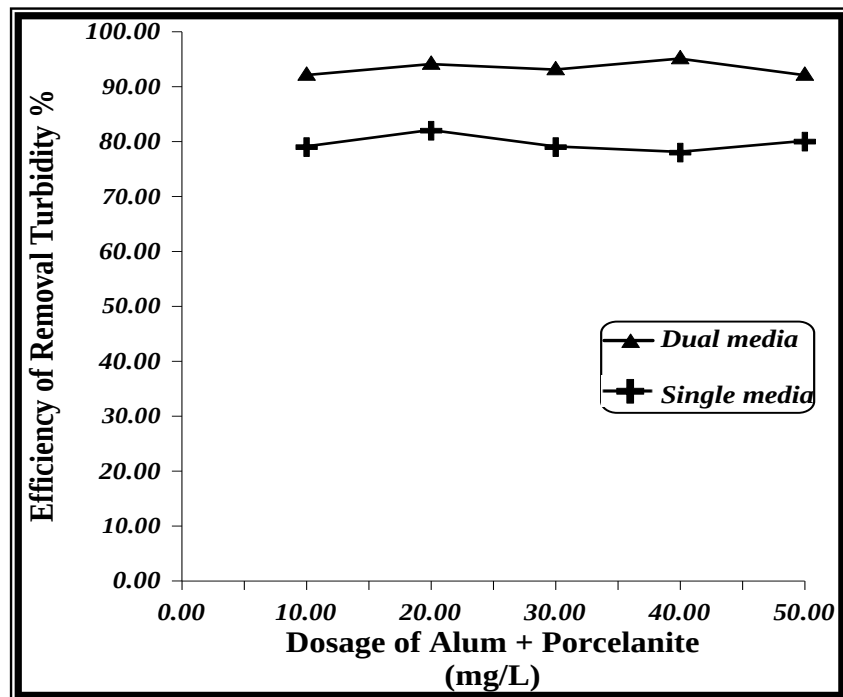


Fig. (5-14): Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

These figures indicate that the using of dual media was better than that of single media by about 11% after adding alum without coagulant aid, the

above percentage can be increased to a value of 14% after adding alum with coagulant aid porcelanite.

5. Initial turbidity of $T_0=200\text{NTU}$

Table (5-6) presents the relation between dosage of coagulants (alum, alum with porcelanite) for two types of filter media (single media , and dual media) with initial turbidity of 200 NTU.

Table (5-6): Residual Turbidity Before and After Filtration Process of the Initial Turbidity of (200 NTU)

Run No.	Coagulant type	Dose mg/l	Filter type	Residual Turbidity		Eff. %
				Before filtration	After filtration	
1	Alum	10	Single media	25	6.2	75
2		20		20	4.52	77
3		30		16.22	4.32	73
4		40		14.5	3.66	75
5		50		12.7	2.75	78
6	Alum	10	Dual media	24.2	3.8	84
7		20		21.5	2.35	89
8		30		18.25	1.85	90
9		40		14.33	1.65	88
10		50		13.02	0.98	92
11	Alum+Porcelanite	10	Single media	15.5	3.55	77
12		20		13.5	2.66	80
13		30		11	1.95	82
14		40		9.05	1.66	82
15		50		8.2	1.2	85
16	Alum+Porcelanite	10	Dual media	16.8	2.05	88
17		20		12.25	0.66	95
18		30		10.4	0.4	96
19		40		9	0.5	94
20		50		8.5	0.22	97

Fig. (5-15 and 5-16) show the efficiency of filter of turbidity removal with initial value of 200 NTU after adding alum ,alum with porcelanite respectively.

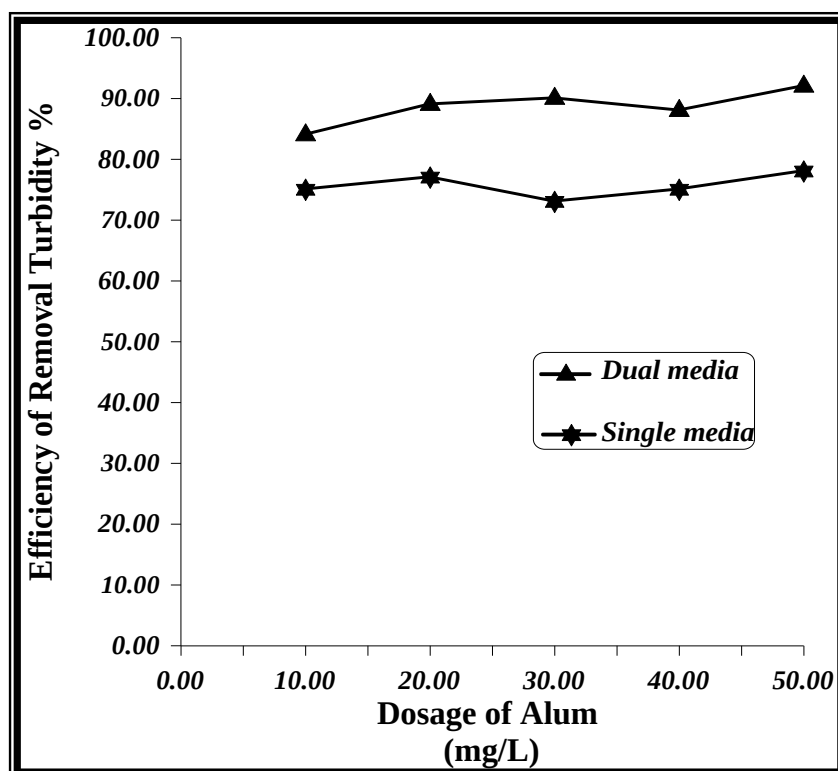


Fig. (5-15): Turbidity Removal Versus Dosage of Alum of Both Single and Dual Media Filter

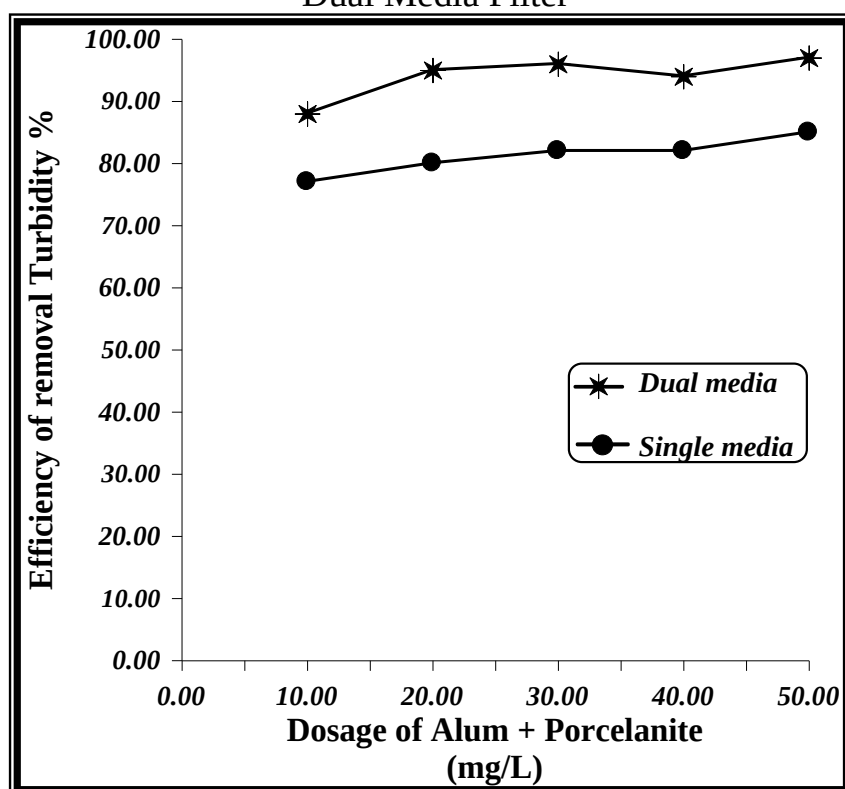


Fig. (5-16) Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Media Filter

It can be concluded that the using of dual media was better than of using single media by about of 13%

5.4 Experimental Tests

Table (A-1) indicates the summery of experimental tests (pH, TDS , conductivity and temperature) before and after coagulation process of water as shown in appendix (A).

Table (A-2) presents the average results of all experimental tests before and after filtration process of water as shown in appendix (A).

5-5 Study No. 3

This study includes all the experimental work of coagulation and filtration processes of the wastewater

5.5.1 Effect of Coagulation Process on the Organic Matter of Wastewater:

In order to give inclusive evaluation of performance of coagulation process in treating pollutants of water and wastewater , the present study deals with the removal of organic matters from wastewater by using this process of treatment .

Fig. (5-17) shows the efficiency of coagulants in removal of the biochemical oxygen demand (BOD₅), the BOD₅ is considered as a measurement of organic matter. The experiments were done by adding different dosages of (alum)and (alum with porcelanite).

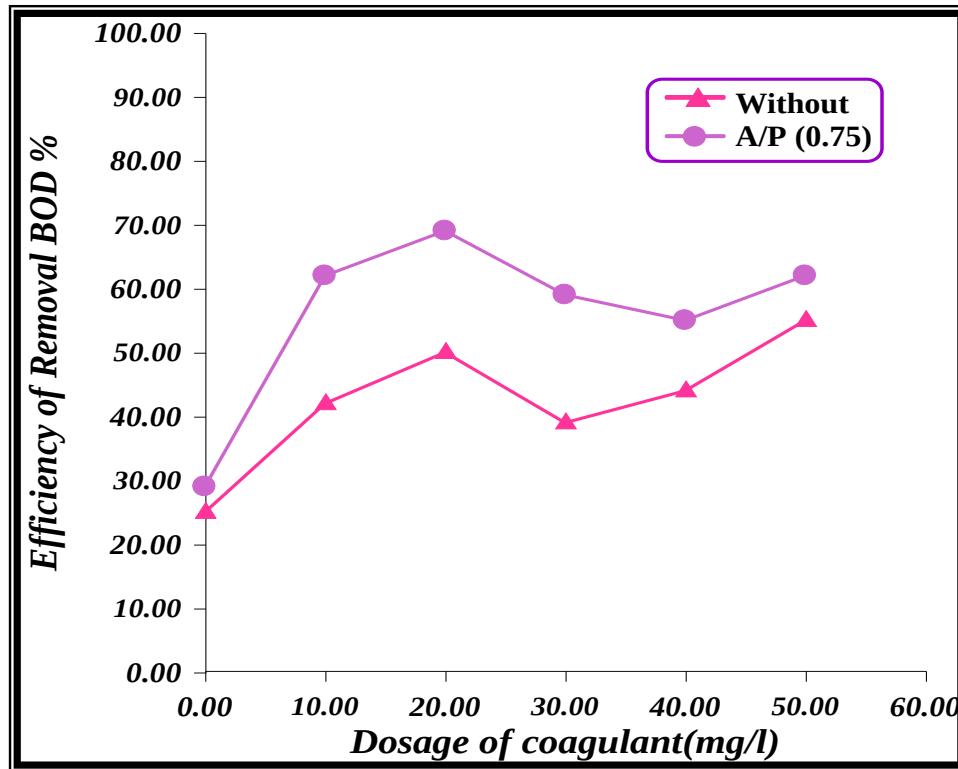


Fig. (5-17): Removal Efficiency of BOD₅ Versus Dosages of Coagulant

The efficiency of alum with coagulant aid of porcelanite material in removal of BOD₅ was better than that the efficiency of removal BOD₅ obtained by using alum only.

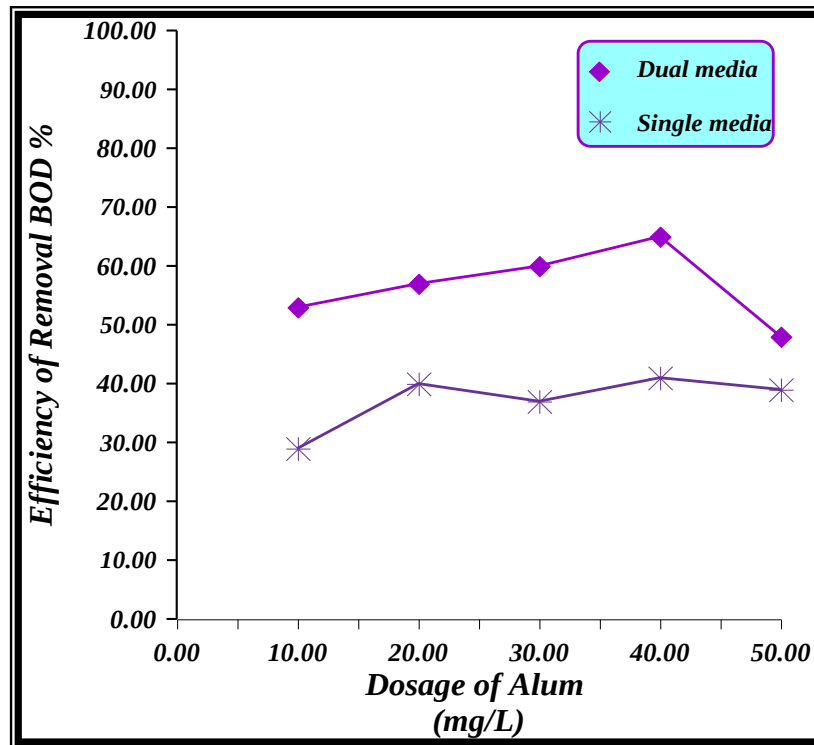
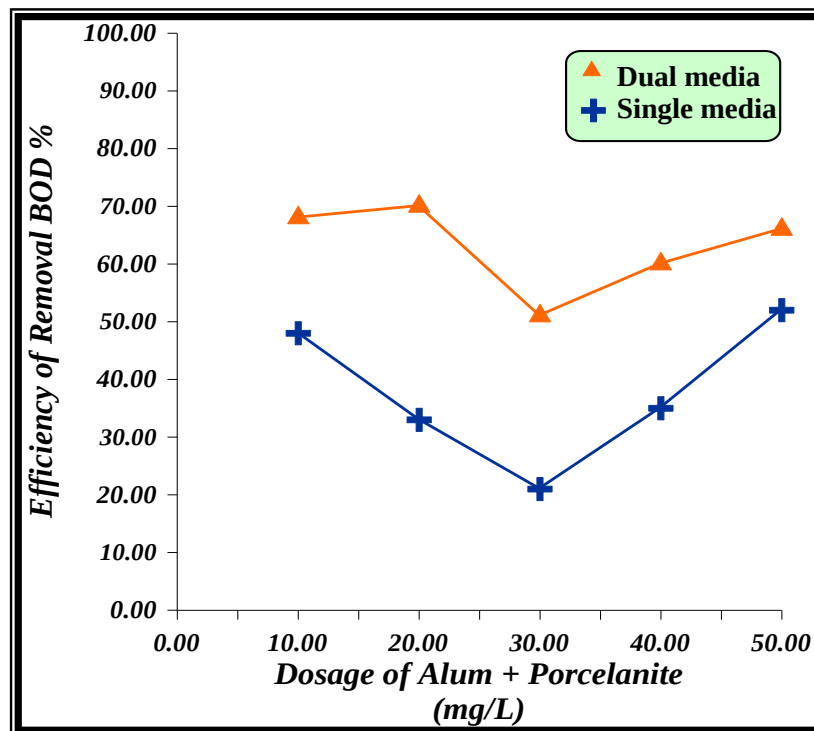
5.5.2 Effect of Filtration on The Biochemical Oxygen Demand (BOD₅)

Table (5-7) presents the results of the BOD₅ before and after filtration process. These results are obtained by adding different dosages of coagulant and coagulant aid with the coagulation process, and also by using two types of filter media with the filtration process.

Table (5-7): Efficiency of Removal BOD₅ in the Filtration Process

Coagulant type	Dose mg/ℓ	Filter type	Residual BOD		Efficiency %
			Before filtration	After filtration	
Alum	10	Single media	52	37	29
	20		67	40	40
	30		89	56	37
	40		85	50	41
	50		61	37	39
Alum	10	Dual media	60	28	53
	20		74	32	57
	30		82	33	60
	40		51	18	65
	50		78	40.5	48
Alum+Porcelanite	10	Single media	77	40	48
	20		60	40	33
	30		48	38	21
	40		49	32	35
	50		104	50	52
Alum+Porcelanite	10	Dual media	75	24	68
	20		56	17	70
	30		78	38	51
	40		77	31	60
	50		88	30	66

Fig. (5-18) and (5-19) indicate that the efficiency of removal of BOD₅ by using (alum)and (alum with porcelanite)respectively, for both single and dual filter media.

Fig. (5-18): BOD₅ Removal Efficiency by Filtration ProcessFig. (5-19): BOD₅ Removal Efficiency by Filtration Process

It was noted that the efficiency of BOD₅ removal by using alum with coagulant aid of porcelanite material in the coagulation process and when using of porcelanite material with sand as a dual media in filtration process

was being better than the efficiency obtained by using alum only with single media filter.

Analysis of results refers that the efficiency by using alum only with dual media was better than the efficiency by using single media by about of (19%) .

Fig. (5-19) presents that the efficiency by using alum with coagulant aid porcelanite by using dual media was better than that of efficiency obtained by using single media by about of (25 %)

5.6 Experimental Tests

Table (A-3and A-4) present summery of experimental tests (pH, TDS , conductivity and temperature) before and after coagulation and filtration processes of wastewater as shown in appendix (A).

Regression Analysis Technique

In this chapter, data of water and wastewater are arranged in four studies (Efficiency of removal turbidity and BOD₅, with coagulation and filtration processes). The data are analyzed to achieve the main objective of this research. Along with data of factors (independent variables) that are assumed to have a reliable impact on efficiency of removal (initial concentration , pH, temperature , dosage of coagulant, alum to porcelanite ratio ,and sand to the porcelanite ratio) are also analyzed to assess their effects.

5.7 Statistical Descriptive of Independent Variables

The most predominant independent variables were investigated in this study are shown in Table (5-10).

Table (5-10): Description of Independent Variables

Independent Variables	Description
X_1	Initial concentration (I.C)
X_2	pH
X_3	Temperature
X_4	alum to porcelanite ratio (A/P)
X_5	dosage of coagulant in (mg/L)
X_6	sand to the porcelanite ratio (S/P)

5.8 Regression Models

Stepwise multiple linear regression models in three forms of transformation were used for each one of studies (turbidity, BOD₅, in coagulation and filtration processes) to investigate which form gives the best fitting of data (i.e. appropriate model).

It is very important to explain that the method of transformation are being used to reduce complex models to linear ones and use a regression model of simple form in the transformation variables, rather than a more complicated one in the original variables. Transforms are used to force all variables to normal distribution and to correct a positive skew distribution. Therefore, it should be noted that there are nonlinear models that are intrinsically linear (i.e. they seemed nonlinear only in their appearance, but they are intrinsically linear). Then, the nonlinear models can be divided into

two types which can be called intrinsically linear and intrinsically nonlinear models. If a model is intrinsically linear it can be expressed by suitable transformation of the variables in the standard linear model form of Eq. (5.2). If a nonlinear model cannot be expressed in this form then it is intrinsically nonlinear .

One very general form for the linear model would be:

$$Y = f(x_1, x_2, \dots, x_q, D) \quad \dots (5.1)$$

Where f is unknown function, D is a dummy variable (if needed).

The following models were proposed and investigated:

$$1. Y = g + a * x_1 + b * x_2 + \dots + f * x_6 \quad \dots (5.2)$$

$$2. Y = a * x_1 + b * x_2 + \dots + f * x_6 \quad \dots (5.3)$$

$$3. \ln Y = g + a * x_1 + b * x_2 + \dots + f * x_6 \quad \dots (5.4)$$

Where Y = efficiency of removal (turbidity, BOD₅, in coagulation , and filtration processes) in percent ; $x_1, x_2, \dots, x_6$ = the independent variables (as mentioned before in Section 5-1).

5.9 Results of Study No.1:

The findings of the present study are based on the results of the linear regression analysis summarized in Table (5-11A and B) to choose the appropriate model.

Table (5-11A) :Testing Models

Model No.	Model formula
A	$a * x_1 + b * x_2 + c * x_3 + d * x_4 + e * x_5$
B	$a * x_1 + b * x_2 + c * x_3 + d * x_4 + e * x_5 + f$
C	$\exp(a * x_1 + b * x_2 + c * x_3 + d * x_4 + e * x_5 + f)$

Table (5-11B) Models Summery

Rank	Model	Std. Error	R ²
1	B	5.183	0.565
2	A	5.206	0.551
3	C	5.292	0.546

Model (B) was found to be the most suitable model to express the efficiency of removal turbidity in the coagulation process.

The predicted model was as :

$$Y = a \cdot x_1 + b \cdot x_2 + c \cdot x_3 + d \cdot x_4 + e \cdot x_5 + f \dots \dots \dots (5-5)$$

Where:

Y= efficiency of removal turbidity.

In this model, five out of all independent variables assumed to have a reliable impact on efficiency: initial concentration(X_1), pH (X_2), temperature (X_3), alum to porcelanite ratio(X_4) and dosage of coagulant (X_5), are the most significant variables.

The best fitting of data gives the best model which has the higher value of R^2 , the smaller value of the standard error of the estimate .Then, the model gives a coefficient of determination of ($R^2=0.565$) to show that 0.565 of the variation in dependent variable was explained by all independent variables appeared in regression equation, and the standard error of the estimate of (5.183). Table (5-12) displays the coefficient of this model .

Table (5-12) :Model Coefficient

Model	a	b	c	d	e	f
$Y = a \cdot x_1 + b \cdot x_2 + c \cdot x_3 + d \cdot x_4 + e \cdot x_5 + f$	8.15E-04	0.108	-1.197	-0.257	2.444	3.897

There is a correlation matrix between the dependent variable and the five independent variables as shown in table (5-13).

Table (5-13): Correlation Matrix

	X1	X2	X3	X4	X5	Y
X1	1	-0.413	0.014	0	0	0.529
X2	-0.413	1	-0.037	0.072	-0.078	-0.087
X3	0.014	-0.037	1	-0.377	0.108	0.059
X4	0	0.072	-0.377	1	0	-0.312
X5	0	-0.078	0.108	0	1	0.365
Y	0.529	-0.087	0.059	-0.312	0.365	1

The adequacy of this model can be seen from Figure (5-20), which presents the variation of the estimated and observed values of the efficiency of removal turbidity in coagulation process.

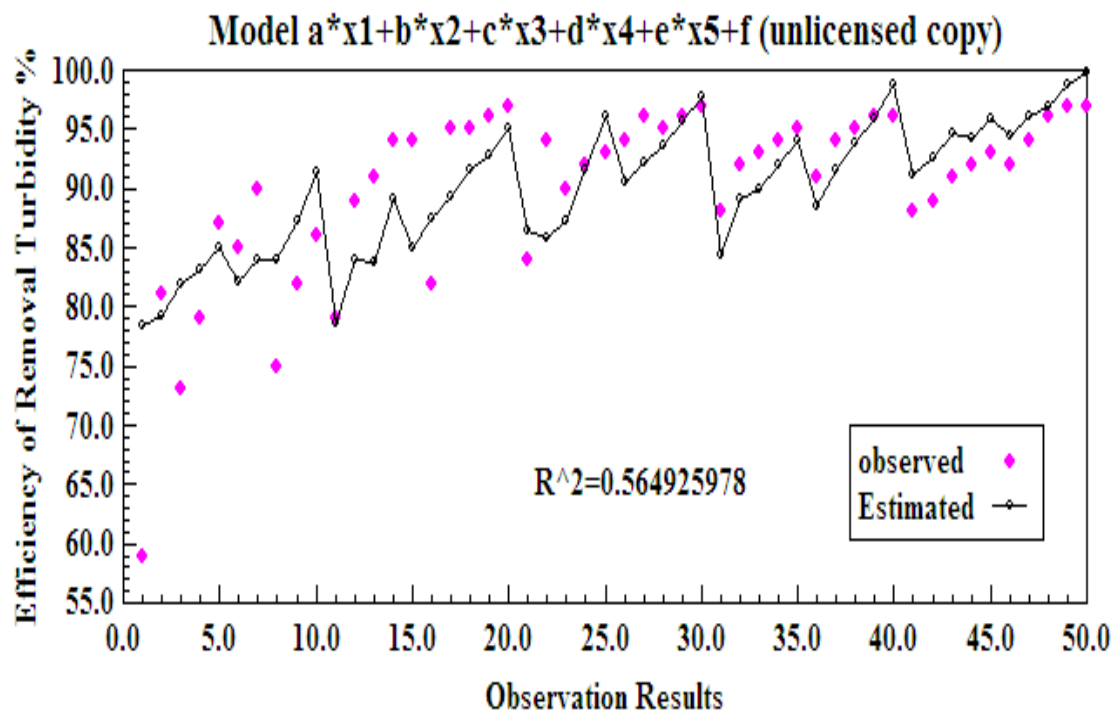


Fig. (5-20) :The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model

5.10 Results of Study No.2:

The findings of the present study are based on the results of the linear regression analysis summarized in Table (5-14 A and B) to choose the appropriate model.

Table (5-14A): Testing Models

Model No.	Model formula
A	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6$
B	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g$
C	$\text{Exp}(a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g)$

Table (5-14B) :Models Summery

Rank	Model	StdError	R ²
1	B	3.971	0.80
2	A	4.655	0.7195
3	C	81.704	0

Table (5-14B) shows that model (B) was found to be the most suitable to represent the efficiency of removal turbidity in the filtration process.

The model was predicted as:

$$Y = a*x_1 + b*x_2 + c*x_3 + d*x_4 + e*x_5 + f*x_6 + g \dots \dots \dots (5-6)$$

where Y = efficiency of removal turbidity in the filtration process

In this model, six out of all independent variables assumed to have a reliable impact on efficiency: initial concentration (X_1), pH (X_2), temperature (X_3), alum to porcelanite ratio (X_4) dosage of coagulant (X_5), and sand to porcelanite ratio (X_6) are the most significant variables.

When the data was fitted very well, then the explanatory power of the model is measured by coefficient of multiple determination $R^2=0.80$ and the standard error of estimate was 3.971; Table (5-15) displays details of the coefficient.

Table (5-15) :Model Coefficient

Model	a	b	c	d	e	f	g
$Y=a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g$	0.357	1.839	0.486	-26.400	0.157	-52.154	124.165

There is a correlation matrix between the dependent variable and the four independent variables.

Table (5-16) Correlation Matrix

	X1	X2	X3	X4	X5	X6	Y
X1	1	0.073	0.104	0.353	-0.406	-0.01	0.0097
X2	0.073	1	-0.065	-0.133	-0.508	0.0005	-0.028
X3	0.104	-0.065	1	-0.107	0.023	-0.332	0.398
X4	0.353	-0.133	-0.107	1	0	0	-0.318
X5	-0.406	-0.508	0.023	0	1	0	0.146
X6	-0.01	0.0005	-0.332	0	0	1	-0.792
Y	0.0097	-0.028	0.398	-0.318	0.146	-0.792	1

The adequacy of this model can be seen from Figure (5-21), which shows the variation of the estimated and observed values of the efficiency of removal turbidity in filtration process.

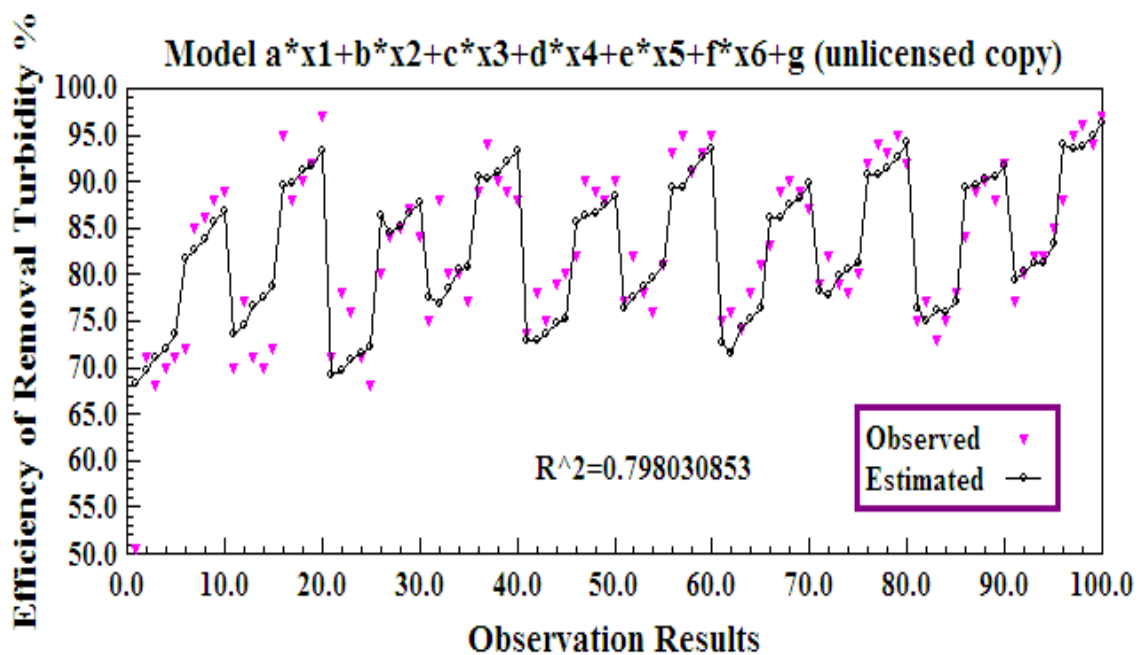


Fig. (5-21) :The Variation of the Estimated and Observed values of the Efficiency by Using the Linear Model

5.11 Results of Study No.3:

The findings of the present study are based on the results of the linear regression analysis summarized in Table (5-17 A and B) to choose the appropriate model.

Table (5-17-A) :Testing Models

Model No.	Model formula
A	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5$
B	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f$
C	$\text{Exp}(a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f)$

Table(5-17-B) Model Summery

Rank	Model	StdError	R ²
1	B	3.681	0.908
2	C	4.108	0.886
3	A	5.145	0.776

Table (5-17-B)shows that model (B) was found to be the most suitable to represent the efficiency of removal BOD₅ in the coagulation process.

The model was predicted as:

$$Y=a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f.....(5-7)$$

where Y = efficiency of removal Biochemical Oxygen Demand (BOD₅)from wastewater in coagulation process.

In this model, five out of all independent variables assumed to have a reliable impact on efficiency: initial concentration(X_1), pH (X_2), temperature (X_3), alum to porcelanite ratio(X_4) and dosage of coagulant (X_5), are the most significant variables.

When the data was fitted very well, then the explanatory power of the model is measured by coefficient of multiple determination $R^2=0.908$ and the standard error of estimate was 3.681; Table (5-18) displays details of the coefficient.

Table (5-18) :Model Coefficient

Model	a	b	c	d	e	f
$y=a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f$	0.106	-51.168	-2.993	-48.283	-9.8334	535.216

There is a correlation matrix between the dependent variable and the five independent variables as shown in table (5-19).

Table (5-19) Correlation Matrix

	X1	X2	X3	X4	X5	Y
X1	1	0.179	0.257	-0.621	0.0043	0.749
X2	0.179	1	-0.433	-0.555	-0.549	0.239
X3	0.257	-0.433	1	0.135	0.191	-0.164
X4	-0.621	-0.555	0.135	1	0	-0.819
X5	0.0043	-0.549	0.191	0	1	0.046
Y	0.7493	0.239	-0.164	-0.819	0.046	1

The adequacy of this model can be seen from Figure (5-22), which shows the variation of the estimated and observed values of the efficiency of removal BOD₅ in coagulation process.

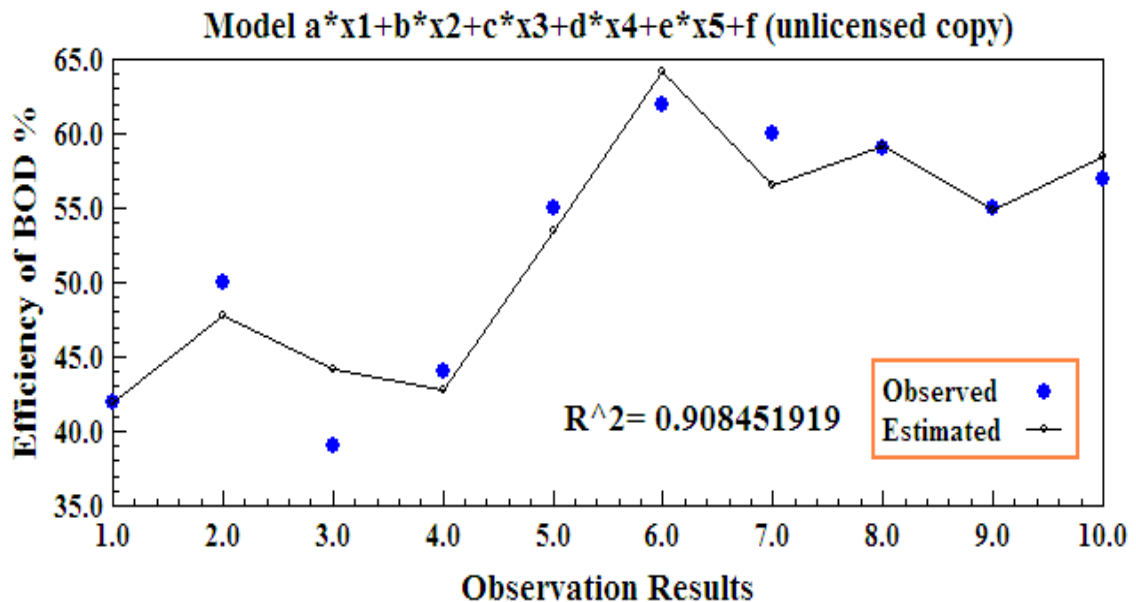


Fig. (5-22) :The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model

5.12 Results of Study No.4:

The findings of the present study are based on the results of the linear regression analysis summarized in Table (5-20 A and B) to choose the appropriate model.

Table (5-20-A) :Testing Models

Model No.	Model formula
A	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6$
B	$a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g$
C	$\text{Exp}(a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g)$

Table (5-20-B) :Model Summery

Rank	Model	Std .Error	R ²
1	B	8.904	0.718
2	A	9.008	0.6896
3	C	58.504	0

Table (5-20-B) shows that model (B) was found to be the most suitable to represent the efficiency of removal BOD₅ in the filtration process.

The model was predicted as:

$$Y=a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g \dots\dots\dots(5-8)$$

where Y = efficiency of removal turbidity in the filtration process

In this model, six out of all independent variables assumed to have a reliable impact on efficiency: initial concentration(X_1), pH (X_2), temperature (X_3), alum to porcelanite ratio(X_4) dosage of coagulant (X_5), and sand to porcelanite ratio (X_6) are the most significant variables.

When the data was fitted very well, then the explanatory power of the model is measured by coefficient of multiple determination $R^2=0.718$

and the standard error of estimate was 8.904; Table (5-21) displays details of the coefficient.

Table (5-21) :Model Coefficient

Model	a	b	c	d	e	f	g
$Y=a*x_1+b*x_2+c*x_3+d*x_4+e*x_5+f*x_6+g$	0.248	-9.996	-0.269	-7.327	-8.045	-74.819	187.105

There is a correlation matrix between the dependent variable and the five independent variables as shown in table (5-22).

Table (5-22) :Correlation Matrix

	X1	X2	X3	X4	X5	X6	Y
X1	1	-0.118	-0.311	0.054	0.224	0.007	0.261
X2	-0.118	1	-0.115	0.3199	-0.146	0.772	-0.708
X3	-0.311	-0.115	1	0.022	0.107	-0.216	0.0616
X4	0.054	0.3199	0.022	1	0	0	-0.096
X5	0.224	-0.146	0.107	0	1	0	-0.005
X6	0.007	0.772	-0.216	0	0	1	-0.791
Y	0.261	-0.708	0.0616	-0.096	-0.005	-0.791	1

The adequacy of this model can be seen from Figure (5-23), which shows the variation of the estimated and observed values of the efficiency of removal BOD₅ in filtration process.

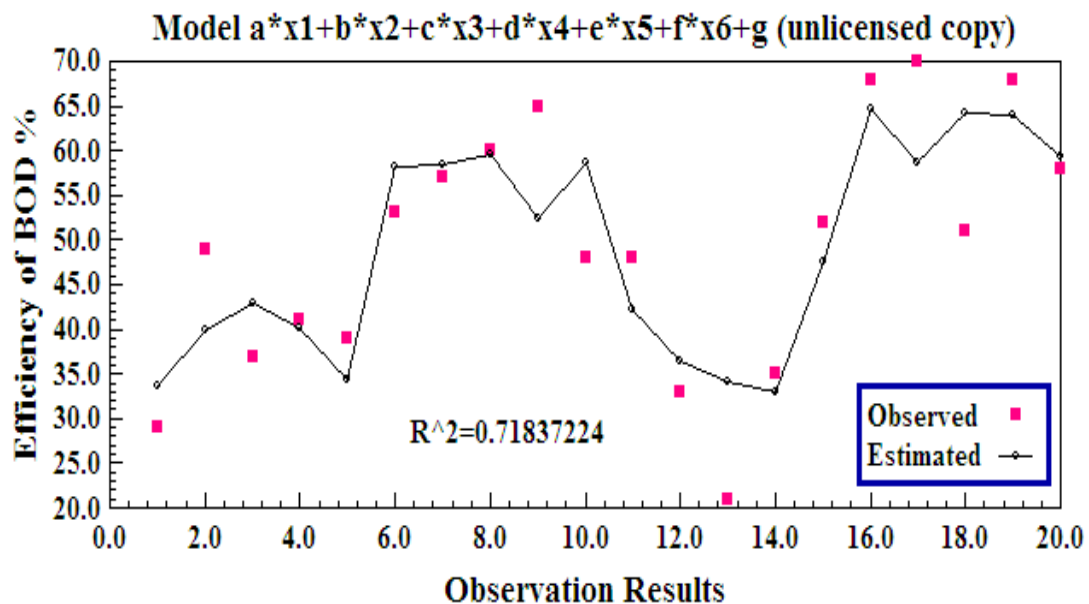


Fig. (5-23): The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model

CHAPTER SIX

Conclusions and Recommendations

6-1 Conclusions

- 1- The best percentage of alum with coagulant aid of porcelanite material was 75 % of alum and 25% of porcelanite material. This percentage was appeared for all dosages used in this study. The porcelanite gives better efficiency when using with alum to remove turbidity more than efficiency obtained when using alum only and for the different levels of turbidity used in this study.
- 2- It can be obtained high level of BOD removal efficiency after coagulation process by about (14%) when adding alum with coagulant aid of porcelanite material more than when adding alum only .
- 3- It can be concluded that the using of dual filter composed of porcelanite and sand gives a better performance than that of single media filter of sand material only .
- 4- The dual filter was efficient in turbidity removal better than of single filter. In which the turbidity of the treated water was less than (3.8 NTU). The maximum turbidity removal efficiency for the single filter was (85 %) and for dual filters was (97 %) when using porcelanite as coagulant aid with alum. The maximum turbidity removal efficiency for the single filter was (81%) and for dual filters was (92%) when using alum without coagulant aid.
- 5- The BOD removal efficiency for dual filter was greater than that of single filter by about (19 %) when adding alum in coagulation process, and about (25 %) when adding porcelanite with alum in coagulation process.

6- A statistical analysis is as shown in table (6-1):

Table (6-1): A Statistical Analysis of Data

Study No.	Predicted model	R²	standard error
1	$Y = 3.897 + 8.15E-04 X_1 + 0.108 X_2 - 1.197 X_3 - 0.257 X_4 + 2.444 X_5$	0.565	5.183
2	$Y = 124.165 + 0.357 X_1 + 1.839 X_2 + 0.486 X_3 - 26.400 X_4 + 0.157 X_5 - 52.154 X_6$	0.80	3.97
3	$Y = 535.216 + 0.106 X_1 - 51.168 X_2 - 2.993 X_3 - 48.283 X_4 - 9.8334 X_5$	0.91	3.68
4	$Y = 187.105 + 0.248 X_1 - 9.996 X_2 - 0.269 X_3 - 7.327 X_4 - 8.045 X_5 - 74.819 X_6$	0.72	8.904

6.2 Recommendations for Future Studies :

- 1- Future study will be needed to show the effect of porcelanite material as coagulant aid with alum on the heavy metal removal and evaluating the adsorption capacity of porcelanite rocks in heavy metal removal .

- 2-The selecting of the best effective size and the best thickness of porcelanite rocks as a dual filter media with different design parameters (filtration rate, backwashing process and depth of filter)were recommended in future study.

List of Contents

Subject

Page

Acknowledgement	I
Abstract	II
List of content	IV
Table of symbols and abbreviations.....	VIII
Table of figures.....	IX
Table of tables.....	XII

Chapter One: Introduction

1-1 General	1
1-2 Scope of the problem.....	2
1-3 Objectives of the study.....	2
1-4 Thesis layout.....	3

Chapter Two : Literature Review

2-1 Introduction.....	4
2-2 Coagulation process.....	5
2-2-1 Variables of coagulation process.....	5
2-2-2 Aluminum sulphate (Alum).....	5
2-3 Coagulant aids.....	7
2-3-1 Adsorbent-weighting agents	7
2-3-1-1 Local material (Porcelanite).....	8
2-4 Factors Effecting coagulation process.....	10
2-4-1 Coagulant solution concentration.....	10
2-4-2 Sequence of chemicals application.....	10
2-4-3 pH value.....	11
2-4-4 Mixing intensity (rapid and slow).....	11
2-4-4-1 Rapid mixing.....	11
2-4-4-2 Flocculation studies(slow mixing).....	13
2-5 Effect of coagulation and flocculation processes on the wastewater	14
2-6 Sedimentation process.....	15
2-7 Filtration process.....	16
2-7-1 Filtration process Variables.....	17

2-7-1-1	Influent characteristics	17
2-7-1-2	Filter media.....	18
2-7-1-3	Depth of filtering material.....	22

Chapter Three: Theoretical Background

3-1	Introduction	24
3-1-1	Coagulation.....	24
3-1-2	Flocculation	24
3-2	Characteristics of colloids	25
3-3	Stability and instability factors.....	30
3-4	Destabilization of colloidal dispersions.....	31
3-5	Mechanisms of destabilization	32
3-5-1	Double – layer compression.....	33
3-5-2	Adsorption of soluble polymeric metal hydroxide species	34
3-5-3	Precipitation of a metal – hydroxide.....	35
3-5-4	Enmeshment in a Precipitate (Sweep Coagulation).....	36
3-6	Chemistry of Coagulation With Alum.....	37
3-7	Local (Porcelanite) Material	40
3-7-1	Chemical analysis of Iraqi porcelanite.....	41
3-7-2	Mineralogical Analysis of Porcelanite in Iraq.....	43
3-8	Mechanisms of Filtration	44
3-8-1	Transport mechanism.....	45
3-8-2	Attachment mechanism.....	47
3-8-3	Detachment mechanism.....	48
3-9	Parameters Effecting the Coagulation and Filtration Processes...	48
3-9-1	Temperature.....	48
3-9-2	pH.....	49
3-9-3	Turbidity.....	49
3-9-4	Conductivity.....	49
3-9-5	Total Dissolved Solids (TDS).....	49

3-9-6 Biochemical Oxygen Demand.....	50
--------------------------------------	----

Chapter Four : Experimental Work

4-1 Introduction.....	52
4-2 The Pilot plant units	53
4-2-1 The tank used in the experimental work	53
4-2-2 Rapid mixing.....	54
4-2-3 Flocculation process.....	54
4-2-4 The pumps used.....	54
4-2-5 Flow-meter.....	54
4-2-6 The filter used.....	55
4-3 Apparatuses	55
4-3-1 Turbidimeter.....	55
4-3-2 Standard sieves.....	55
4-3-3 Balances.....	55
4-3-4 Conductivity meter.....	56
4-3-5 pH meter.....	56
4-3-6 DO meter.....	56
4-4 Turbidity material.....	58
4-5 The coagulants used.....	57
4-5-1 Alum.....	58
4-5-2 Coagulant aid (powder porcelanite).....	58
4-6 Filter media.....	59
4-6-1 Sand.....	59
4-6-2 Local porcelanite rocks.....	60
4-6-3 Supporting gravel layer.....	61
4-7 Experimental procedure.....	61
4-7-1 Synthetic turbid water	61
4-7-2 Determination of coagulant dosage	61
4-7-3 Determination of the best percentage of coagulant And Coagulant Aid	62
4-7-4 Measurement of Organic Contents (Biochemical Oxygen Demand BOD5)	62

Chapter Five: Results and Discussion

5-1	Introduction	64
5-2	Study No.1	64
5-3	Study No. (2).....	66
5-3-1	Clarification Process of Water.....	66
	1. Initial turbidity $T_0=10$ NTU.....	67
	2. Initial turbidity $T_0=50$ NTU	67
	3. Initial turbidity $T_0=100$ NTU.....	68
	4. Initial turbidity $T_0=150$ NTU	69
	5. Initial turbidity $T_0=200$ NTU	70
5-3-2	Filtration process of water.....	71
	1. Initial turbidity $T_0=10$ NTU	71
	2. Initial turbidity $T_0=50$ NTU.....	74
	3. Initial turbidity $T_0=100$ NTU.....	76
	4. Initial turbidity $T_0=150$ NTU.....	78
	5. Initial turbidity $T_0=200$ NTU.....	80
5-4	Experimental tests.....	82
5-5	Study No. 3.....	82
5-5-1	Effect of coagulation process on the organic matter of wastewater:.....	82
5-5-2	Effect of filtration process on the biochemical oxygen demand (BOD_5).....	83
5-6	Experimental tests.....	86
	Regression Analysis Technique	86
5-7	Statistical description of independent variables.....	87
5-8	Regression Models.....	87
5-9	Results of Study No.1.....	88
5-10	Results of Study No.2.....	91
5-11	Results of Study No.3.....	93
5-12	Results of Study No.4.....	95

Chapter Six: Conclusions and Recommendations

6-1	Conclusions.....	97
6-2	Recommendations for future study.....	99
	Appendix A.....	A-1
	Appendix B.....	B-1

Table of Symbols and Abbreviation

Symbol or Abbreviation	Description
A/P	Alum to Porcelanite ratio
a,b,c,...,g	Model Coefficient
BOD ₅	Biochemical Oxygen Demand
D.O	Dissolved Oxygen
E.S	Effective size
L/hr	Liter per hour
NTU	Nephelometric Turbidity Unit
R ²	Coefficient of multiple determination
r.p.m	Rounded per minute
TDS	Total Dissolved Solid
T ₀	Initial Turbidity
U.C	Uniformity coefficient
X ₁ , X ₂ ,..., X ₆	Independent variables
X ₁	Initial concentration I.C
X ₂	pH
X ₃	Temperature
X ₄	Alum to porcelanite ratio A/P
X ₅	Dosage of coagulant in mg/L
X ₆	Sand to the porcelanite ratio S/P

Table of Figures

No.of Figure	Title	Page
Figure(2-1)	The wastewater treatment (Asia, and Akporhonor, 2007)	14
Figure(3-1)	Particle size and treatment processes, [After (Benefield et al., 1982)].	25
Figure(3-2)	A colloidal particle and double layer (a) A negative colloidal particle with its electrostatic field (b) Distribution of electrostatic potential, shear plane, and zeta potential (Ravina .L,1985).	28
Figure(3-3)	Forces Acting on Colloids (Ravina .L, 1985)	30
Figure(3-4)	Examples of Coagulation and Flocculation by Bridging (HDR Engineering Inc., 2001)	32
Figure(3-5)	Effect of electrolyte concentration on double layer compression, [After (Benefield et al., 1982).	34
Figure(3-6)	Equilibrium solubility domain of aluminum hydroxide in water , [After (C. R., 1971)].	39
Figure(3-7)	Map showing the location of porcelanite sample sites	42
Figure(3-8)	Transportation Mechanisms in Rapid Depth Filtration	47
Figure(4-1)	A Schematic Diagram of the pilot plant used in the study for treatment of water and wastewater	52
Figure(4-2)	The pilot plant used	53
Figure(4-3)	The first balance	56
Figure(4-4)	pH meter	56
Figure(4-5)	D.O meter	57

Figure(4-6)	Particle Size Distribution of Kaolinite	58
Figure(4-7)	Particle Size Distribution of powder Porcelanite Used	59
Figure(4-8)	Particle Size Distribution of Sand material	60
Figure(4-9)	Particle Size Distribution of Porcelanite Rocks Samples Used in this Study	61
Figure(4-10)	Samples of BOD ₅ Inside the Incubator	63
Figure(5-1)	Variation of Efficiency of removal Turbidity and Dosage of Coagulant with Different Dosages of Porcelanite	66
Figure(5-2)	Turbidity Removal Versus Different Dosage of A /P under the Initial Turbidity of (10 NTU)	67
Figure(5-3)	Turbidity Removal Versus Different Dosage of A /P at the Initial Turbidity of (50 NTU)	68
Figure(5-4)	Turbidity Removal Versus Different Dosage of A /P at the InitialTurbidity of (100 NTU)	69
Figure(5-5)	Turbidity Removal Versus Different Dosage of A /P at the InitialTurbidity of (150 NTU)	70
Figure(5-6)	Turbidity Removal Versus Different Dosage of A /P at the InitialTurbidity of (200 NTU)	71
Figure(5-7)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	73
Figure(5-8)	Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual	73
Figure(5-9)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	75
Figure (5-10)	Turbidity Removal Versus Dosage of Alum with	75

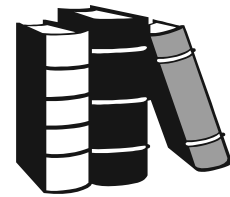
	Coagulant Aid Porcelanite of Both Single and Dual	
Figure(5-11)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	77
Figure(5-12)	Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Filters	77
Figure(5-13)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	79
Figure(5-14)	Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual Filter	79
Figure(5-15)	Turbidity Removal Versus Dosage of Alum of Both Single and Dual filters	81
Figure(5-16)	Turbidity Removal Versus Dosage of Alum with Coagulant Aid Porcelanite of Both Single and Dual	81
Figure(5-17)	Removal Efficiency of BOD ₅ Versus Dosages of coag.	83
Figure(5-18)	BOD ₅ Removal Efficiency by Filtration Process	85
Figure(5-19)	BOD ₅ Removal Efficiency by Filtration Process	85
Figure(5-20)	The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model	90
Figure(5-21)	The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model	92
Figure(5-22)	The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model	94
Figure(5-23)	The Variation of the Estimated and Observed Values of the Efficiency by Using the Linear Model	96

Table of Tables

No.of Table	Title	Page
Table(3-1)	Reactions for hydrolysis of Al(III),[After (Dentel and Gossett, 1987)].	38
Table(3-2)	Effects of alum – dosage on treatment criteria (Schulz and Okun, 1984)	40
Table(3-3)	Chemical analysis of local porcelanite samples	43
Table(4-1)	Chemical analysis of Kaolinite Used	57
Table(4-2)	Chemical analysis of Iraqi Alum	58
Table(4-3)	Chemical and physical analysis of porcelanite used in this study	58
Table(4-4)	Percentages of Alum with Porcelanite	62
Table(5-1)	Summery of Experiments of Study No.1	65
Table(5-2)	Efficiency of Filter Before and After Filtration Process for the Initial Turbidity (10 NTU)	72
Table(5-3)	Efficiency of Filter Before and After Filtration Process under the Initial Turbidity (50 NTU)	74
Table(5-4)	Efficiency of Filter Before and After Filtration Process of the Initial Turbidity of (100 NTU)	76
Table(5-5)	Efficiency of Filter Before and After Filtration Process for the Initial Turbidity of (150 NTU)	78
Table(5-6)	Residual Turbidity Before and After Filtration Process of the Initial Turbidity of (200 NTU)	80
Table(5-7)	Efficiency of Removal BOD ₅ in the Filtration Process	84

Table(5-10)	Description of Independent Variables	87
Table(5-11-A)	Testing Models	88
Table(5-11-B)	Models Summery	89
Table(5-12)	Model Coefficient	89
Table(5-13)	Correlation Matrix	90
Table(5-14-A)	Testing Models	91
Table(5-14-B)	Models Summery	91
Table(5-15)	Model Coefficient	92
Table(5-16)	Correlation Matrix	92
Table(5-17-A)	Testing Models	93
Table(5-17-B)	Models Summery	93
Table(5-18)	Model Coefficient	94
Table(5-19)	Correlation Matrix	94
Table(5-20-A)	Testing Models	95
Table(5-20-B)	Models Summery	95
Table(5-21)	Model Coefficient	96
Table(5-22)	Correlation Matrix	96
Table(A-1)	Summery of Experimental Data Before and After Coagulation Process of Water	A-1
Table(A-2)	Average Values of Experimental Tests Before and After Filtration Process for Water	A-2
Table(A-3)	Experimental Tests Before and After Coagulation Process for Wastewater	A-3
Table(A-4)	Experimental Tests for Wastewater in Filtration Process	A-3

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الخلاصة

في هذه الدراسة تم اختيار مادة البورسلنايت كمادة مساعدة للتخثير مع الشب وكذلك استخدامها كمرشح ثنائي مع الرمل لتقييم كفاءة هذه المادة وذلك من خلال التجارب العملية.

ولقد تطلب العمل إنشاء منظومة معالجة مختبرية. العمل التجريبي تضمن فحوصات لكل من المياه ومياه المجاري

وتتضمن المنظومة المختبرية مرحلتين : المرحلة الأولى تتعلق بكل من عمليات التخثير والتلييد والترسيب باستخدام جرعة مختلفة من الشب ومادة البورسلنايت وقيم عكورة تراوحت بين (10- 200 NTU) .

والمرحلة الثانية تتعلق بعملية الترشيح باستخدام نوعين من المرشحات ، المرشح الاول يحتوي على طبقة مفردة من الرمل بارتفاع 40 سم بينما النوع الثاني هو مرشح ثنائي باستخدام طبقة من الرمل بارتفاع 30 سم مع طبقة من صخور البورسلنايت بارتفاع 10 سم.

وقد أظهرت النتائج بان مادة البورسلنايت أكثر كفاءة عند استخدامها مع الشب في إزالة العكورة ولجميع مستويات الكدرة .

فقد وجد ان كفاءة إزالة العكورة عند مستوى عكورة ابتدائية (10 و 50 NTU) كانت بحدود (72.8 و 84%) عند اضافة الشب فقط في عملية التخثير وهذه النسبة تزداد لتصبح (79 و 93%) بعد إضافة الشب مع مادة البورسلنايت .

وكانت كفاءة إزالة العكورة عند مستويات الكدرة (100،150،200 NTU) هي (90.5 %) عند إضافة الشب فقط في عملية التخثير بينما عند إضافة مادة البورسلنايت مع الشب فان كفاءة الإزالة تزداد لتصبح (95%).

وقد بينت النتائج في هذه الدراسة بان المرشح الثنائي باستخدام صخور البورسلنايت مع الرمل أكثر كفاءة في إزالة العكورة من استخدام الرمل فقط في عملية الترشيح ,حيث ان نسبة ازالة العكورة باستخدام المرشح الثنائي كانت بحدود (86%) بينما نسبة الازالة باستخدام مرشح الرمل كانت (74 %) عند استخدام الشب فقط في عملية التخثير. وهذه الكفاءة تزداد لتصل (93 %) و (80 %) باستخدام المرشح الثنائي ومرشح الرمل على التوالي عند استخدام مادة البورسلنايت مع الشب في عملية التخثير

وكذلك وجد بان استخدام البورسلنايت مع الشب افضل من استخدام الشب فقط في ازالة المحتوى العضوي (طلب الاوكسجين البايوكيميائي BOD) حيث أعطى الشب المحلي كفاءة إزالة (BOD) بحدود

(46%) بينما عند استخدام البورسلنايت مع الشب فان كفاءة إزالة (BOD) تزداد لتصبح بحدود (60%) .

من الملاحظ من النتائج بان المرشح الثنائي أكثر كفاءة من الرمل في تقليل المحتوى العضوي (BOD)، حيث ان كفاءة ازالة ال BOD باستخدام المرشح الثنائي أفضل من استخدام مرشح الرمل بحدود (19 %) عند استخدام الشب فقط في عملية التخثير، بينما عند استخدام الشب مع البورسلنايت في عملية التخثير، فان كفاءة إزالة ال BOD بعد عملية الترشيح باستخدام المرشح الثنائي أفضل من مرشح الرمل بحدود (25 %).

وبعد رسم النتائج تم تحليلها إحصائيا باستخدام البرنامج الإحصائي (Data fit) .