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Investigating the Mechanism of a Linen Filter for Sesame Oil Filtration at Different Pressures and Temperatures

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INFO

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ABSTRACT

Pressing is a common method to extract oil from oilseeds. In this method, no additives are added to the oil. The oil obtained using this method has impurities that make the color cloudy and reduce its shelf life. So, it is necessary to separate these impurities to increase the quality. In order to separate impurities from oil, a set including: pump, filter, flow control valve, pressure control valve and tank was designed and built. In this research, sesame oil was purified using a linen filter, and the compressibility of the cake and the effect of temperature and pressure on the efficiency of the filter were investigated. The compressibility coefficient for the cake in the linen filter was equal to 0.13, which shows that the porosity of the cake is relatively low. Variance analysis of linen filter efficiency data showed that temperature and pressure have no significant effect on the separation efficiency of this filter and the average separation efficiency of this filter was 76%, also temperature and pressure in the selected ranges did not affect the filter separation efficiency.

INTRODUCTION

Today, vegetable oils play a major role in supplying the basket of consumer commodities. These oils are extracted from different oil seeds. Seed pressing is the most widely used method to extract oil from oil seeds (Singh and Bargale, 2000). In this method, no additives are added to the oil, as a result, the obtained oil retains all its properties and vitamins. The oil produced by the pressing method contains a significant amount of plant waste material that makes the color of the oil cloudy. In addition, during storage, these materials are precipitated and the oil becomes two-phase, so it is necessary to separate these materials from the oil (Liauw *et al.*, 2008). Currently, these substances are separated from the oil to a certain extent by the sedimentation method and in some cases by using different filters.

Filtration is a mechanical method to separate the solid dispersed phase from the fluid continuous phase. A filter to separate solids from oil is selected experimentally based on its needs and cost. In this selection, filter characteristics including material, thickness, pore size and filter resistance are considered. In solid-liquid filtration, the separation performance is strongly influenced by the properties of particles, shape, distribution and size of particles (Adewoye and Ogunleye, 2012). The separated material is gradually sedimented on the filter and reduces the separation performance and reduces its useful life (Gryta, 2008).

Filters can be natural, synthetic (glass), fabric or non-fabric such as paper, ceramic, cellulose, artificial membrane, or in some cases porous metal, based on the need and cost of use. In the research, the effect of filter type and pressure on cake formation during microcrystalline cellulose filtration was investigated (Mattsson *et al.*, 2012). The obtained results showed that depending on the type of filter, the filtration resistance changes and increases the pressure and also the characteristics of filters and microcrystalline cellulose showed that clogging and blocking of filters do not happen.

Sediments formed on all types of filters in three ways 1) Forming the cake 2) Sediment on the wall and 3) Pore blockage occurs. In the first type, the particles are collected on the surface of the filter and a permeable layer (cake) is formed, which increases the hydraulic resistance and reduces the flow by increasing the thickness of the cake. To reduce the cake effect, it is necessary to increase the fluid pressure. On the other hand, increasing the pressure leads to more caked compression and reduces the efficiency of the filter. Investigating the amount of cake resistance in separation processes has been the focus of researchers. In the research, a constant pressure and constant flow rate system was used to obtain the cake resistance resulting from calcium carbonate sediment (Mahdi and Holdich, 2013). The results showed that by increasing the applied pressure, the calcium carbonate cake resistance is between 1×109 and 1×1011 m/kg.

In the second type, which is the sediment on the pore wall, the impurity particles collect on the pore wall and cause the filtered pores to narrow and reduce fluid passage. The third type of sediment, which is orifice blockage, occurs when the particle size is larger than

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the size of the filter pores and closes the inlet opening of the pores, thus stopping the flow of fluid. The studies of Tracey and Davis on the microfiltration of protein suspension showed that the size of the pores has an effect on the formation of the type of sediment, and initially the particles are sedimented on the wall and after the pores are narrowed, a cake is formed (Tracey and Davis, 1994). In another study, Grenier et al. investigated the sedimention mechanism under the influence of filter pore size. The results showed that the most clogging occurs in a filter whose pore size is equal to the size of impurity particles (Grenier *et al.*, 2008).

Cake compression in solid-liquid separation is a function of the size, shape and amount of particle accumulation on the filter and the compression coefficient of the material is between 0-1. The amount of incompressible particles is 0, 0.0-0.25 is low compressibility, 0.25-0.6 is medium compressibility, and 0.6-1 is high compressibility (Tiller *et al.*, 1987). Bourcier et al. (Bourcier *et al.*, 2016) investigated the compressibility of calcium carbonate cake in three geometric shapes: spherical, cubic and needle. The results showed that needle-shaped particles have the highest compressibility (0.92) and spherical particles have the lowest cake compressibility (0.40) (Bourcier *et al.*, 2016).

In the flow of fluids, especially oils, oil temperature and fluid pressure are effective. Therefore, the filtration performance is checked under the influence of fluid pressure and temperature. Ribeiro et al. investigated the effect of temperature and pressure on membrane flux, and separation of solvent from oil. The results showed that an increase in pressure causes an increase in flux and a decrease in separation, and an increase in temperature causes an increase in the separation flux in both polymeric and polysulfone membranes. The highest separation percentage (67.12) was obtained at the lowest pressure (15 bar) and temperature (45 °C) (Ribeiro *et al.*, 2006).

Nowadays, sesame oil is produced in large quantities by pressing method, and its impurities are separated by sedimentation method. If a suitable filter is used, the separation time can be reduced and the discontinuous separation process can be converted into a continuous separation method. The purpose of this research was to investigate the performance of a linen filter in separating sesame oil impurity. In this research, the filtration of sesame oil was done using the mentioned filter, and the efficiency of the filter was investigated at different pressures and temperatures.

MATERIALS AND METHODS

The sesame oil used in this research was purchased from one of the stores in Kerman. This oil was produced using a press machine and had vegetable particle impurity. To measure the amount of impurity, a sample of oil was placed in a centrifuge (SENTRIFUGE RST24) for 15 minutes at 3000 rpm and the separated impurity was measured using a digital scale with an accuracy of 0.01 g. The viscosity of crude oil was measured using a capillary tube viscometer and its density was measured by determining the mass of oil inside a graduated cylinder with a certain volume of oil. The viscosity and density were obtained as 0.038 Pa.s, 830 kg/m^3 respectively.

In order to separate impurities from oil, a set including: pump, filter, flow control valve, pressure control valve and tank was designed and built (Fig. 1). The oil tank was actually an oil bath where the desired oil temperature was set. The pump used was a positive displacement gear type that had the ability to create pressure in the range of 200-500 kpa and its flow rate could be adjusted from 1 to 2 liters per minute. The filter chamber was made of transparent glass and the filter used was of linen type with an effective surface of 6×10^4 m^2. On the way to transfer the oil to the filter, a valve before the filter in order to control the flow rate and a valve in the oil return way to the tank to adjust the pressure were used.

Flow rate through the filter

As mentioned in the introduction, its flow rate decreases with sediment of impurity on the filter. To check how the flow rate changes in the filter for sesame oil filtration; the filter was placed in the filter housing and after turning on the pump, the flow rate of the pump was measured during different stages of filtering. In each test, the required oil with specific impurity was poured into the system tank and after turning on the pump, the oil was transferred to the filter with equal pressure and flow rate. After passing through the filter, the pumped oil was collected in a container placed on the load cell and the mass of the filtered oil was recorded at different moments. The oil mass was converted to volume by using the calculated density. The volume of filtered oil was measured and its graph was drawn by using Excel software and were analyzed. In these experiments, the amount of oil impurity was 50 g/L the filtration pressure was 20 kPa, and the oil temperature was kept constant at 28˚c.

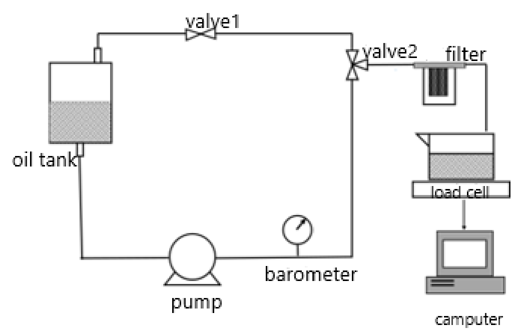

Fig 1. Filtration circuit

Compressibility of the cake

The compressibility of the cake is a phenomenon in which the resistance of the cake increases with the increase of applied pressure. If the sediment is cake type, the filter used is suitable for a filtration process, but the formation of the cake itself causes a gradual decrease in the passage of oil to some extent, this decrease can be compensated by increasing the pump pressure. But increasing the pressure of the pump causes the cake to condense and eventually stops the flow. Compressible cake has a very non-uniform structure with a soft skin (low hardness) and high porosity. This skin causes the pressure to have a small effect on the output flow rate of the filter (Tiller *et al.*, 1987). If the compressibility of the cake is high, increasing the pressure applied to the cake will reduce porosity and increase resistance to flow. In general, the compressible of cake is the less, it is more suitable for filtration, and the flow rate can be increased by increasing the pressure. Therefore, it is necessary to check the compressibility of the cake formed before choosing a filter. The relationship between the specific resistance of the cake (α) and the pressure value (p) is expressed by the following power relation (Tiller *et al.*, 1987):

$$\alpha=\alpha_0 P^n \quad (1)$$

Where, α_0 is the specific resistance of the cake at a pressure below 100 kPa (Grenier *et al.*, 2008) and n is the compressibility coefficient of the cake, which is a number between zero and one (Gupta and Yan, 2016). In general, the closer n to zero, the cake formed is incompressible and its effect on the filtration performance is less. Equation (1) was linearized, and with having the specific resistance of the cake at different pressures, the value of n can be estimated from Equation 2.

$$\ln\alpha=\ln\alpha_0+n\ln p \quad (2)$$

To check the compressibility of the cake, after turning on the pump and filling the filter tank using the pressure control valve, the pressure of the oil entering the filter was set to 20 kPa and the oil output was measured. Also, for 60 and 130 kPa pressure after adjusting the pressure of the oil entering the filter until the output decreases, the volume of the oil leaving the filter was measured and the flow rates were compared. Then the specific resistance value of the cake (α) was calculated and the changes of the cake resistance were checked. According to equation (1), the value of lnα related to lnp was determined in the diagram of lnα against lnp (Equation 2) and linear regression was passed between the points and the value of the slope of the line (n) was calculated. After calculating α_0 (specific resistance of cake per unit pressure) at pressure below 1 bar using equation (1), a relationship between cake resistance and working pressure was determined.

Investigating the effect of temperature and pressure on filter efficiency

Since temperature and pressure are two factors that affect the flow rate of a fluid and thus the efficiency of the filter, the effects of these two factors on the efficiency of the filter were investigated. To calculate the efficiency of the filter, the sample was taken of the filtered oil in each test (specific temperature and pressure) and separated the remaining impurity in the filtered oil using a centrifuge and determined its value with a digital scale with an accuracy of 0.1 gram. The efficiency (EB) of each filter in different working conditions was calculated using Equation (3):

$$E_B=\frac{M_1-M_2}{M_1}*100 \quad (3)$$

Where, M_1 is the mass of oil impurity before filtering and M_2 is the mass of oil impurity after filtering.

Therefore, the efficiency of the selected filter at three pressures (20, 60, and 130 kPa) and three temperatures (28, 38, and 48 °C) was investigated using factorial experiments in a completely randomized design with two replications. Analysis of variance was performed using Minitab software

RESULTS AND DISCUSSION

Flow rate through filter

Fig. 2 shows the results of filtration with the linen filter, where the volume of filtered oil has been measured over time. In the linen filter diagram, its volume gradually increases. The concave shape of the filtration curves shows that as the filtration time increases, the sediment increases and the resistance to flow increases. As a result, the volume of filtered oil decreases. This difference in the filtration process shows that before Sediment formation, the volume of filtration is greater than after Sediment formation. Because the impurity in the oil causes clogging and narrowing of the pores of filter. Clogging of the pores occur after 230 ml filtering of oil.

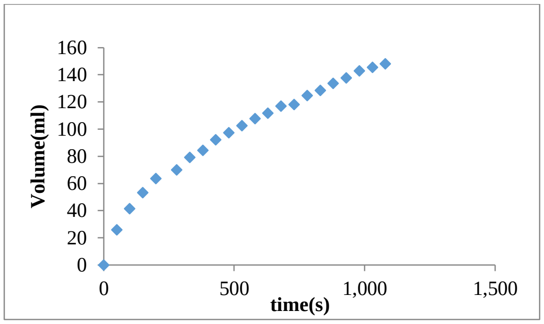

Fig 2. Experimental data of cumulative volume of filtered oil over time

Fig. 3 shows the results of oil filtration with a linen filter at three pressures of 20, 60 and 130 kPa, where the volume of filtered oil was measured over time. In general, the trend of the graphs is a linear increase. This filtration process in the filter shows the constancy of the filtration volume before and after the formation of sediment. The initial rapid increase in the filtration rate of the linen filter at pressures of 20, 60, and 130 kPa was up to 30, 50, and 70 ml, respectively, which indicates an increase in filtration rate with increasing pressure. With the passage of time, this filtration difference gradually increased and the filtration rate reached 120, 180, and 260 ml at the end of pressures of 20, 60, and 130 kPa, respectively. The endpoints also indicate the increase in filtration volume with increasing pressure. Although the graphs have a gradual increase, but from the last point that is clear in the figure, the volume decreases and remains constant.

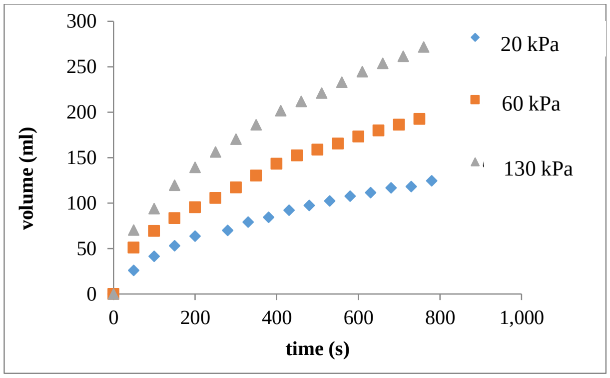

Fig 3. Experimental data of cumulative volume of filtered oil over time at pressures of 60, 20 and 130 kPa

Effect of pressure on cake resistance and filter

According to the equation of the passed line from the experimental data of the linen filter at different pressures based on the cake formation model (Table 1), Since the increase in pressure reduces the porosity in the cake, the resistance value of the cake increases with the increase in pressure and also the resistance of the filter is reduced. Because the increase in pressure causes the volume of filtered oil to increase in the initial times of filtration. For this reason, the value of B in Table 1 has decreased, and as a result, the resistance of the filter, R_S in Table 2, has also decreased.

Table 1. Linear equation of experimental data of linen filter at three pressures of 20, 60 and 130 kPa

Pressure (kPa)	Linear equation	A	B	R^2
20	$y = 5\times10^{10}x + 540026$	5×10^{10}	540026	0.98
60	$y = 2\times10^{10}x + 154240$	2×10^{10}	154240	0.98
130	$y = 1\times10^{10}x + 31968$	1×10^{10}	31968	0.99

Table 1. Filter resistance and cake resistance at three pressures and values of lnα and lnp

Pressure (kPa)	α*10^7 (*m/kg*)	$R_S(m^{-1})$	*lnα*	*lnp*
20	37.8	102320	19.75	9.9
60	45.4	87673	19.93	11
130	49.2	39371	20	11.77

Compressibility of the cake

According to equation (4), the high compressibility coefficient of the cake increases the resistance of the cake against the passage of the filtered current. The results of compressibility determination in fig. 4 show that according to equation (2), the slope of the line (n) passed through three points related to filtration at different pressures is 0.13. This value indicates that the cake resulting from sesame oil impurity is a cake with low compressibility and a uniform structure with low porosity (Tiller *et al.*, 1987). Therefore, the flow rate was increased by increasing the pressure. The relationship between the pressure and the resistance of the cake resulting from the impurity of sesame oil with a compressibility coefficient of 0.13 can be expressed as follows for the sesame oil filtration system:

$$\alpha=9.9E7(P^{0.13})$$

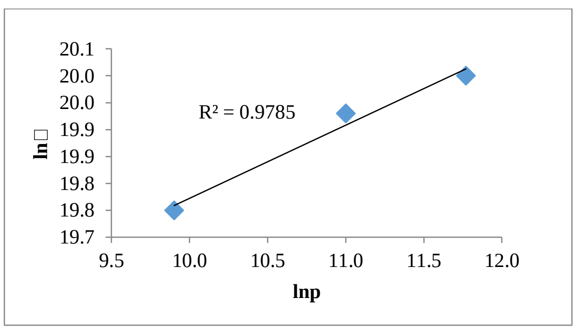

Fig 4. Compressibility diagram of sesame oil impurity cake in the pressure range of 20 to 130 kPa

Filter efficiency

Analysis of the variance of the test data related to the efficiency of the linen filter was investigated under the influence of temperature and pressure factors, the results of which are shown in Table 3. The results showed that temperature and pressure in the said range did not have a significant effect on the efficiency of the linen filter. The effect of temperature in the filtration process has only reduced the viscosity and increased the filtration rate (Thomassen *et al.*, 2005). Pressure also increased the speed of filtration and did not made change on the filter efficiency. The linen filter had an efficiency of 76% in separating impurities from sesame oil.

Table 3. Analysis of variance to investigate the effect of temperature and pressure on the efficiency of filters

Sources of changes	Degrees of freedom (df)	Sum of squares (ss)	F	P
Temperature (T)^{ns}	2	17.36	0.19	0.83
Pressure (P)^{ns}	2	17.36	0.19	0.83
T*P^{ns}	4	164.93	0.90	0.50
Error	9	411.10		
Total	17	610.26		

CONCLUSIONS

Investigations done on sesame oil filtration using Linen filter and results of variance analysis of filter efficiency data showed that this filter has 76% separation. Pressure increased the speed of filtration and did not made change on the filter efficiency also, the amount of cake resistance increased with increasing pressure and the filter resistance decreased. Also, temperature and pressure in the range of 38, 28, and 48 °C and 20, 60, and 130 kPa, respectively, had no effect on the separation efficiency.

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