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A Theoretical Analysis of the Plate Heat Exchanger's Ideal Operating Conditions for Producing Soybean Milk

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Abstract: Heat exchanger optimization is a very efficient thermal design inquiry. The goal of the research is to determine an optimal channel flow velocity as well as an optimal total plate number based on overall information on the effectiveness of employing chilled water to cool soybean milk. Heat transfer coefficient, Prandtl number, Reynolds number and pressure drop measurements were applied for milk and water. The rheological properties of soybean milk have been investigated at various temperatures (5, 10, 30, 50, 70 and 90 °C). The operational circumstances of PHE in soybean procedures were investigated at different numbers of plates, flow rates and flow velocities. Based on the present study, total substances showed non-Newtonian pseudoplastic conduct in any respect at any temperature and the power law model has a decent correlation. The cost estimation of the plate heat exchanger was observed at the lowest flow velocity of (2.25) m/s and number of plates is 17.

1 Introduction

Soymilk is one of the most famous drinks these days because of its nutritive and beneficial properties (Ayushi et al 2018). It is a plant-based beverage and it is a staple of East Asia. The reason for its popularity stems mainly from its high protein content. Soybean milk was prepared in this study and its qualities were assessed using several instruments. Soymilk is a cheaper and astonishingly flexible food high in protein made with soybeans. It comes from a seed and is a white fluid. Unlike other sources of protein, milk has very little fat and no cholesterol. (Especially saturated fat.) The high value of protein is similar to that determined in chicken. It is also beneficial for dieters because of its few calories. It is also a great meal for kids, aged and lactating ladies because it contains vegetable protein, which is likely to be very nourishing and simple to digest.

Soymilk, besides its products, is the most expensive source of protein and its derivative, tofu, "soya paneer," creates delectable dishes like matar paneer and palak paneer. Additionally, there are sandwiches, pakoras, patties and soy burgers. Additionally, it is extensively utilized in desserts.

It's an excellent source of potassium and may also be strengthened by adding the vitamins B-12, D and A. Along with calcium. It has a similar amount of protein to cow's milk but fewer calories than whole milk and around the same number of calories as milk with 1% or 2% fat. There are either very few or no stable fats in it (Čech et al 2022).

In general, soymilk includes approximately 3.6% proteins, 8–10% total solids, 2% fats, 2.9% carbs and 0.5% ash (Basharat et al 2020).

The rheological properties are seriously imperative for producing things like warm juice, burning chocolate and creamy coffee, in which the rheological characteristics remain taken into consideration as a pointer to the value of the item. Designs within side methods include fluid flows, pump size, abstraction, or else filtration is needed. Understanding statistics for rheology and the produce's rheology is essential for the evaluation of flow circumstances in diverse food processing procedures (Marcotte et al 2001).

In several component operations, including employing pipelines, impelling, mechanical divisions, boilers, freezing, evaporating, ventilating and departing, it is important to understand the rheological features of the food. This has been covered in several studies (Sopade et al 2003).

To be capable of studying the rheological behavior of any material, one first must understand the overall terminology for fluid flow. There are two types of fluid: Newtonian and non-Newtonian. A non-Newtonian fluid is unique in that its properties are changed from Newtonian fluids, such as apparent viscosity variations with applied stress or powers. The connection between the shear stress and the shear rate in non-Newtonian fluids is non-linear (Barman et al 2016).

The observation of non-Newtonian flow and heat transference through heat exchangers with plates is of countless significance due to food production, as diverse procedures consist of this tool, including refrigeration and heating uses for milk, citrus juices and pulp from tropical fruit sterilization techniques. A major PHE benefit is their relationship's adaptability, ease of protection, washing and excessive alternative heating (Carezzato et al 2007).

A heat exchanger is a device that transmits energy from a hot fluid to a cold fluid. However, the fluid is transient *via* the heat exchanger and the temperature of the fluid changes along with the HE's (heat exchanger) distance. The heat exchanger (HE) is a method to recuperate hotness among the two procedure streams. The use of heat exchangers is important in power plant life, preservation, air-conditioning structures and space (Zohuri 2017).

PHEs are extensively used within manufacturing and are used expansively in numerous industries, including conservation, air conditioning, nutrition, chemistry and the production of energy structures. Because of the new enhancements to the plating scheme, besides different mechanical reliability features, heat exchanger plates (PHEs) are currently being utilized in height pressure requests as well. Heat exchanger plates are categorized in the class of compacted strategies because of their slighter capacity-to-surface area ratio **(**Ayub et al 2019).

A plate heat exchanger commonly involves a number of ridged or stamped metallic plates in joint contact. All plates have four opening portions, for example, apertures for input and outlet, in addition to closures calculated to straighten the fluids in alternative flowways. Nearby plates shape the flow passageways so that the 2 streams change heat even temporarily over alternative passages. They are commonly utilized in various commercial applications, providing efficiency, affordability, design flexibility and small size as indicated in **Fig 1 (**Zhang et al 2019).

Performance development and optimization of those mechanisms may be followed through assessing some of the diverse metrics, founded upon the necessities of both their application and exact use. For example, those mechanisms may consist of element physical savings, dimension decreases, production price decreases, pumping control decreases or a few mixtures of those objects. Although some of these metrics stay moderately straight-forward in idea (for example, price and dimensions decrease), heat capability is affected by a lot of parameters, excluding the heat exchanger's geometry, the inlet circumstances at temperature, velocity, moisture on the airside and the inlet circumstances (temperature, pressure and mass fluidity) in relation to the refrigerant **(**Ploskas et al 2018).

There are certainly uncommon difficulties in actual creation that require a single goal. Once those objects are incompatible, not only one answer may absolutely satisfy completely unbiased activities concurrently.

Within these bags, trading off among two or more impartial occupations is sought to bring the optimum choice. Therefore, a sensible approach to a multipurpose problem is towards a research group of answers; it all accomplishes the goals at an appropriate level without being conquered through another resolution **(**Konak et al 2006).

Heat exchanger optimization remains a compromise between pressure drop and heat transmission. A source with a quicker flow velocity often has a higher heat transmission, resulting in a smaller area for heat transmission and as a result, a cheaper capital expense. A developed velocity, on the other hand, could induce

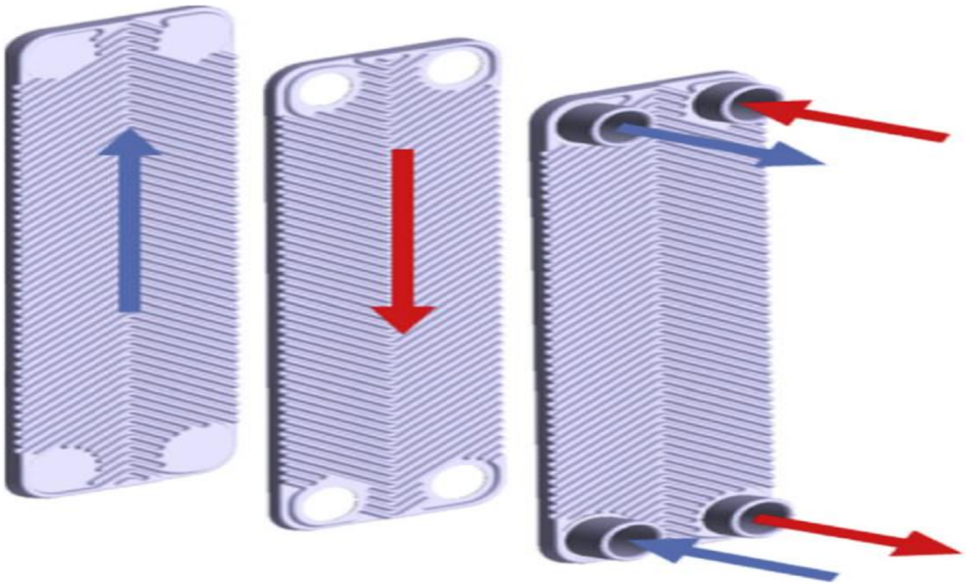

Fig 1. Schematic of PHE's alternate passageways for hot and cold fluid flow (Sarraf et al 2015)

a pressure drop, increasing power consumption and raising the cost of power (Muralikrishna and Shenoy 2000)

The goal of the present study is to determine the best working conditions for HE with plates for processing soy milk.

2 Materials and Methods

2.1 Processing of Soybean Milk

Soya milk has been produced by the Food Technology Institute (ARC), Ministry of Agriculture (Egypt), as shown in **Fig 2** using the subsequent technique:

Pasteurization and sterilization are split into two steps, in addition to homogenization and boiling. Pure soy milk that has been cooked in a double-jacketed container through the jacket's saturated steam The soymilk is allowed to reach its desired temperature range of 90 to 100ºC. Currently, a few stable flavors are available; for example, stabilizers include cocoa, fat (corpulence) and dietary reagents. This method does not only eliminate the volatile off-tastes, but it also additionally deactivates the inhibitors of trypsin as well as some enzymes not yet deactivated, which may have resulted in the development of an ill taste during storage.

- Soybean milk between 90 and 100ºC after the boiling degree is formerly pumped to 2-level homogenizers, disturbances from the homogenizer particles right all the way down towards forming a homogeneous mix so that the fluid substances may remain mixed together extra evenly.
- PHE creates homogeneous soymilk at temperatures ranging from 90ºC to 4ºC; the number of plates often utilized ranges from 9 to 11 plates. To chill soybean beans, cool water at 1ºC was used. Currently, the flow of both hot and cold fluids exists in opposite directions.
- Soybean is then stored in a storage container at 4 degrees Celsius; at this point, flavors such as vanilla are added and it is now packed (Ayushi et al 2018).

2.2 Rheological Properties of Soya milk

Shear rate and shear stress, in addition to the viscosity of soymilk soft drinks, have been determined using a Brookfield rotational viscometer version (HA DVIII Ultra) (Brookfield Engineering Laboratories, Inc.). The temperature was maintained by using a thermostatically controlled water bath **(**Alpaslan and Hayta 2007).

The samples of soybean milk were taken during the processing and rheological factors such as viscosity, shear stress and shear rate of soybean milk were measured at dissimilar temperatures by a Brookfield Engineering Labs rheometer.

The juice was placed in a minor sample adapter and then a constant-temperature water bath was utilized to maintain the desired temperature. Rheological properties measurements were made at dissimilar temperatures (5, 10, 30, 50, 70 and 90ºC) using the spindle SC4-21 rotating at different rpm (10–100 rpm) and different shear rates (46.5–220.7 s^{-1}), as shown in **Fig 3**.

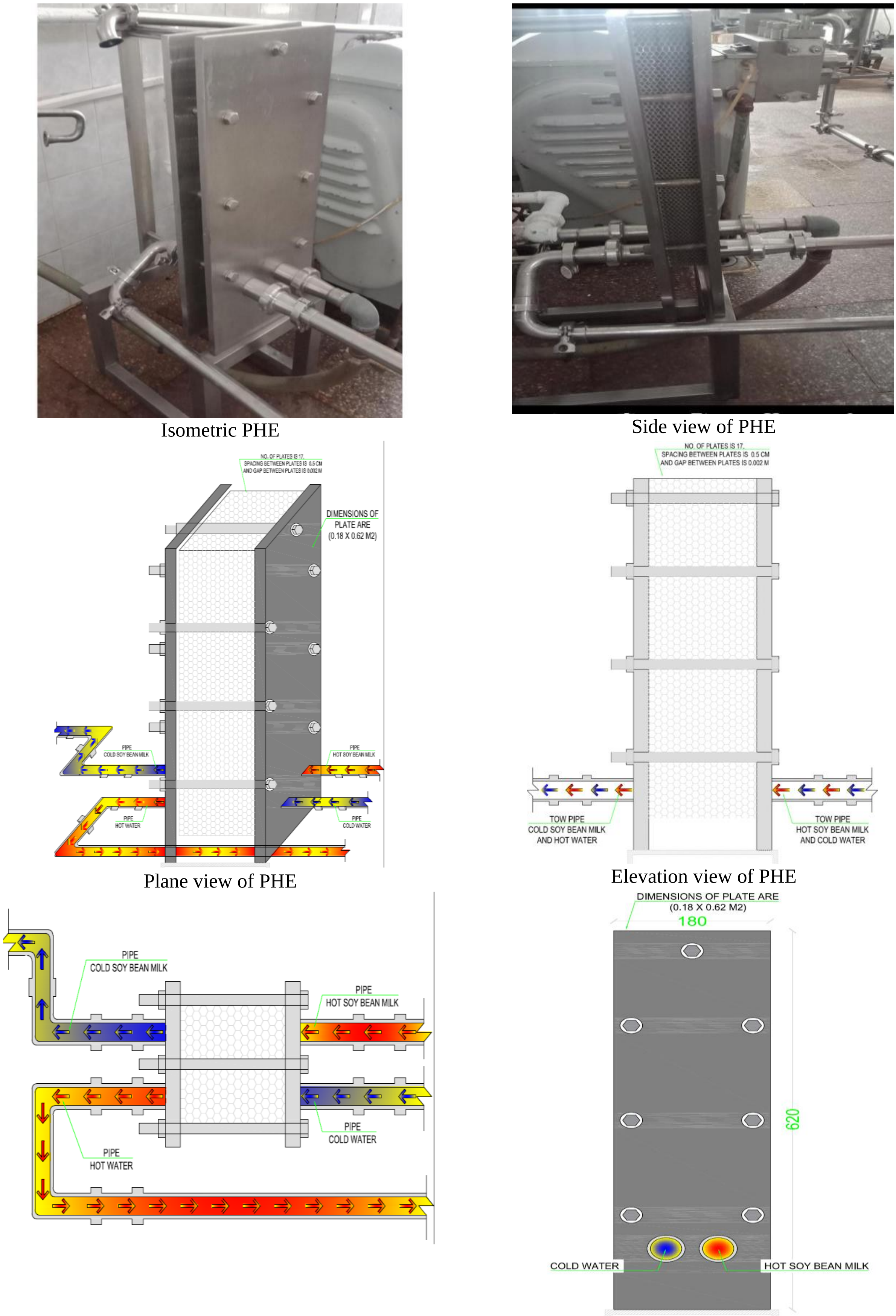

Fig 2. Plate Heat Exchanger in Soybean unit

Fig 3. Brookfield Rheometer (Brookfield Engineering Laboratories 1998)

2.3 Procedure for Calculation

Simple heat transfer calculations are used and discussed below to help you understand the results of experiments.

The heat exchanger rate has been calculated for a heat exchanger plate's hot in addition to cold sides:
(Cabral et al 2010)

$$Q = m_h C_{p,h} (T_{(h, in)} – T_{(h, out)}) \quad (1)$$

$$Q = m_c C_{p,c} (T_{(c, out)} – T_{(c, in)}) \quad (2)$$

The fluid's attributes (ρ, μ and Cp) remain estimated by existing bulk temperatures; the following calculation was made by Kakaç et al (2020)**:**

$$T_{c,b} = \frac{(T_{c,in} + T_{c,out})}{2} \quad (3)$$

$$T_{h,b} = \frac{(T_{h,in} + T_{h,out})}{2} \quad (4)$$

Zohuri (2017) stated that to compute the total coefficient of heat transfer (UD), the entire surface area as well as the logarithmic average temperature ought to be identified, as the intended mean temperature logarithmic is:

$$\Delta T_m = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln(T_{h,in} - T_{c,out})/(T_{h,out} - T_{c,in})} \quad (5)$$

The actual rate of heat transfer (Q) may be decided by:

$$Q = U_D A \, \Delta T_m \quad (6)$$

In a PHE, the active heat transfer area, A, has been determined by multiplying the following:

A = (No. of plates - 2) × (area per plate) (7)

Reynolds number (Re) could describe a dominant flow that has obtained equivalent diameter, mass velocity and viscosity (Liang et al 2017):

$$Re = \frac{G D_e}{\mu} \quad (8)$$

The mass velocity (*G*) and equivalent diameter (D_e) channel of the heat exchanger plate is described in the following calculation according to Abou Elmaatya et al (2017):

$$G = \frac{m}{A_f} \quad (9)$$

$$D_e = \frac{4b * w}{2\,(b+w)} \quad (10)$$

The heat transfer coefficient (hi) and the Prandtl number (Pr) were acquired by the next equations (Moreau 2021):

$$Pr = \frac{\mu\, Cp}{K} \quad (11)$$

$$h_i = 0.2536 \frac{K}{D_e} Re^{0.65} pr^{0.4} \quad (12)$$

The convective coefficient (U_D) was found according to Gut and Pinto (2004):

$$\frac{1}{U_D} = \frac{1}{U_C} + Rd \quad (13)$$

Where,

$$\frac{1}{U_C} = \frac{1}{h_i} + \frac{1}{h_{io}} \quad (14)$$

2.4 Cost Estimate

The total annual cost is the sum of the capital expenses, operating costs and system upkeep costs over the course of a year.

The cost of PHE may be calculated by the next equations (Najafi et al 2011).

2.5 Cost of Energy

The following computation determines the annual energy costs for PHE for both hot and cold sides: (Peter and Timmerhaus 1991).

$$\text{Total energy cost} = \left[CII * \frac{\Delta P}{\eta} * \frac{\text{operating hours}}{\text{year}} \right]_h + \left[CII * \frac{\Delta P}{\eta} * \frac{\text{operating hours}}{\text{year}} \right]_c \quad (15)$$

2.6 Pressure drop calculations

The following formulae can be used to calculate the jf (friction factor) of a plate heat exchanger's surface: (Najafi et al 2011)

$$jf = 0.6\, Re^{-0.3} \quad (16)$$

According to Miura et al (2008), heat exchanger pressure drop is made up of two parts: pressure drop inside canals because of friction and pressure drop in harbors. As a result, a decrease in friction pressure for both hot and cold fluids may be observed.

The following pressure drop inside the plates was intended:

$$\Delta p = 4jf \; \frac{L\,P}{D_e} \left[\frac{\rho\, \upsilon_c^{2}}{2}\right] \quad (17)$$

Where,

$$\upsilon c = \frac{\text{volumetric flow rate}}{w * b * N_c} \quad (18)$$

The number of canals for every pass, Nc, for every fluid, is clear such as:

$$Nc = \frac{N_p - 1}{2} \quad (19)$$

Wherever Np is the overall number of plates in the exchanger, there is the equivalent number of channels for the two fluids in each pass. Ports pressure drop was intended by way of Turgut (2017)**:**

$$\Delta p = 1.3 \frac{\rho\, \upsilon_{port}^2}{2} Np \quad (20)$$

Where,

$$\upsilon_{port} = \frac{m}{\rho\, A_{port}} \;, A_{port} = \frac{\pi\, d_{port}^2}{4} \quad \text{and} \quad d = 0.036 \text{ m} \quad (21)$$

2.7 Fixed Cost

2.7.1 Purchased Cost

According to Najafi et al (2011), the cost of a heat transfer is assumed through accomplishing equivalences:

The constant cost = (purchased cost) (1+0.6) (0.15) (22)

Purchased cost = 75228.2($A^{0.5053}$) (23)

As A is the region for heat transmission in meters, (1+0.6) installation and maintenance costs and 15% depreciation.

2.8 Annual Total Cost

In addition to fixed costs, the annual total cost includes energy costs.

Total cost = (Cost of energy + Fixed cost) (24)

2.9 A Case Study

The optimization of PHE operating conditions for soya milk production.

Through the development of energy consumption, energy saving has become a priority. One of the most important energy consumers is the heat exchanger. Heat transfer technology is one of the most effective and economical ways to improve heat transfer efficiency.

It was demonstrated through the use of a research case that it was possible to establish the best explanation for the given heat load.

- It's necessary to cool (1.416 k_g/s) from 90 to 4°C of soymilk; by cooling water (12.358 k_g/s) to (1˚C), performance PHE data are obtainable (ARC, 2018), as presented in **Table 1**.
- Sizes of plate (0.18 × 0.62 m^2)
- Space between plates (0.5 cm).
- gap between plates, (b=0.002 m)

Table 2 show the physical properties of hot and cold fluids and are evaluated at bulk temperatures according to equation 3 and 4.

Table 1. Performance information of PHE used in soy-bean milk processing

Property	Soy milk	cold water
Temp. at the inlet, ºC	90	1
Temp. at the outlet, ºC	4	11
Mass flow rate, (K_g/s)	1.4166	12.358
Equivalent diameter in (m)	0.00395	
Reynold's No. (Re)	657.08	20544.65
Convective of the heat transmission coefficient, h_i, (K_J/m.s. ºC)	9760.99	64320.57
Overall heat rate, (U_D), K_J/m.s. ºC	1392.76	
Heat rate in (K_J/s)	32504.21	
No. of plates	11	
Velocity in (m/s)	3.82	

Table 2. Display physical fluid characteristics of chilled water and soy milk (μ, ρ, K and C_p)

Property	A hot soya fluid	A cold-water fluid
μ in (K_g/m. s)	(4.731×10^{-3})	(1.32×10^{-3})
P in (K_g/m^3)	1020	1000
Cp in (J/K_g. k)	4240	4180
K in (W/m. K)	0.52	0.64

2.9.1 Plate Heat Exchanger

PHE is constructed comprised of numerous metallic plates and fluids that pass between the plates to transport heat. The fluid's potential exposure to a larger surface area increases when it is disseminated around the plate. Plate heat exchangers provide for A low minimum temperature is widely utilized to improve the coefficient of heat transfer and effectively quantify energy savings.

PHE is a key piece of heat recovery equipment that uses corrugated plates to transfer heat from hot to cold fluids. The plates have a substantial surface area per volume for heat transfer.

3 Results and Discussion

3.1 Soymilk's rheological properties

The results obtained are exemplified in the later visions.

3.1.1 Shear stress and shear rate relations

Shear stress and shear rate values are plotted in **Fig 4** for soybean milk at different temperatures (5, 10, 30, 50, 70 and 90 °C). The results showed that all the materials exhibited non-Newtonian pseudoplastic behavior at all temperatures examined, where stress is a linear function of shear rate.

Shear Stress: shear rate data was discovered to correspond well to the constitutive calculation (Imeson 1992).

$$\tau = k\gamma^n \quad (25)$$

Where, τ: Shear stress, P_a.
K: Plastic viscosity (consistency index), P_a. s.
γ: Shear rate, s^{-1}.
n: Flow behavior index.

The fluctuations of (k) values at temperatures between (5-90ºC) can be referred to as the change in the structure of soybean milk with temperature as it consists of pectin, which can be affected by temperature and flow behavior indices (n) did not show a decent trend through temperature.

Fig 5 and **Table 3** should be plotted to analyze the consistency index (k) and flow behavior index (n). The fluctuations of (k) values at temperatures between (5-90ºC) can be referred to as the change in structure of soybean milk with temperature, which can be affected by temperature and flow behavior indices (n).

3.1.2 Effect of temperature on the apparent viscosity of soybean milk

Fig 6 displays the difference of viscosity with temperature (5, 10, 30, 50, 70 and 90°C) by different shear rates of (46.5 - 220 s^{-1}).

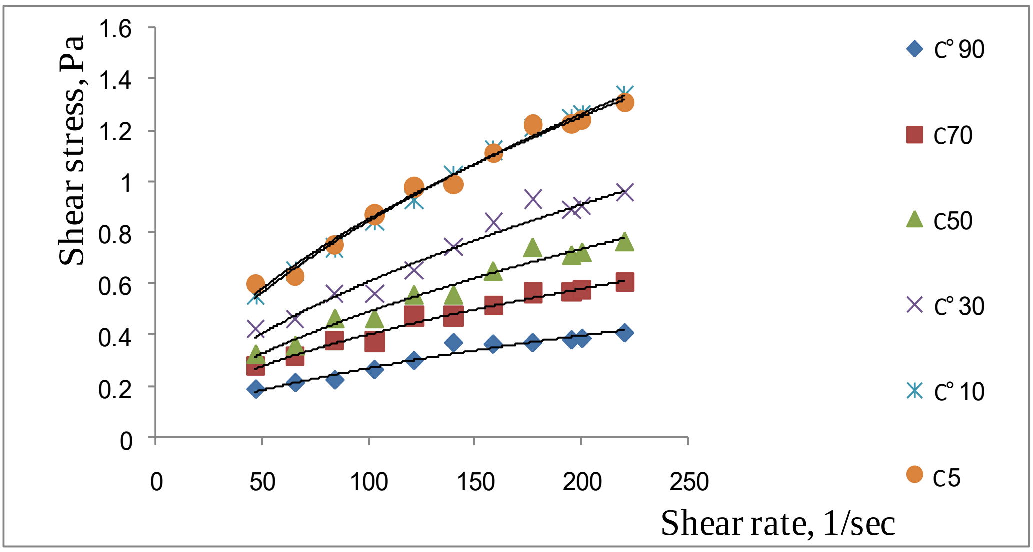

Fig 4. Sh. stress and sh. rate relationships at different temperatures

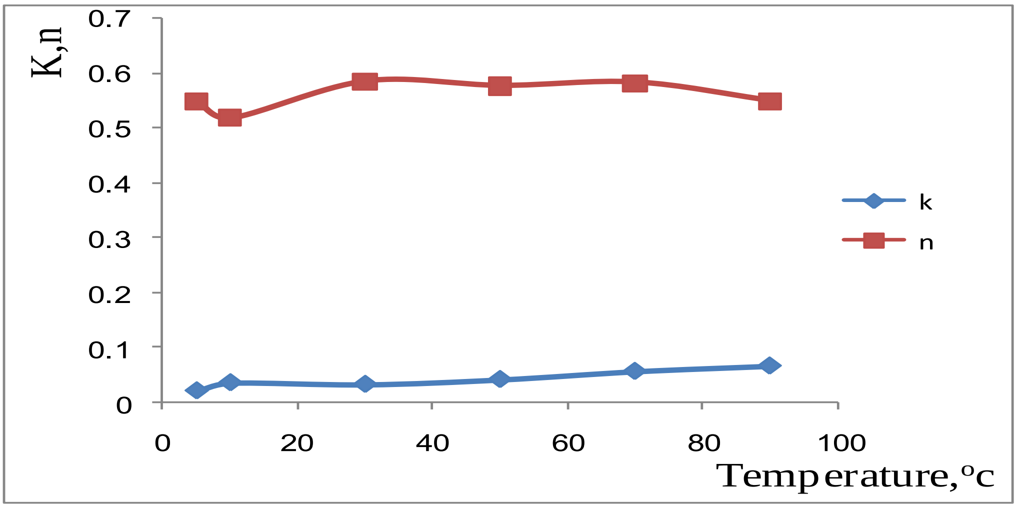

Fig 5. Indexes measuring consistency versus temperature and flow behavior.

Table 3. Constancy index and flow behavior index at various temperatures

Temperature, °C	K	n
90	0.067	0.55
70	0.057	0.583
50	0.042	0.577
30	0.033	0.585
10	0.036	0.519
5	0.021	0.548

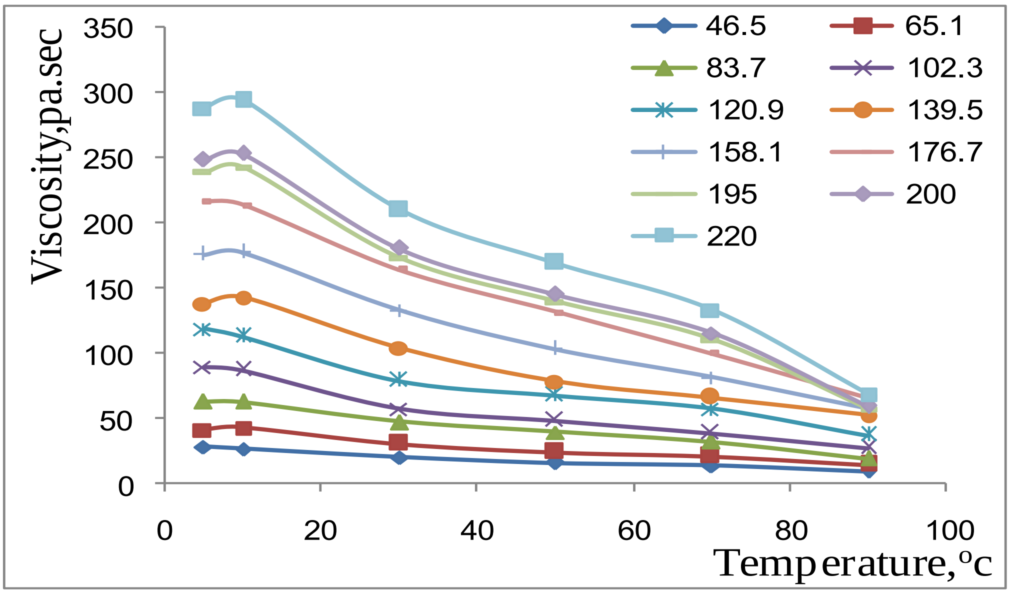

Fig 6. Relationship between apparent viscosity and temperature of soybean milk

In any shear rate investigation, the results showed that increasing temperature reduces the apparent viscosity of soybean milk.

Variations in viscosity across a range of temperatures can be explained by the local aggregation of discrete particles throughout the spindle, which can induce an untrue rise in viscosity. **Fig 6** depicts how viscosity decreases as temperature rises.

According to several writers, the Arrhenius equation accurately explains the relationship between liquid viscosity and temperature (Al-Arfaj et al 2017).

$$\mu = A\ e^{(Ea/RT)} \quad (26)$$

Otherwise

$$\ln \mu = \ln A + (Ea / RT) \quad (27)$$

Where (A) is a constant and (R) is gas constant, 8.314 ($J.k^{-1}.mol$), also (Ea.) is the activation energy, (k_J/k_g mol) and (T) is temperature, K, as shown in **Table 4.**

Fig 7 depicts the effect of temperature on the apparent viscosity of soymilk using the Arrhenius equation, with the best-fit lines drawn. A similar pattern was seen at all the studied shear rates.

3.1.3 Study of the optimum operating conditions of the PHE

The best plate heat exchanger characteristics based on the lowest total annual cost have been determined.

Table 4. Activation energy at different temperatures

Shear rate, S^{-1}	Activation energy, Ea k_J/k_gmole
46.5	10716.75
65.1	10392.5
83.7	9469.646
102.3	11340.3
120.9	10633.61
139.5	9976.8
158.1	10808.2
176.7	11182.33
195	12895.01
200	12903.33
220	12944.9

The entire cost of a plate heat exchanger varies depending on the application and includes power and heat transfer area costs. Variable heat exchanger components are determined by heat transmission area, flow velocity and pressure drop. Power usage is proportional to the running cost.

In most practical applications, heat exchangers are operated according to specific necessities, where pumping energy consumption is essential to transfer fluid flow over passages in low-pressure heat exchangers. **Figs 8** to **12** demonstrated the relative importance of volumetric flow velocity, annual cost area and power cost in addition to annual total cost.

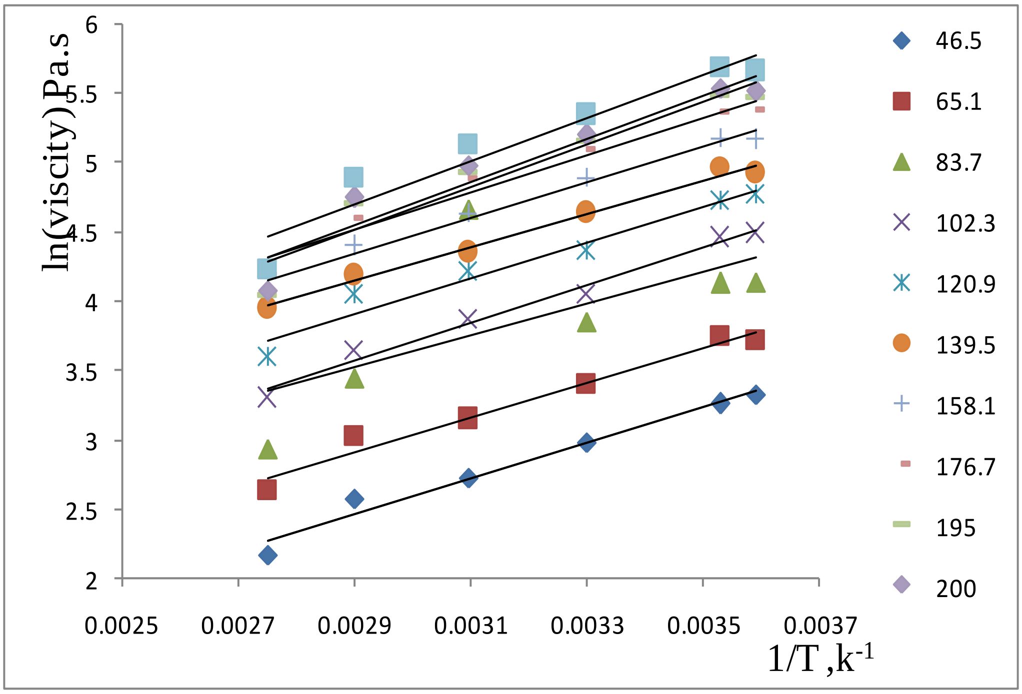

Fig 7. Relation between 1/T and ln (viscosity) at shear rates (46.5 – 220 s^{-1}) of soybean milk.

Fig 8 illustrates the relationship between flow velocity, power cost, area cost and annual total cost. The consequences show that as flow velocity increased, power costs climbed but area costs decreased. In comparison to the example study, the optimal flow velocity of soy milk is close to 2.25 m/s at a total annual cost of 35,000 EGP.

Fig 9 illustrates the relationship among flow velocity, power cost, area cost and annual total cost. Findings show that while area cost reduced with increasing flow velocity, power cost increased. In contrast to the previous study, the optimal flow velocity of soybean milk was 2.25 m/s at a total annual cost of 25,000 EGP.

Fig 10 illustrates the relationship among flow velocity, power cost, area cost and annual total cost. Findings demonstrate that as flow velocity increased, power costs climbed but area costs decreased. In contrast to the previous study, the optimal flow velocity of soybean milk is 2.25 m/s at a total annual cost of 27500 EGP.

Fig 11 illustrates the relationship among flow velocity, power cost, area cost and annual total cost. Findings demonstrate that power costs rise as flow velocity increases, whereas area costs fall as flow velocity rises. In contrast to the example study, the optimal flow velocity of soybean milk is around 2.25 m/s at a total annual cost of 33500 EGP.

Fig 12 illustrates the relationship among flow velocity, power cost, area cost and annual total cost. Findings demonstrate that as flow velocity increased, power costs climbed but area costs decreased. In contrast to the previous study, the optimal flow velocity of soybean milk is 2.25 m/s at a total annual cost of 35,000 EGP.

Fig 13 through **17** show the correlation between power cost, area cost and total annual cost for determining the ideal number of plates to employ for soymilk production.

Show the relationship among the number of plates, power costs, area costs and total annual costs in **Fig 13.** According to the results, 17 plates were the ideal amount to employ for the PHE in the soybean milk method. As the number of plates rose, the cost of electricity was reduced while the cost of the area increased.

Fig 14 illustrates the relationship among the number of plates, the cost of power, the cost of the area and the overall cost per year. The optimal number of plates to be utilized in the PHE in soymilk processing, according to the results was 11. As the number of plates rose, the cost of electricity reduced while the cost of the area increased.

Fig 15 depicts the relationship among the number of plates, the cost of power, the cost of the area and the overall cost per year. The results showed that 12 plates were the ideal number to employ in the PHE in the soybean milk process. As the number of plates rose, the cost of electricity reduced while the cost of the area increased.

Fig 16 depicts the relationship among the number of plates, power cost, area cost and total annual cost. Results showed that 13 plates were the optimum number to employ in the PHE for soybean milk processing. As the number of plates rose, the cost of electricity decreased while the cost of land climbed.

Fig 17 depicts the relationship among the number of plates, power cost, area cost and total annual cost. Results showed that 15 plates were the ideal amount to employ in the PHE in the soybean milk process. As the number of plates rose, the cost of electricity reduced while the cost of the area increased.

The ideal conditions for a PHE were tested in a soymilk manufacturing unit. The results showed that the flow rate of soy milk should be around 2.25 m/s at a total annual cost of 35000 EGP/year and the ideal number of plates utilized in PHE in the soybean milk processing should still be 17.

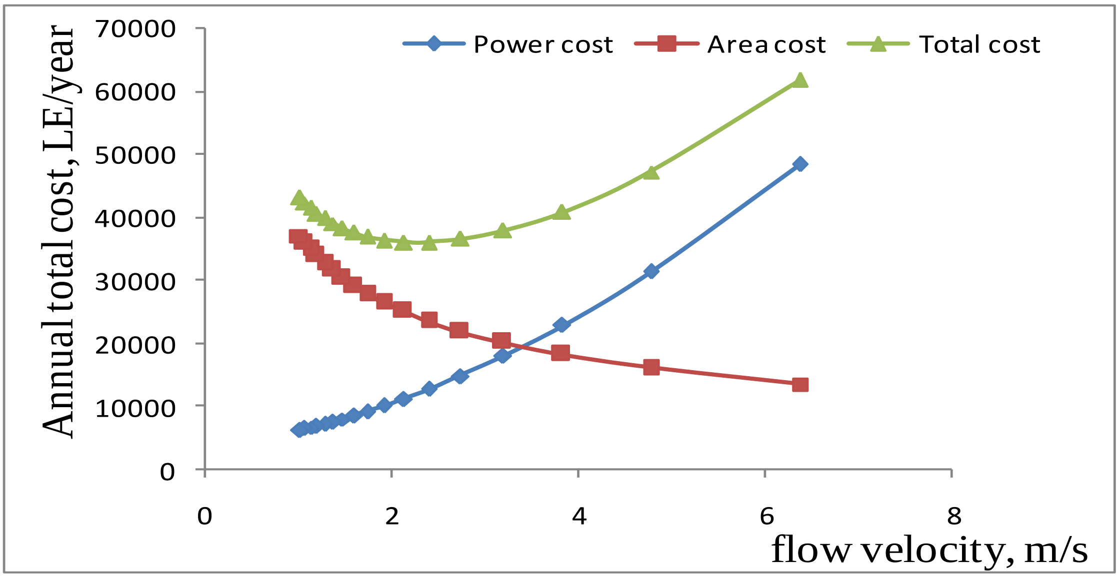

Fig 8. Relationship between the total annual cost, area cost, power cost and flow velocity at milk mass flow rate (1.4166 k_g/s) and water flow rate (12.358 k_g/s).

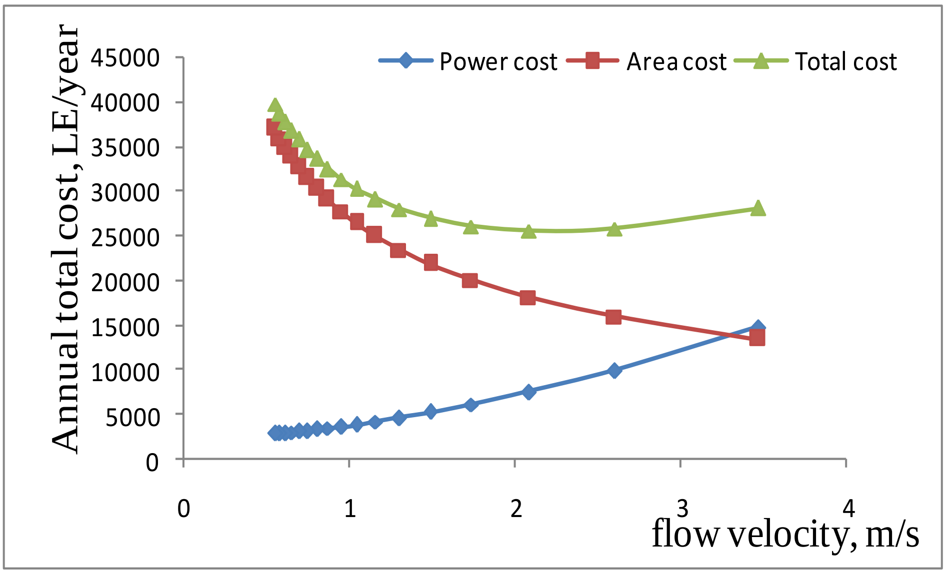

Fig 9. Relation among the total annual cost, area cost, power cost and flow velocity at milk mass flow rate (1.25 k_g/s) and water flow rate (10 k_g/s).

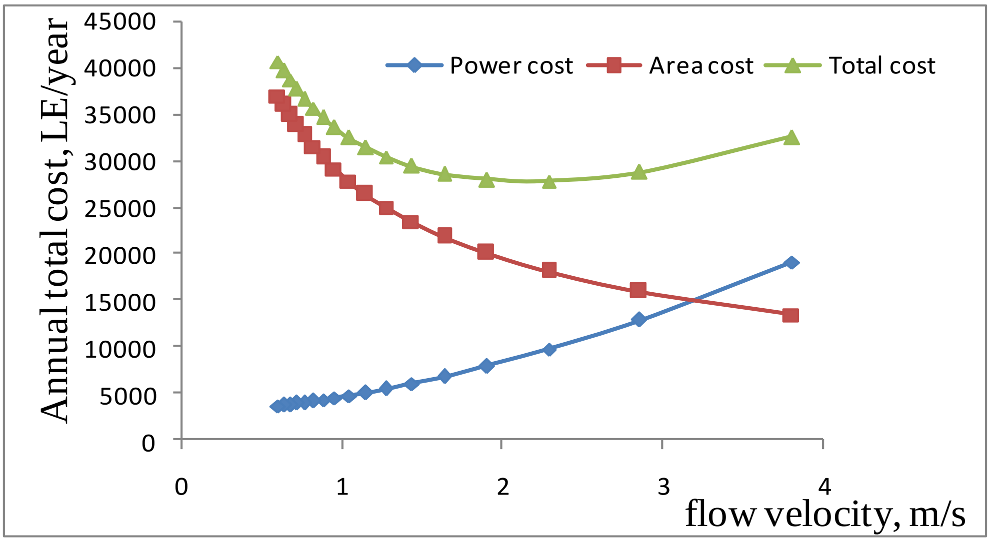

Fig 10. Relation among the total annual cost, area cost, power cost and flow velocity at milk mass flow rate (1.375 k_g/s) and water flow rate (11 k_g/s).

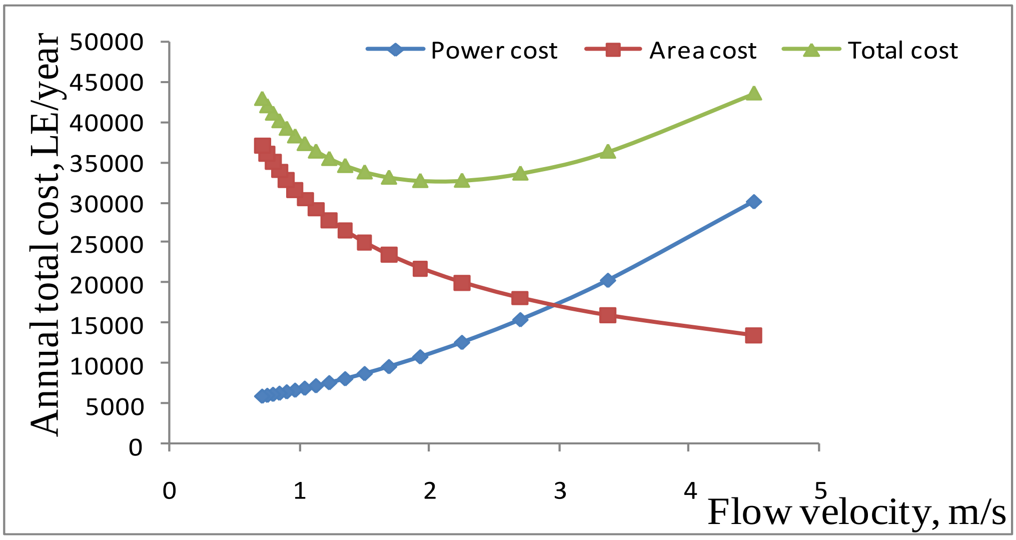

Fig 11. Relation among the total annual cost, area cost, power cost and flow velocity at milk mass flow rate (1.625 k_g/s) and water flow rate (13 k_g/s).

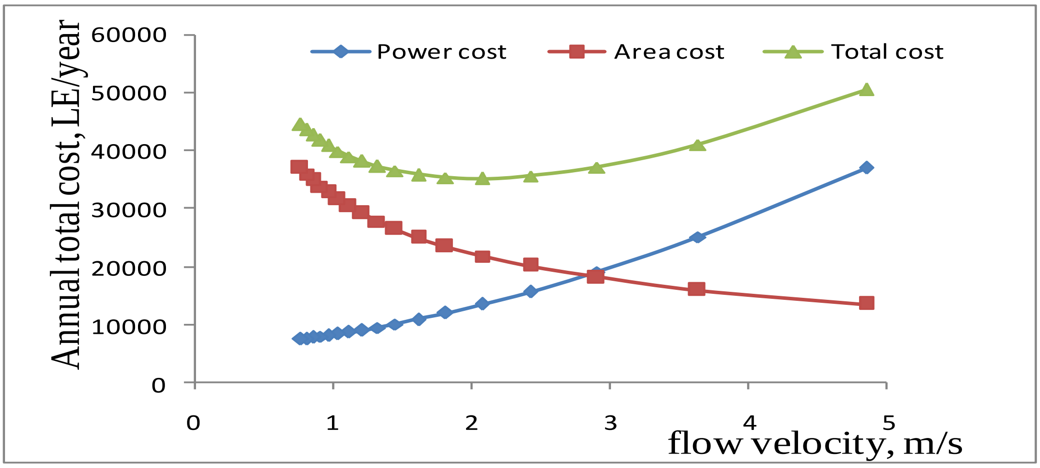

Fig 12. Relationship between the total annual cost, area cost, power cost and flow velocity at milk mass flow rate (1.75 kg/s) and water flow rate (14 kg/s).

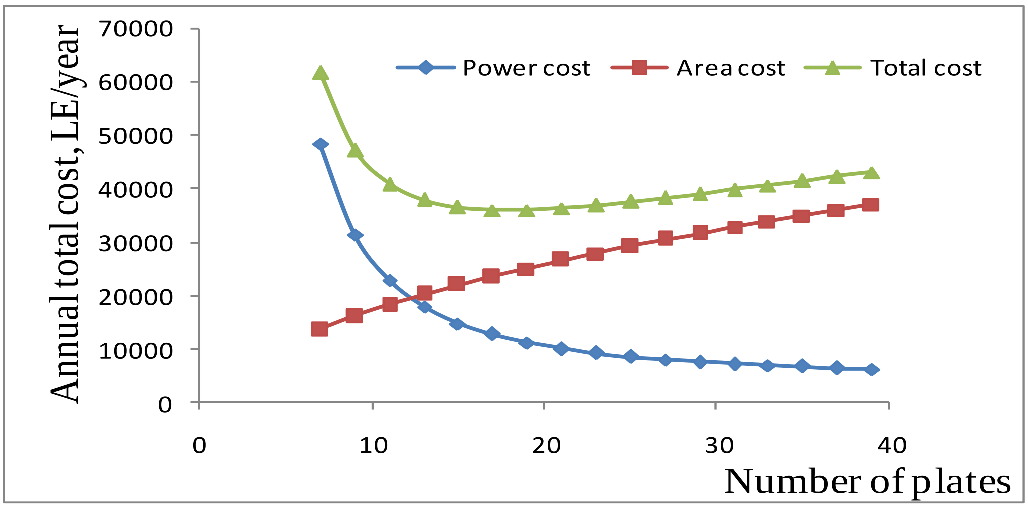

Fig 13. Relationship between total annual cost and number of plates, area cost, power cost at mass milk flow rate (1.4166 k_g/s) and water flow rate (12.358 k_g/s).

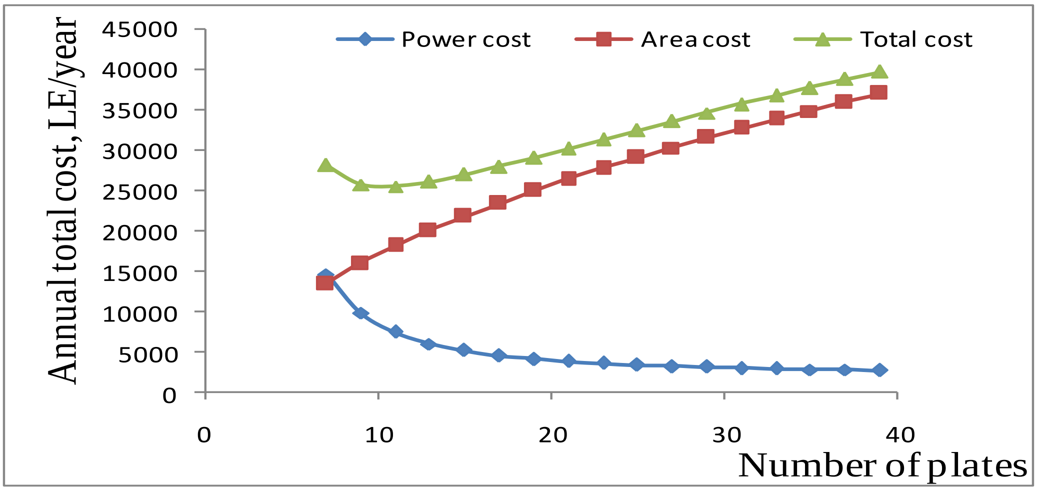

Fig 14. Relationship between total annual cost and number of plates, area cost, power cost at milk mass flow rate (1.25 kg/s) and water flow rate (10 kg/s).

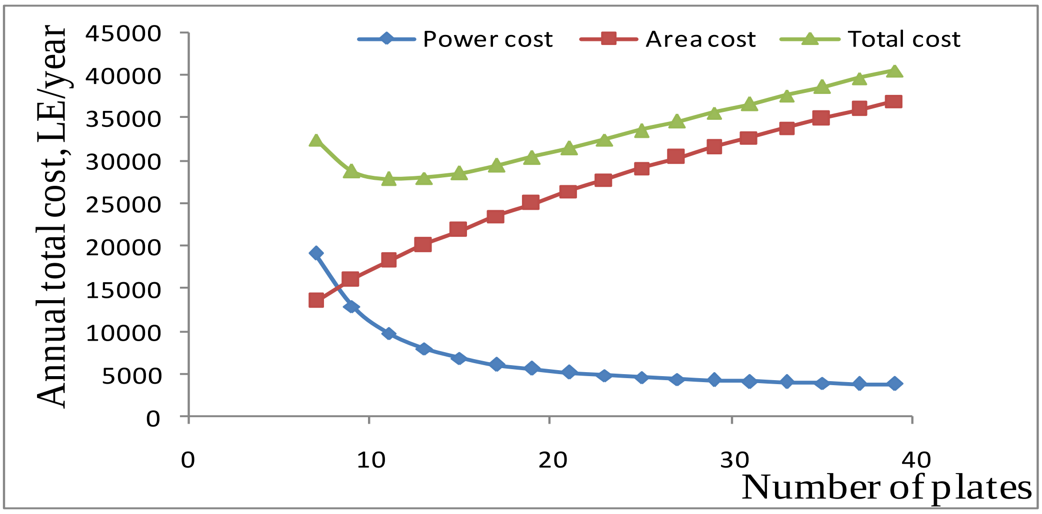

Fig 15. Relationship between total annual cost and the number of plates, area cost and power cost at a mass flow rate of milk (1.375kg/s) and water flow rate (11kg/s).

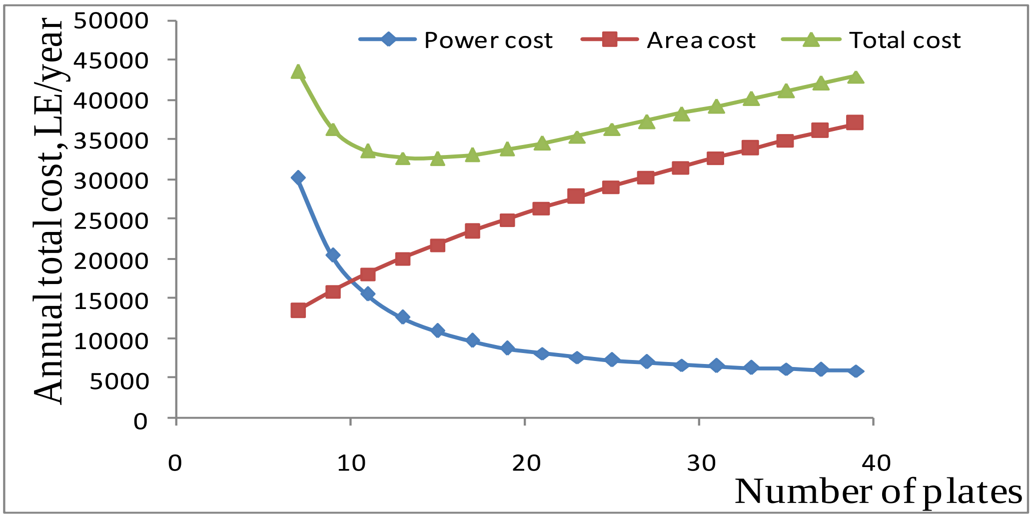

Fig 16. Relationship between total annual cost and number of plates, area cost, power cost at mass flow rate of milk (1.625kg/s) and water flow rate (13kg/s).

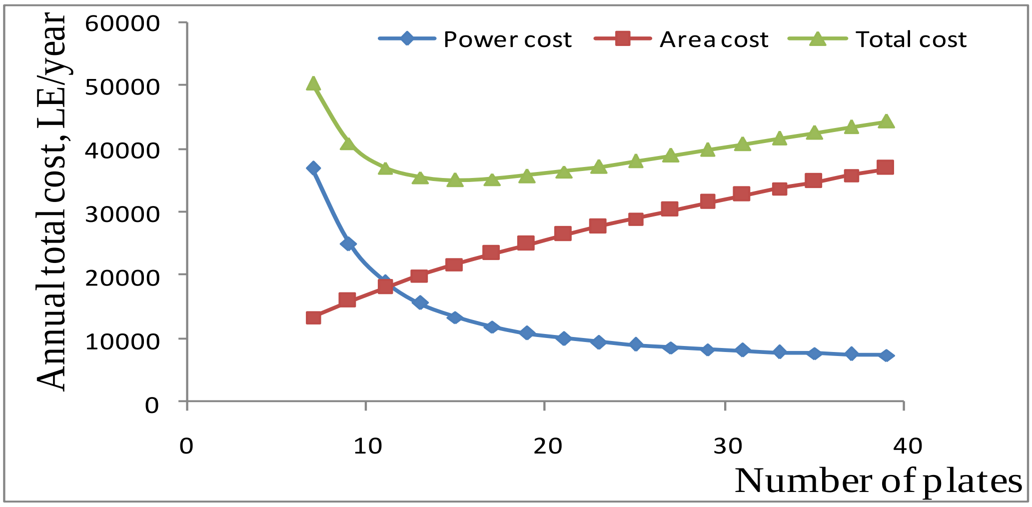

Fig 17. Relationship between total annual cost and number of plates, area cost, power cost at milk mass flow rate (1.75 kg/s) and water flow rate (14 kg/s).

Conclusion

The shear rate and shear stress data for soybean milk samples at temperatures extending from 5 to 90°C were presented because of the rheological properties of soybean milk. Based on consequences, all materials showed non-Newtonian pseudoplastic performance at all temperatures and were well related using the power law model.

In a PHE, calculations are conducted to optimize the flow rate and number of plates. The example study that shows optimal outcomes is available. For both fluids, a Reynolds number, heat transfer coefficient and pressure drop were established. It was found that the optimal number of plates is 17, the lowest total annual cost is 35000 EGP/year and the lowest flow velocity is 2.25 m/s.

Nomenclature

Q: Rate of heat exchanger, W
m: Mass flow rate, k_g/s
T: Temperature, (°C)
$T_{h, in}$: Hot temp. inlet, °C
$T_{h, out}$: Hot temp. outlet, °C
$T_{c, in}$: Cold temp. inlet, °C

$T_{c, out}$: Cold temp. outlet, ºC
Cp: Specific heat, k_J/ k_g. K
Tb: Temperature's bulk, ºC
$T_{c, b}$: Cold bulk temperature, ºC
$T_{h, b}$: Hot temperature's bulk, ºC
ΔT_m: Temperature difference's log mean.
A: Area that of transfer of heat, in (m^2)
G: Mass's velocity, in ($k_g/h_r.m^2$)
De: Equevalent diameter, in (m)
b: space among the plates, m.
W: The plate's thickness, m
L: Length, in (m)
ρ: fluid density, k_g/m^3
h_i: coefficient convective heat transfer, (k_J/ m.s. ºc)
U_D: Overall coefficient heat transfer, (kJ/m.s. ºc)
Re: Reynolds Number
μ: viscosity, in P_a. s
k: conductivity of heat, in (Btu/h. ft. °F)
ΔP: Pressure drop, in P_a
jf: Frictional factor
p: No. of passes
vc: The volumetric flow rate, in (m^3/s)
Nc: channels number
C_{II}: Electricity price, (EGP/k_W.h)
Ap: the port's area, (m^2)
η : Heat exchanger efficiency 70% for each cold and hot side.
EGP: Egyptian pounds per year
In: (Inlet)
h: hot side
C: cold side
Out: (Outlet)
P: Plate
H: Heat
E: Exchanger

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