UNIVERSITY OF BABYLON
COLLEGE OF ENGINEERING
DEP. OF CIVIL ENGINEERING

IMPROVING THE PERFORMANCE OF LOCALLY PRODUCED ALUM

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

By

INTIDHAR JABIR IDAN

2002

جامعة بابل
كلية الهندسة
قسم الهندسة المدنية

تحسين أداء الشب المنتج محلياً

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

أعدت من قبل المهندسة

انتظار جابر عيدان

2002

الملخص

الهدف الرئيسي من هذه الدراسة هو تحسين أداء الشب المحلي مختبريا. وذلك من خلال سلسله من التجارب التي أجريت على الشب المحلي والتي تضمنت:

1- غسل الشب المحلي وذلك للتخلص من الشوائب والمواد العالقة على سطح الشب.

2- تركيد محلول الشب وذلك للتخلص من المواد القابلة للترسيب قبل إضافة محلول الشب إلى الماء الخام.

3- رج الشب المحلي وذلك للتخلص من الأطيان والشوائب الموجودة بالشب بطريقه جافه.

4- تسخين الشب المحلي حيث إن عملية التسخين تسمح للأطيان والشوائب بالتكتل بالأضافه إلى إمكانية إحتراق الشوائب القابلة للإحراق.

أستخدم الشب المحلي بعد التحسين بجرعات مختلفة في إزالة كدر مصطنعه تراوحت بين (10- 100 NTU) من خلال خمس مستويات للكدر (10 NTU، 25، 50 ، 75، 100) بالأضافه إلي الكدر المصطنعه فقد استخدم الشب في إزالة بكتريا القولون البراز يه (E.coli) بتركيز (1*104خليه\مل) وذلك لتقييم قدرة الشب على إزالة البكتريا المرضية الموجوده في الماء الخام.

ولغرض اختبار كفاءة الطرق أعلاه في تحسين أداء الشب المحلي، أجريت سلسله أخرى من التجارب استخدم فيها الشب المحلي و الشب النقي في إزالة الكدر المصطنعه و البكتريا و بنفس الظروف التي استخدم فيها الشب المحلي بعد التحسين وذلك لإمكانية مقارنة النتائج.

بينت التجارب و التحاليل الكيميائية للشب المحلي قبل وبعد التحسين إن:

1- الشب المحلي غير كفوء في إزالة الكدر بمستويات (100 NTU) وأقل.
2- الشب المغسول فعال في إزالة الكدر بمستويات (50NTU) واقل.
3- الشب المرسب فعال في إزالة الكدر بمستويات (75 NTU)وأقل.
4- الشب المرجوج فعال في إزالة الكدر بمستويات تتراوح بين (NTU)(50-100) .
5- الشب المسخن فعال في إزالة الكدر العالية، حيث تم الحصول على كفاءة إزالة (93.4%، 95.7% ، 97.2%) لإزالة الكدر بمستويات (50 NTU، 75 ، 100) على التوالي. إن هذه النسب هي أعلى من النسب المتحققة من استخدام الشب النقي.
6- في إزالة البكتريا ، أعطى الشب المحلي قبل التحسين إزالة مقدارها (81.8%) بينما أعطى الشب النقي إزالة مقدارها (99.5%) في حين حقق الشب المحلي بعد التحسين أزاله جيدة تراوحت بين (98.58% - 99.6%).

أخيرا ، مما سبق نستنتج انه يمكن استخدام الشب المغسول والمرسب خلال فصلي الصيف والخريف عندما تكون مستويات الكدر واطئه في نهري دجله والفرات في حين يمكن استخدام الشب المرجوج والمسخن خلال فصلي الربيع والشتاء عندما تكون مستويات الكدر مرتفعه.

مستخلص

بسم الله الرحمن الرحيم

أَفَرَأَيْتُمُ الْمَاءَ الَّذِي تَشْرَبُونَ 68
ءَأَنتُمْ أَنزَلْتُمُوهُ مِنَ الْمُزْنِ أَمْ نَحْنُ
الْمُنزِلُونَ 69 لَوْ نَشَاءُ جَعَلْنَاهُ
أُجَاجًا فَلَوْلَا تَشْكُرُونَ 70

صدق الله العظيم

سورة الواقعة / الآيات (68-70)

CERTIFICATE

We certify that we have read this thesis, titled **" improving the performance of locally produced alum "**, and as examining committee examined the student **" Intidhar Jabir Idan"** 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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We certify that this thesis, titled **” improving the performance of locally produced alum ”** was prepared by “**Intidhar Jabir Idan**” under our supervision at Babylon University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

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الإهداء

إلى ...

ينـــابيع فـــجري

إلى ...

شمـــس عمـــري

إلى ...

بســـمة وجـــودي

إلى ...

من مُـلـيء بحـبهم قـلـبي

إلى...

من أوصى بـهم ربـي

إلى أمي و أبي

إلى ...

الذين كانوا لي سندا وظلا خيم عليّ بالدفء والحب فهونوا عليّ مصاعبي

أخواتي ... أسرار ، بـان ، هـدى

أخـوتي ... علي ، أحمد ، حسين

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INTIDHAR

2002

Abstract

In this study, a series of experiments have been performed to improve the performance of locally produced alum. This included:

1- Washing locally produced alum to get rid of particle impurities on the surface of the alum.
2- Settling alum solution to get rid of materials that are capable of settling before adding the alum solution to raw water.
3- Shaking locally produced alum to get rid of particle impurities found in the alum in a dry way.
4- Heating locally produced alum to assist in aggregation of impurities, besides burning impurities that are capable of combustion.

Different doses of improved locally produced alum have been used to remove turbidities at five selected levels, namely, (10, 25, 50, 75, 100 NTU). Besides, the alum has been used to remove the E.coli in concentration ($1*10^4$ cell/ml) to evaluate the alum capacity to remove pathogenic microorganism in raw water.

The efficiency of improving locally produced alum has been tested by comparing the obtained results with those of locally produced alum and pure alum under the same test condition.

The results indicated that:

1- Locally produced alum is less effective in removing the turbidities in a level of (100 NTU) and less.
2- Washed alum is very effective in removing the turbidities in (50 NTU) levels and less.

3- Settled alum is effective in removing turbidity with levels of (75 NTU) and less.
4- Shaken alum is effective in removing turbidity with levels ranging between (50 -100 NTU).
5- Heat-treated alum is very effective in removing the high turbidities, where the efficiency reaches (93.4%, 95.7%, 97.2%) to remove the turbidities in the levels (50, 75, 100 NTU) respectively, these percentage are more than that achieved by using the pure alum.
6- In removing the bacteria, the locally produced alum gives percentage removal (81.8%), and the pure alum gives percentage removal (99.5%). While the locally produced alum after improving is achieved good percentage removal ranged between (98.58 - 99.6%).

From the above, it is concluded that the washed and settled alum can be used during summer and autumn when the turbidities levels are low in Tigris and Euphrates, while the heated and shaken alum can be used during spring and winter when the turbidities levels are high.

Chapter One 1

Introduction

1-1: Foreword

The first step to protect a water supply system is to have a clean water source. To do that, one must control the land within the watershed surrounding the supply. Protecting the sources of water is not enough to assure that tap water is safe to drink.

Both natural and man-made contaminants can still enter even the most well protected water supply. Water treatment is necessary as the second step of protection.

Treatment of raw water loaded with suspended matters, such as most of the surface water in Iraq, requires principally the separation of the solid and colloids particles that cause turbidity from the raw water. 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 processes:

1- By clarification or settling which makes use of 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, operation and efficiency of filters depend to a large extent on the method and efficiency of clarification process previously given to the raw water.

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. Taste and odor-producing compounds from algae, decaying organics, or contaminants from wastewaters are removed by coagulation (Viessman and Hammer, 1985).

Proper use of chemical coagulants is not only maximizes the destabilization of particulate material which comprises a water's turbidity, but can also lead to improvements in water quality as characterized by less conventional parameters. For example, concentration of both organic and inorganic micro pollutants can be significantly reduced by proper coagulation prior to the various solids-liquid separation processes employed in water treatment (Dentel, 1991).

1-2 : A view on locally produced alum

The use of aluminum salts in drinking water treatment goes back several centuries, when it was used to clarify water drawn from muddy rivers and streams.

Large-scale commercial use of aluminum salts dates from the beginning of the twentieth century, when aluminum sulfate (alum) began to be used as a coagulant for color and turbidity removal (Berberich, 1998).

Table (1-1) points out the chemical analysis for alum according to AWWA standard (AWWA, 1985).

Table (1-1): AWWA standards for unpurified alum, [After (AWWA, 1985)].

Acidity %	Basicity %	Total soluble iron %	Total alumina %	Insoluble matter %	pH
NIL	> 0.05	< 0.75	> 17	< 10	< 3.0

Almost all municipal water treatments plants in Iraq use the locally produced alum as a coagulant agent, which is found at Al-Meshiraq, (250Km) to the west of Baghdad (Al-Marshidi, 2000).

The latest analysis of the locally produced alum, which was conducted in the laboratory of the General Corporation for Water and Sewage in the year (2001), showed that the percentage of impurities in locally produced alum was (14.45%). This percentage of impurities is greater than the upper limit of the unpurified lumps of alum, which is (10%). Because of impurities present in the alum, the operators in water treatment plants suffered from the presence of large masses of sludge left in the alum solution preparation tanks. These large quantities of sludge produced resulted not only from the impurities present in the alum, but also from the bad preparation of alum solution. Large amounts of alum are added to previously treated water, resulting in partially dissolved alum.

The results also showed that the content of alumina was (14%), which is less than the minimum limit of (17%). This may lower the effectiveness of alum. Hence large doses of alum must be added to the raw water to get certain turbidity removal.

Another chemical analysis of Iraqi alum, which includes acidity, basicity, total soluble iron, and pH were found to be within the limits of AWWA standard.

From the above information, it is concluded that the most important factors that affect the quality of the locally produced alum are alumina and percentage of impurities.

1-3: Objectives of the study

The main objectives of the present work are :

1- Studying the ability of improving the locally produced alum properties by reduction the percentage of its impurities and increasing its content of alumina, through conducting simple processes on locally produced alum.
2- Studying the performance of the locally produced alum after washed, settled, shaken, and heated by using these products as a sole coagulant to remove turbidities in the range of (10 -100

NTU), and bacterial suspension in a concentration of ($1*10^4$ cell/ml).

3- Make a comparison between the results for locally produced alum after improved of its contents with results from locally produced alum and also, with the results of pure alum.

1-4 : Thesis layout

This thesis comprises six chapters. Chapter two gives a presentation of the recent and relevant studies on the choice of coagulant, aluminum sulfate (alum), effects of alum, and improving alum performance.

The basic colloidal chemistry, theories of stability, and instability are presented in chapter three. In addition, mechanisms of destabilization and mechanisms of coagulation with alum are presented too. Materials used in this study and their chemical analysis, laboratory experiments, and the setup of tests, are described in chapter four. The apparatus employed are illustrated as well.

Chapter five includes the results of the different experiments and the relevant discussions. Finally, conclusions and recommendations for future studies are present in chapter six.

Chapter Two 2

Literature Review

2-1: General

Many impurities in water are present as colloidal dispersions, i.e., they occur in particulate form with an approximate size range of (100 nm) to (1 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. 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 (Tebbutt, 1998).

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 (Casey, 1997).

2-2: The choice of coagulant

The list of coagulant and flocculent chemicals approved by the Environmental Protection Agency (EPA) for use in potable water included over (1100) products by name; most of these products consist of organic polyelectrolytes formulations (Dentel, 1991).

The choices of a coagulant in water treatment plants have several objectives. Improved water quality is an important criterion but other goals may be the ability to increase water production while maintaining water quality, decreased chemical cost or other operating costs (such as backwashing or sludge handling costs), improved sludge properties or decreased sludge volume to facilitate solids management, decreased requirement for operators' attention to allow them to perform other tasks, or complete automation of plant functions during some hours of the day (Dentel and Kingery, 1989). However, proper product selection must periodically be assured by comparison with available alternatives. Product comparisons must be updated as water or process conditions change, as different products become available, or as comparable costs of competing product change. Ideally, product performances should be evaluated and compared under the range of anticipates treatment conditions. For example, one product might be more sensitive to variations in temperature than another, leading periodically to poor treatment. Coagulant assessment only under average conditions would not indicate this product's disadvantage. Thus, the optimized selection of a coagulant becomes increasingly difficult (Dentel, 1991).

2-3: Temporal variations

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 (Dentel and Kingery, 1989).

As pointed out by Black and Hannah (1961), 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; (4) Coagulant type and dosage; and (5) Alkalinity. 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 (Casey, 1997).

2-4: Aluminum sulfate

The most significant inorganic coagulants are aluminum and iron salts. These are most typically simple salts such as aluminum salts sulfate or ferric chloride (Dentel, 1991).

Most surface water treatment plants in Iraq use aluminum in the form of alum to help in removing harmful waterborne microorganisms and other particles by causing them to clump together (coagulate) into larger particles that are easily removed by sedimentation and filtration. Alum can be bought in various forms, namely, granulated, kibbled (in lumps), and liquid. Where (10 kg) of this salt contains the equivalent of (1.53 kg) of aluminum oxide it can theoretically react to produce (2.34 kg) of floc. It is sold on the basis of its (Al_2O_3) content and is graded (and priced) as (14-15%), (16%) or (17-18%) (Smethurst, 1997).

2-5: Effects of alum

Casey (1997) stated that the effectiveness of added ions of opposite charge increases dramatically with their valence, a finding first observed by Schulze and Hardy and often expressed as the Schulze-Hardy rule, which states: ”the precipitation of a colloid is effected by that ion of an added electrolyte which has a charge opposite in sign to that of the colloidal particles, and the effect of such ion increases markedly with the number of charges it carries”.

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

(i) Its effectiveness in destabilizing the predominantly negatively charged colloids found in natural waters, as shown in Table (2-1).

(ii) Its relatively low cost.

(iii) 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.

(iv)Its availability.

In addition, aluminum salts make drinking water more palatable by clarifying the water and removing many impurities that affect its quality. This is discussed in the following sub-items.

Table (2-1): Effectiveness of coagulants, [After (Casey, 1997)].

Electrolyte	**Relative power of coagulation**	
	Positive colloids	**Negative colloids**
NaCl	1	1
Na_2So_4	30	1
Na_3Po_4	1000	1
$BaCl_2$	1	30
$MgSo_4$	30	30
$AlCl_3$	1	1000
$Al_2(So_4)_3$	30	>1000
$FeCl_3$	1	1000
$Fe(So_4)_3$	30	>1000

2-5-1: Organics removal by alum

The organic content of natural waters derives in part from naturally occurring products of biological activity in the aquatic and terrestrial environments and in part from man's activities. The naturally occurring organics are frequently referred to as humic substances.

The organic content of water is troublesome for a number of reasons (Edzwald et al., 1979):

1- The organic content of natural waters is largely responsible for problems associated with color.

2- Certain organic compounds contribute to taste and odor problems in drinking water supplies.

3- When chlorine is added to drinking water supplies in concentrations required for disinfection, it has been found to react with the organic content of the water to produce a variety of chlorinated products. The most ubiquitous products, and the products found in the highest concentration, are chloroform and other trihalomethanes; trihalomethanes may increase the risk of certain cancers.

Semmens and Filed (1980) stated that a coagulation process with alum as the sole coagulant was found to capable of achieving significant organics removal from the raw water. They found that a total organic carbon (TOC) reduction of greater than (50) percent might be achieved at high alum doses. They also stated that organics removal has increased with an increasing alum dose, and alum doses higher than those normally used for turbidity removal are needed to obtain the best organics removal. However, good organics removal always coincided with good turbidity removal.

Reckhow and Singer (1984) stated that alum coagulation has been selectively removed organics responsible for chloroform production. This feature of alum can remove a significant proportion of the organics, which represents the formation potential for total trihalomethanes and total organic halogen (Tox).

Hundt and O'Melia (1988) have concluded that, in the coagulation of water with aluminum sulfate, organic color in the form of humic and fulvic acids are removed by precipitation of an insoluble basic humate of fulvate. This is formed by the interaction of a partially hydrolyzed aluminum ion of empiric formula [$Al(OH)_{2.5}$] and an ionic group, probably a carboxyl, on the organic molecule.

2-5-2: Inorganic removal by alum

Inorganic pollutants of increasing concern include heavy metals such as lead, mercury, cadmium, chromium, etc.; the problem with heavy metals is that, unlike organic pollutants, they are not broken down by bacteria. Consequently, they may persist in the water or bottom sediments for many years and eventually enter human food chains. A summary of the effects of four heavy metals on human health is presented in Table (2-2) (Olivers et al., 1998).

Dentel (1991) showed that removal of heavy metals by alum may vary widely, as shown in Table (2-3). Even when removal of such contaminants is substantially less than (100%), maximizing removal in this respect assists in obtaining an increased overall removal through all processes employed at a plant.

Table (2-2): Effects of four heavy metals on human health, [After (Olivers et al., 1998)].

Mercury	**Arsenic**
Fatigue	Headache
Headache	Fatigue
Irritability	Vomiting
Loss of coordination	Diarrhea
Numbness of hands and feet	Abdominal pains
Shortening of attention	Muscular pains
Memory loss	Anemia
Kidney damage	General paralysis
Death	Coma
	Death
Lead	**Cadmium**
Intestinal colic	Degenerative bone disease
Irritability	Severe crippling
Anemia	High blood pressure
Blood in urine	Heart malfunction
Brain Damage	
Partial paralysis	
Mental retardation	

Table (2-3): Effectiveness of coagulation for removal of selected inorganic contaminants, [After (Sorg and Logsdon, 1980)].

Contaminant	Removal characteristics	
	Coagulation with alum	Coagulation with ferric salts
Arsenic (III)	Poor	Fair
Arsenic (V)	Good (pH<7.5) Fair (pH>7.5)	Excellent
Barium	Poor	Poor
Cadmium	Good (pH>8.5) Fair-poor (pH<8.5)	Excellent (pH>8) Fair-low (pH<8)
Chromium (III)	Excellent	Excellent
Chromium (VI)	Poor	Poor
Lead	Excellent	Excellent
Mercury	Fair-poor	Fair-poor
Radium	Poor	Poor

2-5-3: Virus removal by alum

There are more than (100) different viruses that are known to be excreted with human feces. Viruses are known to be the causative agent of many diseases. Infections hepatitis, polio, echo, Coxsackie, and adenoviruses are a few of those viruses that have been found in the feces of infected humans (Clarke and Chang, 1959).

Many investigations have been made into the effectiveness of chemical coagulation and flocculation for the removal or inactivation of viruses. York and Drewry (1974) studied the effectiveness of some chemical coagulants which included aluminum sulfate [$Al_2(So_4)_3$], ferric chloride ($FeCl_3$), ferric sulfate [$Fe_2(So_4)_3$,xH_2O], and ferrous sulfate ($FeSo_4$). The virus concentrations in the supernatant, after coagulation and settling, are plotted against the coagulant dose in Figure (2-1). The figure shows that the virus concentration decreases to a minimum value as the coagulant dose is increased. They also found that from the four common coagulants, it appears that aluminum sulfate is more favorable for virus removal. Aluminum sulfate produced excellent virus removal (>99 percent) at relatively low dosed (20-35 mg/l).

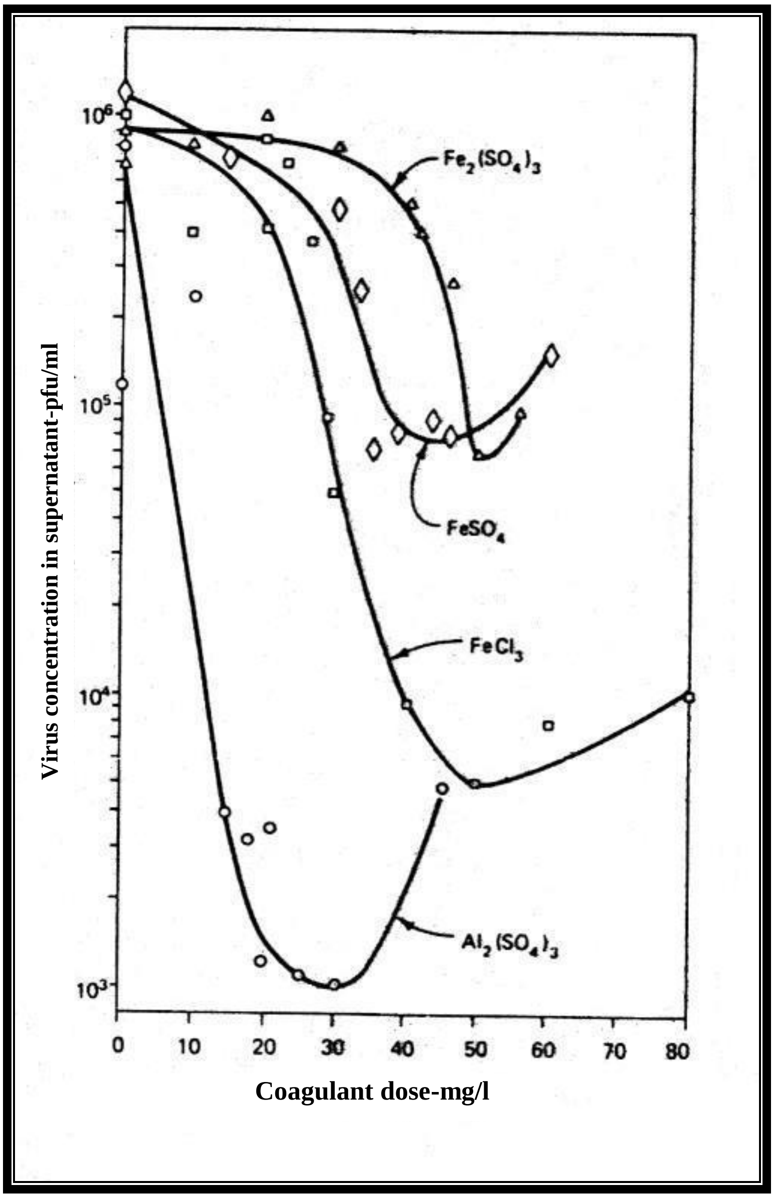


Figure (2-1): Effect of coagulant on virus concentration in the supernatant, [After (York and Drewry, 1974)].

2-6: Improving alum performance

The researcher could not find previous works that are comparable to the scope of the thesis. However, many researchers studied the capability of improving the alum performance, either by using other chemicals, which are coagulant aids beside alum, or by improving the parameters affecting the coagulants performance, such as coagulant solution concentration, sequence of chemicals application, pH, and such physical factors like mixing intensity (rapid and slow) and the duration of mixing. The following is a review of such studies.

2-6-1: Coagulant aids

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. Such coagulant aids involve acids and alkalis aids, adsorbent-weighting agents, and Polyelectrolytes.

2-6-1-1: Acids and alkalis aids

Acids and alkalies are added to water to adjust certain chemical properties of raw water such as pH and alkalinity as well as principally for excess removal of turbidity for better efficiency and economy.

Typical acids used to lower the pH are sulfuric and phosphoric. Alkalies used to raise the pH are lime and soda ash. Adding an alkali to water is one of the approaches that have been used to enhance the performance of alum (Viessman and Hammer, 1985).

2-6-1-2: Adsorbent-weighting agents

Reihl (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.

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.

Al-Marshidi (2000) stated that 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).

2-6-1-3: Polyelectrolytes

Polyelectrolytes are polymers that contain ionized functional groups such as carboxyl, hydroxyl, amino, and other groups. Functional groups are located periodically along the chemical linking chain, and they may possess a negative charge (anionic polymers), positive charge (cationic polymers), or an overall neutral charge (nonionic polymers) (Smethurst, 1997).

Polyelectrolytes are either derived from natural sources or synthesized by chemical manufacturers. A major benefit obtained with polyelectrolytes is a very large increase in floc size. The pair of photomicrographs shown in Figure (2-2) illustrates this enormous increase in floc size. Figure (2-2-a) shows a normal alum floc of typical flocculent appearance. When an anionic polyelectrolyte is added, the size of the floc is increased by several orders of magnitude, as shown in Figure (2-2-b), (AWWA, 1971).

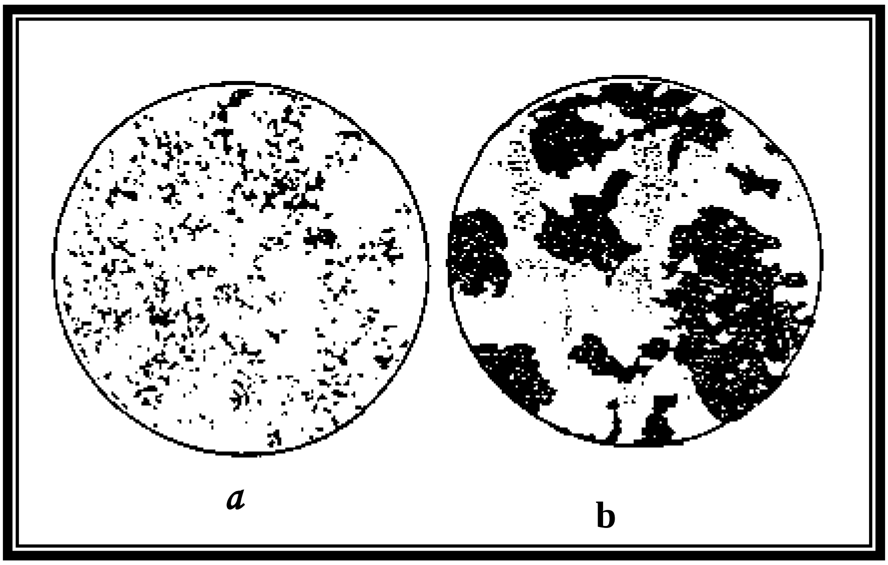


Figure (2-2): Photomicrograph of alum floc without and with polyelectrolyte aid, [After(AWWA, 1971)].

York and Drewry (1974) stated that when polyelectrolytes used as coagulant aids, they offer the advantage of building a large, dense rapid settling floc. However, removal of virus and other contaminants was not significantly improved by using the polyelectrolytes as coagulant aids. They also showed that the use of these coagulant aids would not enable reducing the dosage of alum. Consequently, the researchers concluded that in general the use of polyelectrolytes as coagulant aids with alum did not significantly increase the performance of the coagulation system more than results obtained with alum alone.

Robinson (1974) showed that activated silica, which is formed by neutralizing a concentrated solution of sodium silicate (Na_2SiO_3), to a pH of (6-7), with the consequent formation of polysilicic acid $(H_2SiO_3)_n$, is an anionic polyelectrolyte which has been used as a coagulant aid in water treatment practice. However, the disadvantages inherent in the use of activated silica is the maintenance of equipment and discharge lines, since the lines that transport the material to the points of application frequently become plugged. He also stated that another disadvantage is the significant decrease in filter runs.

Jahn (1988) reported that in several countries in Africa (Chad, Nigeria, Sudan and Tunisia), indigenous plants are added to drinking water by rural villagers to remove turbidity or unpleasant tastes and odors.

Schulz and Okun (1992) stated that seeds from various plants were used as coagulants or as coagulant aids at different regions over the world. Such as plants were Nirmali, Tomarind tree, Guar plant, Red sorrela plant, Fenugreek, Lentils, and Moringa Olifera tree.

Smethurst (1997) found that in some areas the cost of polyelectrolyte is about twice the cost of alum, and it therefore follows that if an economical balance is aimed at then every part of polyelectrolyte should reduce the alum dose by at least two parts.

2-6-2: The variables affecting on coagulants performance

Optimum coagulation treatment of raw water implies the attainment of a very complex equilibrium in which many variables are involved. Thus for a given water, there will be interrelated optimum condition such as coagulant solution concentration, sequence of chemicals application, pH, and such physical factors like mixing condition. According to (Dentel, 1991), these interrelations are so complex that it is impossible to predict from purely theoretical bases the optimum coagulant dose for any particular water. Not withstanding these difficulties, knowledge of the effects on coagulation of the several variables can lead to more intelligent application of empirical methods.

2-6-2-1: Strength of the coagulant solution

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 a turbidity hump peaks between (1-3) percent alum concentration and ends at about (7.5) percent as shown in Figure (2-3). He suggested 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%).

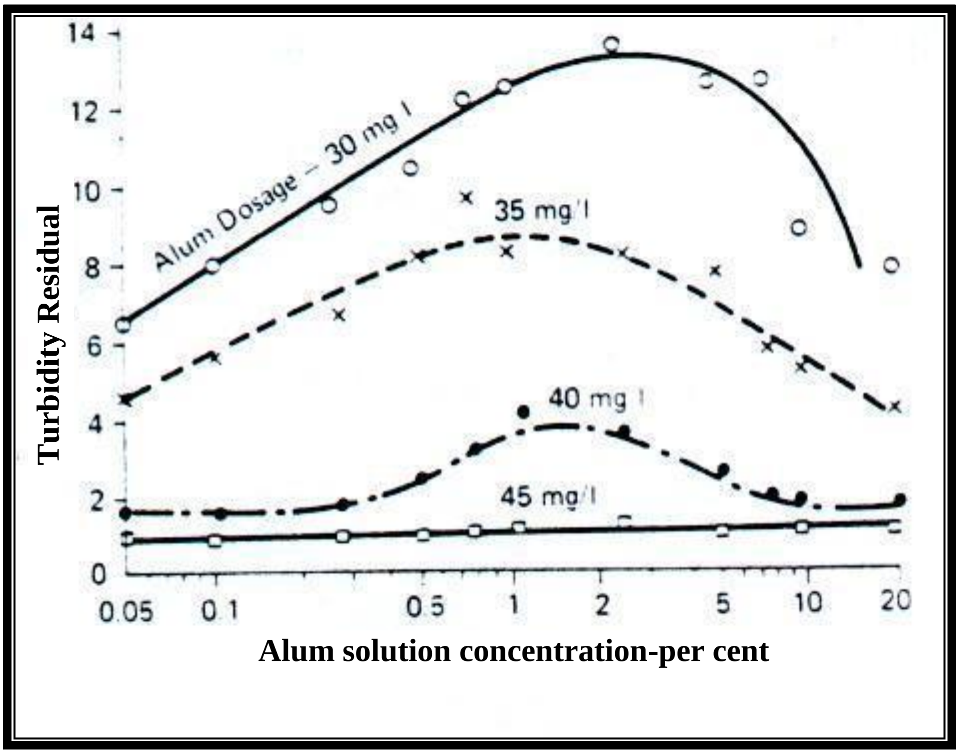


Figure (2-3): Effect of alum solution concentration on flocculation, [After (Kawamura, 1973)].

2-6-2-2: 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).

2-6-2-3: pH (Hydrogen ion concentration)

There have been many researches showing that pH 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.

Black and Hannah (1961) found that the best flocculation zone occurred by using aluminum sulfate at pH (7.5-8.5).

Black and Chen (1967) found that good coagulation takes place in pH range (6.5-7.5), for three types of suspension with alum dosage was more than (10mg/l). The soluble concentration of aluminum ions (Al^{3+}) in specific pH range decrease as pH value increase this is due to the reaction of (OH^-) with (Al^{3+}).

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.

2-6-2-4: 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.

Many techniques are used to provide rapid mixing for dispersal of chemical in water. Basically there are two groups (1) Hydraulic rapid mixing, channels or chamber with baffles producing turbulent flow condition, over flow weirs, and hydraulic jumps. (2) Mechanical rapid mixing, the power required for agitation of the water is imparted by impellers, propellers or turbines. Generally mechanical rapid mixers are more suitable for water treatment plant than hydraulic ones.

Smethurst (1997) stated that in many of the more successful mixing basins which are mechanically stirred the velocity gradient (G) for the respective contact time (T) are as shown in Table (2-4).

Table(2-4):Recommended G and T values for rapid mixing, [After(Smethurst, 1997)].

Contact time T, (sec.)	Velocity gradient G, ($sec.^{-1}$)	GT
20	1000	20000
30	900	27000
40	750	30000

2-6-2-5: Flocculation studies

Flocculation is the agglomeration of destabilized particles into microfloc, and later into bulky floccules, which can be settled, called floc, (Degremont, 1991).

Griffith and Williams (1972) reported that the higher the raw water salt content the higher the velocity gradient (G) value.

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.

Benefield et al., (1982) stated that the pH must be controlled to establish optimum conditions for coagulation. Control is complicated by the fact that the aqua-metal ions of (Al^{+3}) and (Fe^{+3}) are acidic in nature. If the natural alkalinity is not sufficient to react with the alum and buffer the pH, it may be necessary to add alkalinity to the water in the form of lime or soda ash.

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.

Chapter Three 3

Theory of coagulation

3-1: Introduction

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 (1μm) although some authors consider the colloidal range to extend up to a size of (10μm). The size relationships are shown in Figure (3-1) (Benefield et al., 1982).

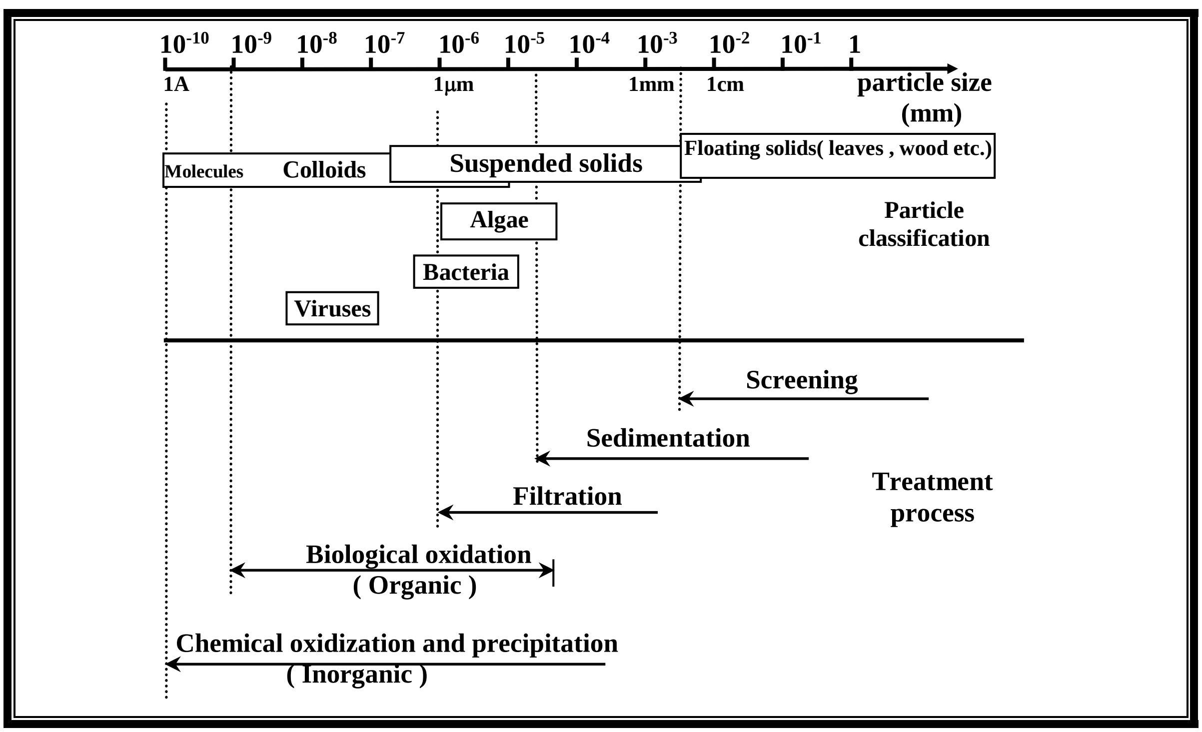


Figure (3-1): Particle size and treatment processes, [After (Benefield et al., 1982)].

The size of particles is the most significant property responsible for the stability of a sol (a colloidal dispersion in a liquid). With larger particles the ratio of surface area to mass is low and mass effects, such as sedimentation by gravity forces, predominate. For colloids, the surface area to mass ratio is high and surface phenomena, such as electrostatic repulsion and hydration, become important (Viessman and Hammer, 1985).

3-2: Nature of suspensions in water treatment

There are two types of colloids: hydrophobic and hydrophilic.

Hydrophobic colloids have no affinity for water and are considered to derive their stability from the nature of their individual particles, which possess like charges and, thus, repel each other. These charges may arise from preferential adsorption of a single ion type on the particle surface or from the chemical structure of the particles surface itself. The possession of charge, positive or negative, by a colloid gives rise to its envelopment by an " electrical double layer ", resulting in a potential gradient in the particles vicinity, as shown in Figure (3-2) (Al-Layla et al., 1980).

Since all particles in a given colloidal dispersion are similarly charged, such a suspension is stable by virtue of the electrostatic repelling forces, which prevent particles coming together under the influence of Brownian motion and Van der Waals attractive forces. It is not possible to measure the potential at the solid–particle boundary but the potential at the rigid–solution boundary or plane of shear can be measured. This latter is called the Zeta potential (ζ) and is related to the particle charge and the double layer thickness as follows:

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

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.

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).

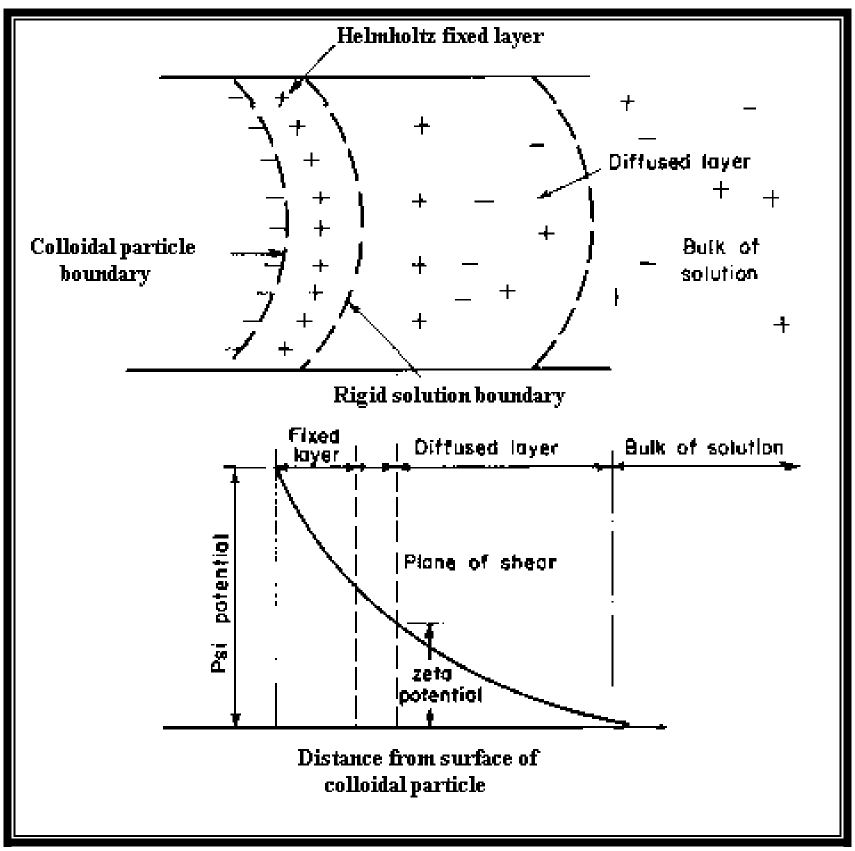


Figure (3-2): Electrochemical behavior at the surface of colloidal particles, [After (Al-Layla et al., 1980)].

Hydrophilic colloids have, as their name implies, a marked affinity for water. Their stability is due mainly to bound water layers, which prevent close contact between particles, although charge is also considered to contribute to their stability. These mainly organic substances may be single macromolecules or aggregates of macromolecules and may be in true solution or in suspension. They derive their charge from the ionization of attached functional groups such as the carboxyl, hydroxyl, sulphate, phosphate and amino groups. The magnitude of this charge is dependent upon the extent of ionization of the functional groups, which in turn, is influenced by the pH of the medium. The charge also influences the solubility of hydrophilic colloids; the minimum solubility being frequently found to coincide with the isoelectric point which, in the majority of cases, lies within the pH range (4 - 6.5) (Viessman and Hammer, 1985).

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).

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. Black (1960) showed that 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. Historically, two broad theories have been proposed to explain the mechanisms involved (C. R., 1971):

1- 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.
2- 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.

3-4: Destabilization of colloidal dispersions

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 particles.

3-5: Mechanisms of destabilization

Many researches suggested 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).

If an electrolyte is added to a colloidal dispersion, the surface charge on the particles will remain unchanged if that charge originates from crystal imperfections (i.e., clay particles). However, the added electrolyte will increase the charge density in the diffuse layer and result in less volume of the diffuse layer being required to neutralize the surface charge. Thus, the diffuse layer shown in Figure (3-3), curve (ABCD) is compressed toward the particle surface as shown by the curve ($A^/B^/C^/D^/$). The total net charge in the diffuse layer has not changed (area CAD = area $C^/A^/D^/$), but the thickness of the layer has been reduced.

Benefield et al. (1982) stated that 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 Figure (3-4).

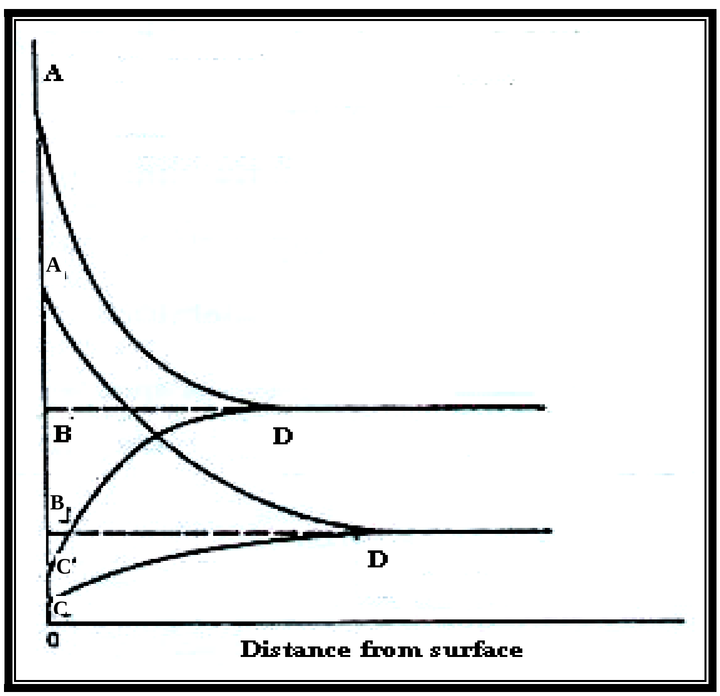
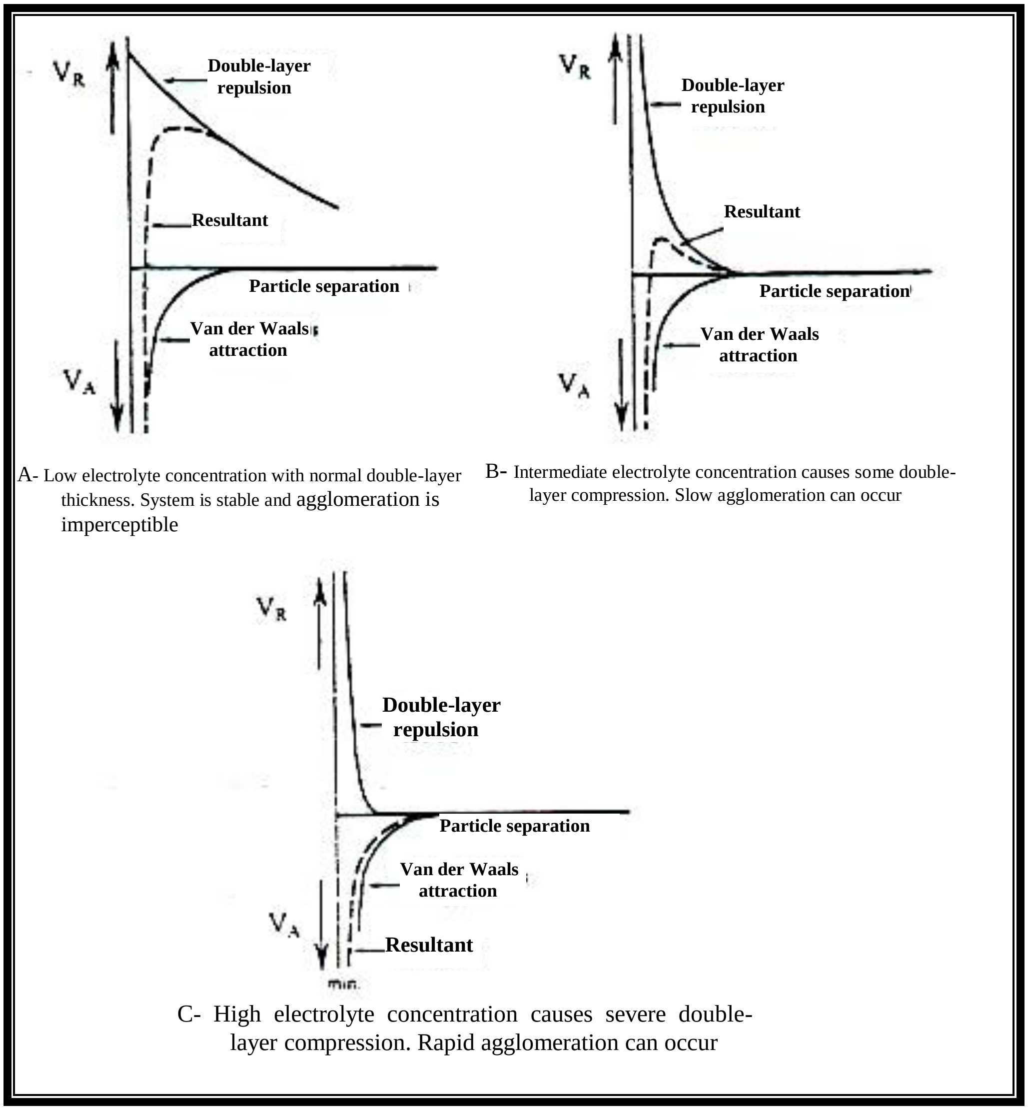


Figure (3-3): Charge distribution in the diffuse double layer of a negative particle surface at two-electrolyte concentration for a constant surface charge, [After (Benefield et al., 1982)].



A- Low electrolyte concentration with normal double-layer thickness. System is stable and agglomeration is imperceptible

B- Intermediate electrolyte concentration causes some double-layer compression. Slow agglomeration can occur

C- High electrolyte concentration causes severe double-layer compression. Rapid agglomeration can occur

Figure (3-4): Effect of electrolyte concentration on double layer-compression, [After (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.

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. Thus, as shown later in Figure (3-10), 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, as represented schematically in Figure (3-5). The Figure indicates several possible pathways by which the metal hydroxide could end up on particles surfaces.

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. This is simplistically diagrammed in Figure (3-6).

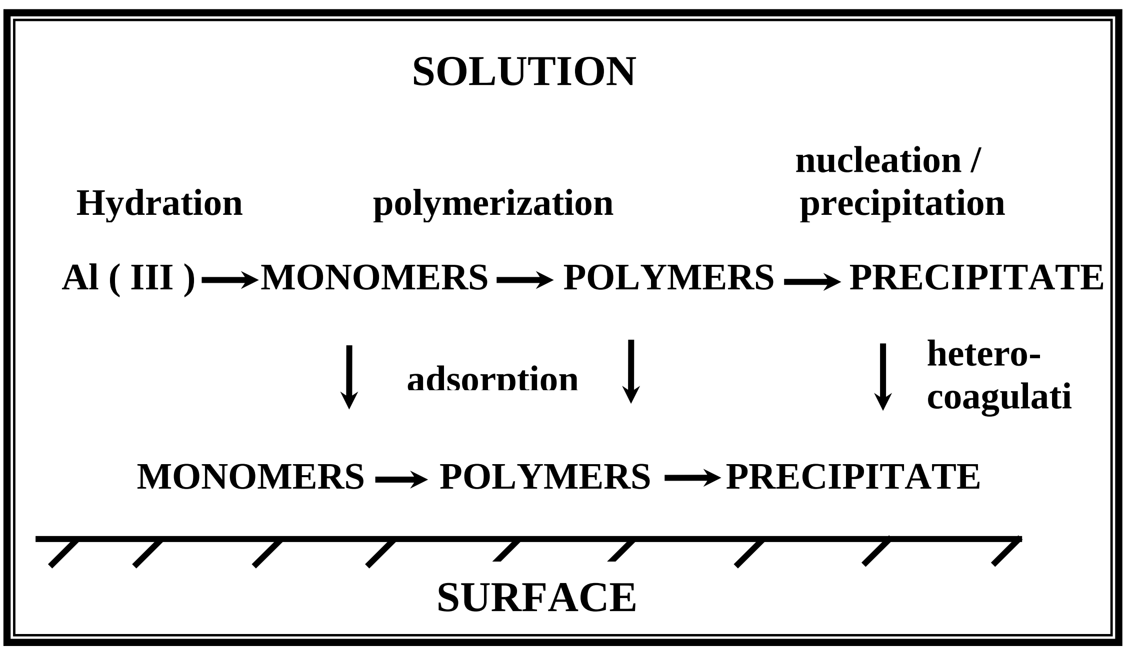


Figure (3–5): Schematic representation of the various pathways followed by aluminum hydroxide in solution or at a surface in contact with solution, [After (Dentel, 1987)].

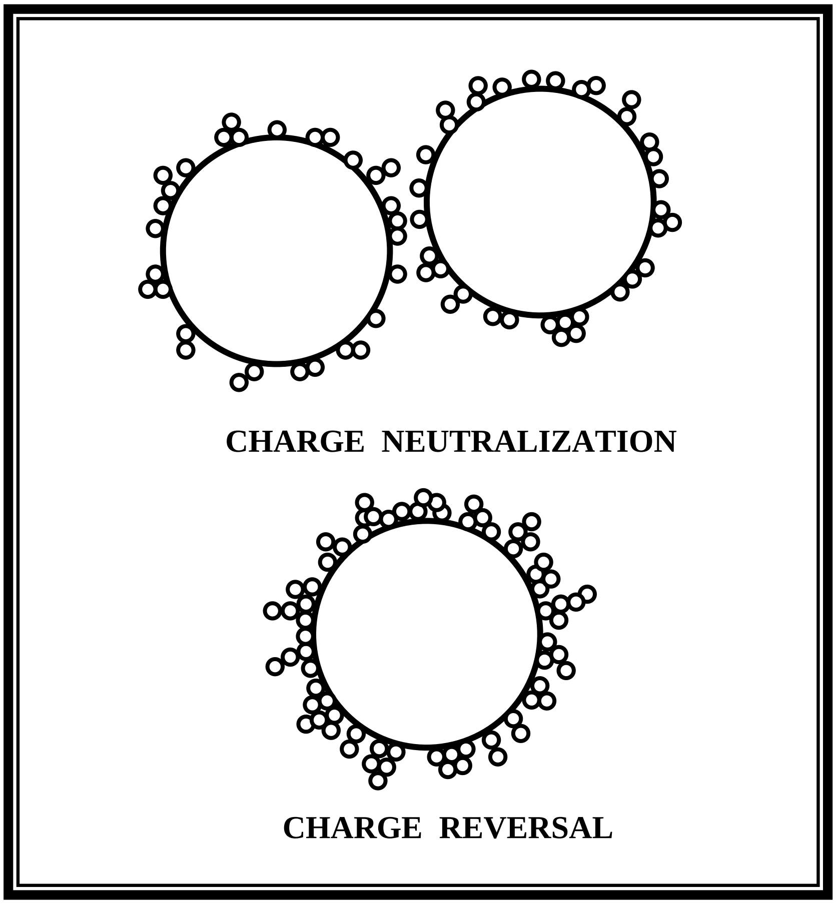


Figure (3-6): Schematic representation of the deposition of metal hydroxide species onto particles, [After (Dentel,1987)].

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 [$Al_2(So_4)_3$], [$FeCl_2$], [$MgCo_3$] , and [$Ca(OH)_2$] can induce coagulation through the formation of insoluble [$Al(OH)_3$(s)], [$Fe(OH)_3$(s)], [$Mg(OH)_2$(s)], and [$CaCo_3$(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 [Al $(OH)_3$ (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 [$Al(OH)_3$(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 [$Al(OH)_3$(s)] precipitation is enhanced by the possibility of mutual or hetero-coagulation between the negatively charged solution and the positively charged [$Al(OH)_3$(s)] (Jorden, 1972) .

3-6:Chemistry of coagulation

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

$$\mathbf{Al_2(SO_4)_3 .18H_2O+3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3+3CaSO_4 +6CO_2 +18H_2O}$$

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

$$\mathbf{Al^{3+} +3HCO_3^{-} \longrightarrow Al(OH)_3 + 3CO_2}$$

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.

$$2Al(OH)_3 \longrightarrow Al_2O_3.3H_2O$$

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

$$Al(OH)_3 + 3H^+ \longleftrightarrow Al^{3+} + 3H_2O$$

$$Al(OH)_3 + OH^- \longleftrightarrow Al(OH)_4^-$$

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+}	$Al(OH)_3 + 3H^+$	$Al^{3+} + 3H_2O$
$Al(OH)^{2+}$	$Al^{3+} + 1H_2O$	$Al(OH)^{2+} + 1H^+$
$Al(OH)_2^+$	$Al^{3+} + 2H_2O$	$Al(OH)_2^+ + 2H^+$
$Al(OH)_3^0$	$Al^{3+} + 3H_2O$	$Al(OH)_3^0 + 3H^+$
$Al(OH)_4^-$	$Al^{3+} + 4H_2O$	$Al(OH)_4^- + 4H^+$
$Al_2(OH)_2^{4+}$	$2Al^{3+} + 2H_2O$	$Al_2(OH)_2^{4+} + 2H^+$
$Al_3(OH)_4^{5+}$	$3Al^{3+} + 4H_2O$	$Al_3(OH)_4^{5+} + 4H^+$
$Al_7(OH)_{17}^{4+}$	$7Al^{3+} + 17H_2O$	$Al_7(OH)_{17}^{4+} + 17H^+$
$Al_{13}(OH)_{32}^{7+}$	$13Al^{3+} + 32H_2O$	$Al_{13}(OH)_{32}^{7+} + 32H^+$

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).

A stepwise conversion of the positive aluminum ion to the negative aluminate ion $[Al(OH)_4]^-$ is assumed as shown in Figure (3-7). The scheme given in figure (3-7) is hypothetical, but the formation of polynuclear ionic aluminum hydroxo complexes such as those represented by structures (d) or (e), is well substantiated by various workers (Stumm and Morgan, 1962). However, because of the complicated aqueous chemistry of aluminum, many researchers disagree about the exact nature of the hydrolyzed species (Hundt and O'Melia, 1988).

There is a general agreement that under equilibrium conditions aluminum exists primarily as the insoluble solids $Al(OH)_3$ as shown in Figure (3-8) (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).

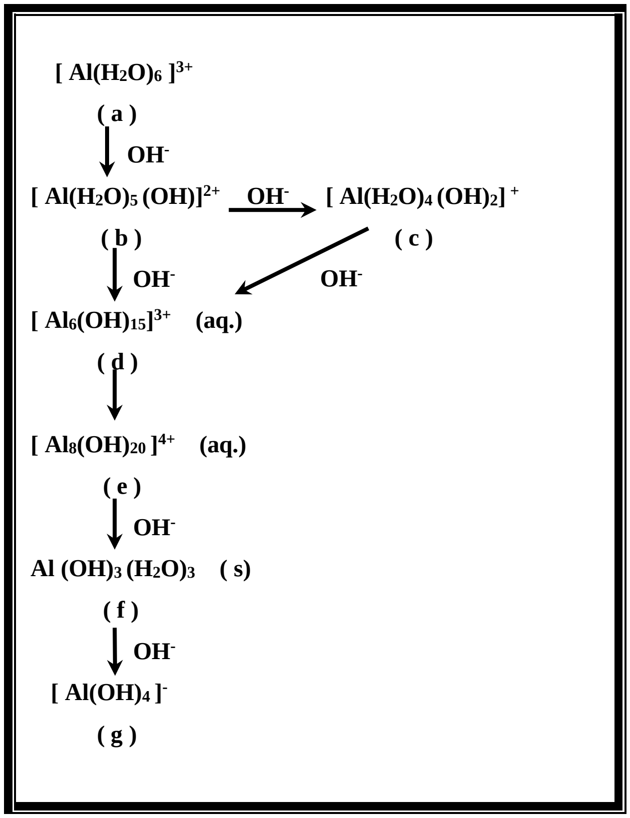


Figure (3–7): Stepwise conversion of the tri-positive aluminum ion to the negative aluminate ion, [After (Stumm and Morgan , 1962)].

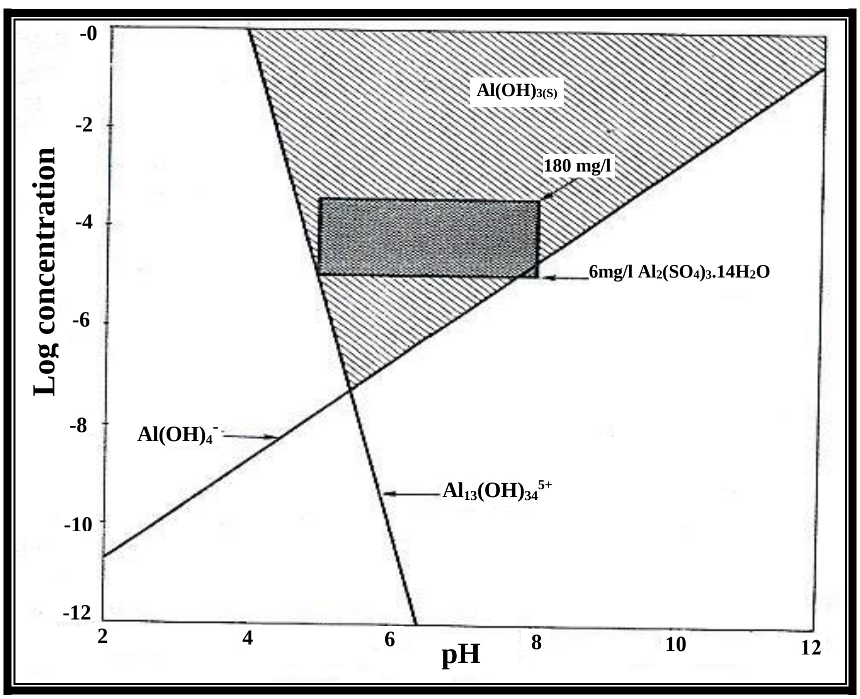


Figure (3-8): Equilibrium solubility domain of aluminum hydroxide in water , [After (C. R., 1971)].

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). Species present as a function of pH for (0.0001 M) aluminum are shown in Figure (3-9) (Sullivan and Singley, 1968).

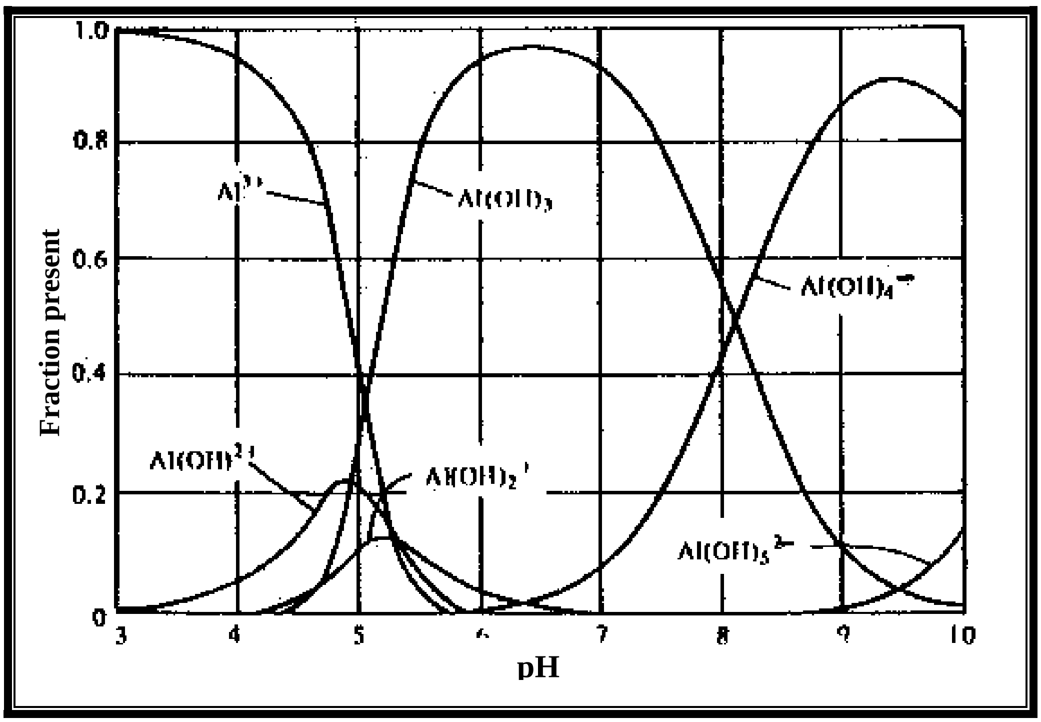


Figure (3-9): Species present Vs. pH for $1*10^{-4}$ M aluminum perchlorate under nonequilibrium conditions,

[After (Sullivan and Singley , 1968)].

3-7: Solubility diagram for aluminum hydroxide

There have been many papers showing that pH is one of the most important variables of those that have to be considered for effective flocculation. The metal coagulant of aluminum has been shown to precipitate and coagulate most rapidly and with minimum solubility in a certain pH range. Typical solubility curves for alum floc shows in Figure (3–10). This diagram provides the basis for stability plots, which define favorable coagulation conditions useful for dose control purposes.

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 (Kawamura, 1976).

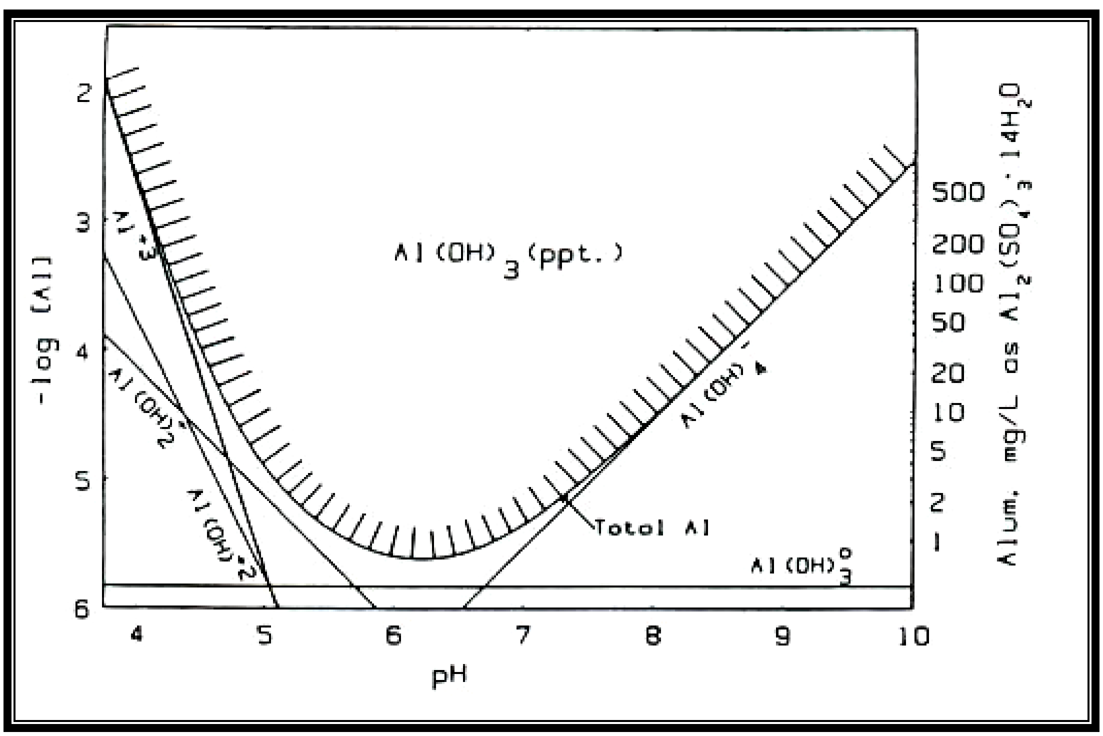


Figure (3-10): Solubility diagram for aluminum hydroxide species, [After (Dentel, 1991)].

3-8: Stability diagram

Amirtharajah and Mills have published " design and operation diagram " for alum coagulation, such a diagram places coagulation results on a log [Al] vs. pH plot as zones of stable or destabilized suspensions, and is known in the colloidal science literature as a stability diagram. The diagram for alum from Amirtharajah and Mills is presented in Figure (3-11) (Amirtharajah and Mills, 1982). The Figure identifies the following zones: I: Stable suspension; II: adsorption destabilization ; III: restabilization ; IV : sweep coagulation. Optimum sweep zones, together with equilibrium concentration of monomeric and total soluble aluminum at the solubility limit, are also shown (Dentel, 1991).

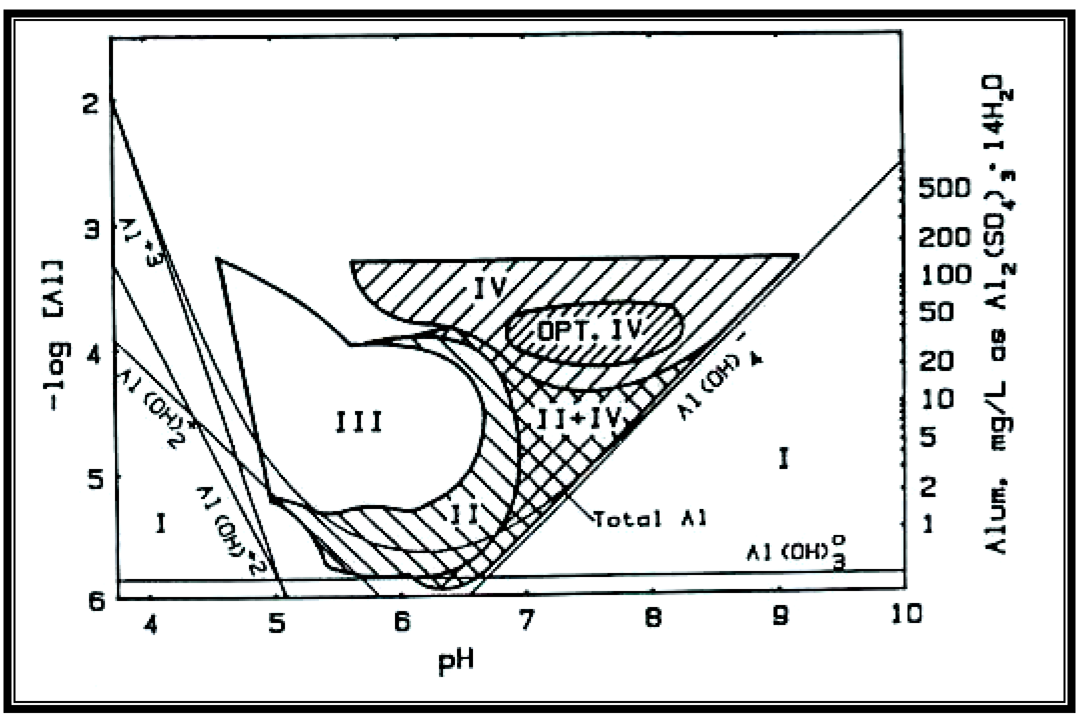


Figure (3-11): Design and operation diagram for alum coagulation, [After (Amirtharajah and Mills, 1982)].

Stumm and O'Melia demonstrated that, species such as [$Al(OH)^{2+}$]may themselves contribute to double – layer compression or adsorb onto particle surfaces, they also suggested that adsorption of the positively charged polynuclear species onto negatively charged particles leads to overall charge neutralization in " zone II " coagulation, while the physical enmeshment of particulates in a metal hydroxide precipitate (sweep floc)brings about " zone IV " coagulation (Stumm and O'Melia , 1968) .

Evidently, colloidal surface area and surface characteristics, surface chemistry, and temperature may significantly alter the form of stability diagram. Thus, even though a number of research studies have used this diagram in selecting coagulant doses for experiments, it is not an accurate means of selecting either the coagulant or dose to use for given raw water (Johnson and Amirtharajah, 1983).

Chapter Four 4

Materials and Experimental work

4-1: Materials

The following articles illustrate briefly the materials used in this study and their chemical analysis.

4-1-1: Local alum

Local alum produced in Al-Meshraq is used for this study. The chemical analysis of alum had done for the year 2001 by the laboratory of the General Corporation for Water and Sewage and the results are tabulated in Table (4-1) below.

Table (4-1): Chemical analysis of locally produced alum

Acidity %	Basicity %	Total soluble iron %	Total alumina %	Insoluble matter %	pH
NIL	0.08	0.024	14	14.45	3.08

4-1-2: Pure alum

Pure alum produced in Sweden by Kemira Kermit AB, Helsing Borg is used for this study too. The chemical analysis of this alum had done for the year 2001 by the laboratory of the General Corporation for Water and Sewage and the results are tabulated in Table (4-2) below.

Table (4-2): Chemical analysis of commercial produced alum

Acidity %	Basicity %	Total soluble iron %	Total alumina %	Insoluble matter %	pH
NIL	0.1	0.05	17.14	0.012	3.01

4-1-3 : Nutrient agar

In this study Nutrient agar produced in England by Unipath LTD, Basing Stoke, Hampshire is used as a nutrient medium for bacterial growth. Preparation of the culture media is done as follows (AWWA, 1985):

1- Added (28gm) of Nutrient agar to (1 litre) of distilled water.
2- Mixed the contents and dissolve by heating.
3- The solution is sterilized by autoclave at (121^0C) and (15 P.S.I.) for (15 min.).
4- The sterilized solution is cooled to ($43\text{-}45^0$C) and mixed well before pouring into the plates.

4-2 : Experimental work

The following sub-section gives a description of the techniques used in the study.

4-2-1: Solution preparation

Solutions are prepared daily and as needed, as follows:

4-2-1-1: Local and pure alum solutions

Alum is prepared by dissolving (10gm) of lump alum into (1 litre) of distilled water and stirred vigorously to produce a (1%) solution strength [each (1 ml) solution is equivalent to (10 mg) of alum].

4-2-1-2: Preparation of suspension

Two types of suspensions are prepared:

1-Kaolinite clay suspension

2-Bacteria suspension

4-2-1-2-1: The Kaolinite clay suspension

Tap water is used to produce synthetically turbid water. However, the quality of tap water varies from time to time due to the change in quality of raw water whereas it is necessary to conduct the study on the same level of pH, alkalinity, temperature, and suspended matter. Consequently, enough quantity of tap water is stored in two tanks of (20 and 1000 litre capacity). The Kaolinite clay, which passed through sieve No.200 and having a particle size distribution as shown in Figure (4-1) is added to the water in (20 litre) tank and mixed vigorously by the electrical mixer to produce turbid water, then the turbidity is measured by the turbidity meter. To obtain certain turbidity levels, the suspension in the (20 litre) tank is diluted by adding water from the second tank.

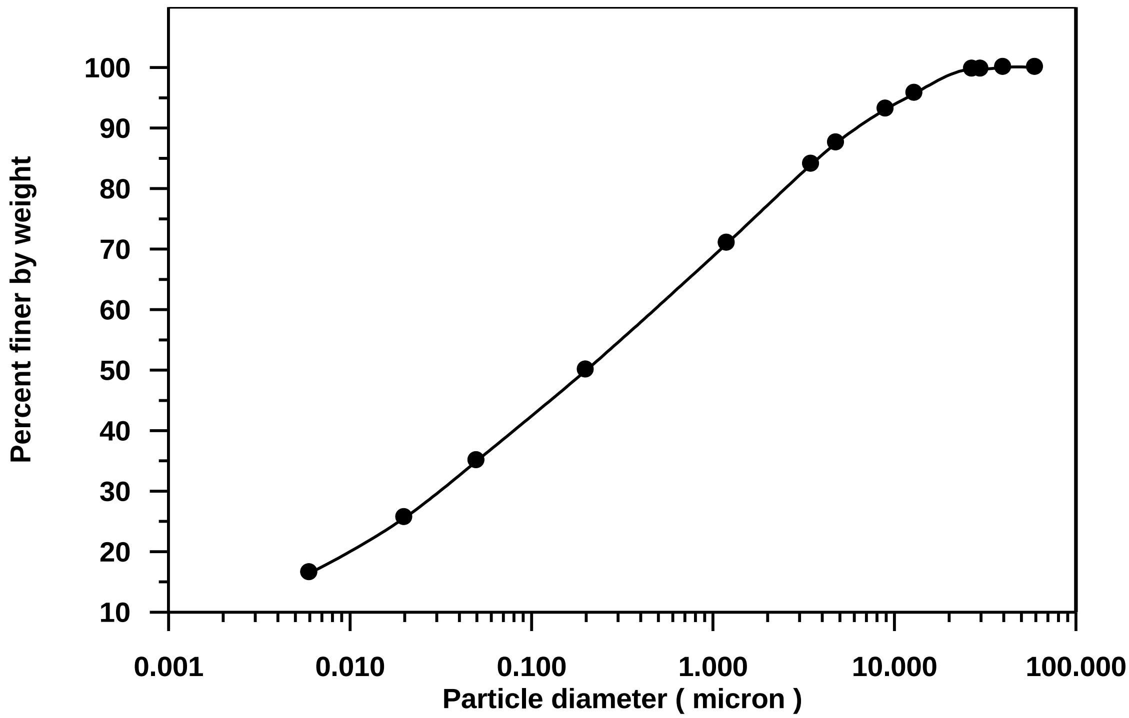


Figure (4-1): Particle size distribution of the Kaolinite clay

4-2-2-2: Preparation of the bacterial suspension

The bacteria used in the experimental work are the Escherichia coli (E. coli). This bacterium is chosen because it is (Steel and McGhee, 1979):

1-Normally inhabited in the intestinal tract of man and animals and is excreted with the feces, so it is considered non-pathogenic but may cause infections of the genitor-urinary tract. The E. coli, therefore, are useful as indicators to the pollution.

2-Easy and economical to culture and enumerate.

3- More resistant to unfavorable environmental conditions and water treatment methods than other pathogens (i.e. pathogens die out at least as rapidly as the E. coli).

The tank of (1000 litre) is filled with tap water had a turbidity of (5 NTU); the water is allowed to stand for at least (24 hours) to remove any residual chlorine.

To make sure that the water is cleared from any types of bacteria or viruses, it is decided to take the water from the tank and sterilized by autoclave at (121^0C) and (15 P.S.I.) for (15 min), then water is left to cool to (37^0C), then the suspension of E. coli is added to the sterilized water.

The suspension of E. coli is prepared by the following procedures (AWWA,1985):

1- Sterile a loop wire over flame and cool by stab into agar for several times.
2- Take a very small amount of bacteria by loop wire from bacterial culture.
3- Tube contains (10 ml) of (0.9%) normal saline, which is prepared by dissolving (9gm) of NaCl into (1 litre) of distilled water, may inoculate by touching with charged loop.
4- Mix the content of the tube by shaking.
5- To determine the number of bacteria, the optical density of liquid inoculation in tube is measured by Spectrometer, in which (0.1) meaning that the inoculated tube contains ($1 * 10^4$ cell/ml).

After the suspension of E.coli is added to sterilized water, the sample is incubated in incubator at (37^0C for 24 hours) to ensure bacterial growth and universal distribution in the water.

Before jar tests are run, the suspension of E.coli is mixed and then the optical density of the suspension is measured by the spectrometer

4-2-2: Jar testing

The conventional method for assessing coagulation is the jar test. This procedure has the advantages of simplicity and flexibility, and it simulates the three processes of coagulation, flocculation, and sedimentation.

After two types of synthetic suspension of water are prepared, a set of six (1-litre) beakers, are used for testing and determining the optimum dosages of alum. Alum is applied by a set of dosing tubes available with the jar tester, after that the jar tester is run at (100 rpm) for (1 minute) as a rapid mixing, then the speed is reduced to (40 rpm) for (30 minutes) to obtain a flocculation process. Then the beakers are removed from under the stirring mechanism and the contents have been allowed to settle for (30 min), after which samples of the settled water are withdrawn from (3 cm) below the surface of water at the beakers. The above procedure is repeated three times, and the averages of the recorded measurements have been adobted.

Jar test procedures are utilized in order to determine the effect of adding different types of alum on residual turbidity and bacterial removal.

4-2-3: Determining the bacterial density of water

The standard plate count, as described by AWWA is adopted for determining the bacterial density of water. The following steps can be summarized the method (AWWA, 1985):

1- The sample is diluted by adding (1ml) from the sample of water to (9 ml) of (0.9%) normal saline and shaken vigorously (25 times).

2- The required sample, which is (1ml), withdrawn with a standard sterile pipette and incubating sterile Petri dish.
3- Pouring (15-20 ml) from liquefied Nutrient agar medium at a temperature of (43 - 45^{0}C). The cover of the dish should be lifted just enough for the introduction of the pipette or the culture medium.
4- The agar and the sample is mixed and uniformly spread over the bottom of the dish by tilting and rotating the dish, then allowed it to solidify.
5- The plate is incubated in incubator at (37^{0}C for 24 hours). In this method, bacterial growth occurred both on surface and in the depth of the incubated medium.
6- After incubation, the number of colonies which develop per millilitre is counted, which represent the actual number of individual cells.

For each sample, two plates are made and the average of two plates represented the result.

4-2-4: Experimental studies

In order to action the goal of this study, the experiments works are divided into four main studies.

4-2-4-1: Study No. 1 (Washed alum)

Because the locally produced alum contains high percentage of impurities; therefore, the aim of this study is to get rid of impurities and the suspended particles in the surface of alum, which pool in increasing the percentage of insoluble matter and this may lead to reduce the efficiency of alum.

In this study particular weight of the locally produced alum (unpacked and un granular) is put in screening, then the alum is washed by spariger water for (10 seconds) and then left to dry at room temperature in order to get rid of moisture found in the sample.

After drying, (10 gm) of lump alum dissolving into 1 litre of distilled water and stirred vigorously to produce (1%) solution strength.

4-2-4-2: Study No. 2 (Settled alum)

The chemical analysis of locally produced alum, indicated that the percentage of impurity was (14.45%). So the aim of this study is to get rid of the impurities and suspended particles in alum by settling it before adding alum solution to raw water.

To determine the optimum time for settling impurities, (10%) of alum solution strength is prepared and left to settle, then the solution of alum withdrawn from the middle of the settling column at equal periods. 20 mg/l from withdrawn alum solution is used in removing turbidity from synthetic water has a turbidity of 100 NTU. Residual turbidity is measured, and the relationship between settling time and residual turbidity is drawn as shown in Figure (4-2).

Figure (4-2) indicates that the best time for settling is (15 minutes). For this reason, after the preparation of the alum solution, it is left to settle for 15 minutes then alum solution is withdrawn and diluted with distilled water to (1%) of alum solution strength before using it in the experiments.

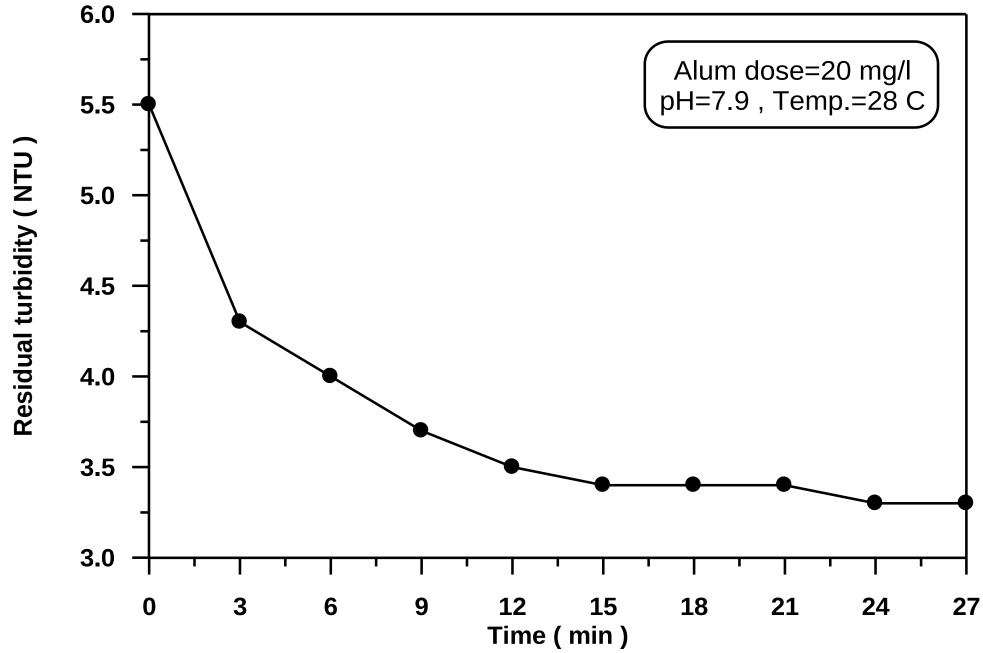


Figure (4-2): Optimum time for settling the impurities from local alum

4-2-4-3: Study No. 3 (Shaken alum)

The specific gravity of the impurities is in the range (2.61- 2.8), while the specific gravity of the alum is (1.33); therefore, when a mixture of impurities and alum are shaken, the impurities will settle in the bottom and alum will remain on the upper part.

In this study, two standard sieves [sieve No.40 (0.42 mm) and sieve No.80 (0.18 mm)] are put one above the other and the sieve with the larger openings must be on the top. Then particular weight of the crushed alum is put in the sieve No.40, and then the sieves are shaken in the electrical shaker for (15 minutes). The alum passing from sieve No.40 and remained on the sieve No.80 is taken. The above procedure is done to control, as possible, on the diameter of the particles and consequently on their weights.

The alum is put in a container with conical section and shaken by electrical shaker for 15 minutes; about 80% of the alum, from the upper part is used in the experiments.

4-2-3-4: Study No.4 (Heat-treated alum)

This study is aim to get rid of the impurities that are capable of burning such as organic materials, the excessive moisture that causes error in the weight of alum during preparation, and to get rid of the suspended particles that aggregated by heating and consequently increasing in weight and that leads to their settling without consuming the alum.

In this study, particular weight of alum is taken and crushed slightly, and then the sample is put in an electrical oven at (100^0C) for one hour. After that the alum is used in the experiments.

4-3: Apparatus

The apparatus that were used are illustrated in the following paragraphs with their corresponding names and properties: -

1- Digital balances

Two balances are used for weighting the materials used in the experimental work. The first is a digital balance with digital indicator type (Metter AC 100) with accuracy of ($1*10^{-4}$) grams. The second is an electronic balance (TARE " SARTORIUS " type 1507) with a capacity of (12 Kg) and sensitivity of (∓ 0.1 gm).

2- Magnetic stirrer

An IKAMAGRET (Oberflachen Temp. Heizplatte) magnetic stirrer, with rotating capacity up to (1200 rpm), is used for solutions preparation.

3- Electrical stirrer

HIEDOLPH manufactured by LABs CO. (Germany) of a (280-2200 rpm) rotating capacity, is used for mixing synthetic water in a tank.

4- Turbidimeter

A turbidity meter type (HACH A2001–LAB, Turbidimeter), with measurement units NTU, is employed for measuring the turbidity of water.

5- Jar tester

A Zeitschaltuhr sedimentation jar tester of a (35-210 rpm) rotating capacity is used to simulate the coagulation steps of raw water.

6- pH Meter

A pH meter type PHILIPS (PW9420) (manufactured in U.K.) is utilized for the hydrogen ions concentration measurements.

7- Oven

The Memmert oven type U50 (manufactured in Germany), is used to heat alum and for sterilization.

8- Incubator

The Heraeus D-6450 Hanau type B 6060 is used to incubate the plates.

9- Autoclave

A Karl Kol B autoclave type D-6072 (manufactured in Germany), is used for sterilization.

Chapter Five 5

Results and Discussion

5-1: Introduction

Laboratory results obtained by using jar test are analyzed and discussed in the following sections. Results obtained by using locally produced alum and pure alum are used in evaluating the performance of improved locally produced- alum as a primary coagulant.

5-2: Characteristics of Euphrates water

5-2-1: Turbidity

During several months in a year, the Euphrates River is low in turbidity, especially during the seasons of summer and autumn. The turbidity of the Euphrates River usually increases during winter due to high flow rates and as a result of rains and melting of snow at the sources of the river.

During the past ten years (1991-2000), the turbidity of the Euphrates River seems to be low. Figure (5-1) shows the monthly variation of the turbidity during the past ten years (1991-2000). It can be seen from the figure that the maximum value of turbidity during the past ten years was observed in November (1997), which was (100NTU); the minimum value of turbidity was in February (2000), which was (9NTU).

The aforementioned range of values of turbidity has been considered as the base for the experimental work. Consequently, the laboratory works conducted on the synthetic turbidity were in the range (10 - 100 NTU).

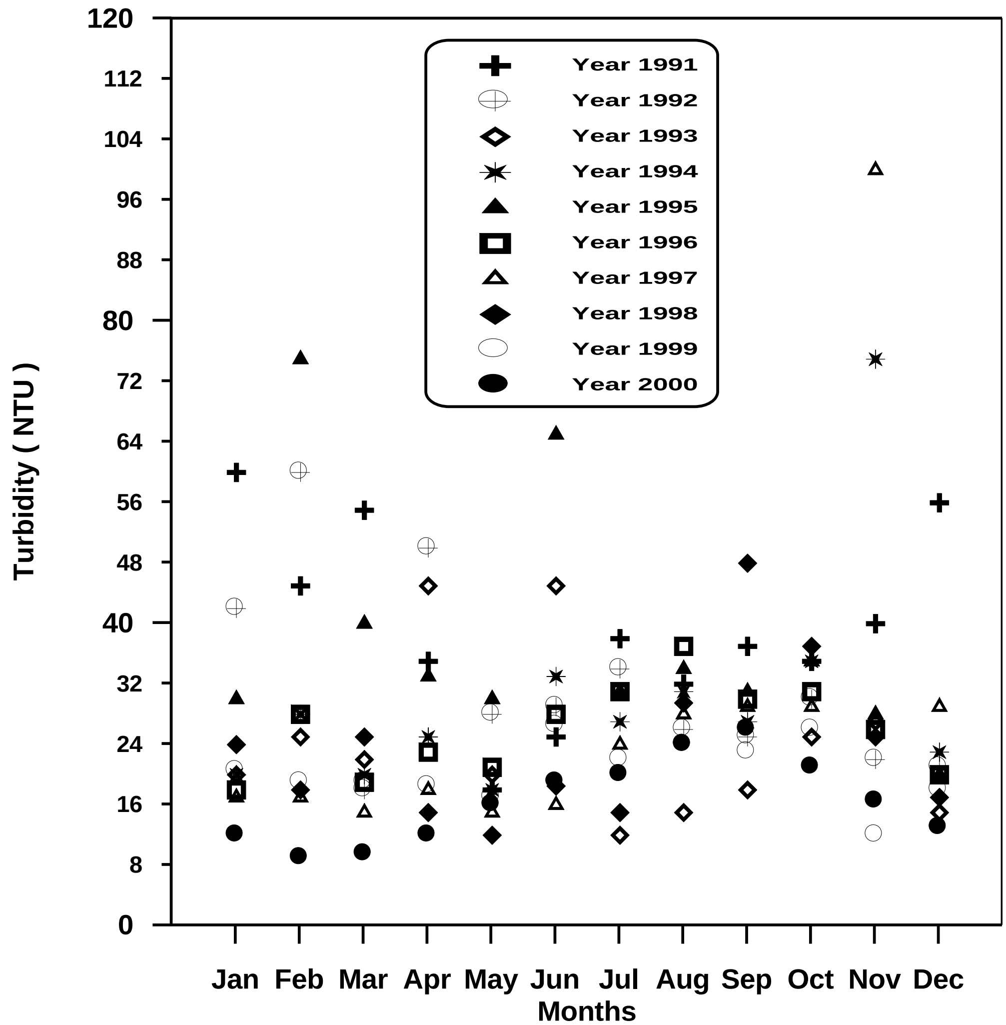


Figure (5-1): Variation of turbidity in Euphrates River during (1991-2000),[Based on data from (D.B.W.W.,2001)].

5-2-2: Alkalinity

Figure (5-2) shows the monthly variation of alkalinity in Euphrates River during the period (1991) through (2000). It can be seen from the figure (5-2) that alkalinity as ($CaCo_3$) was in the range (68-228 mg/l); the alkalinity increases during winter season as the flow rates are increased, and decreased during summer. Also it can be seen that the alkalinity of Euphrates water is high. So the adding of an alkaline material to Euphrates water is not need for enhancing the performance of alum coagulation.

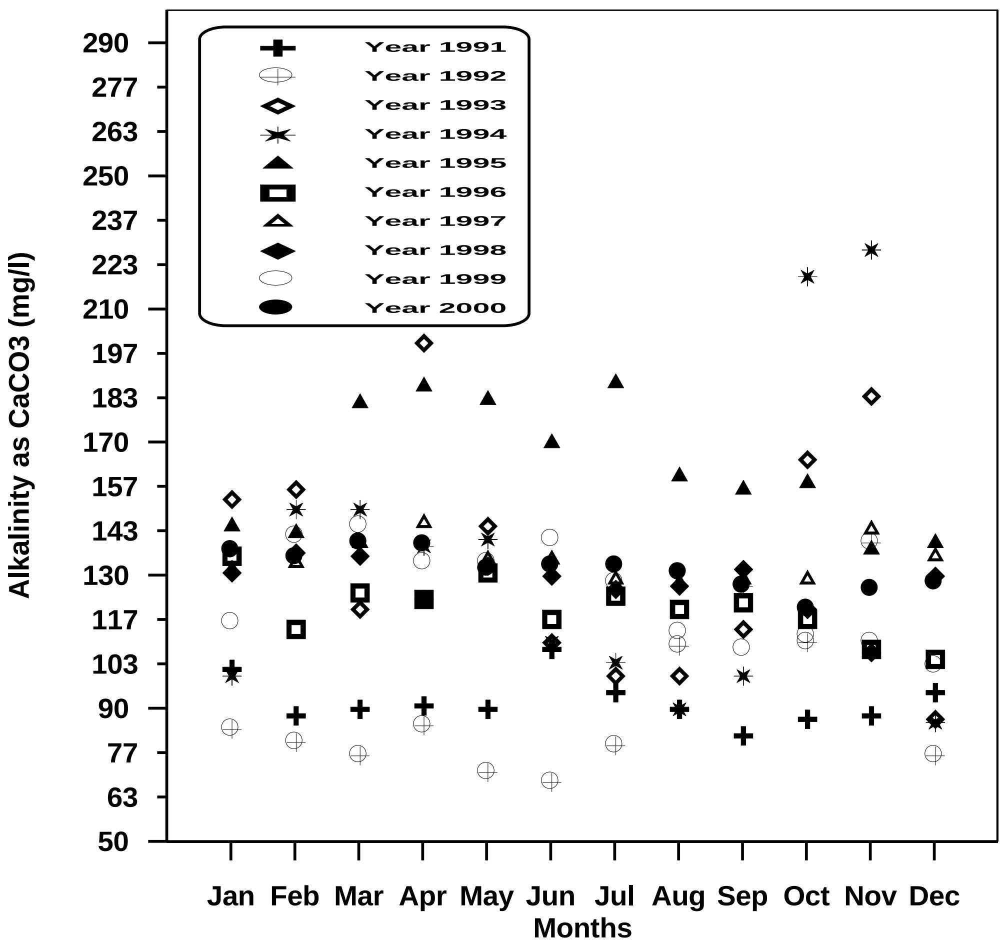


Figure (5-2): Variation of the alkalinity in Euphrates River during (1991-2000),[Based on data from (D.B.W.W.,2001)].

5-2-3: pH(Hydrogen ion concentration)

Figure (5-3) shows the monthly variation of Hydrogen ion concentration (pH) in the Euphrates River during the years (1991) through (2000). It can be seen that the maximum value of pH during the past ten years was observed in January (1992), which was (9.11), whereas the minimum value was in May (1996), which was (6.8).

From figure (5-3) it can be seen that the pH of Euphrates River is in the approximate pH range of alum coagulation. Consequently, the pH of Euphrates River is sufficient for alum coagulation without pH-adjustment.

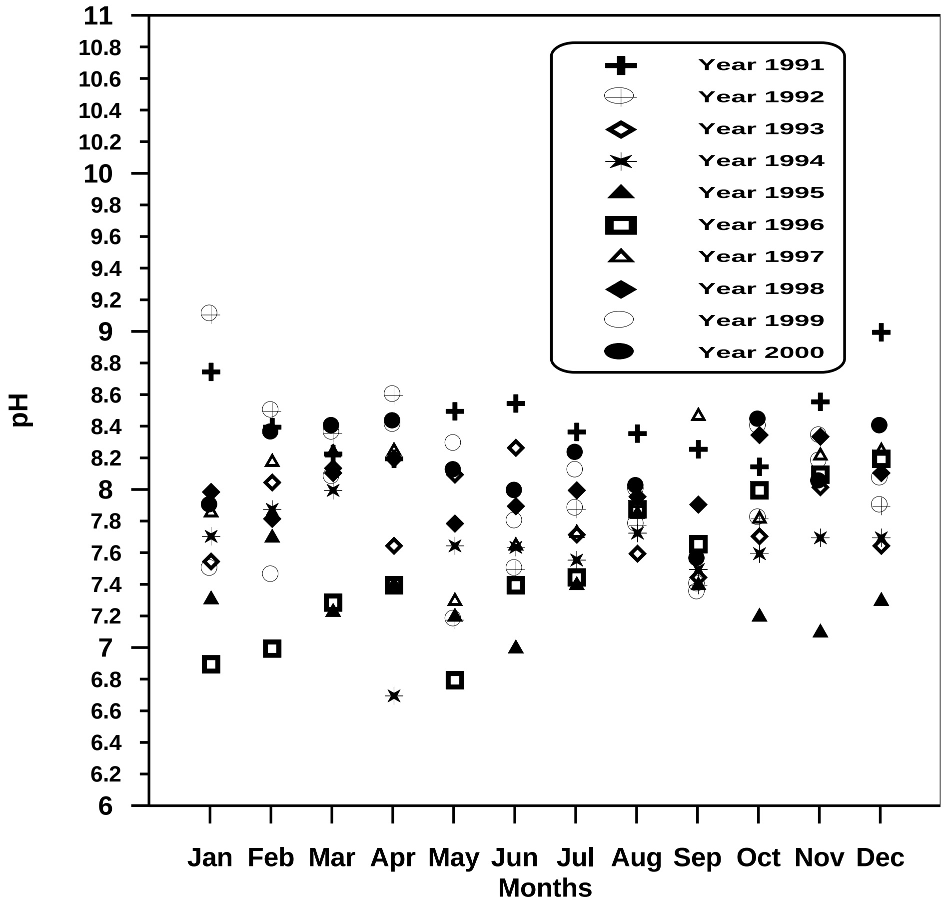


Figure (5-3): Variation of the pH in Euphrates River during (1991-2000),[Based on data from (D.B.W.W.,2001)].

5-2-4: Bacterial pollution

Natural water contains bacteria as part of the biotic components of the environmental system. When there is a source of organic pollution such as sewage water, the bacteria will increase in number and differ in types.

The daily domestic water consumption in Iraq amounts to about (7.8 million cubic meter). Of this quantity, about (5.8 million cubic meter) is returned as polluted water, which is discharged to surface water bodies, particularly the rivers. Thus, bacterial pollution in Iraqi surface water mainly results from untreated sewage water. A study of Euphrates water showed that the maximum densities recorded for total coliform (Tc) and fecal coliform (Fc) were ($0.24*10^6$ cell/100ml) and ($0.24*10^6$ cell/100ml) during the year (1998), ($24*10^6$ cell/100ml) and ($2.4*10^6$ cell/100ml) during the year (1999) respectively, (Sabri el al., 2001).

Figures (5-4) and (5-5) show the bacterial density along the Euphrates River starting from Quaim to south Nasiriyia during March, April, May, July, and October 2000. It can be seen from the figures that the maximum densities for Tc and Fc were ($240*10^6$ cell/100ml) and ($15*10^6$ cell/100ml), respectively. According to these densities, it is clear that the Euphrates recorded during the year 2000, the maximum averages compared with the other years. This is because that the numbers recorded before that in Euphrates River were when there were treatment plants for waste water or because of the increasing of the discharges in that years, and it is known that the increasing of the discharges in the river will increase the dilution of waste water and this lead to decreases bacterial pollution.

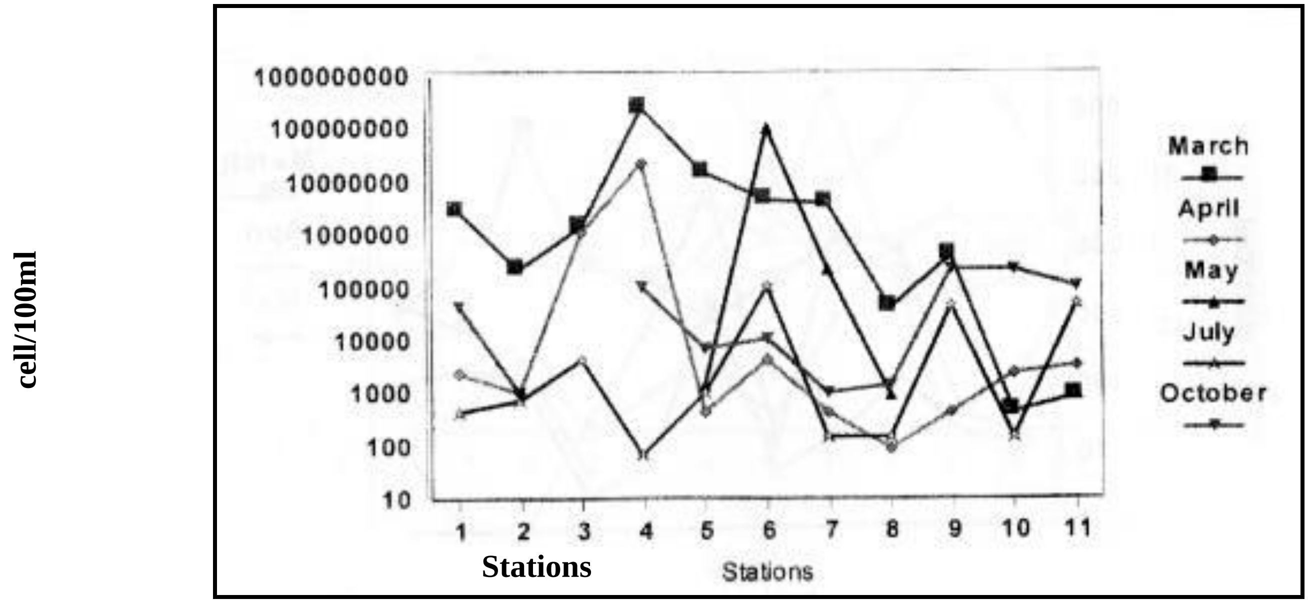


Figure (5-4): Densities of total coliform along the Euphrates River during the year 2000,where:1- Quaim 2-Rawa 3- Haditha 4-Heet 5- Ramady 6- Faluga 7- Mussayab 8- Hilla 9- Diwaniya 10- Symawa 11- Nasiriyia, [After (Sabri et al., 2001)].

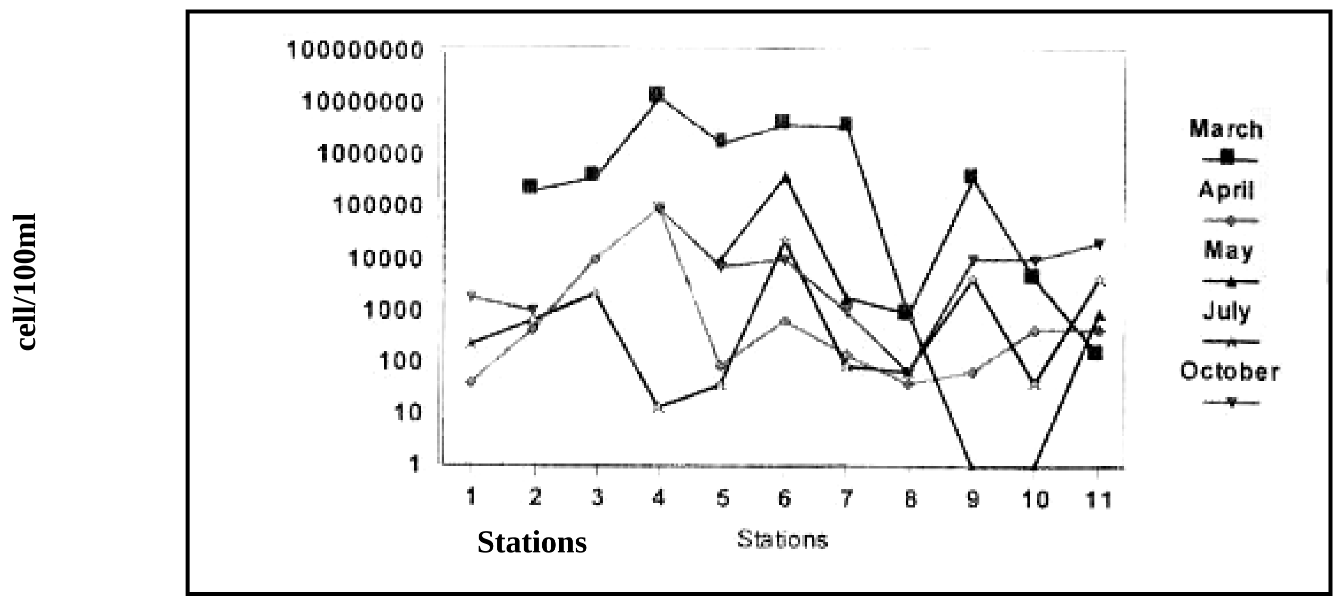


Figure (5-5): Densities of fecal coliform along the Euphrates River during the year 2000, [After (Sabri et al., 2001)].

5-3: Analysis of alum

The locally produced alum, pure alum, washed alum, shaken alum, and heated alum are analyzed for determining the percentages of their constituents. The analyses are conducted in the laboratory of the General Corporation for Water and Sewage. The results of the analysis are illustrated hereinafter.

5-3-1: Locally produced alum

As it has been shown previously in Table (4-1), the percentage of impurities in locally produced alum is (14.45%). This percentage of impurities is greater than the upper limit of the unpurified lumps of alum, which is (10%).

The results also showed that the percentage of alumina (Al_2O_3) is (14%), whereas the minimum limit of percentage of alumina is (17%). The percentages of impurities and alumina represented the main reason to lower the effectiveness of locally produced alum. Another chemical analysis of Iraqi alum, which includes acidity, basicity, total soluble iron, and pH, are found to be within the limit of AWWA standard.

5-3-2: Pure alum

The results of analysis of pure alum in Table (4-2) pointed out that all alum contents of pure alum are within the limits of AWWA standard. It can be seen from Table (4-2) that the percentage of the insoluble matter is

(0.012%) which is too small, beside the good percentage of alumina, which is (17.14%).

5-3-3: Washed alum

Table (5-1) shows the chemical analysis of locally produced alum after washing. The results show that the locally produced alum is improved after washing, whereas the percentage of insoluble impurities became (7.52%), which is less than the upper limit of the unpurified lumps of alum. This means that there is a decreasing in the insoluble matter of about (50%). This could be attributed to that the insoluble matter on the surface of locally produced alum formed an appreciable percentage of the total insoluble matter and that might lead to decreasing the efficiency of the locally produced alum; therefore, the way equipment, transportation, and storage of the locally produced alum is very important in maintaining it from the outside conditions.

The results of chemical analysis of washed alum also showed that the percentage of alumina is improved and became (16.86%), which is approximately within the limits of AWWA standard.

Table (5-1): Chemical analysis of washed alum

Acidity %	Basicity %	Total soluble iron %	Total alumina %	Insoluble matter %	pH
NIL	0.12	0.028	16.86	7.52	3.01

5-3-4: Shaken alum

Table (5-2) shows the chemical analysis of locally produced alum after shaking. It can be seen from the table that the percentage of insoluble matter is (5.47%), which is less than the upper limit of the unpurified lump of alum, and the percentage of alumina content is (17.66), which is greater than the minimum limit of (17%). From the above it can be concluded that the shaken alum is within the limit of AWWA standard.

Table (5-2): Chemical analysis of shaken alum

Acidity %	Basicity %	Total soluble iron %	Total alumina %	Insoluble matter %	pH
NIL	0.15	0.032	17.42	5.47	3.02

5-3-5: Heat-treated alum

Table (5-3) shows the chemical analysis of locally alum after heating. The results of heat-treated alum pointed out that the percentage of insoluble matter became (12%) after it was (14.45%). This means that there is a decrease in the percentage of insoluble matter of about (17%), which means that part of the insoluble matter found in alum had the ability to burn, leading to a decrease of the percentage of insoluble matter. However, the percentage of impurities is still greater than the upper limits of the unpurified lumps of alum, which is (10%). Nevertheless, the insoluble matter found in the heated alum is accumulating impurities, which settle very fast due to its weight and without consuming the alum.

The results also showed that the percentage of alumina is improved and became (18.3%), which is greater than the minimum limit of AWWA standard and greater than that in pure alum.

Table (5-3): Chemical analysis of heated alum

Acidity %	Basicity %	Total soluble iron %	Total alumina %	Insoluble matter %	pH
NIL	0.18	0.038	18.3	12	3.05

5-4: Comparison between the performance of locally produced and commercially produced alum

The performances of locally produced and commercially produced alum in turbidity and bacterial removal are illustrated in the following paragraphs.

5-4-1: Residual turbidity

Figures (5-6) through (5-10) show the residual turbidity after adding different alum doses of local and pure alum to the synthetic turbidity of 10, 25, 50, 75, and 100 NTU, respectively. The figures show that with the continuous increase of the dosage of each of the local alum or pure alum, the residual turbidity is reduced to a minimum level after which it started to increase. This phenomenon is due to the fact that negative charges on colloids are neutralized by the positive ions created by the hydrolysis of alum, i.e., stabilization of the contents of the liquid. Best stabilization occurs when the negative and positive charges are equal; a further increase in positive ions due to higher dosage of alum will cause charge reversal on colloidal particles. At higher alum dosages, the turbidity is significantly reduced by formation of aluminum hydroxide precipitates that increases the particle collision rate and, at higher alum doses, large precipitates enmesh the smaller particles and remove them from suspension by settling.

It can be seen from figures (5-6) through (5-10) that the percentage of turbidity removal increases with the increase of the initial turbidity for both local and pure alum; the maximum percentage removal is achieved at initial turbidity of (100 NTU). The figures also indicate that the optimum doses of alum for all synthetic turbidities are the same for both local and pure alum, but the residual turbidities after using pure alum are always less than the residual turbidities after using local alum. These results were expected because that the pure alum contains higher concentration of alumina than local alum; besides, the percentage of impurities in pure alum is very low compared with that of local alum.

Table (5-4) summarizes the optimum doses for local and pure alum for minimum residual turbidities produced.

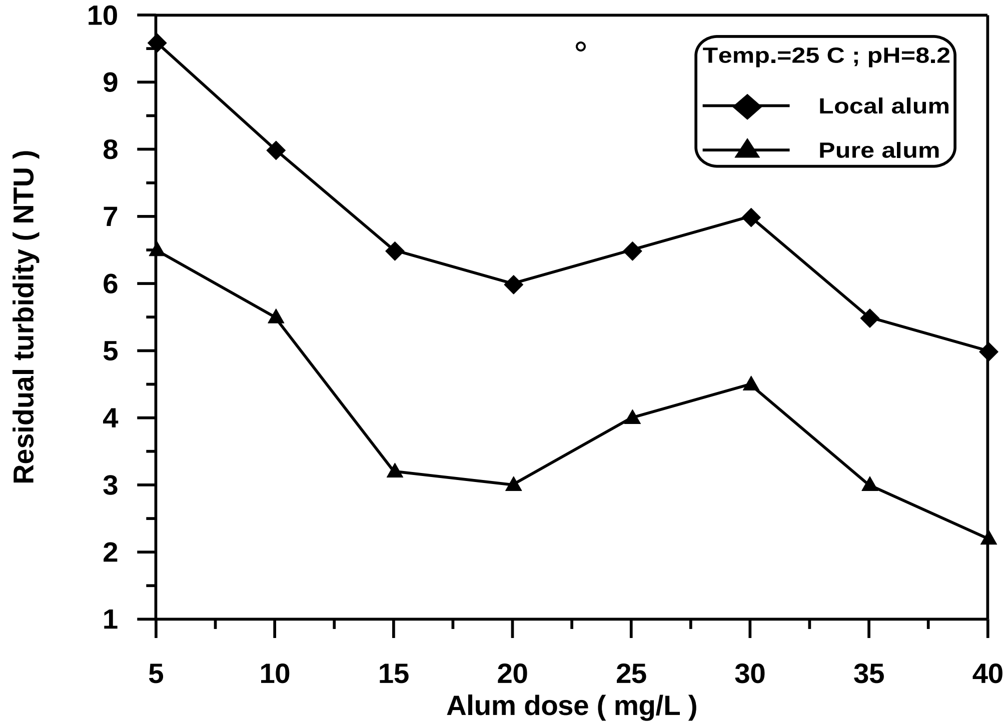


Figure (5-6): Residual turbidity after coagulation with local and pure alum for water turbidity of 10 NTU

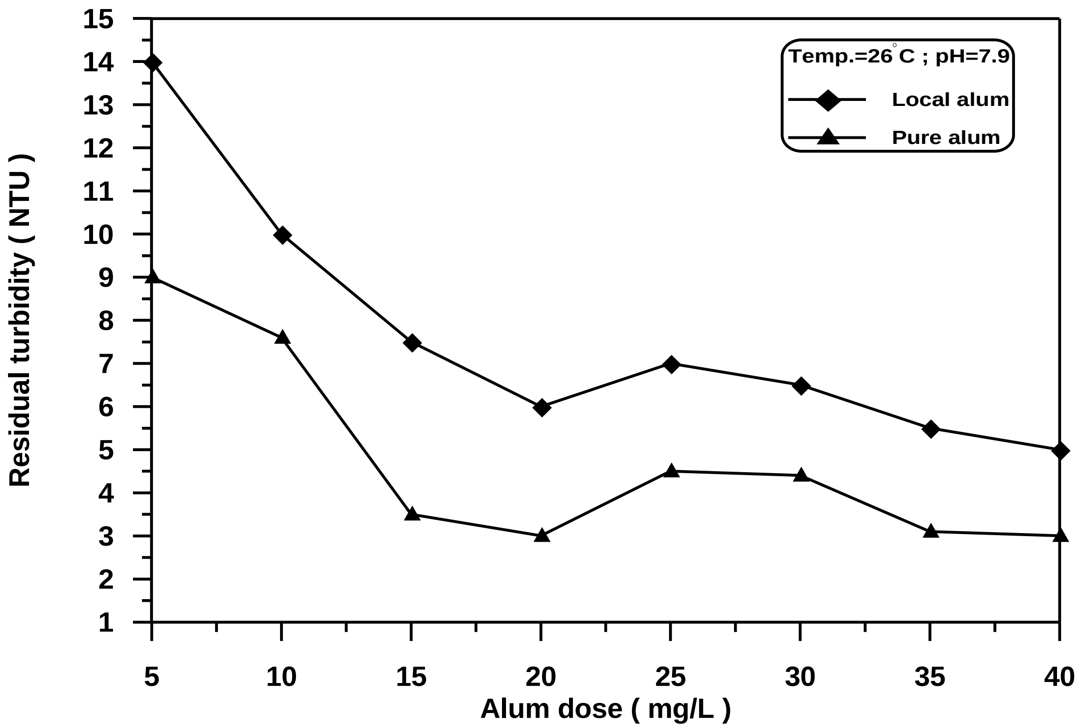


Figure (5-7): Residual turbidity after coagulation with local and pure alum for water turbidity of 25 NTU

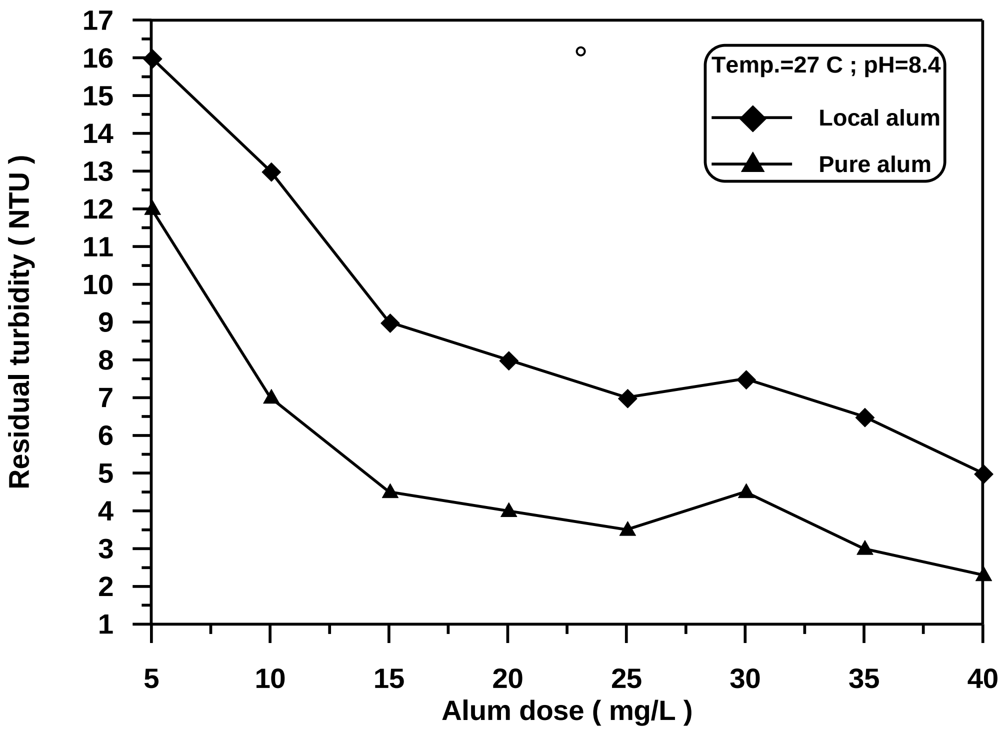


Figure (5-8) Residual turbidity after coagulation with local and pure alum for water turbidity of 50 NTU

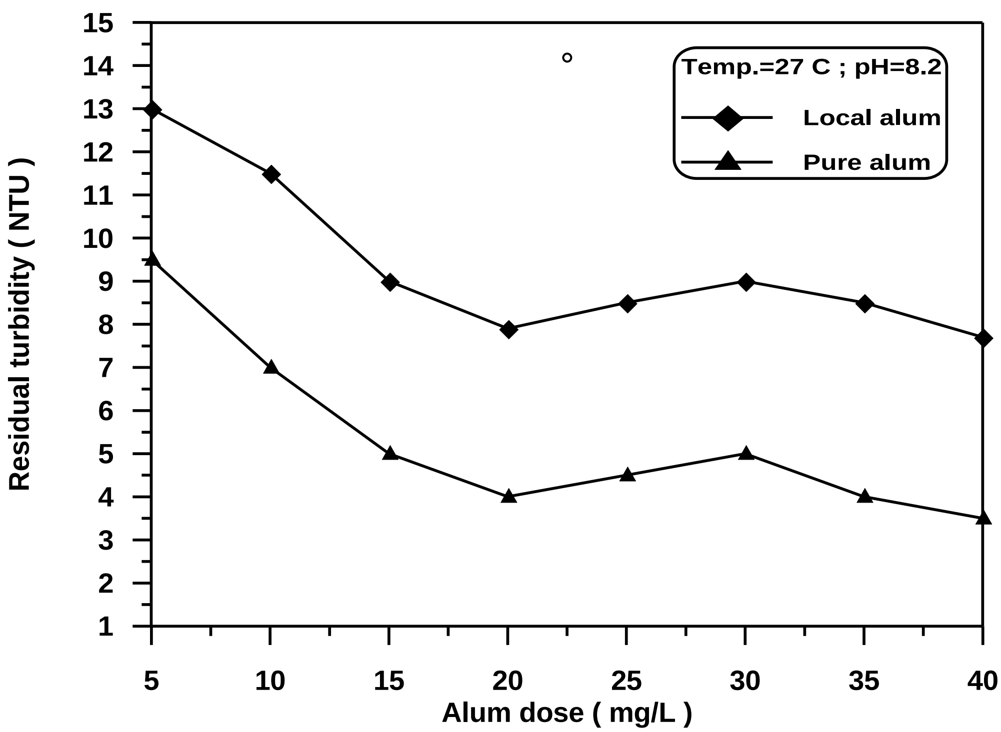


Figure (5-9): Residual turbidity after coagulation with local and pure alum for water turbidity of 75 NTU

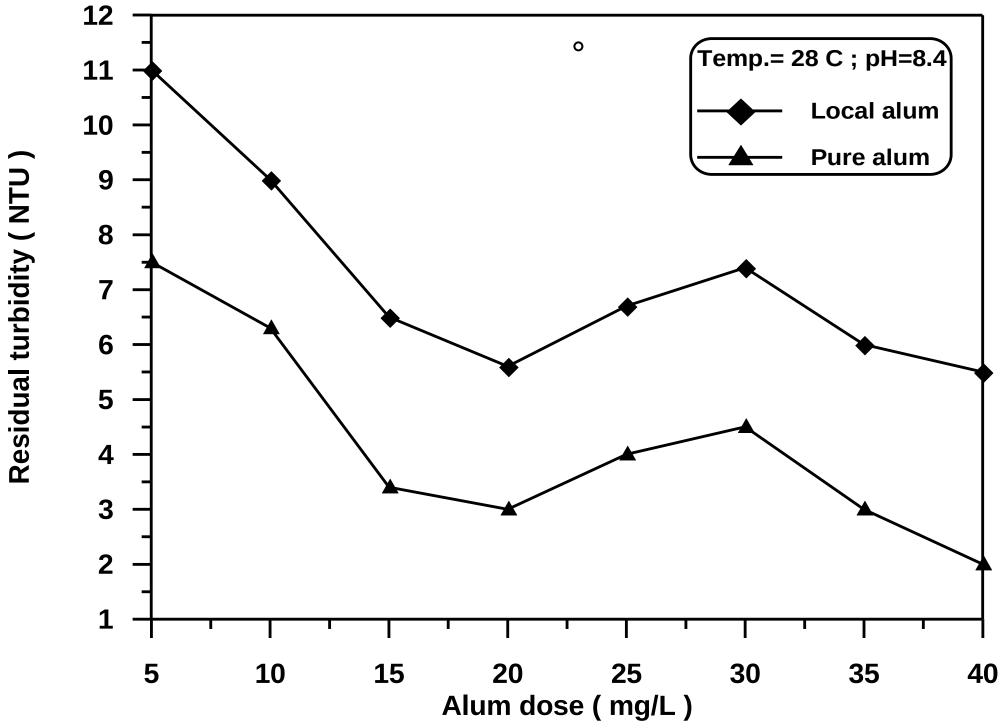


Figure (5-10): Residual turbidity after coagulation with local and pure alum for water turbidity of 100 NTU

Table (5-4): Optimum doses of local and pure alum

Turbidity (NTU)	Optimum alum dose (mg/l)	Residual turbidity after using pure alum (NTU)	Residual turbidity after using local alum (NTU)
10	20	3	6
25	20	3	6
50	25	3.5	7
75	20	4	7.9
100	20	3	5.6

5-4-2: Residual bacteria

Figure (5-11) shows the effect of coagulation with pure and local alum on the percentage of residual bacteria. It can be seen from the figure that the coagulation process with pure alum as a sole coagulant is capable of achieving significant bacterial removal from the tested water; a minimum percentage of residual bacteria of (0.5%) has been achieved at alum dose of (40 mg/l). While the coagulation with local alum produced somewhat higher percentage of residual bacteria compared with pure alum; a minimum percentage of residual bacteria of (18.2%) has been achieved at the same pure alum dose, which is (40mg/l). The figure also shows that the percentage of residual bacteria is decreased with the increasing of the alum dose, but an alum dose is higher than that normally used for turbidity removal is which needed to obtain the best residual bacteria.

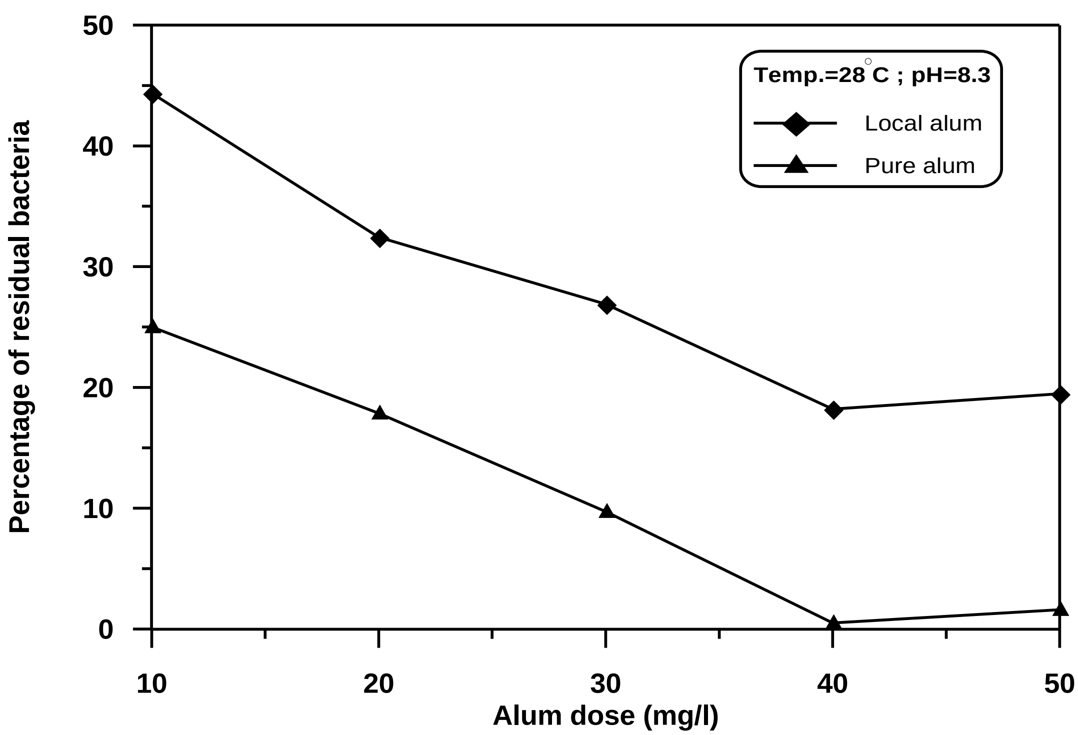


Figure (5-11): Effect of coagulation with local and pure alum on the percentage of residual bacteria

5-5: The performance of washed alum

5-5-1: The effect of washed alum on residual turbidity

The effects of washing alum on the residual turbidities of water with 10, 25, 50, 75, and 100NTU synthetic turbidities are given in Figures (5-12) through (5-16), respectively.

Figures (5-12) through (5-14) show that the optimum doses of washed alum are 20,20, and 25 mg/l for initial turbidities 10, 25, and 50 NTU, respectively. The figures point out that residual turbidities obtained by using washed alum as a sole coagulation are better than those obtained by using locally produced alum. Moreover, the results are close to those obtained by using pure alum, because the initial turbidities (10, 25, and 50 NTU) are considered low turbidity levels and washed alum contains a good percentage of alumina which is (16.86%); besides, washed alum contains (7.52%) as insoluble matter which helps in the coagulation processes by increasing the mass of solids and provides nuclei for the flocs to form larger flocs later (i.e., the insoluble matter in washed alum worked as weighting agents).

Figures (5-15) and (5-16) show the relation between the washed alum dose and residual turbidities for initial turbidities of 75 and 100 NTU, respectively. The optimum doses of alum are 20 mg/l for minimum residual turbidities of 5 and 3.7 NTU; these residual turbidities are somewhat higher than the results obtained by using pure alum.

Table (5-5) summarizes the optimum doses for the washed alum for minimum residual turbidities for the considered initial turbidities.

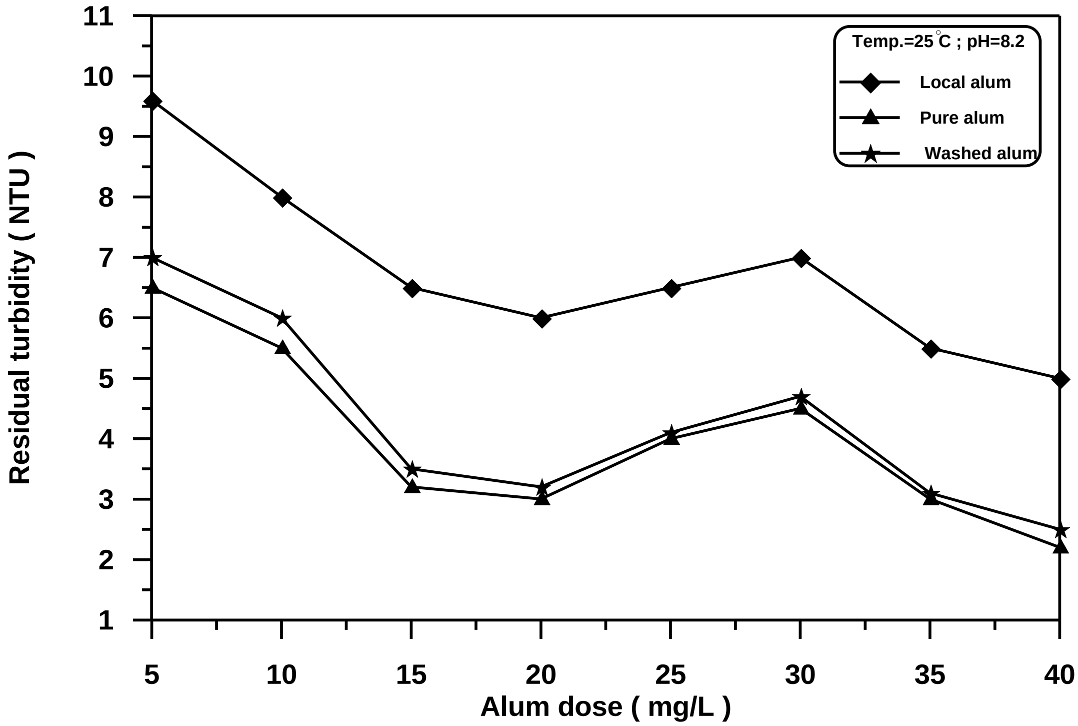


Figure (5-12): Residual turbidity after coagulation with washed alum, local alum, and pure alum for water turbidity of 10 NTU

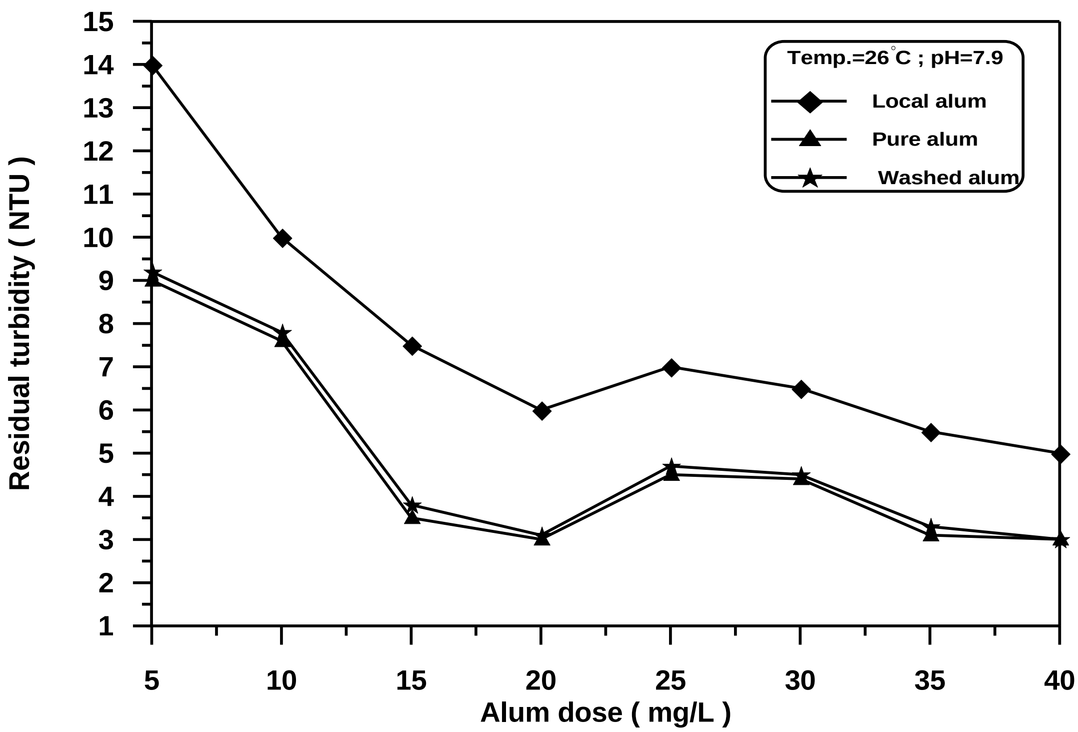


Figure (5-13): Residual turbidity after coagulation with washed alum, local alum, and pure alum for water turbidity of 25 NTU

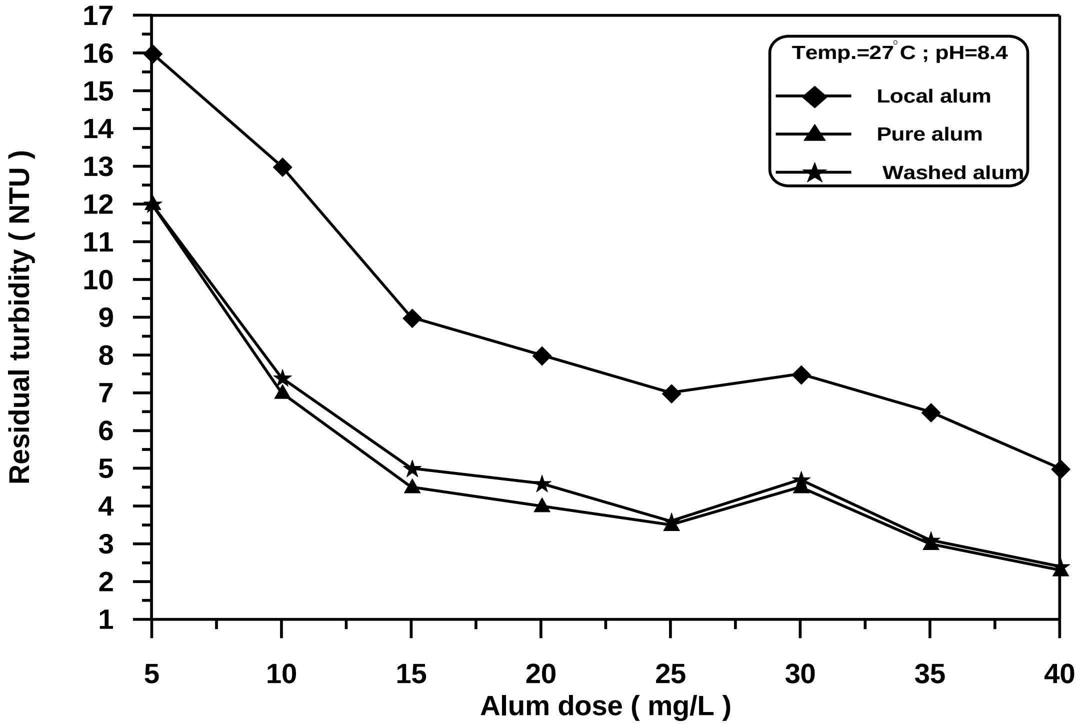


Figure (5-14): Residual turbidity after coagulation with washed alum, local alum, and pure alum for water turbidity of 50 NTU

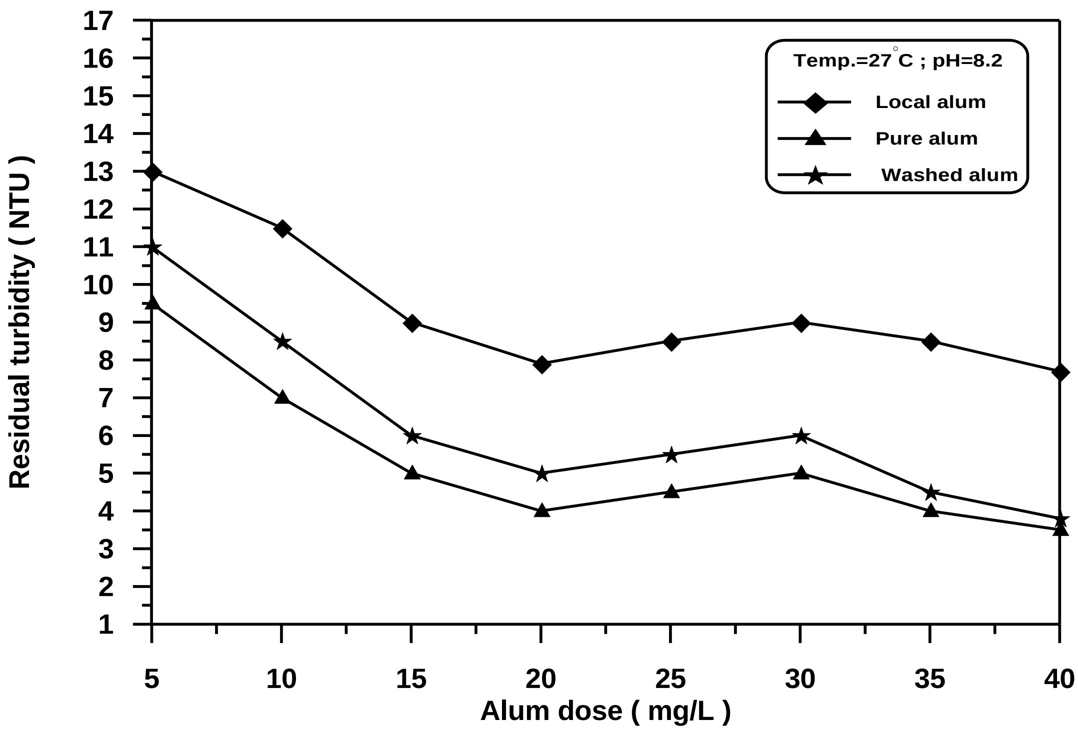


Figure (5-15): Residual turbidity after coagulation with washed alum, local alum, and pure alum for water turbidity of 75 NTU

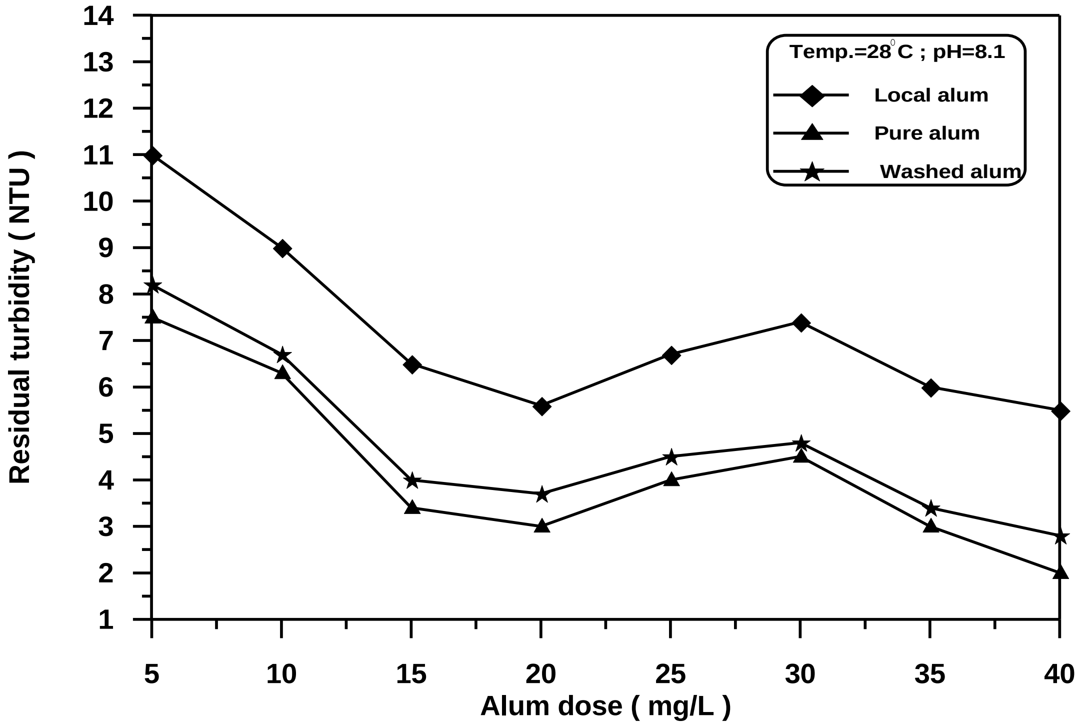


Figure (5-16): Residual turbidity after coagulation with washed alum, local alum, and pure alum for water turbidity of 100 NTU

Table (5-5): Optimum doses of washed alum

Turbidity (NTU)	Optimum alum dose (mg/l)	Residual turbidity (NTU)
10	20	3.2
25	20	3.1
50	25	3.6
75	20	5
100	20	3.7

5-5-2:The effect of washed alum on residual bacteria

Figure (5-17) shows the effect of the washing of alum on the percentage of residual bacteria. The optimum alum dose that gives minimum percentage of residual bacteria, that is (0.71%) was (40mg/l). It can be seen that the result obtained by using the washed alum is better than the result from local alum, whereas it is very close to that obtained from using pure alum.

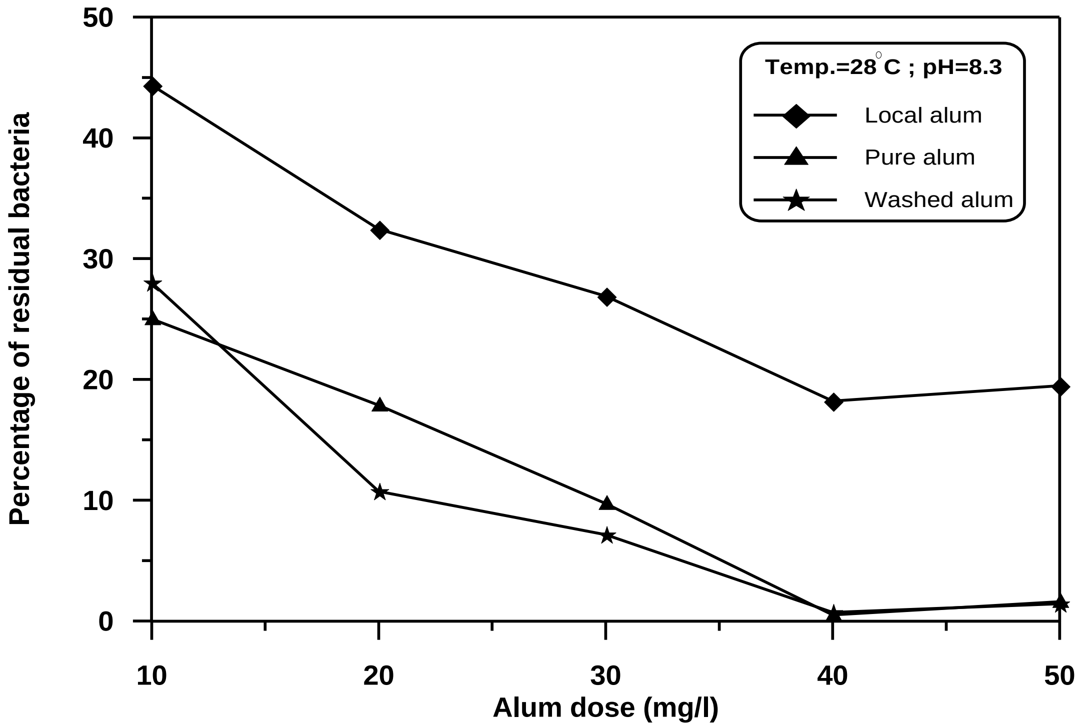


Figure (5-17): Effect of coagulation with washed alum, local alum, and pure alum on the percentage of residual bacteria

5-6: The performance of settled alum

5-6-1: The effect of settled alum on residual turbidity

Figures (5-18) through (5-22) show the results of experiments work, which conducted by using settled alum to clarify synthetic turbidities. It can be seen from figures that the efficiency of settled alum for turbidities removal are similar to the washed alum but with less efficiency, this may be because that the insoluble matter in alum consumed part of the alum during the settling process.

Table (5-6) summarizes the optimum doses of settled alum for minimum residual turbidities for the considered initial turbidities.

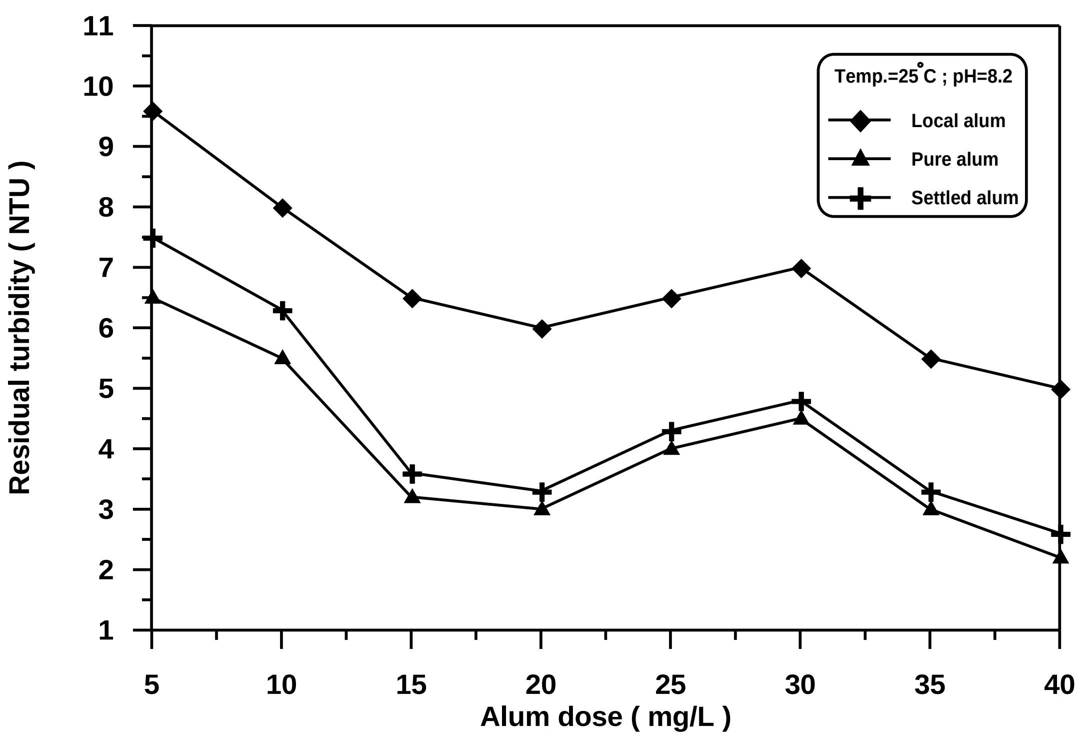


Figure (5-18): Residual turbidity after coagulation with settled alum, local alum, and pure alum for water turbidity of 10 NTU

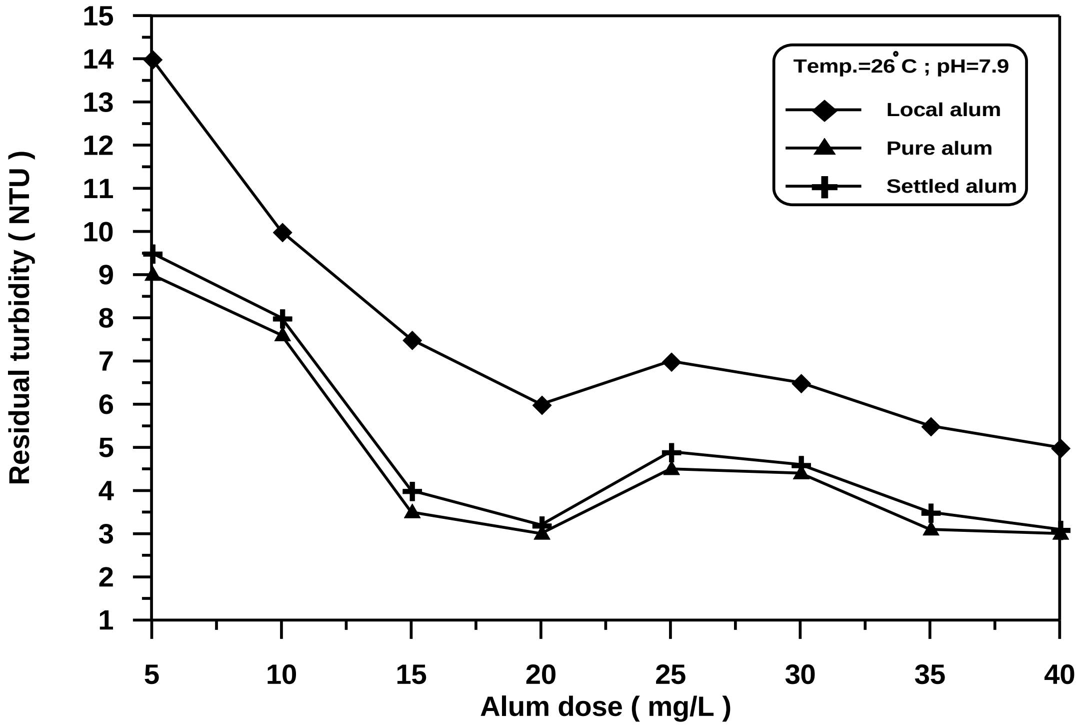


Figure (5-19): Residual turbidity after coagulation with settled alum, local alum, and pure alum for water turbidity of 25 NTU

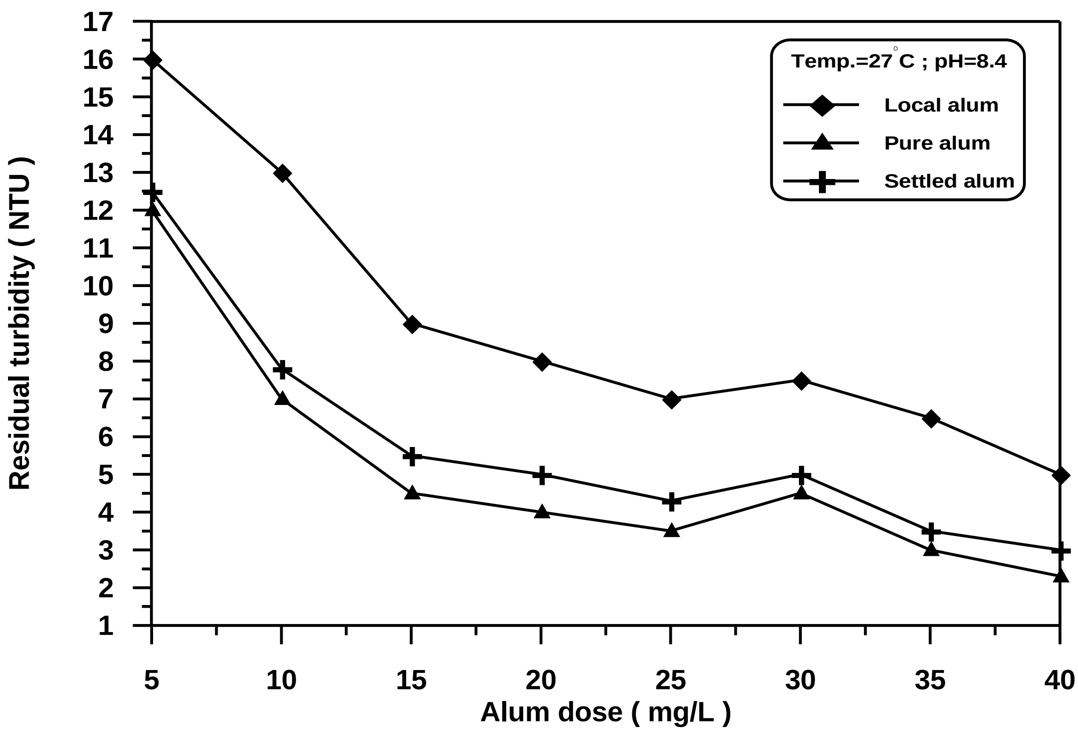


Figure (5-20): Residual turbidity after coagulation with settled alum, local alum, and pure alum for water turbidity of 50 NTU

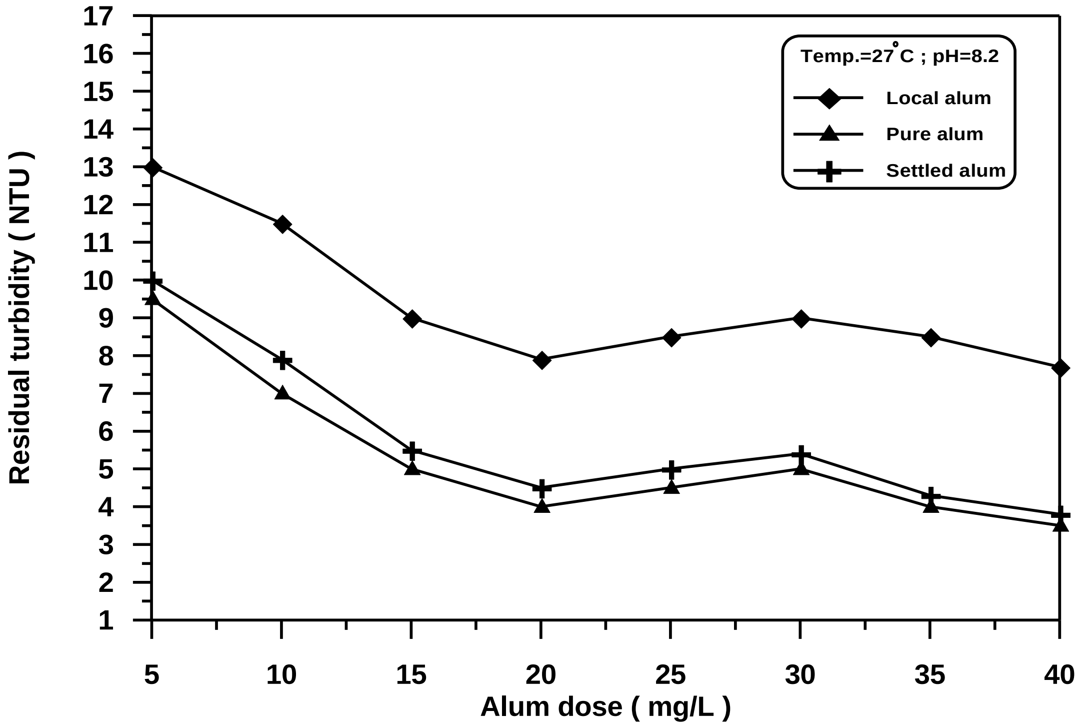


Figure (5-21): Residual turbidity after coagulation with settled alum, local alum, and pure alum for water turbidity of 75 NTU

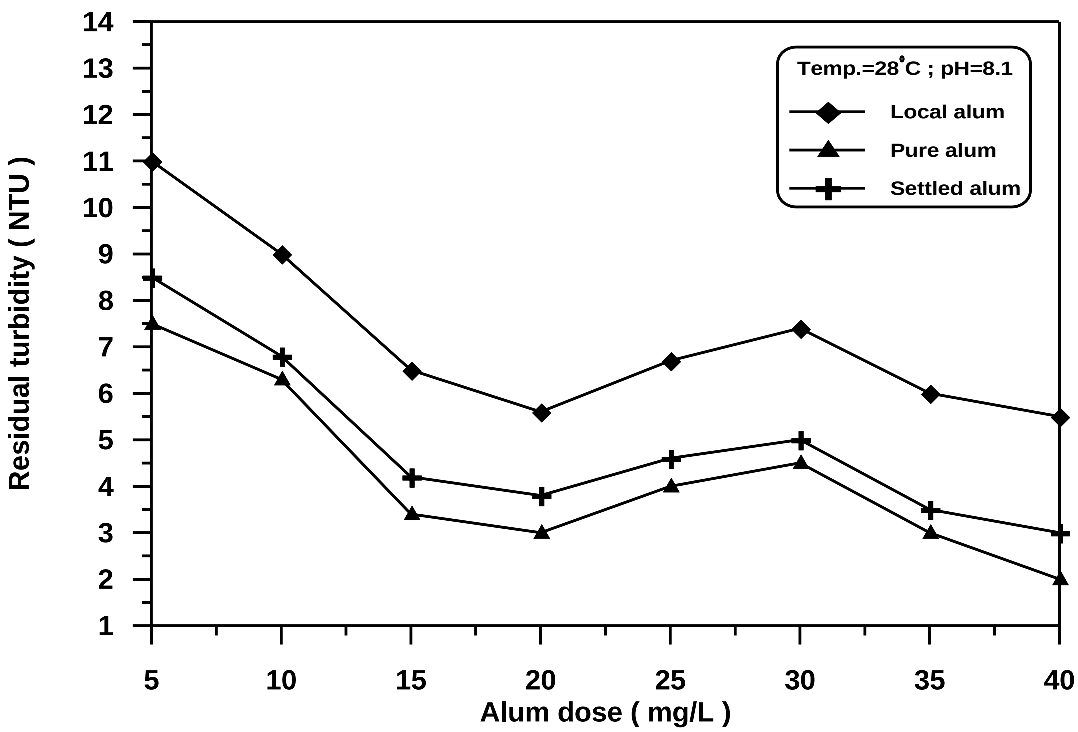


Figure (5-22): Residual turbidity after coagulation with settled alum, local alum, and pure alum for water turbidity of 100 NTU

Table (5-6): Optimum doses of settled alum

Turbidity (NTU)	Optimum alum dose (mg/l)	Residual turbidity (NTU)
10	**20**	**3.3**
25	**20**	**3.2**
50	**25**	**4.3**
75	**20**	**4.5**
100	**20**	**3.8**

5-6-2:The effect of settled alum on residual bacteria

Figure (5-23) shows the effect of settled alum on percentage of residual bacteria. It can be seen that the results by using settled alum are better than those of locally produced alum, and minimum percentage of residual bacteria is (1.42%) can be achieved at alum dose of (40 mg/l). Also it can be seen from the figure that the efficiency of settled alum for bacterial removal is similar in its efficiency in removing the turbidities, as it is less than the washed alum.

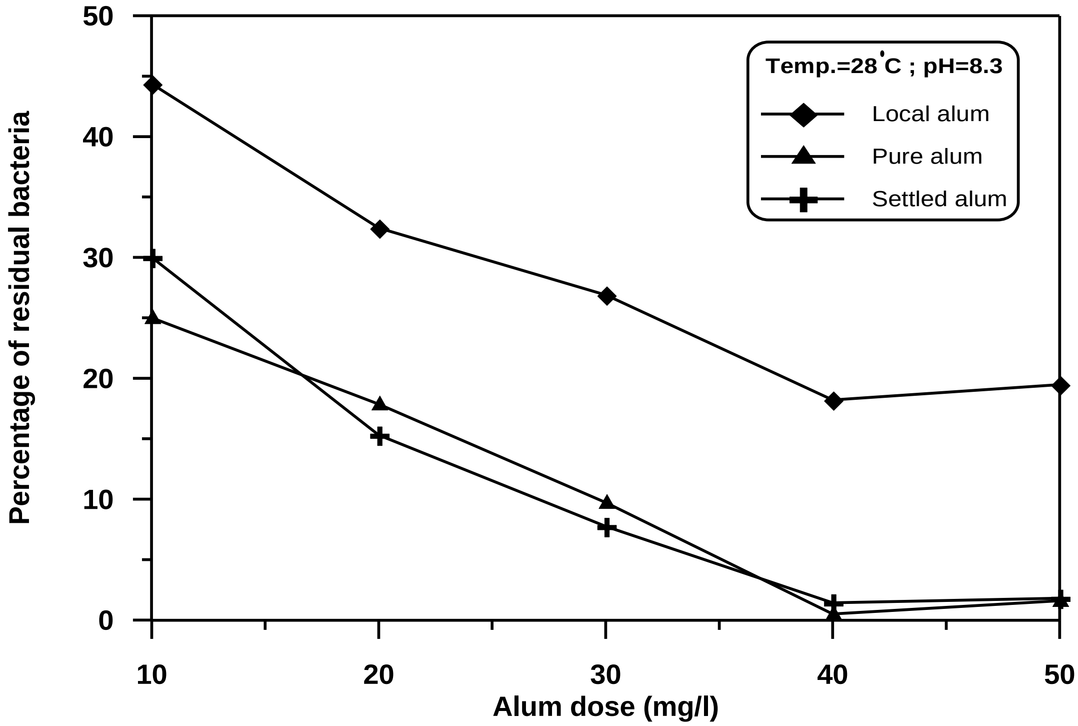


Figure (5-23): Effect of coagulation with settled alum, local alum, and pure alum on the percentage of residual bacteria

5-7: The performance of shaken alum

5-7-1: The effect of shaken alum on residual turbidity

The effect of shaken alum on the residual turbidity for synthetic turbidities of 10, 25, 50, 75, and 100 NTU are given in Figures (5-24) through (5-28), respectively.

Figures (5-27) and (5-28) show that for initial turbidities (75 and 100 NTU), which are considered as high turbidity levels, the optimum alum doses are (20mg/l) for minimum residual turbidities (4.1) and (3.2), respectively. This indicates that the residual turbidities obtained by using shaken alum as a sole coagulant are better than those obtained by using local alum. Also the results of using shaken alum are very close to the results from pure alum. This could be attributed to the fact that shaken alum contains a high percentage of alumina, which is higher than that of pure alum. However, the presence of the insoluble matter in shaking alum lead to the decreasing of its efficiency because of consuming part of the alumina in removing the insoluble matter found in alum.

Table (5-7) summarizes the optimum doses of shaken alum for minimum residual turbidities for the considered initial turbidities.

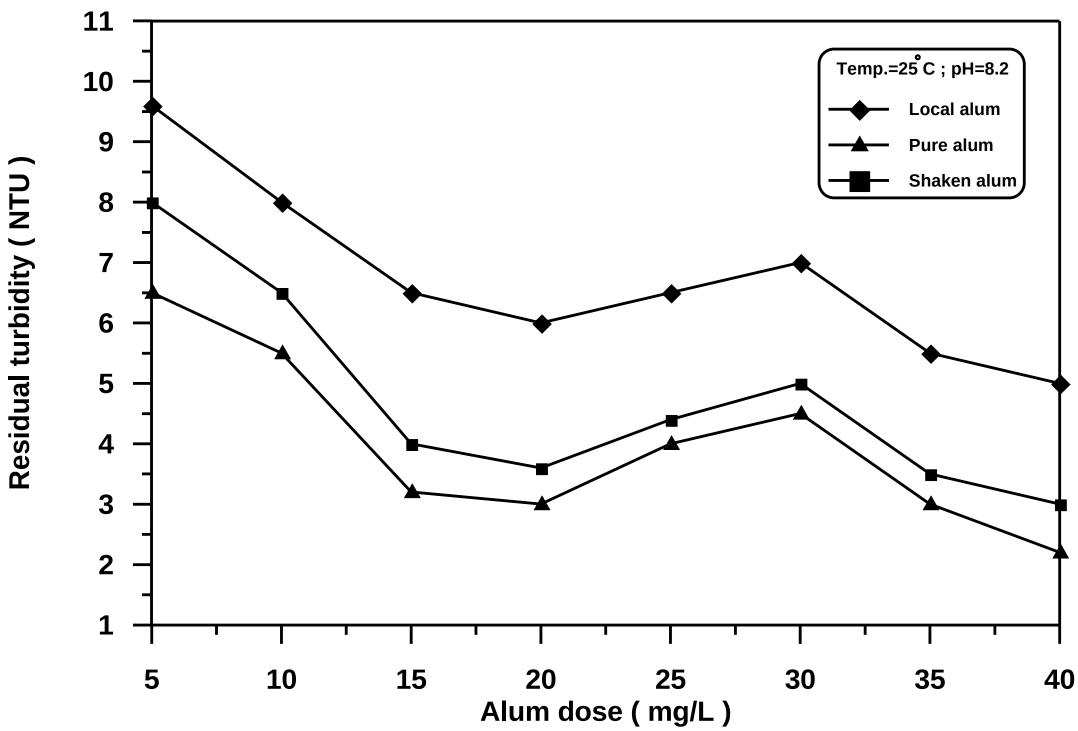


Figure (5-24): Residual turbidity after coagulation with shaken alum, local alum, and pure alum for water turbidity of 10 NTU

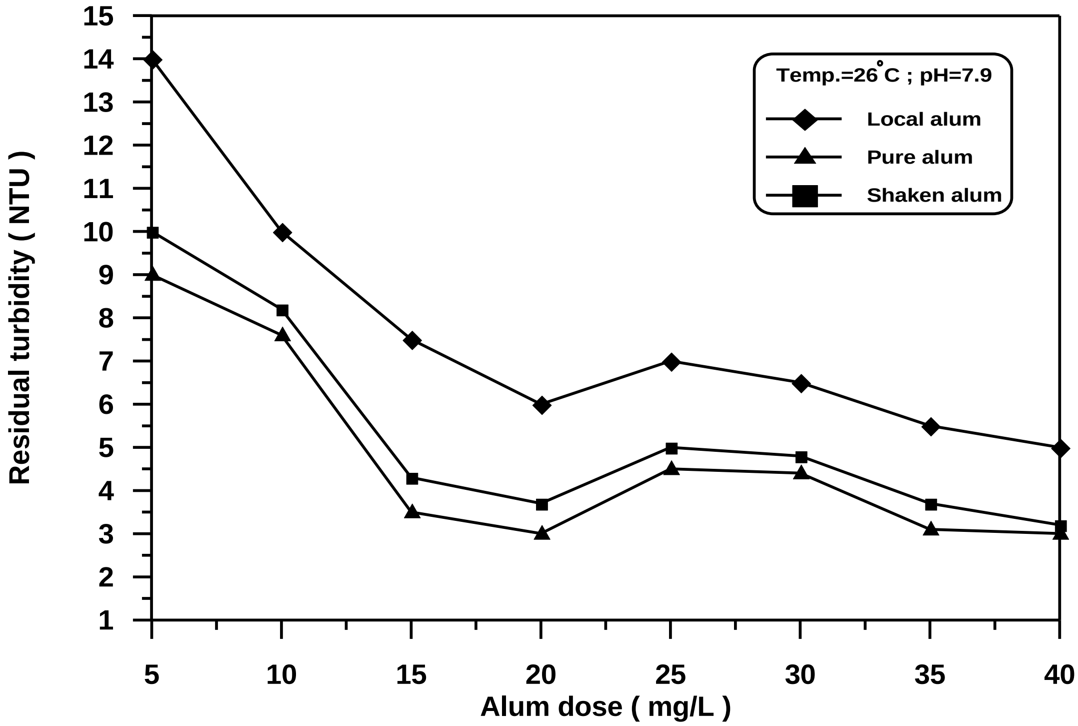


Figure (5-25): Residual turbidity after coagulation with shaken alum, local alum, and pure alum for water turbidity of 25 NTU

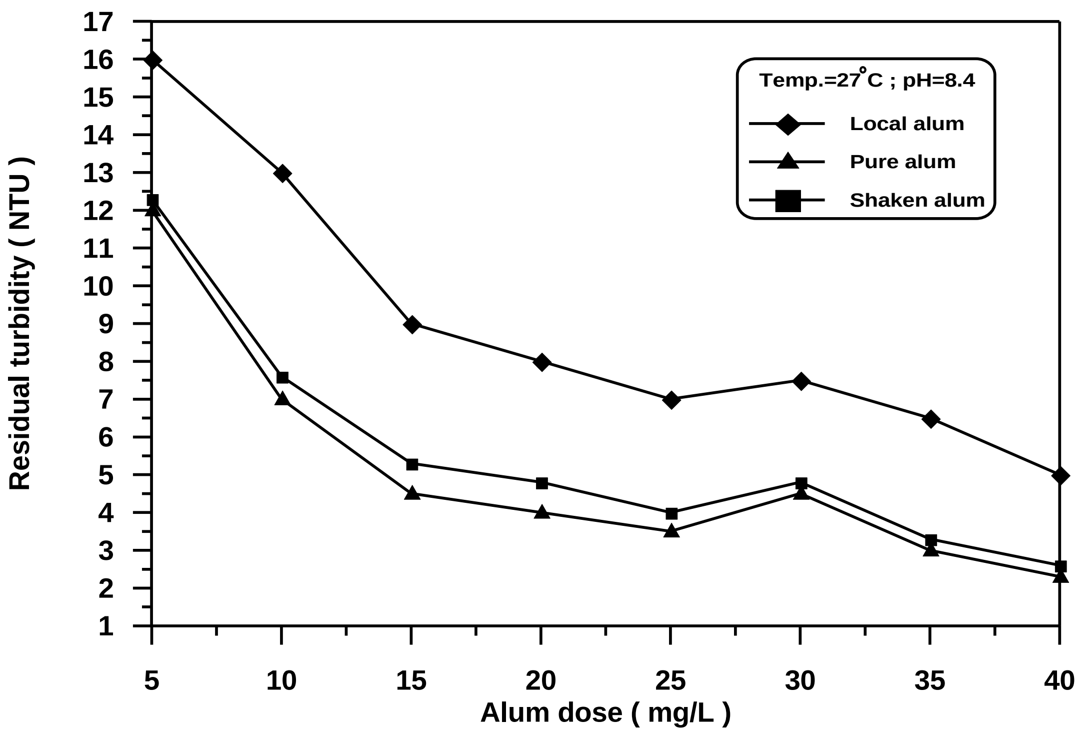


Figure (5-26): Residual turbidity after coagulation with shaken alum, local alum, and pure alum for water turbidity of 50 NTU

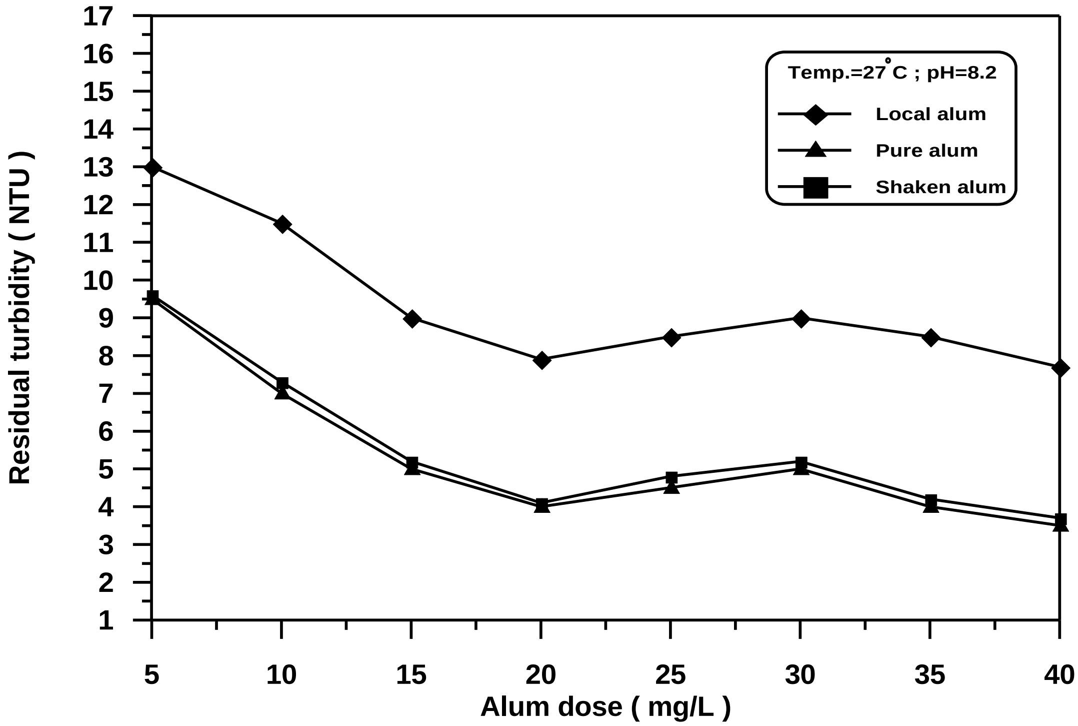


Figure (5-27): Residual turbidity after coagulation with shaken alum, local alum, and pure alum for water turbidity of 75 NTU

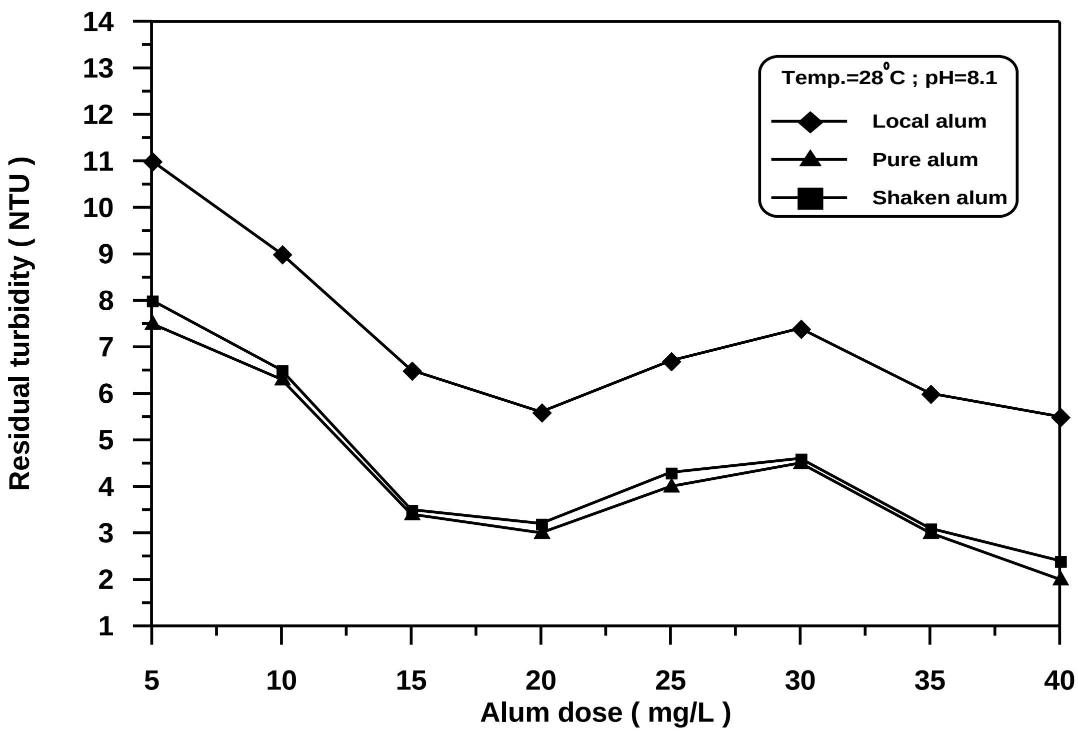


Figure (5-28): Residual turbidity after coagulation with shaken alum, local alum, and pure alum for water turbidity of 100 NTU

Table (5-7): Optimum doses of shaken alum

Turbidity (NTU)	Optimum alum dose (mg/l)	Residual turbidity (NTU)
10	20	3.6
25	20	3.7
50	25	4
75	20	4.1
100	20	3.2

5-7-2:The effect of shaken alum on residual bacteria

Figure (5-29) shows the effect of shaken alum on the percentage of residual bacteria. The optimum alum dose that gives the minimum percentage of residual bacteria of (1.13%) is (40mg/l). It can be seen from the figure that the result obtained by using the shaken alum is better than that from local alum.

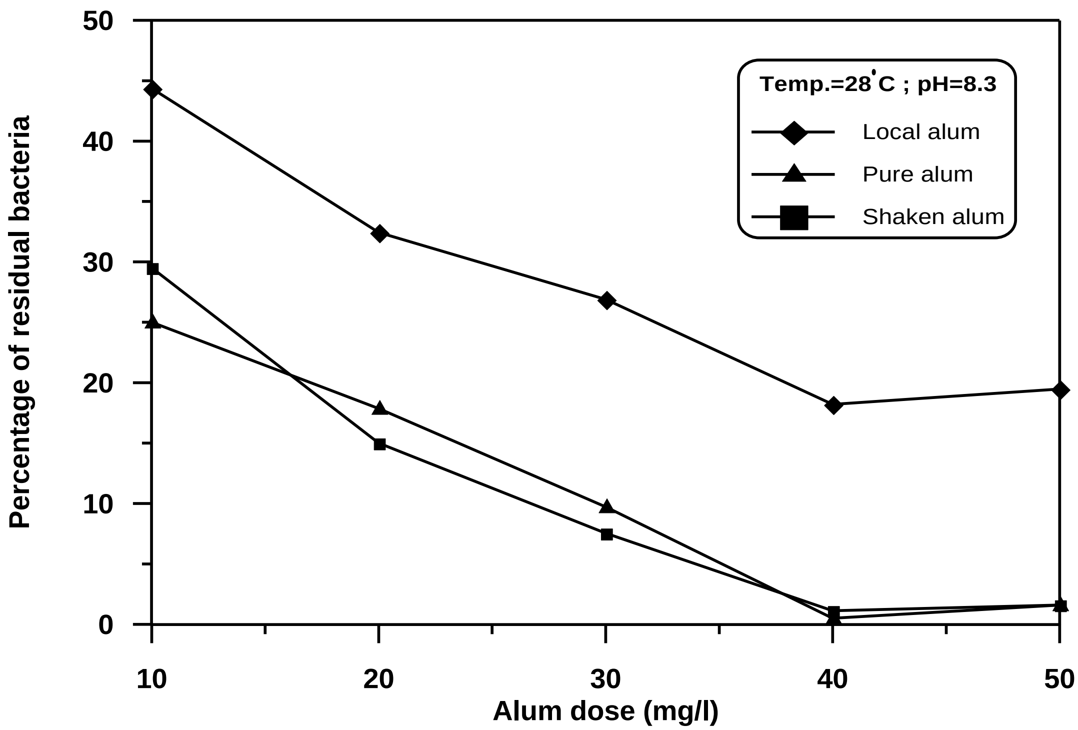


Figure (5-29): Effect of coagulation with shaken alum, local alum, and pure alum on the percentage of residual bacteria

5-8: The performance of heat-treated alum

5-8-1: The effect of heat-treated alum on residual turbidity

Figures (5-30) through (5-34) show the results of the experiments conducted by using heat-treated alum to clarify synthetic turbidities of 10, 25, 50, 75, and 100 NTU, respectively.

Figures (5-32) through (5-34) show that heat-treated alum is very effective with high turbidity levels. The minimum residual turbidities are 3.3, 3.2, and 2.8 NTU for initial turbidities of 50, 75, and 100 NTU, respectively, which are lower than those obtained from pure alum. The high reduction in turbidities by using heat-treated alum is due to its high alumina content, which is (18.3%).

Table (5-8) summarizes the optimum doses of heated alum for minimum residual turbidities for the considered initial turbidities.

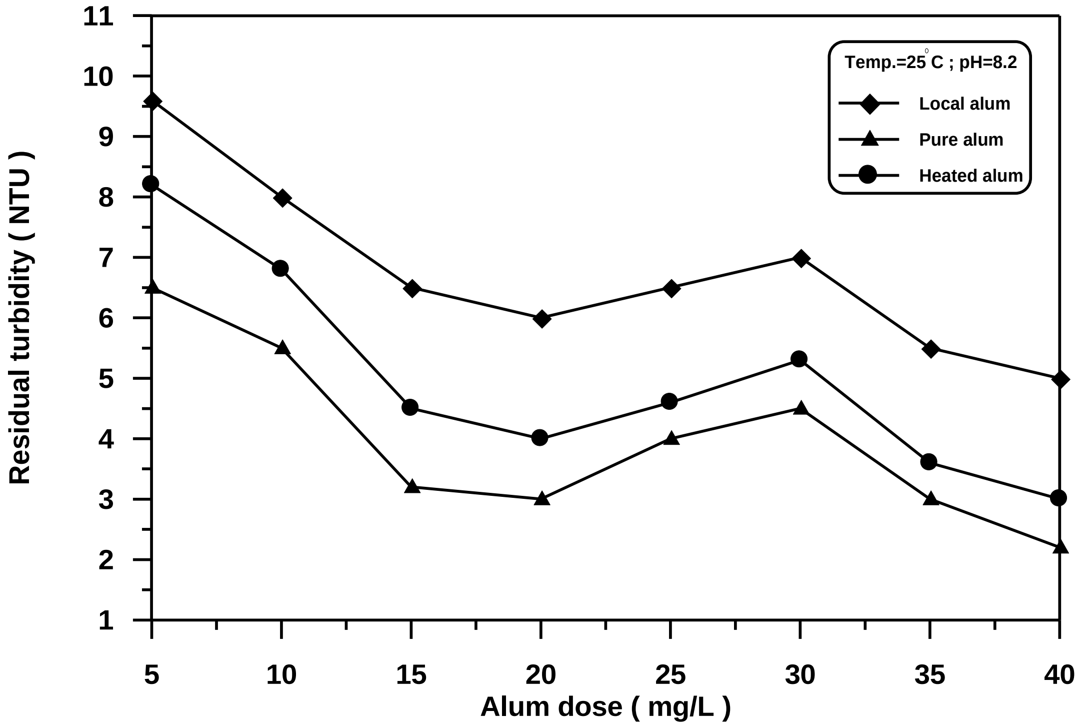


Figure (5-30): Residual turbidity after coagulation with heated alum, local alum, and pure alum for water turbidity of 10 NTU

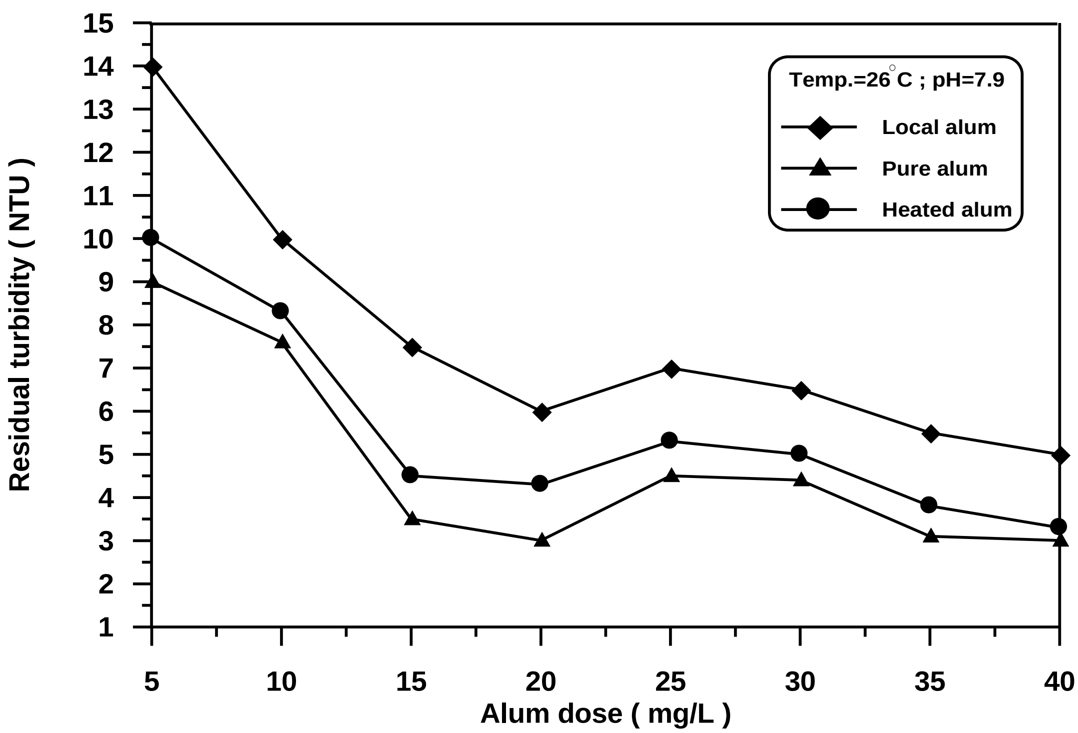


Figure (5-31): Residual turbidity after coagulation with heated alum, local alum, and pure alum for water turbidity of 25 NTU

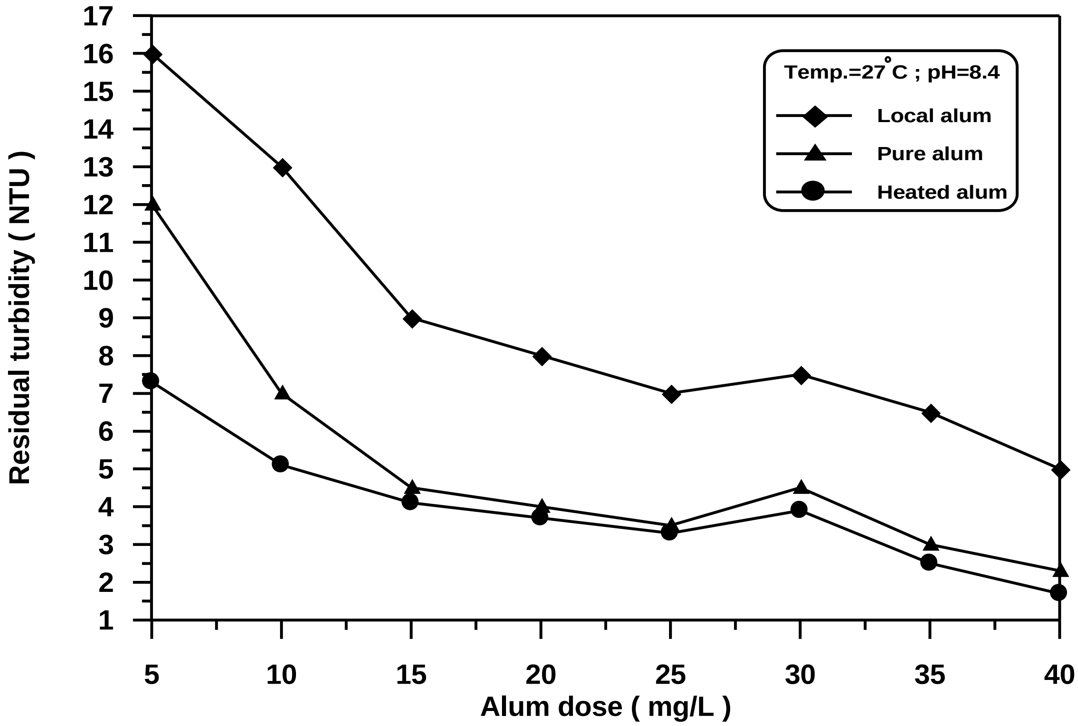


Figure (5-32): Residual turbidity after coagulation with heated alum, local alum, and pure alum for water turbidity of 50 NTU

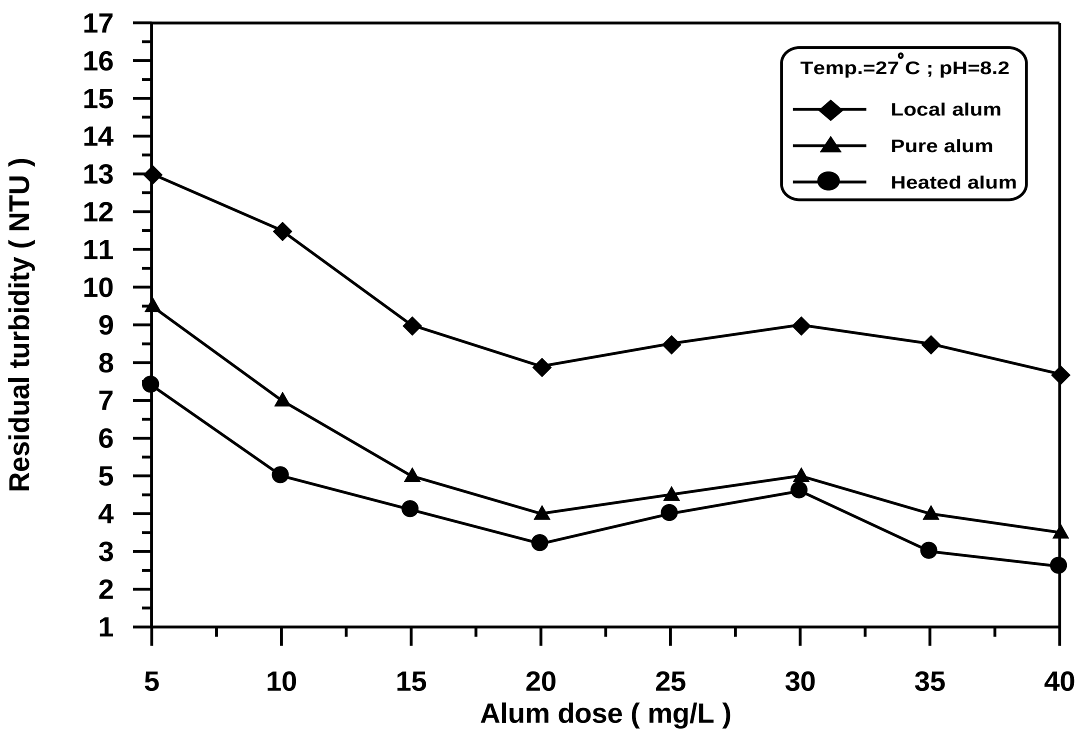


Figure (5-33): Residual turbidity after coagulation with heated alum, local alum, and pure alum for water turbidity of 75 NTU

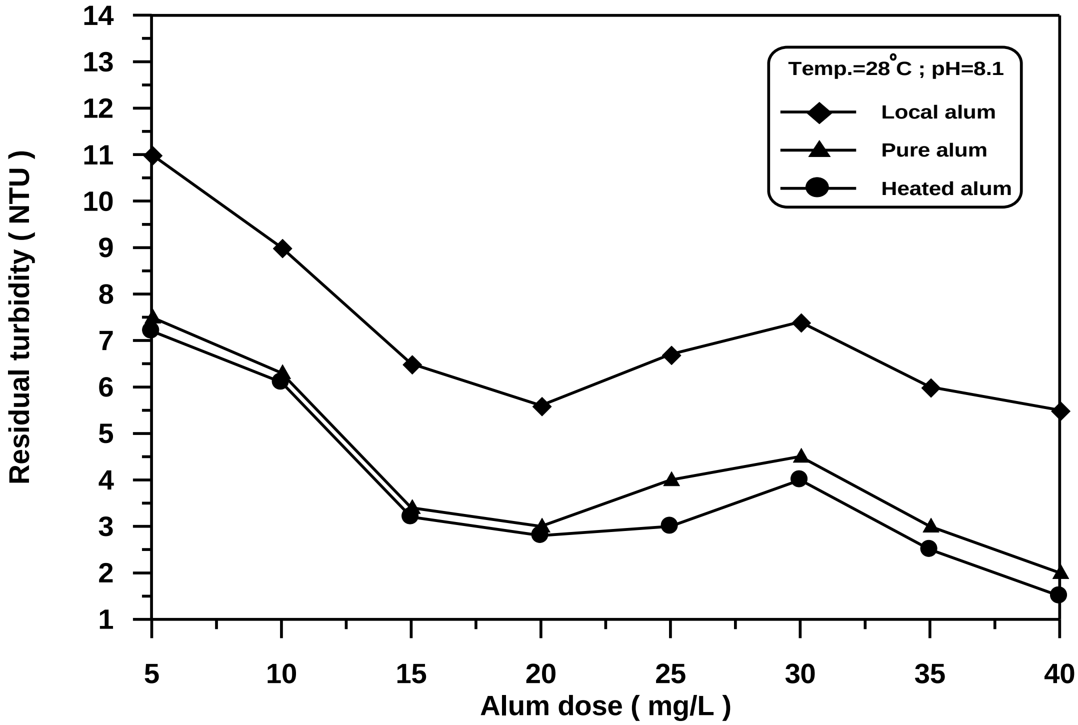


Figure (5-34): Residual turbidity after coagulation with heated alum, local alum, and pure alum for water turbidity of 100 NTU

Table (5-8): Optimum doses of heated alum

Turbidity (NTU)	Optimum alum dose (mg/l)	Residual turbidity (NTU)
10	20	4
25	20	4.3
50	25	3.3
75	20	3.2
100	20	2.8

5-8-2:The effect of heat-treated alum on residual bacteria

Figure (5-35) shows the effect of heat-treated alum on the percentage of residual bacteria. A minimum percentage of residual bacteria of (0.4%) has been obtained by using an alum dose of (40mg/l). It can be seen that the results of using heated alum are better than those of pure alum. This referred to that the heating alum is very effective in removing the E.coli, consequently in removing other kinds of bacteria. As it was stated, the E.coli was more resistant for removing from other pathogens.

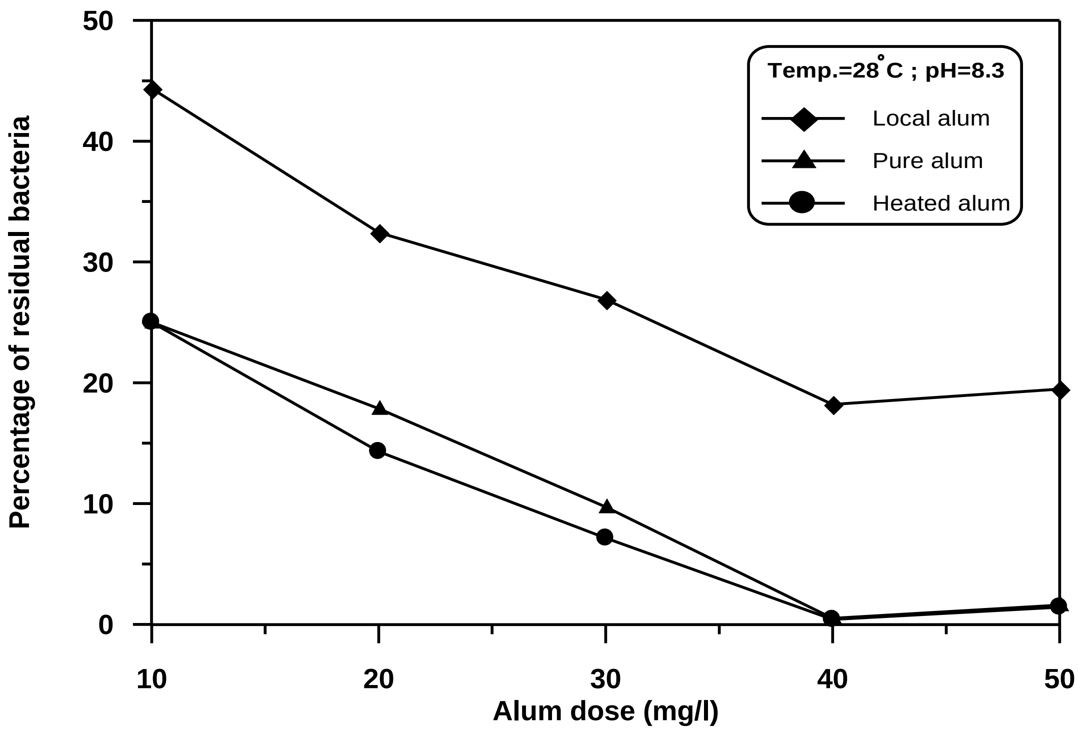


Figure (5-35): Effect of coagulation with heated alum, local alum, and pure alum on the percentage of residual

5-9: Comparative evaluation

5-9-1: The 10 NTU raw water turbidity

Figure (5-36) shows the relation between alum dose and residual turbidity for the types of alum considered in the study. The optimum dose for all types is (20 mg/l). A minimum residual turbidity of (3.2 NTU) is obtained by coagulation with washed alum.

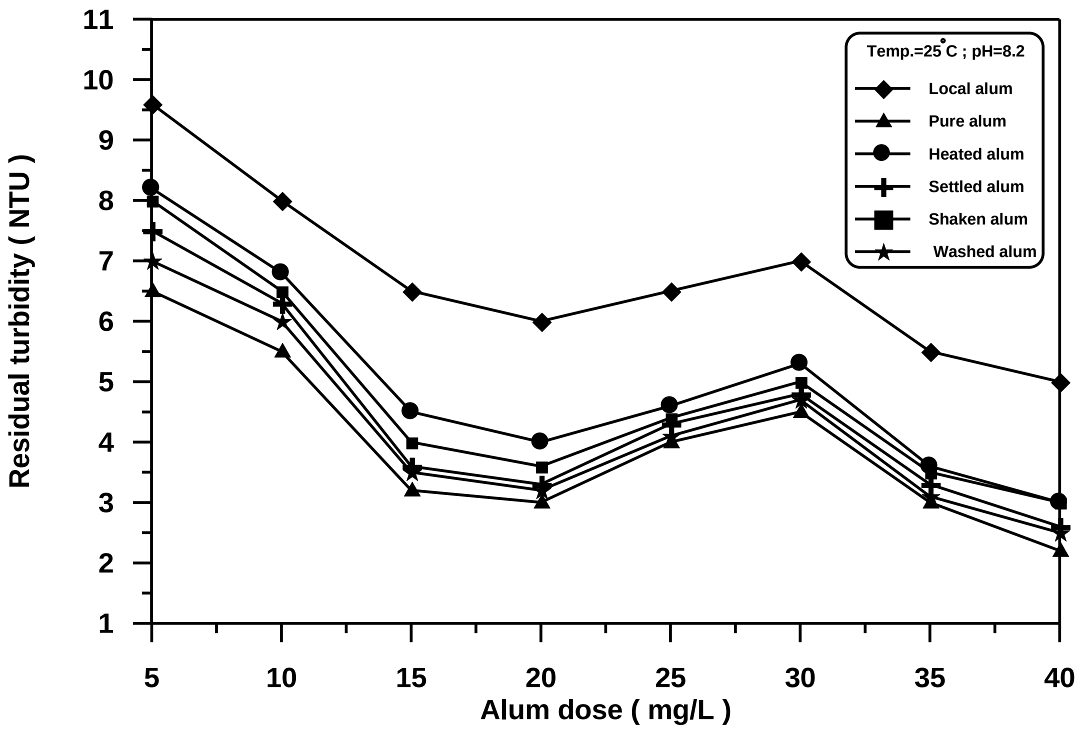


Figure (5-36): Residual turbidity after coagulation with the different types of alum for water turbidity of 10 NTU

5-9-2: The 25 NTU raw water turbidity

Figure (5-37) shows the relation of alum dose versus residual turbidity for the types of alum considered in the study. 20mg/l of alum dose is found to be the optimum alum dose for all types of alum, and the lowest residual turbidity, which is (3.1 NTU) obtained by coagulation with washed alum.

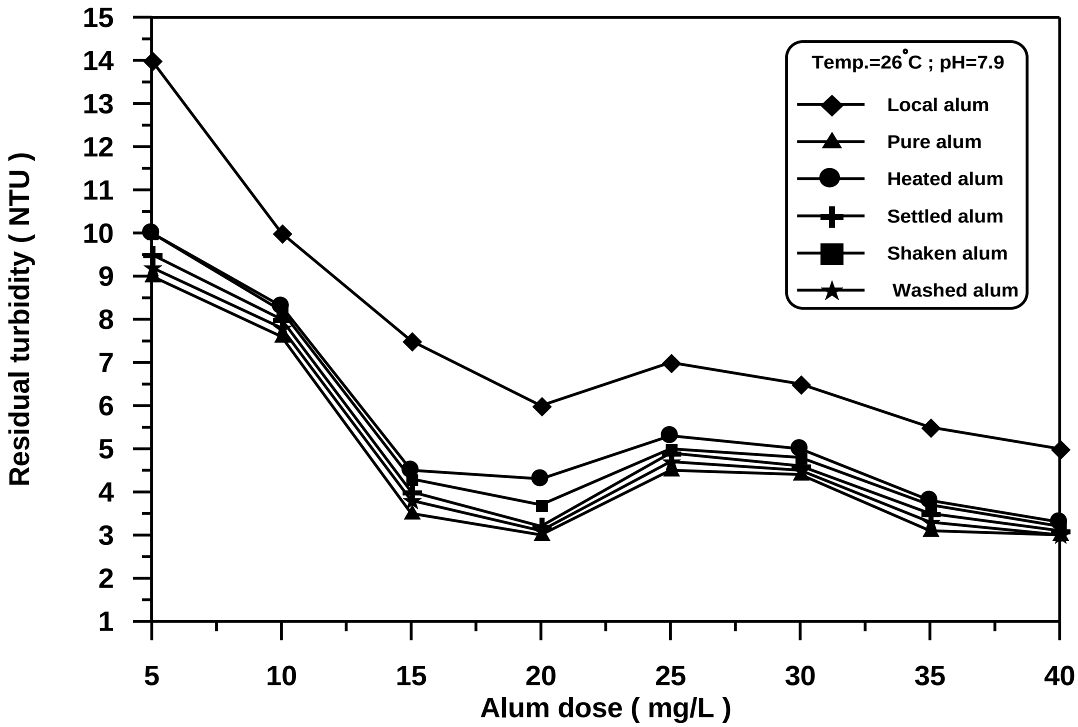


Figure (5-37): Residual turbidity after coagulation with the different types of alum for water turbidity of 25 NTU

5-9-3: The 50 NTU raw water turbidity

Figure (5-38) shows the relation between alum dose and residual turbidity for the types of alum considered in the study. The optimum dose for all types is (25 mg/l). A minimum residual turbidity of (3.3 NTU) is obtained by coagulation with heated alum.

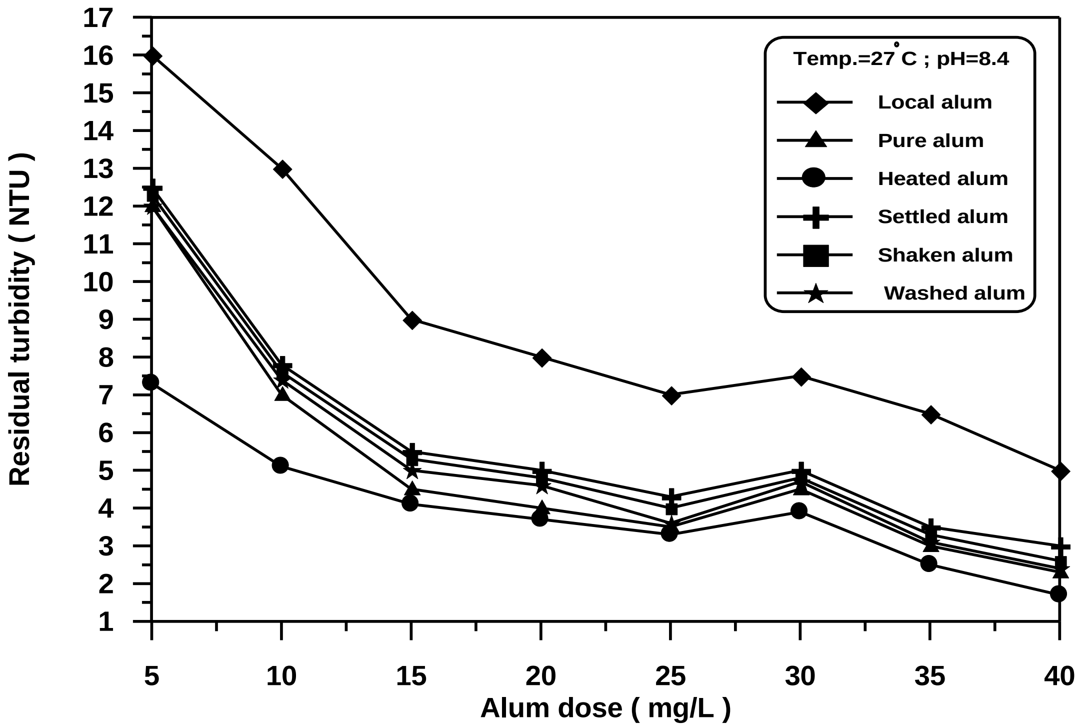


Figure (5-38): Residual turbidity after coagulation with the different types of alum for water turbidity of 50 NTU

5-9-4: The 75 NTU raw water turbidity

Figure (5-39) demonstrates the results of experiments work, which conducted by using the types of alum considered in the study to clarify synthetic turbidity has initial turbidity of (75 NTU). The lowest turbidity is reached by using heated alum at dose of (20 mg/l).

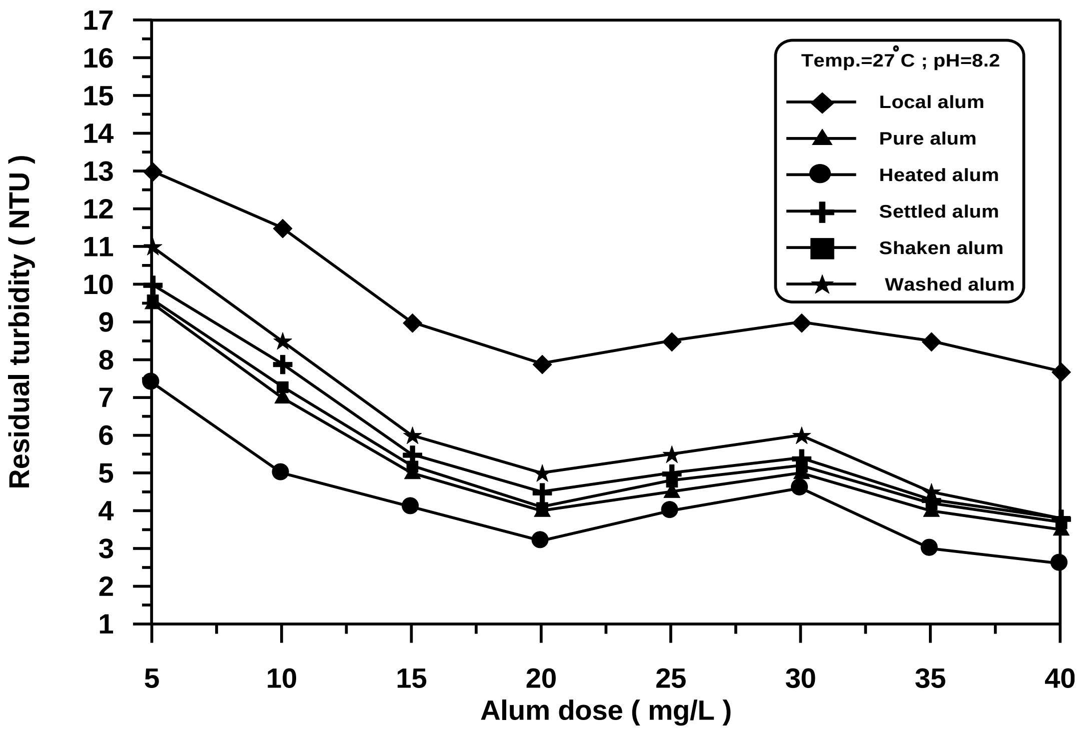


Figure (5-39): Residual turbidity after coagulation with the different types of alum for water turbidity of 75 NTU

5-9-5: The 100 NTU raw water turbidity

Figure (5-40) shows the relation between alum dose and residual turbidity for the types of alum considered in the study. The optimum dose for all types is (20 mg/l). A minimum residual turbidity of (2.8 NTU) is obtained by coagulation with heated alum.

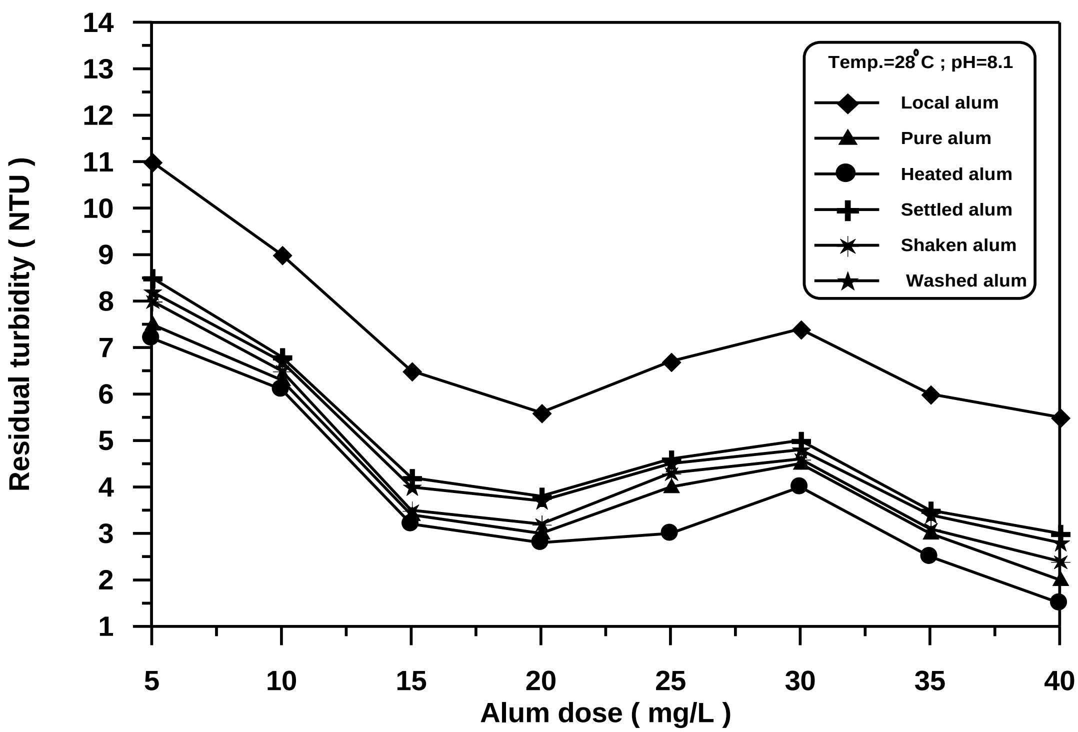


Figure (5-40): Residual turbidity after coagulation with the different types of alum for water turbidity of 100 NTU

5-9-6: Residual bacteria

Figure (5-41) shows the effect of the different types of alum on the percentage of residual bacteria. The optimum alum dose that gives minimum percentage of residual bacteria for all types of alum is (40mg/l). The lowest percentage of residual bacteria, which is (0.4%) has been obtained with heated alum.

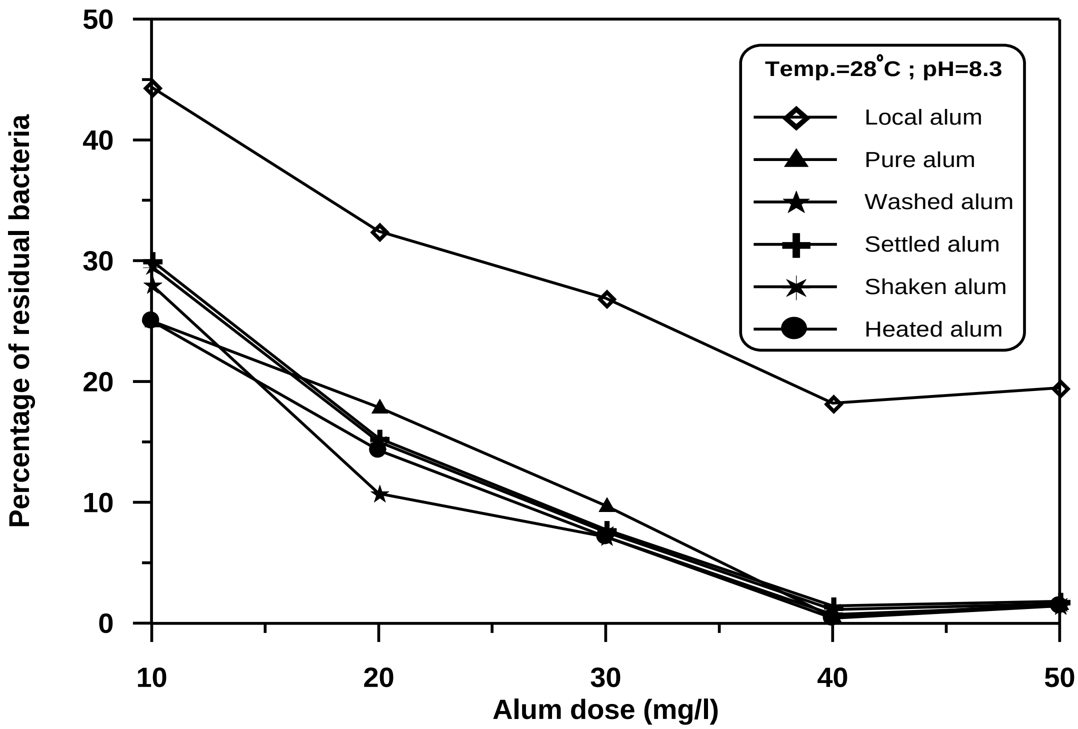


Figure (5-41): Effect of coagulation with different types of alum on the percentage of residual

Chapter Six 6

Conclusions and Recommendations

6-1: Conclusions

The following conclusions are drawn from the present study regarding the use of locally produced alum for water purification. These concluding remarks should be considered with due regard to the limitation of the domains of the different water parameters. The criterion of effectiveness has been considered as the performance of pure alum and the results of the treatments have been evaluated accordingly.

A- Locally produced alum

1- The constituent of locally produced alum does not comply with some of the specifications set by the AWWA.

2- Locally produced alum less effective in removing turbidity of raw water with turbidity level of (100 NTU) and less.

3- For water with high concentration of E. coli, the use of locally produced alum as a sole coagulant is inadequate to reduce significantly the E. coli from tested water.

B- Washed alum

1- The constituent of washed alum confirms with most of the specifications set by the AWWA.
2- Washed alum is effective in removing turbidity of raw water with turbidity level of (50 NTU) and less.
3- Washed alum is very effective in removing E. coli from tested water. The percent removal was (99.29%).

C- Settled alum

1- It was found that it was very important to leave the solution of alum to settling at lest (15 min.), to get red from the impurities in locally alum, before using it for coagulation processes.
2- Settled alum is effective in removing turbidity of raw water with turbidity level of (75 NTU) and less.
3- Settled alum able to reduce significantly the E.coli, where it is capable of removing (98.58%) from the E.coli from tested water.

D - Shaken alum

1-The constituent of shaken alum confirms with all the specifications set by the AWWA.
2- Shaken alum is effective in removing turbidity of raw water with turbidity levels ranging between (50-100 NTU).
3- Shaken alum is very effective in removing E.coli from tested water. The percent removal was (98.87%).

E- Heat-treated alum

1- The constituent of heated alum confirms with most of the specifications set by the AWWA.
2- Heated alum was very effective in removing turbidity of raw water with turbidity levels ranging between (50-100 NTU).
3- Heated alum appears to be the most promising coagulant for removing E.coli from tested water. The percent removal was (99.6%).

6-2: Recommendations

The followings are suggestion for future studies

1- Studying the use of washed, settled, shaken, and heated alum to clarify raw water from Euphrates and Tigris Rivers.
2- Study the performance of washed, settled, shaken, and heated alum as a sole coagulant to clarify raw water at one of the water treatment plants in Hilla city.
3- Conducting an economical study for using washed, settled, shaken, and heated alum.
4- Studying the effect of improving the locally produced alum on the efficiency of operating filters.

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2002

المستخلص

الهدف الرئيسي من هذه الدراسة هو تحسين أداء الشب المحلي , مختبريا. وذلك من خلال سلسله من التجارب التي أجريت على الشب المحلي والتي تضمنت:

1- غسل الشب المحلي وذلك للتخلص من الشوائب والمواد العالقة على سطح الشب.
2- تركيد محلول الشب وذلك للتخلص من المواد القابلة للترسيب قبل إضافة محلول الشب إلى الماء الخام.
3- رج الشب المحلي وذلك للتخلص من الأطيان والشوائب الموجودة بالشب بطريقه جافه.
4- تسخين الشب المحلي حيث إن عملية التسخين تسمح للأطيان والشوائب بالتكتل بالأضافه إلى إمكانية إحتراق الشوائب القابلة للإحراق.

أستخدم الشب المحلي بعد التحسين بجرعات مختلفة في إزالة كدر مصطنعه تراوحت بين (10- NTU 100) من خلال خمس مستويات للكدر(10، 25 ،50 ، 75، NTU 100) و بالأضافه إلي الكدر المصطنعه فقد استخدم الشب في إزالة بكتريا القولون البراز يه (E.coli) بتركيز ($1*10^4$خليه\مل) وذلك لتقييم قدرة الشب على إزالة البكتريا المرضية الموجوده في الماء الخام.

ولغرض اختبار كفاءة الطرق أعلاه في تحسين أداء الشب المحلي، أجريت سلسله أخرى من التجارب استخدم فيها الشب المحلي و الشب النقي في إزالة الكدر المصطنعه و البكتريا و بنفس الظروف التي استخدم فيها الشب المحلي بعد التحسين وذلك لإمكانية مقارنة النتائج.

بينت التجارب و التحاليل الكيميائية للشب المحلي قبل وبعد التحسين إن :

1- الشب المحلي غير كفوء في إزالة الكدر بمستويات (NTU 100) وأقل.
2- الشب المغسول فعال في إزالة الكدر بمستويات (NTU 50) واقل.
3- الشب المرسب فعال في إزالة الكدر بمستويات (NTU 75) وأقل.
4- الشب المرجوج فعال في إزالة الكدر بمستويات تتراوح بين (NTU 100-50) .

5- الشب المسخن فعال في إزالة الكدر العالية، حيث تم الحصول على كفاءة إزالة (93.4%، 95.7% ، 97.2%) لإزالة الكدر بمستويات (50، 75 ، 100 NTU) على التوالي. إن هذه النسب هي أعلى من النسب المتحققة من استخدام الشب النقي.

6- في إزالة البكتريا ، أعطى الشب المحلي قبل التحسين إزالة مقدارها (81.8%) بينما أعطى الشب النقي إزالة مقدارها (99.5%) في حين حقق الشب المحلي بعد التحسين أزاله جيدة تراوحت بين (98.58% - 99.6%).

أخيرا ، مما سبق نستنتج انه يمكن استخدام الشب المغسول والمرسب خلال فصلي الصيف والخريف عندما تكون مستويات الكدر واطئه في نهري دجله والفرات في حين يمكن استخدام الشب المرجوج والمسخن خلال فصلي الربيع والشتاء عندما تكون مستويات الكدر مرتفعه.