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Flow Behaviour as Related to Power Consumption During Orange Concentrate Processing.

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ABSTRACT

The flow behaviour of orange concentrate was studied over the range temperatures between 4 to 70 °C, concentrations (40-66% wt.) and shear rate of 2.2-22 s^{-1}. Shear stress - shear rate data indicated that orange concentrate behaves as a non-Newtonian pseudoplastic fluid. The consistency index (K) differed with increasing temperature. Also flow behaviour index relatively decreased with increasing the temperature at all concentrations studied. The relation between friction factor and Reynolds number was plotted at different shear rates to predict the pressure drop that was used in calculation of the power consumption in the factory.

Keywords: Rheology, juice concentrate, flow behaviour, power consumption.

1-INTRODUCTION

Steady shear rheological data are necessary for the design of continuous flow processes where flow rates or pressure drop in pipes and other flow systems must be predicted. Pressure drop in turn is used to decide the pump size and other fluid moving machinery (Murat and Jozef, 1986

Ibarz et al., (1987) studied the rheological behaviour of apple juice and pear juice. The effect of temperature on this behaviour for concentrated apple juice and pear juice of 71% and 70%, respectively, were examined. Equations were given to describe the change in viscosity with temperature within temperature range 5-60°C. In all cases these juices were Newtonian in behaviour as shown in equation (1):-

$$\tau = \mu\gamma \qquad (1)$$

Ibarz and Pagan, (1987) studied the rheological behaviour of different concentrations of raspberry juice at different temperatures, and found that the juice behaved as a pseudoplastic at higher concentrations and lower temperatures, although at low concentrations and in some cases at high temperatures the behaviour was Newtonian.

Benu and Sindal , (2000) reported that the pressure gradients and the corresponding mass flow rates of five different non-Newtonian fluid foods, were recorded using a continuous recording type flow viscometer capable of operating in both transient and continous flow modes. It was found that the fluids were pseudoplastic in nature and followed the power low model, as shown in the following equation (2).

$$\tau = k\gamma^{n} \qquad (2)$$

The flow was confined to the laminar flow regime and appreciable slippage occurred in all cases. Generalized regression algorithms were applied to predict the pressure gradients in tube flow providing mass flow rate , consistency coefficients and flow behavior indices obtained from a low shear rate rotational Viscometer.

Later on, Shyam and Walid, (2003) reported that an artificial neural network approach was used to develop an explicit procedure for calculating the friction factor, f (friction factor) for power law fluids under turbulent flow conditions in closed pipes. The Regula-Falsi method was used as an iterative procedure to estimate the f values for a range of Reynolds number for power law fluid, Re', and flow behaviour index, (n) using equation (3).

$$\frac{1}{f^{0.5}} = (\frac{4}{n^{0.5}}) \log_{10}\left[\mathrm{Re}\ f^{(1-n/2)}\right] - \frac{0.4}{n^{1.2}} \qquad (3)$$

Later on, Leslaw and Fortuna, (2003) studied the rheological behaviour of concentrated strawberry juice over a wide range of temperatures (10-60°C) and concentrations (50-67.1%), using a rotational rheometer with coaxial cylinders as a measuring system. It was shown that concentrated strawberry juice followed a Newtonian behaviour.

Likewise, Sorour, (2004) studied the rheological properties of fig jam puree over the range of 20-90°C and concentrations of 40-65% and speed of spindle 10-50rpm, where, shear stress-shear rate data indicated that the puree behaved as a non-Newtonian Bingham plastic fluid with yield stress. The yield stress decreased with increasing the temperature except for samples that had solid concentrations from 60-65%, wt. due to high pectin contents. Also, the yield stress increased with every increase in solid concentration at all temperatures investigated.

Leslaw, et al., (2004) studied the rheological properties of seven commercial mustards made by different manufactures, and found that mustard was pseudoplastic and exhibiting a yield stress.

Recently, Nindo et al., (2005) studied the rheological behaviour of blue berry and red raspberry juice concentrates, and found that the flow properties, determined for the juice with a solid content of up to 65% and temperatures between 20-60°C. The two juices were Newtonian over the range of temperatures and solids contents studied.

Recently Jasim et al., (2007) studied the steady-shear and small-amplitude oscillatory rheological properties of tamarind (Tamarindus indica L.) juice concentrate (TJC) were studied in the temperature range of 10–90°C using a controlled-stress rheometer. Under steady-shear deformation tests, shear stress–shear rate data were adequately fitted to the Herschel-Bulkley and Casson model at lower (10–30 °C) and higher (50-90 °C) temperature range, respectively. The model parameters estimated empirically showed temperature dependence as in equations (4, 5).

Herschel-Bulkley model

$$\tau = \tau_o + k\gamma^n \qquad (4)$$

Casson model

$$\tau^{0.5} = \tau_{oc}^{0.5} + k_c\gamma^n \qquad (5)$$

2. EXPERIMENTAL SETUP:

2.1. Materials and Methods:-

Six samples of orange juice concentrate, with different (total soluble solids) concentrations (40, 45, 50, 55, 60, 66wt. %) were taken during the processing of the concentrates. Orange concentrates were obtained from fresh orange fruits previously oil removed by a rasping machine; then the fruits were thoroughly washed to remove any residual oil. The fruits were then transferred for pressing to extract the juice, whereas, the fruits were cut by a group of cylindrical knives. The half part of each fruit was then pressed by a rose head shape to extract the juice, which was cleared and refined from seeds and fine fibers by passing through a sieve 100 mesh equipped with nylon brush. The extracted clear juice was collected in a stainless steel (316) tank to be pumped to the evaporator. The juice was passed to a five effect evaporator where, the juice enters the first evaporator at 12 wt. % solid concentration and flows from the last evaporator at 70°C and 66% concentration.

The concentrate was fed to the chiller to reduce its temperature from 70 to 10°C then pumped to the tank in which the temperature was reduced from 10 to 4°C. The concentrate at 4°C was pumped to the packaging machine.

2.2. Rheological properties:

Flow properties (shear stress, shear rate, and apparent viscosity) of the prepared orange concentrate were measured directly with a Brookfield Digital Rheometer, Model DVIII Ultra (Brookfield Engineering Laboratories INC). The concentrate was then placed in a small sample adaptor; the SC4-25 spindle was selected for the sample measurement.

A thermostatic water bath provided with the Brookfield viscometer was used to regulate the sample temperature. The properties for orange concentrate was studied in the temperature range 30-70 °C and 4 and 10°C, shear rate 2.2-22 s^{-1} and different concentrations 40-66% for plotting shear stress – shear rate data were critically followed.

3. RESULTS AND DISCUSSION

3.1. Shear stress-Shear rate behaviour:-

Shear stress and shear rate values are plotted in Figure 1 for a 66% solids concentration of orange concentrate at different temperatures (4, 10, 30, 40, 50, 60, and 70°C). Similar trends were observed for solid concentrations of 40, 45, 50, 55, and 60 wt% of orange juice, at temperatures (30-70°C) as shown in Figures 2-6.

These results show that all samples exhibited non-Newtonian pseudoplasic behaviour at all the studied temperatures and concentrations, which fairly concides with the results reported by Telis-Romero et al., (1999) who studied the flow behaviour of orange juice concentrates (40-60 wt%)

solids. Besides, the stress-strain data obtained fitted well to the following constitutive equation.

$$\tau = k\gamma^{n} \qquad (6)$$

The rheological behaviour of orange juice was previously discussed in the work of Telis- Romero et al., (1999) who concluded that the juice was followed a pseudoplastic behaviour and fitted to the power law equation.

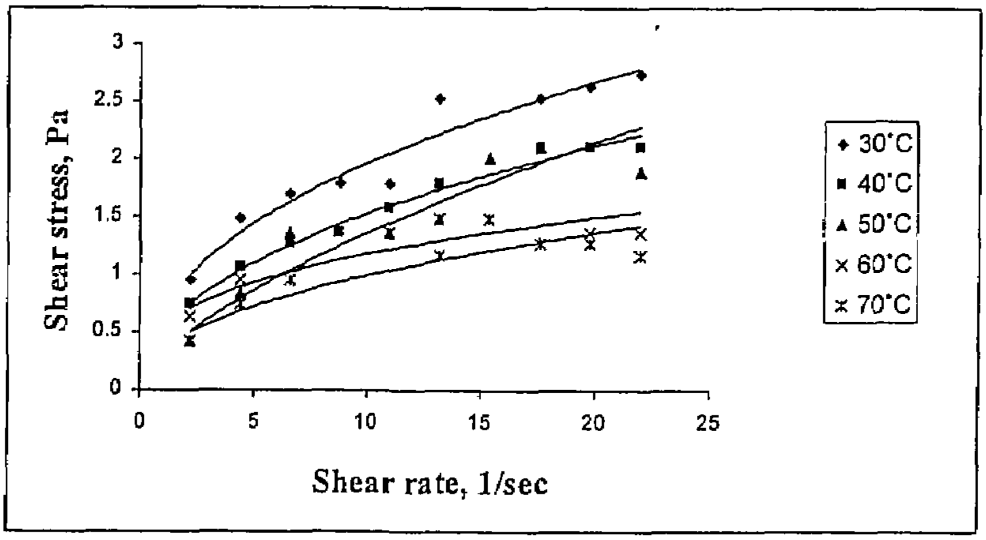

Figure 1 Relation between shear stress and shear rate at different temperatures and 40% solids concentration of orange juice concentrates.

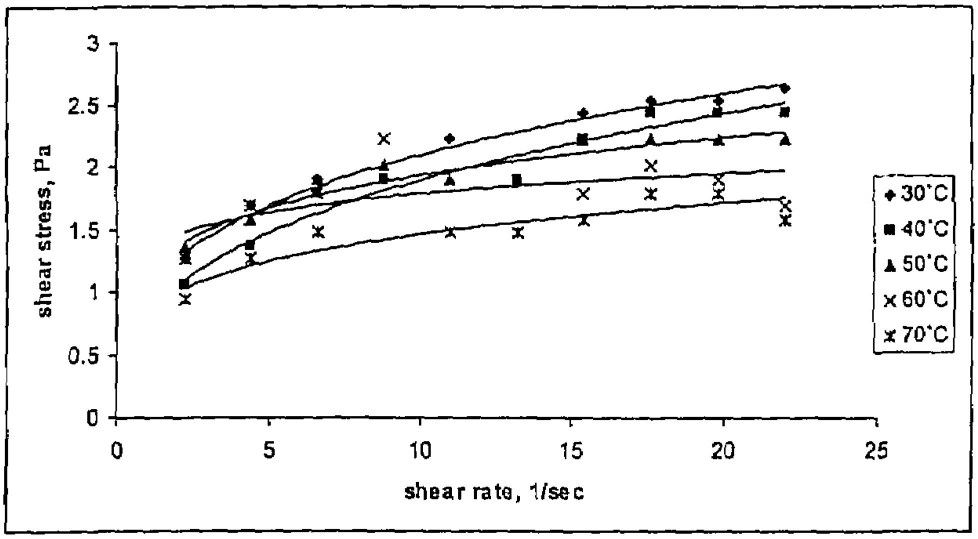

Figure 2 Relation between shear stress and shear rate at different temperatures and 45% solids concentration of orange juice concentrates.

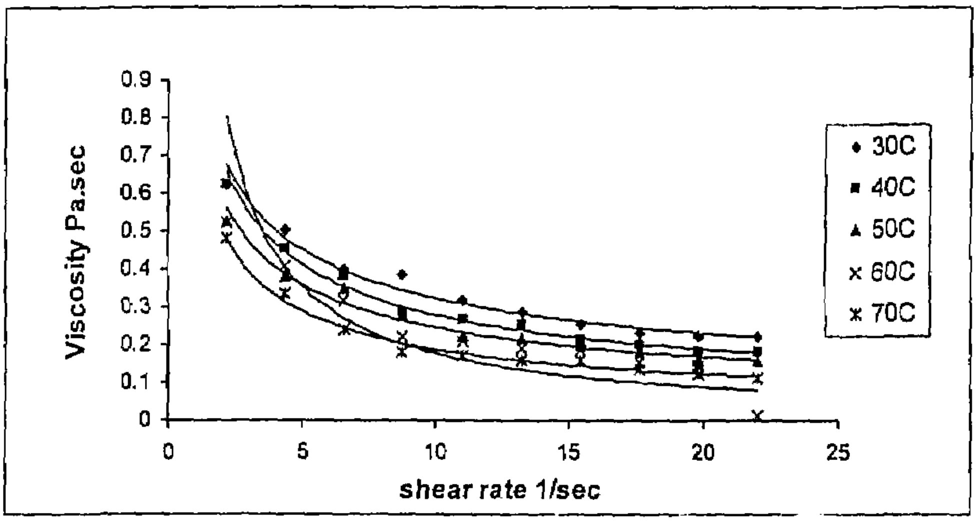

Figure 4 Relation between shear stress and shear rate at different temperatures and 55% solids concentration of orange juice concentrates.

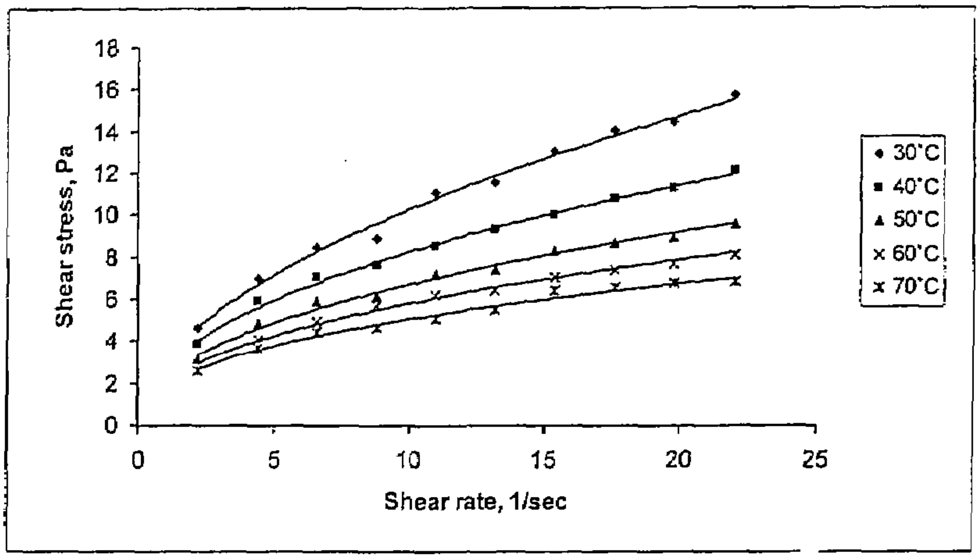

Figure 5 Relation between shear stress and shear rate at different temperatures and 60% solids concentration of orange juice concentrates.

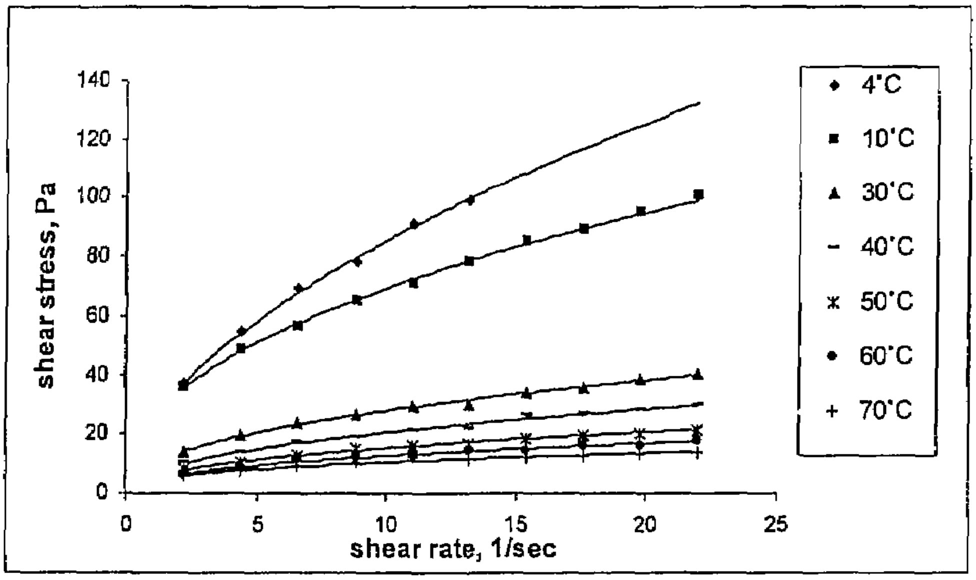

Figure 6 Relation between shear stress and shear rate at different temperatures and 66% solids concentration of orange juice concentrates.

A plot of consistency coefficient (k) versus temperature at different concentrations is here after shown in Figure 7 from which it could be noticed that k decreased with increasing the temperature at concentrations of 55, 60, 66%, but there were fluctuations in k value with increasing the temperature at concentrations of 40, 45, 50% solids in the prepared orange juice concentrate. These fluctuations might be due to the change of structure of orange juice concentrate with different temperatures used.

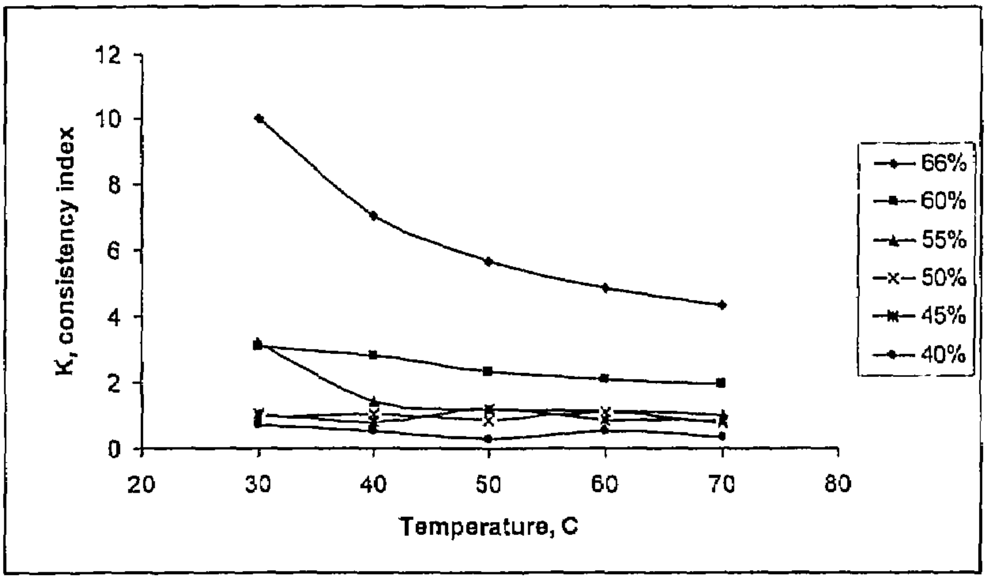

Figure 7 Relationship between k (consistency index) and temperature at different concentrations of orange juice concentrate.

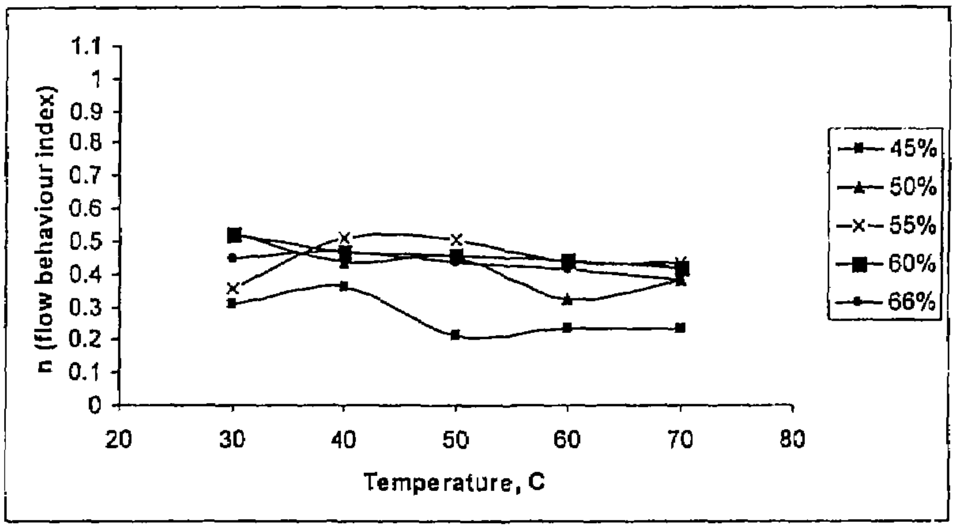

Figure 8 Relationship between n and temperature at different concentrations of orange juice concentrate.

Plotting of n values versus temperature of orange juice of different concentrations are shown in Figure (8), where n relatively decreased with increasing temperature applied at all the concentrations studied.

The relation between k with temperature agrees with the work of (Sorour, et al., 2004) who reported that the fluctuations in k decreased at higher concentrations (60-65%), this might be explained by the fact that pectin set was completely formed at concentrations 60-65%.

3.2. Calculation of power of the pump

It is important to predict the pressure drop in orange concentrate and to calculate the power of the pump needed for pumping the orange concentrate first to the tank, then the power of the pump needed to pump the concentrate to the filler.

The volumetric flow rate (Q) in the studied plant was calculated from the following equation:

$$Q = \frac{mass\ flow\ rate}{\rho} \qquad (7)$$

Where, ρ the density of orange juice concentrate at 4°C is 1396.07 kg/m^3 and at 10°C, 1350 kg/ m^3

Q at 4°C = 3.97×10^{-4} m^3/s, Q at 10°C = 4.11×10^{-4} m^3/s,

Cross- sectional Area of the pipe

$$A = \frac{\pi}{4} D^2 \qquad (8)$$

Where, D is the diameter of the pipe = 0.06354m, D = 0.07625m

At 4°C $A = 3.169 \times 10^{-3}\ m^2$

At 10°C $A = 4.56 \times 10^{-3}\ m^2$

* Velocity of the fluid through the pipe

V at 4°C = 0.1254 m/s

V at 10°C = 0.09 m/s

* **Reynolds number for fluids that fits power law** as reported by Rao and Antheswaran, (1982)is calculated from equation(9)

$$\mathrm{Re} = \frac{\rho D^{n-1} V^{n-2}}{K\, 8^{1-n}} \qquad (9)$$

Where, ρ is the density of the fluid at 4°C, 10 °C

Re at 4°C = 0.5066

Re at 10°C = 1.2227

Friction factor is defined as shown in Figures 9 and 10.

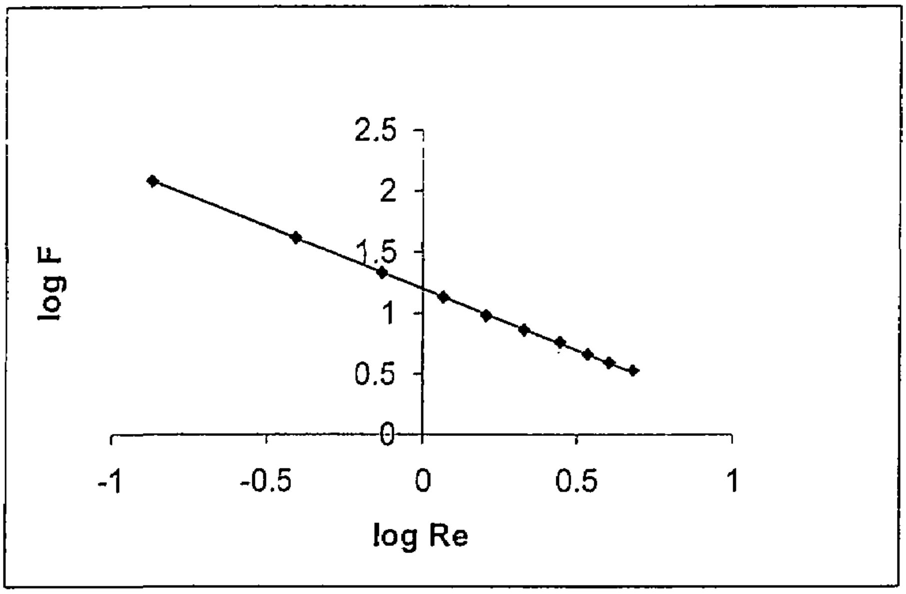

Figure 9 Relation between Reynolds number and friction factor at 66% solids concentration of orange juice at 10°C

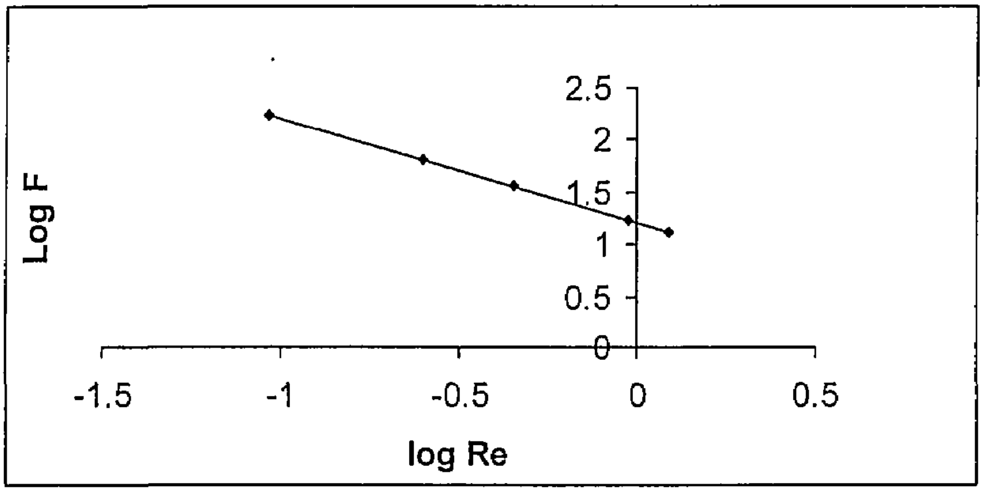

Figure 10 Relation between Reynolds number and friction factor at 66% solids concentration of orange juice at 4°C.

$$f = \frac{15.98}{Re^{1.0005}} \qquad \text{at } 10^{\circ}\text{C}, \quad f = 13.074 \qquad (10)$$

$$f = \frac{16.084}{Re^{0.992}} \qquad \text{at } 4^{\circ}C, \quad f = 31.5767 \qquad (11)$$

*** Calculation of pressure drop**

Pressure drop was predicated from friction factor for laminar flow as shown in the following equation.

$$f = \frac{D\,\Delta P}{2L} \quad \frac{1}{\rho\, v^2} \qquad (12)$$

Where, $L_1 = 80.675$ m, $L_2 = 48.8836$m

ΔP at 4°C = 1066619.7 N/m^2

ΔP at 10°C =282793.28 N/m^2

$$\text{* Power} = \frac{Q\,\Delta P}{\eta} \quad , \quad \eta = 0.7 \qquad (13)$$

Power at 4 °C = 0.812 hp

Power at 10 °C = 0.222 hp

The Calculation of the power of the pump agreed with the work of (Sorour, 2004) for fig jam puree, who reported that the power of the pump needed for pumping fig jam puree to the packaging machine, was 0.38 hp.

CONCLUSIONS

It could be concluded, that orange juice concentrate behaves as a non-Newtonian pseudoplastic fluid. The consistency index k fluctuated with increasing the used temperature and the flow behaviour index (n) relatively decreased with increasing the temperature at all concentrations studied. The relation between friction factor and Reynolds number exhibited the following equations:

$$f = \frac{15.98}{Re^{1.0005}} \quad \text{at } 10^{\circ}C$$

$$f = \frac{16.084}{Re^{0.992}} \quad \text{at } 4^{\circ}C$$

Besides, the pressure drop was calculated at 4°C and 10 °C, then the power of the pump needed to pump the concentrate from the evaporator to the tank and from the tank to the filler were calculated and was found to be 0.812 hp at 4°C and 0.222hp at 10°C respectively.

NOTATIONS

τ : Shear stress, Pa

γ : Shear rate, s^{-1}

K: Consistency index

n: Flow behaviour ind

η: Efficiency of the pump

μ: Viscosity, Pa.sec

τ_0: Yield stress, Pa

f: Friction factor

Re`: Reynolds number for power law fluid

Q: Volumetric flow rate, m^3/s

ρ : Density, kg/m^3

A: Cross- sectional Area of the pipe, m^2

V: Velocity of the fluid, m/sec

ΔP: Pressure drop, N/m^2

L: Length of the pipe, m

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