

Preparation of Porcelanite Ceramic Filter by Slip Casting Technique

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Abstract

This work is conducted to study producing solid block porcelanite filter from Iraqi porcelanite rocks and kaolin clay (as binder material) by slip casting technique, and investigating its ability of removing contaminant (Pentachlorophenol) from water via the adsorption mechanism. Four particle sizes (74, 88, 105 and 125) μm of porcelanite powder were used. Each batch of particle size was mixed with (30 wt. %) kaolin as a binding material to improve the mechanical properties. After that, the mixtures were formed by slip casting to disk and cylindrical filter samples, and then fired at 500 and 700 °C to specify the effects of particle size of porcelanite, temperature and formation technique on porcelanite filter properties. Some physical, mechanical and chemical tests have been done on filter samples. Multi-experiments were carried out to evaluate the ability of porcelanite to form the filter. Porosity, permeability and maximum pore diameter were increased with increasing porcelanite particle size and decreased by increasing temperature, whereas the density shows the reverse behavior. In addition, bending, compressive and tensile strength of samples were increased by increasing temperature, and decreased with increasing porcelanite particle size. Efficiency of disk filter sample to remove pentachlorophenol was 95.41% at a temperature of 700°C using 74 μm particle size of porcelanite. While the efficiency of cylindrical filter sample was 97.57% at the same conditions.

المستخلص:

تتناول هذه الدراسة إنتاج مرشحات البورسيلينايت من صخور البورسيلينايت العراقية ومن أطيان الكاؤولين (كمادة رابطة) بتقنية القولبة الانزلاقية ودراسة إمكانية إزالة خماسي كلوروفينول من الماء بواسطة هذا المرشح بعملية الامتزاز. تم استخدام أربعة أحجام حبيبية للبورسيلينايت وهي (74، 88، 105 و 125) مايكروميتر، حيث تم خلط كل حجم حبيبي مع 30% نسبة وزنية من المادة الرابطة (مسحوق الكاؤولين). بعد ذلك شكلت نماذج المرشح بطريقة القولبة الانزلاقية للحصول على المرشح القرصي والمرشح الاسطواني، وتم حرقت عند درجة حرارة (500 و 700) °م وذلك لمعرفة تأثير كل من (الحجم الحبيبي للبورسيلينايت، درجة الحرارة وتقنية التشكيل) على كفاءة وخواص المرشح البورسيلينايتي الأخرى. تم إجراء عدة فحوصات فيزيائية وميكانيكية وكيميائية حيث تم الحصول عملياً على تقييم خواص المرشح البورسيلينايتي فوجد إن كل من المسامية و النفاذية و اكبر قطر للمسامة تزداد بزيادة الحجم الحبيبي للبورسيلينايت وتقل بزيادة درجة حرارة الحرق، أما الكثافة ومقاومة الانضغاط ومقاومة الشد ومقاومة الانحناء تزداد بزيادة درجة حرارة الحرق وتقل بزيادة الحجم الحبيبي للبورسيلينايت. وصلت كفاءة المرشح القرصي في إزالة خماسي كلوروفينول من الماء إلى 95.41% عند درجة حرارة الحرق 700 °م باستخدام الحجم الحبيبي (74) مايكروميتر، في حين بلغت كفاءة المرشح الاسطواني في إزالة خماسي كلوروفينول من الماء إلى 97.57% عند نفس الظروف.

Keywords: porcelanite, slip casting, ceramic filter.

Introduction

Porcelanite is one of the important industrial sedimentary rocks. The adsorption capacity of porcelanite is due to the large surface area within the structures of its components cristobalite and tridymite (Abed- Ohn, 2003). Adsorption capacity for porcelanite made it important for getting rid of the environment from the different pollution. Porcelanite has a wide range of uses, such as filler, accessory agent, storage medium, carrier, catalyst carrier and catalyst. Its industrial importance arises from its physical properties represented by the porosity, fineness of pores, adsorption power, light weight and low heat conductivity (Jensen and Bateman, 1981).

Many researchers have been studied the Iraqi porcelanite as a filter media to remove undesired materials via a traditional powder technique. Al-Bassam et.al. (1993) have studied the suitability of Iraqi porcelanite as industrial filters for sulfur refining and food products; Abdul-Khaliq (1995) has studied the Iraqi porcelanite to remove heavy metals from industrial waste water; Jabboory (1999) has tested the porcelanite as a filter aid in the filtration of beer and dates syrup; Abed-Ohn (2003) has showed the high efficiency of porcelanite to extract ions of heavy metals from water as coagulant; Mortadha (2008) has studied porcelanite rocks as adsorption agents in the chromatograph columns for purposes of the water purification.

The goal of this paper is to investigate slip casting technique in the production both hollow and solid porcelanite filter ware.

Experimental

Materials

Two types of raw materials, porcelanite rocks and kaolin clay were used in this study. Four particle sizes of porcelanite powder are adopted in this study. The selected sizes in this study are listed in Table 1. While the size of binder material powder (kaolin clay) was less than 74 μm for all mixtures.

Table 1. Selected porcelanite particle sizes.

No.	Particle size (μm)	Mesh
1-	74 - 88	200 -180
2-	88 - 105	180 -140
3-	105 - 125	140 -120
4-	125 - 154	120 - 100

Standard plaster of paris casts is used for slip casting formation. A general is that 3 parts of plaster to 2 parts of water was adopted in this work. Porosity, permeability, hardness, durability of the mould, workability and surface characteristics are all related to the blending process and pouring procedure (Wardell, 1997). Three types of the moulds were made for forming the samples in this study: the first one as a

rectangular for the bending tests, the second one as a disk filter for splitting tensile strength, and the last one as a cylindrical filter samples for compressive strength.

Slip preparation

70 wt% of porcelanite and 30 wt% of kaolin a powder, distilled water, and deflocculates are mixed and stirring with an electric stirrer of different speeds for 3 hours. Deflocculates are gradually added to warm distilled water and then the powder materials are slightly dropped to the solution. The prepared crucibles filter samples are shown in figure 1.



Fig.1. Final shape of the filter samples.

Firing stage

The prepared samples were fired in two temperatures 500 °C and 700 °C in electrical furnace. Soaking time was one hour, and then cooled in the furnace according to the thermal cycle as shown in Figure 2.

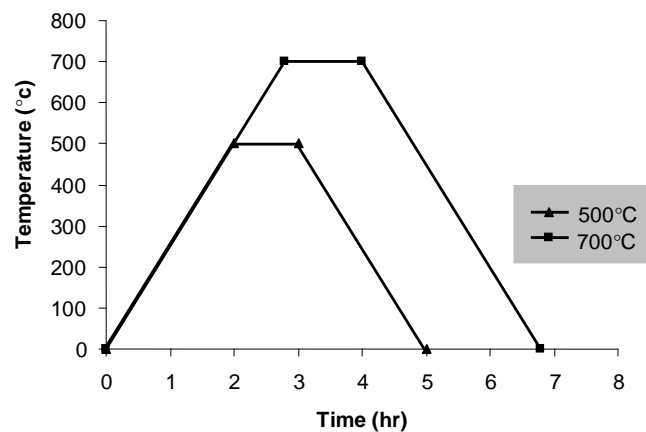


Fig.2 Thermal cycle for firing process.

Testing stage

The tests have been accomplished on the produced samples in order to study the properties of porcelanite filter. These tests can be classified into three types:

1- Physical Tests

The physical tests were executed on the filter samples to predict apparent porosity, bulk density, permeability, and maximum pore size.

2- Mechanical Tests

Bending, compressive and splitting strength tests were accomplished on the samples.

3- Chemical Tests.

Results and discussion

The effects of the porcelanite particle size, firing temperature and manufacture technique on the filter properties were studied.

Physical tests

1- Porosity and water absorption

Figures (3) and (4) show the effect of porcelanite particle size on porosity and water absorption of the filter samples with different temperatures of sintering.

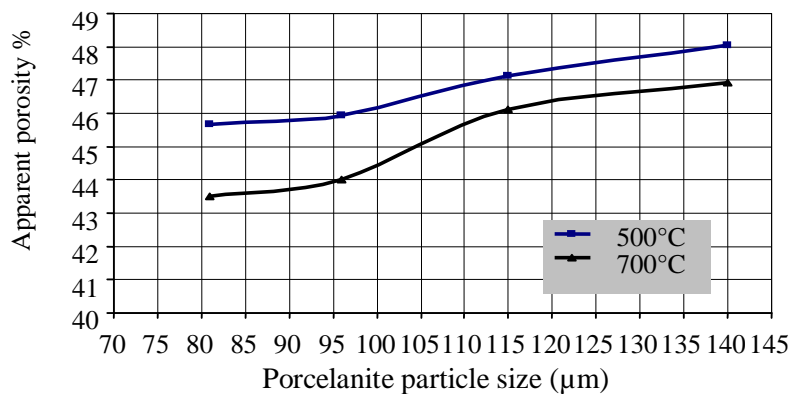


Fig. (3) Effect of porcelanite particle size on porosity of the samples.

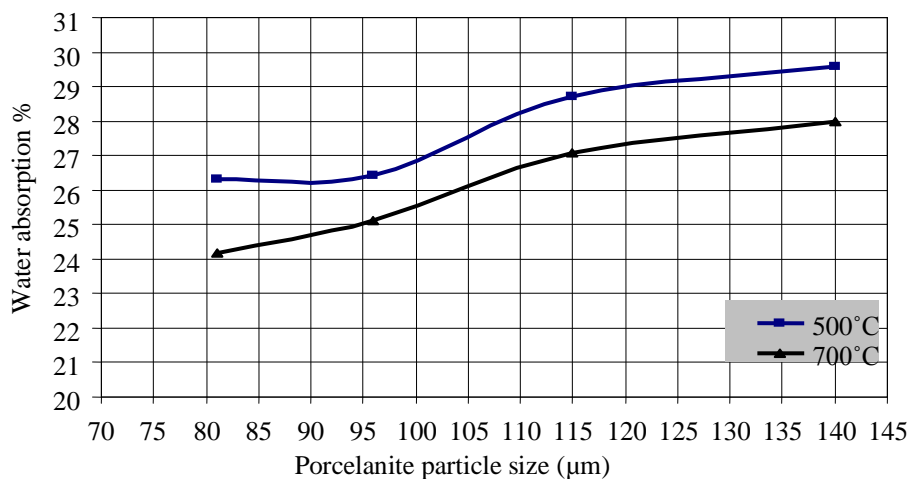


Fig. (4) Effect of porcelanite particle size on the water absorption of samples.

The increasing of particle size will cause an excess in apparent porosity of the porcelanite samples. It is due to this fact, that large particles will leave behind it large volume of pores which in turn gives an increase in porosity value. For most ceramic materials, the apparent porosity is approximately twice the value of the water

absorption. It will be interesting to know that in slip casting technique, the particles in slip are crowded and arranged on the circumference of mould hole (due to the water absorption from slip by mould) which cause a formation of the large pores between these particles in comparison with other formation techniques. Where these pores are formed without application of any force during the formation process (that means it forms without an effect on its shape, size, and numbers). As a result of this, high porosity in porcelanite slip casting body was achieved. But high percentage of the binder material 30% of kaolin, to improve the mechanical properties of the samples, brings about a reduction in the porosity, where the binder material will fill the pores between particles.

Also the sintering temperature affects the resulting porosity, where the porosity decreases with increasing the firing temperature. The reason of that is the shrinkage in size and number of the pores, which result from convergence of the particles one to another during the sintering process.

2- Bulk density

Figure (5) shows the effect of porcelanite particle size on bulk density of filter samples with different temperatures of sintering.

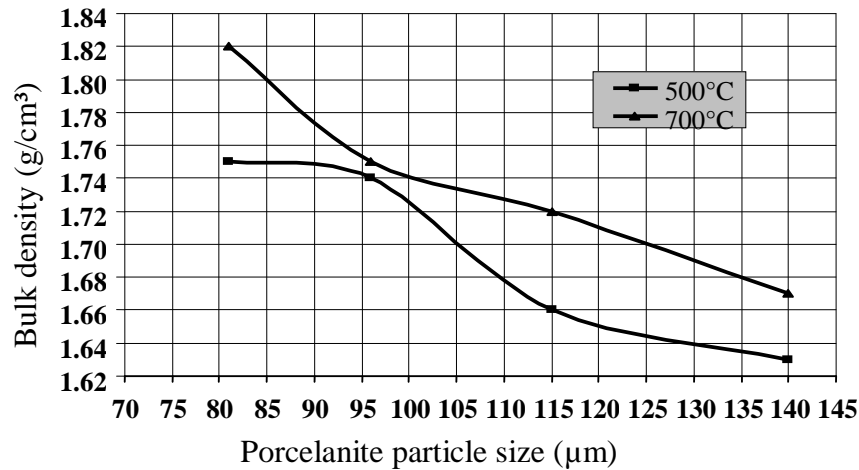


Fig. (5) Effect of porcelanite particle size on bulk density of the filter samples.

A density of samples decreases with increasing size of particles. It has been due to large particle size, the number of particles in unit volume will be less than that of fine particle size. This leaves large pores which directly effect on the bulk density. Also, the sintering temperature has a similar effect on density, where densities of the sample will increase with increasing the firing temperature, due to decreasing the porosity.

3- Maximum pore diameter

Figure (6) shows the effect of porcelanite particle size on maximum pore diameter of the filter samples. It has become customary any increasing in particle size will cause increment in maximum pore diameter. The reason of that is due to particles arrangement with each other. The large particles will form larger pores than that of fine particles do.

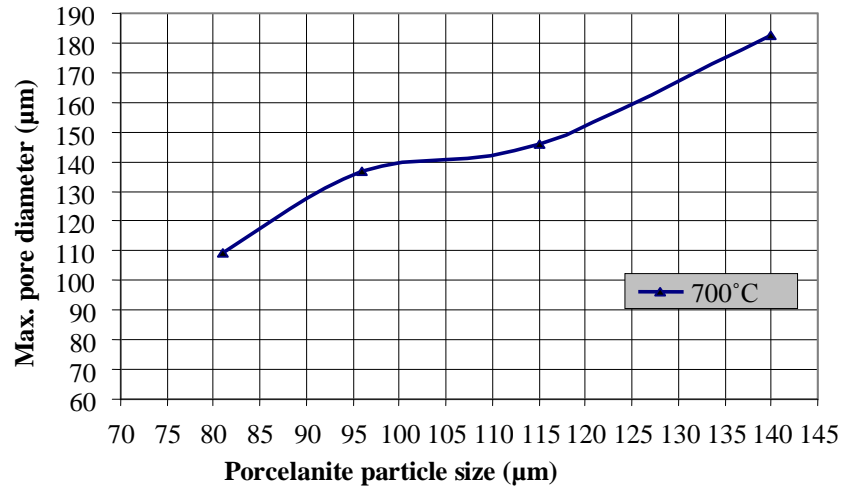


Fig. (6) Effect of porcelanite particle size on maximum pore diameter of the filter samples.

Experimentally, the samples which were fired at 500°C were failed in this test because of the weakness of its mechanical properties.

4- Permeability

The permeability of the body is directly connected to the number of the open channels that connect pores and the exterior wall of the body. Figure (7) shows the effect of porcelanite particle size on the permeability of the filter samples with different temperatures of sintering. According to the Darcy's law, the permeability increases with the increase of pore diameter which is proportionally related to the particle size.

Permeability is affected by the sintering temperature. Where any increase in sintering temperature will cause decrease in the permeability in which the pore diameter is playing an important role for the filtration process.

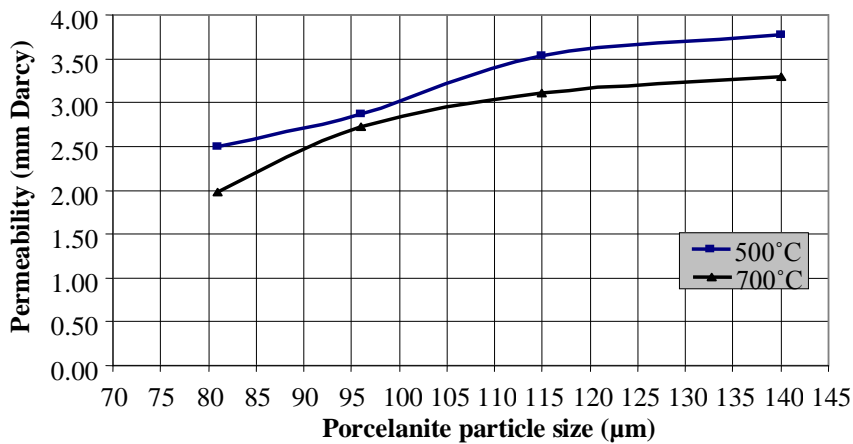


Fig. (7) Effect of porcelanite particle size on permeability of the filter samples.

Mechanical tests

1- Bending strength

Figure (8) shows the effect of porcelanite particle size on the bending strength of the filter samples with different temperatures of sintering. The maximum value for the bending strength is at minimum porcelanite particle size and decreases with increasing particle size. This behavior can be explained that the strength of the material is inversely varying with grain size as in equation of Orowan as follows:

$$\bar{\sigma}_f = k d^{-1/2} \dots\dots\dots(1)$$

Where:

$\bar{\sigma}_f$ = fracture strength,

K = constant depending on the material properties, and

d = grain diameter.

Also Figure (8) shows the effect of sintering temperature on the bending strength. Increasing of sintering temperature increases the strength of the material filter because, it has a lower porosity which agrees with other results (Meyers and Chewla, 1999).

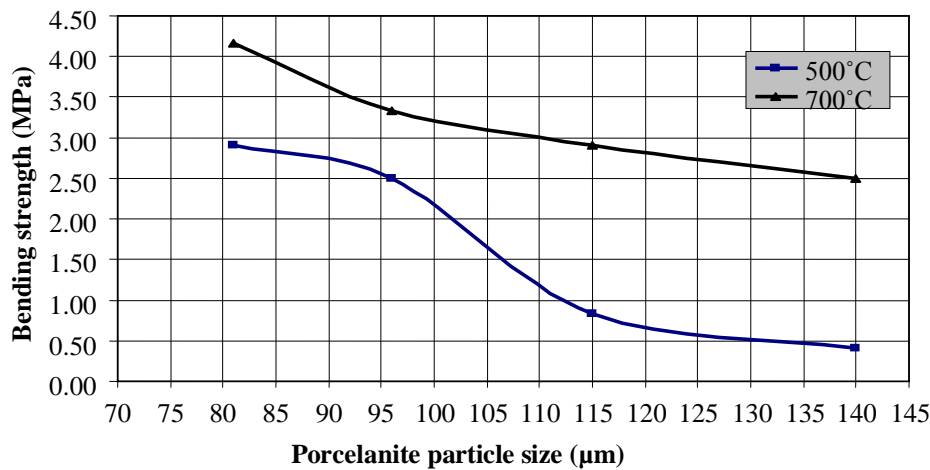


Fig. (8) Effect of porcelanite particle size on bending strength of the filter samples.

2- Compressive and tensile strength

Compressive and tensile strength of the filter have similar behavior as found in bending strength, where it decreases with increasing particle size and it increases with increasing sintering temperature as shown in Figs.(9) and (10).

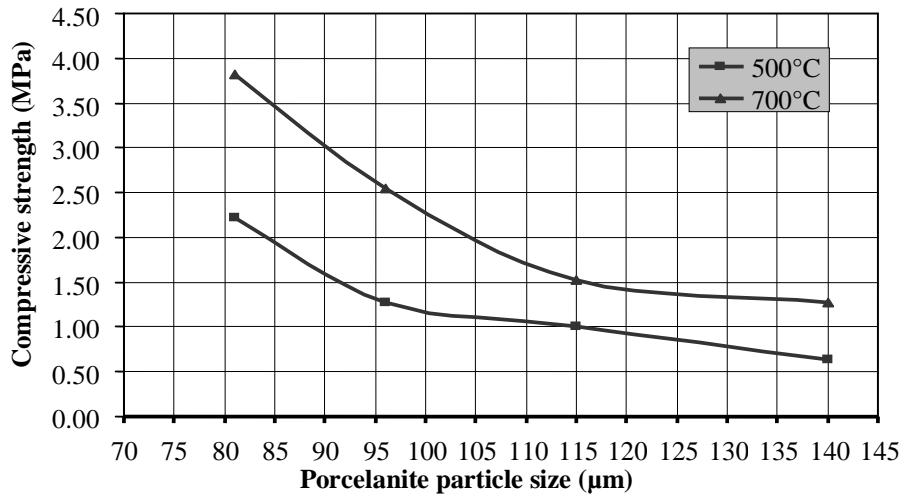


Fig. (9) Effect of porcelanite particle size on compressive strength of the filter samples.

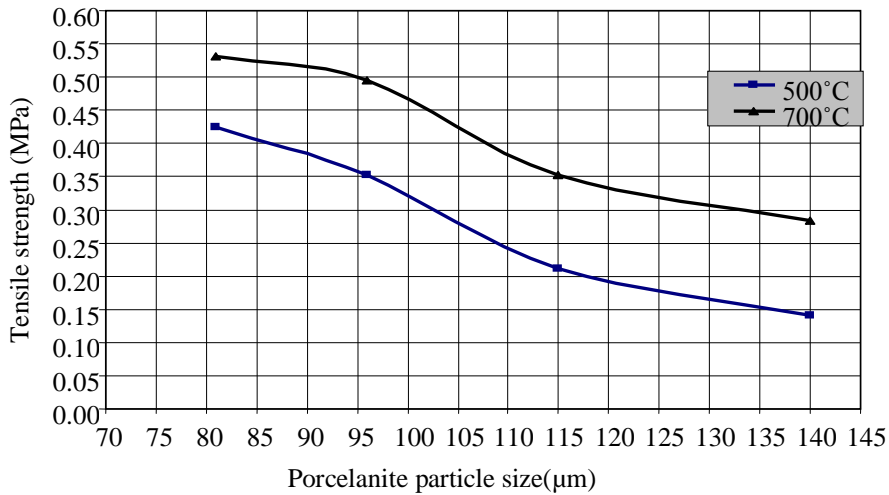


Fig. (10) Effect of porcelanite particle size on tensile strength of the filter samples.

Chemical tests

Determination of absorbency of pentachlorophenol solutions for the spectra

Figure (11) shows the effect of porcelanite particle size on the absorption spectra of pentachlorophenol solutions with different sintering temperatures. The absorption values of solutions were determined directly by using UV-Visible Spectrophotometer. The absorption values of solutions increase with increasing of porcelanite particle size, the reason of that is the efficiency of adsorption process of the filter samples. It may be noted from the experimental work that the concentration of contaminant decreases with decreasing particle size of the filter. This reduction is due to increase of adsorption process. The decreasing of the absorption process was a result of the absorbency proportional to the concentration according to Beer's law. Also Figure (11) shows the effect of sintering temperature on the absorption process of solutions. The increasing of the sintering temperature to specific limit will reduce the absorption values of solutions because of the increase of adsorption process. The increase of firing temperature to specific limit leads to convert the most carbonic

materials in porcelanite powder to gases of carbon oxides and its principal components oxides; this gives an increase of the area in filter sample, which can be busy by the adsorption. This leads to increase the adsorption process and to decrease the concentration of pentachlorophenol in the solution, which will reduce the absorption process of solutions.

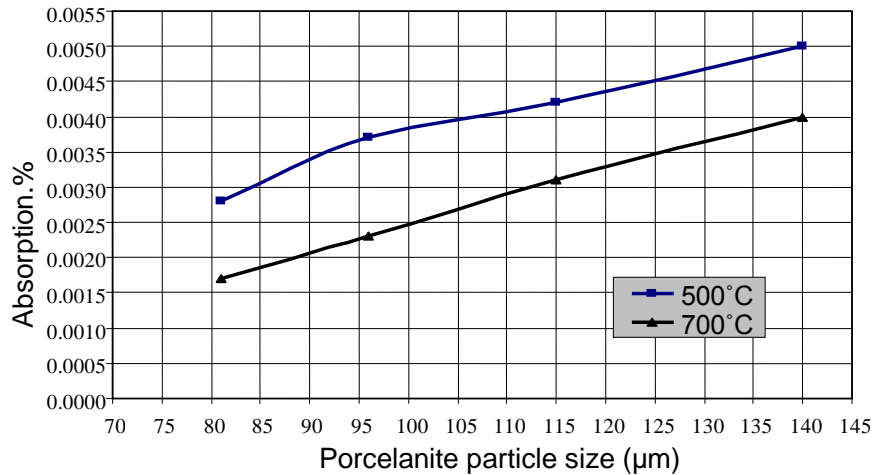


Fig. (11) Effect of porcelanite particle size on absorption spectra of pentachlorophenol solutions in the disk filter samples.

In cylindrical filter samples, the absorption values of solutions decrease in comparison with disk filter samples. The reason of that is the cylindrical filter samples have surface area, which subjects to the solution, larger than that of the disk filter samples. This leads to increase of adsorption process and decrease the concentration of pentachlorophenol in the solution, which will reduce the absorption process of solutions.

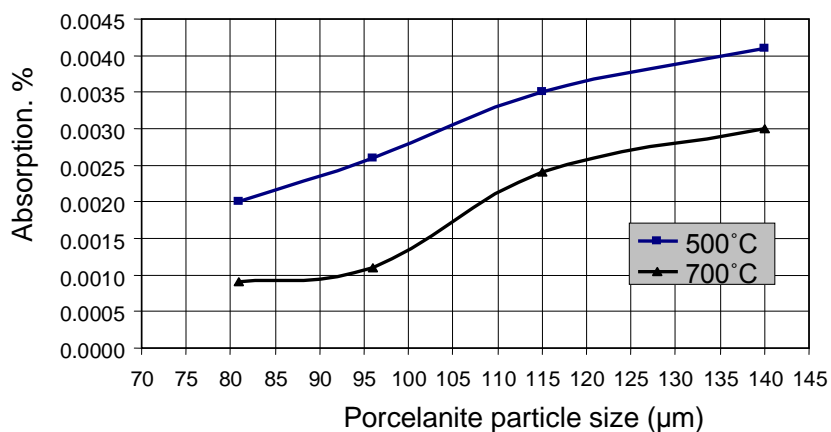


Fig. (12) Effect of porcelanite particle size on absorption process of pentachlorophenol solutions in the cylindrical filter samples.

Filter efficiency

Figures (13) and (14) show the effect of porcelanite particle size on the filter efficiency of removing pentachlorophenol with different temperatures of sintering for disk and cylindrical filter samples respectively. Efficiency of filter samples was increased by increasing the reduction of pentachlorophenol concentration. Filters

made of fine particles are most effective than that of coarse particles. The effect of sintering temperature is obvious from the figures (13) and (14). The filter efficiency depends in large part on temperatures of sintering for filter. Any increasing in sintering temperature to specific limit (appearance of the phase changes) will cause enhancing in efficiency of the filter. The reason of that is transfer the most carbonic materials in porcelanite powder to gases of carbon oxides and its principal components oxides.

Also the difference between the efficiency of disk and cylindrical filter samples is obvious from the figures (13) and (14) respectively. The reason of that is difference of the surface area, which subjected to the solution, between disk and cylindrical filter samples.

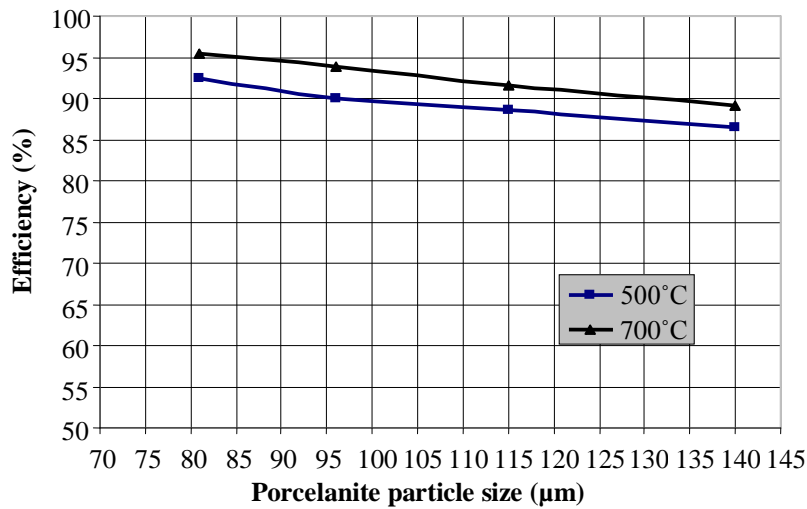


Fig.(13) Effect of porcelanite particle size on the pentachlorophenol removal efficiency of disk filter samples.

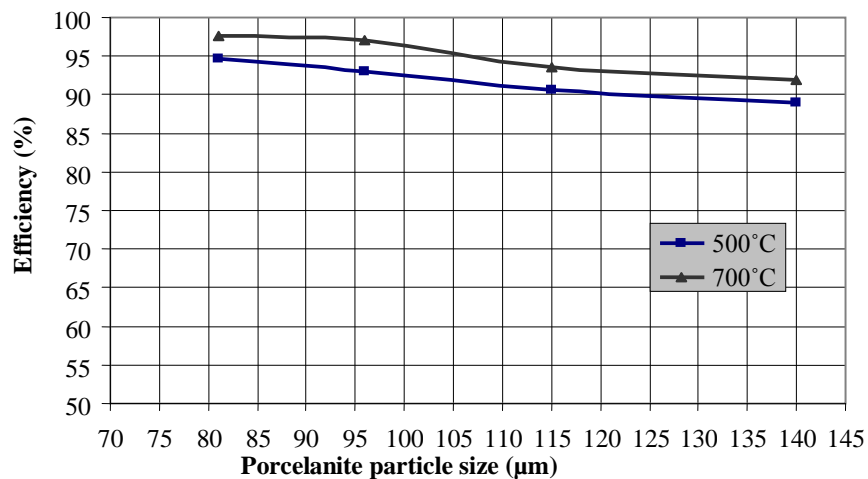


Fig. (14) Effect of porcelanite particle size on the pentachlorophenol removal efficiency of cylindrical filter samples.

Conclusions

Based on the results, the following conclusions are drawn;

- 1- Porosity of filter samples is increased with increasing porcelanite particle size and decrease with increasing the firing temperature. Where the largest porosity was (48 %) at sintering temperature of 500 °C at particle size of 125µm of porcelanite powder.
- 2- Density of filter samples is increased with increasing the firing temperature and decreased with increasing porcelanite particle size. Where the common density was (1.82) g/cm³ at temperature 700°C using the particle size (74)µm of porcelanite powder.
- 3- Permeability of filter samples increases with increasing the porcelanite particle size and decreases with increasing the firing temperature. Where the effective permeability was (3.75) mm darcy at temperature 500°C using the particle size (125)µm of porcelanite powder.
- 4- Maximum pore diameter of filter samples increases with increasing the porcelanite particle size. Where the maximum pore diameter was (182)µm at temperature 700°C using the particle size of (125)µm of porcelanite powder.
- 5- Increasing of the firing temperature for the porcelanite powder leads to change its color from white to rose color as result to phase transformations.
- 6- Both bending and tensile strength of filter samples increase with increasing the sintering temperature and decrease with increasing porcelanite particle size.
- 7- The efficiency of adsorption process increases with decreasing porcelanite particle size and increasing firing temperature. Where adsorption process was best at temperature 700°C.
- 8- Pentachlorophenol removal efficiency of disk filter samples reached 95.41% at temperature 700°C using the porcelanite particle size (74) µm, while pentachlorophenol removal efficiency of cylindrical filter samples reached 97.57% at the same conditions.

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