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EFFECT OF RHEOLOGICAL PROPERTIES ON MIXING PROCESS OF FIG JAM

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Abstract-Mixing of fig jam during process was examined using flat-bladed impeller. The rheological properties of fig jam (65%) was studied at 85°C the effect of apparent viscosity of fig jam on mixing parameters was investigated. The results revealed that fig jam exhibited non-Newtonian Bingham plastic fluid. An impeller mixer was connected with ammeter in order to predict the power of the mixer at different impeller to vessel diameter (D/T). The relation between power number, blend number, pumping number and Reynolds number were determined at different D/T ratios (0.2, 0.3, 0.4 and 0.5).

Keywords: Blend number, mixing of non-Newtonian fluids, mixing parameter, Power number, Pumping number, rheology of fig jam

1. INTRODUCTION

Mixing process occurs widely throughout the food processing industries. It is used to bring about a physical or chemical change in the materials being processed. The energy input through mixing may be used to blend materials giving new physical and rheological properties. Food rheology focuses on flow properties of individual food components which might already exhibit a complex rheological response function. Rheology plays an important role in food manufacture and marketing [1].

Rheology is the study of deformation and flow, being knowledgeable about this physical property of food materials is informative in their processing, handling and storage. During the past few decades, the science of fluids and semi fluids rheology has been improved significantly. Therefore food professionals need to appreciate the fundamental principles and suitable measurements of rheological properties of food as well as the impact of structure and composition on it [2].

The procedure of making fruit jam is a complicated process with a number of variables that affect the quality of the final product. It is essential to be knowledgeable about the fundamental rheology to enhance the technology of different types of jam. Due to this cause, rheology has application in different stages of jam manufacture from process equipment designing to development of products, and quality control. Fruit jams rheological behavior is influenced by different parameters such as composition which one of most important factors is the fruit type and also the technology of the process beside other factor such as shear rate [3].

Liquid agitation is a common unit operation in the chemical engineering and food processing industries and its practical use is widely published [4]. However, most of the literature on liquid agitation addresses Newtonian fluids, while only limited design information is available on the agitation of non-Newtonian fluids. Chemical engineers and food processors often deal with complex fluids in laminar regime which are, usually, highly viscous and shear thinning. It is clear that both vessel and impeller diameters have to be adapted to take these properties into account for distributive as well as dispersive mixing [5,6].Kamiensky, [7] examined the influence of vessel diameter to mixer diameter ratio on power consumption. The results were presented in the form of graphical characteristics of power consumption and mathematically in the form of dimensionless equation. Later, the discharge flow rate number was correlated as a function of the paddle dimensions by an experimental investigation set up by Yuji and Hiromoto [8].

Experimental measurements of the influence of geometry of the pendulum agitators with clapping blades and of the physical parameters of mixed fluid on the homogenization time, the power consumption and the energy of mixing were analyzed and original formulas were proposed for the determination of the above mentioned mixing variables by Masiuk and Kawecka, [9].

Mixing of carrot concentrates to be homogenized using flat–bladed impeller was studied by Mostafa et al., [10]. The rheological properties of Carrot concentrate were studied over the range 10-70°C, solid concentration 66 wt% of Carrot concentrate, and speed of spindle 50-250 rpm. Shear stress-Shear rate data indicated that the concentrate behaves as non-Newtonian Bingham plastic fluid with yield stress. The relation between Power number, Blend number, Pumping number and Reynolds number were calculated at different D/T.

Liquid flow is defined by a series of dimensionless numbers, Reynolds number, Froud number, power number and blend number. These numbers can be used to quantify the performance characteristics of an impeller. Dimensionless numbers are affected by geometric factors, such as the ratio of impeller to tank diameter, D/T, and the ratio of clearance from the tank bottom to tank diameter, C/T. [11, 12]

$$Re = D^2 N\rho / \mu$$

Where, ρ is the density of the concentrate, n is revolution per sec, D is the diameter of the impeller, μ is apparent viscosity, (Pa. sec).

$$Fr = D\backslash N^2/8$$

$$NP = \rho/\rho N^3 D^5$$

The impeller blend number, N_B, is used to predict the blend time, θ, in a mixed system. Blend number, N_B, attempts to predict the effect of impeller D/T on the results:

$$N_B = N\theta(D/T)^{2.3}$$

Where, N_B is the blend number, N is revolutions per second, D is the diameter of the impeller, T is tank diameter, m, and θ is time in second.

The impeller pumping number, N_Q, is used to predict the impeller pumping rate, q.

$$N_Q = q/nD^3$$

Where, q is volumetric flow rate of fluid leaving the impeller blades, m^3, n is revolutions per second of impeller, D is impeller diameter, m, T is tank diameter, m.

All of the dimensionless numbers just discussed are correlated with Re. These correlations depict the trends observed for the applied impeller system for different values of D/T.

The objectives of this paper are, firstly, to develop the effect of impeller to tank diameter ratio, D/T on the plot of the dimensionless groups, power number, N_P, blend number, N_B, flow number, N_Q, versus Reynolds number, Re.

2. EXPERIMENTAL PROCEDURES

2.1 Samples Preparation

A sample of fig jam with solid concentrations 65wt. % was taken during the process of concentration.

Fig jam is obtained from fresh fig fruit which have been cleaned by a special washer, then passed through a bucket elevator that transfer the fig fruit to a refiner which separates the pulp from fiber, the pulp is then packed in a container.

The fig jam is then manufactured by the following procedure:

The fruit pulp is transferred to a vacuum pan with suction then little treated water is added to rinse out the residual fruits pulp from the feeding device. Addition of sugar to the pulp with weight ratio (1:1), and add citric acid was added. The vacuum pan is heated to 85°C with stirring until the fig jam reaches the required concentration (65%).The fig jam is then pumped to the filler where it was packed **[13].**

2.2 Density of concentrate

The bulk density was calculated from equation (30) by dividing the mass (m) of the concentrates by the volume (V) of the concentrates as follows:

$$D_b = {}^{m}\!/\!{}_{V}$$

Where, D_b the bulk density of concentrates (fig jam) kg/cm^3.

m the mass of concentrates (fig jam) kg.

V the volume of concentrates (fig jam) m^3.

2.3 Rheological Properties

Apparent viscosity of fig jam was measured directly with Brookfield Digital Rheometer, model HA DVIII ultra (Brookfield Engineering Laboratories INC) The concentrate was placed in a small sample adapter and the HA-07 spindle was selected for the sample measurement. A thermostatic water bath provided with the instrument was used to regulate the sample temperature. The rheological parameters for Fig jam were studied at 85°C, speed of spindle 50-250 rpm, with increment of 50, at concentration (65%) for plotting shear stress- shear rate data.

Shear rate was calculated using the following equation (Brookfield Manual, 1998 [14]:

$$\gamma = \left[\frac{2\pi R_c^2}{60(R_c^2 - R_b^2)}\right] RPM$$

Where, γ is the shear rate, 1/sec

Rc is the radius of container, cm
Rb is the radius of spindle, cm

2.4 Power Calculation

A laboratory mixer was connected with Ammeter to measure the current at different revolutions per minute and the power of mixer was determined using the following equation:

$$P = IV$$

Where P is the power of the mixer, watt, I was the current, Ampere, and V is the voltage, volt.
The density of fig jam at temperature 85°C, 65% concentration is 1291 kg /m^3.

3. RESULTS AND DISCUSSION

3.1 Shear Stress – Shear Rate Relation

The relation between Shear stress -Shear rate of fig jam (65%) at 85°C was shown in figure(1). The results revealed that fig jam (65%) exhibited non-Newtonian Bingham fluid behavior and the results fitted well to the following equation:

$$\tau = k\,\gamma + \tau_0$$

Where, τ is the shear stress, Pa, k is the consistency index, Pa.sec, γ is the shear rate, sec^{-1} and τ_0 is the yield stress, Pa.

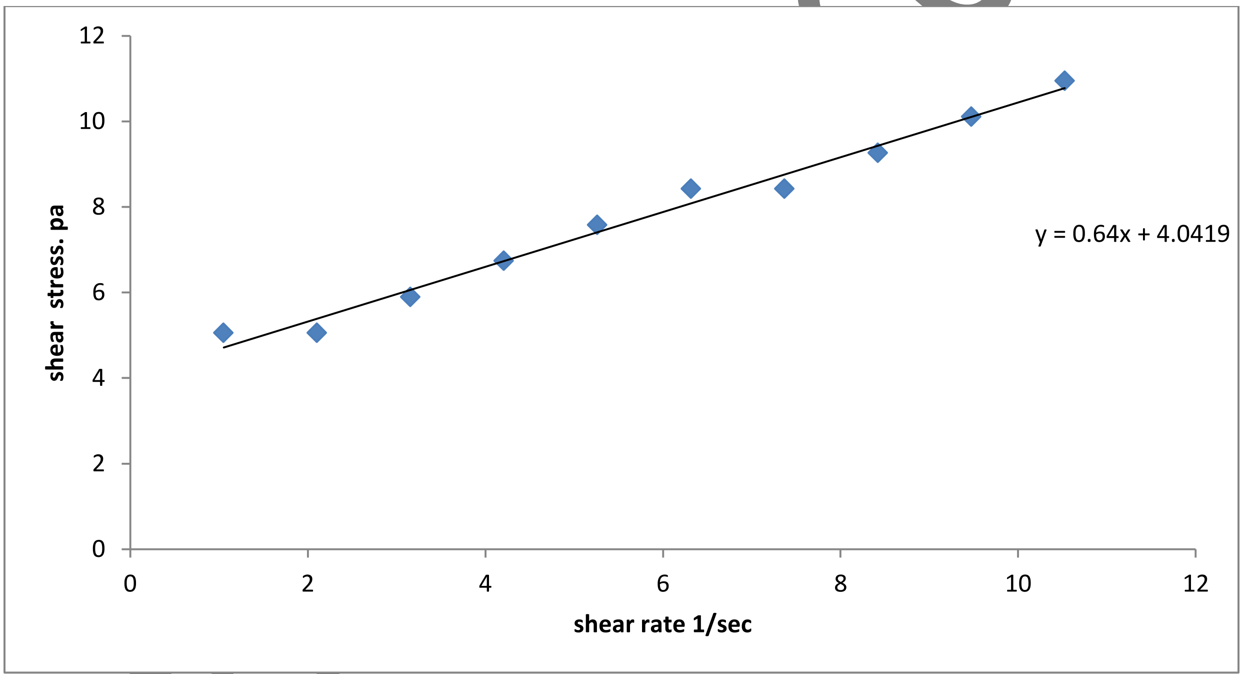

Fig. 3.1 Relation between Shear Stress and Shear Rate at 85 ºC of 65 wt% Fig Jam

3.2 Effect of Impeller to Tank Diameter Ratio on Dimensionless Groups

3.2.1 Power Number – Reynolds Number Plot

Mixing power for fluids depends on the stirrer speed, the impeller and geometry. Also it depends on the properties of the fluid such as density and viscosity.
The relation between Reynolds number and power number was usually expressed in terms of Re and power number Np in a dimensionless equation as following:

$$\log N_P = \log A + B \log Re$$

Where, P_0 is the power number, Re is Reynolds number, A and B are constants. Figures (2-5), show the relation between power number and Reynolds number at different impeller to tank diameter (D/T) ratios at temperature 85°C as evaluated according to equations the results are given in Figs 3.2, 3.3, 3.4 and 3.5 for the different paddle diameters (D) used in the present work.

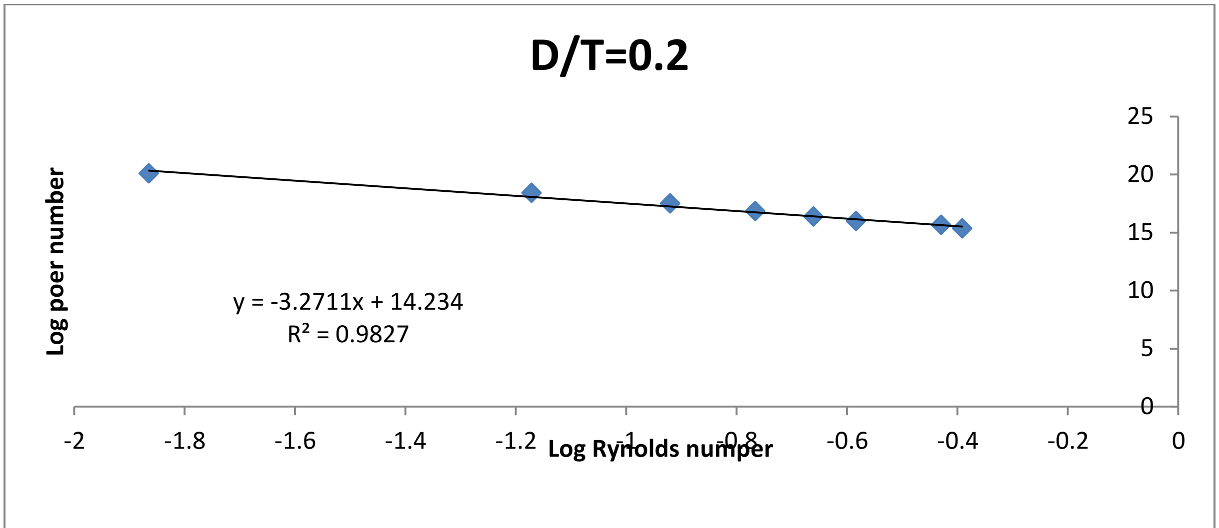

Fig. 3.2 Relation between log N_P and log Re of fig jam **at 85^{o}C**

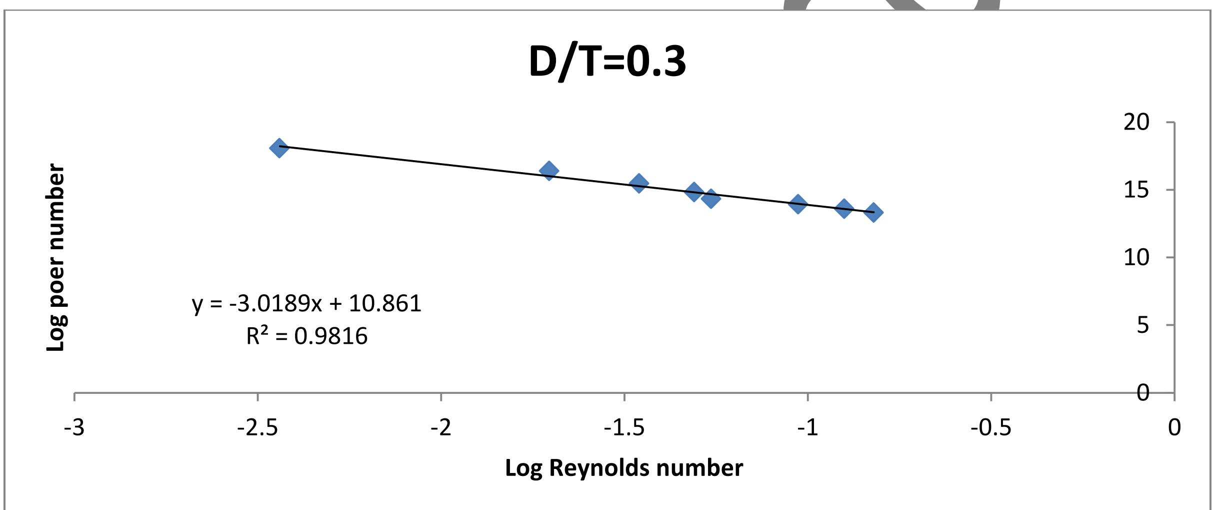

Fig. 3.3 Relation between log N_P and log Re of fig jam at 85^{o}C

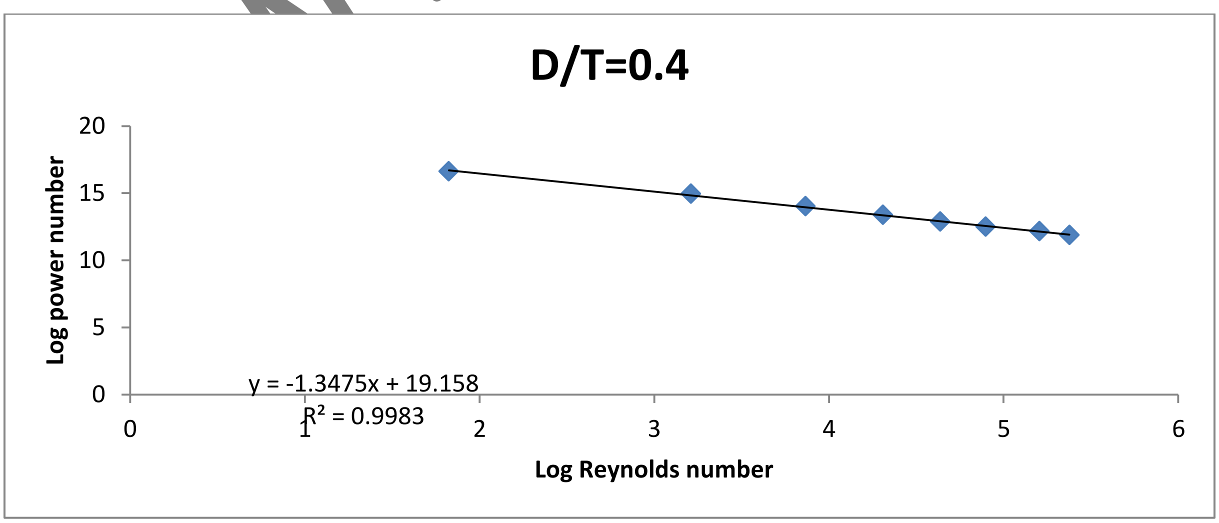

Fig. 3.4 Relation between log N_P and log Re of fig jam at 85^{o}C

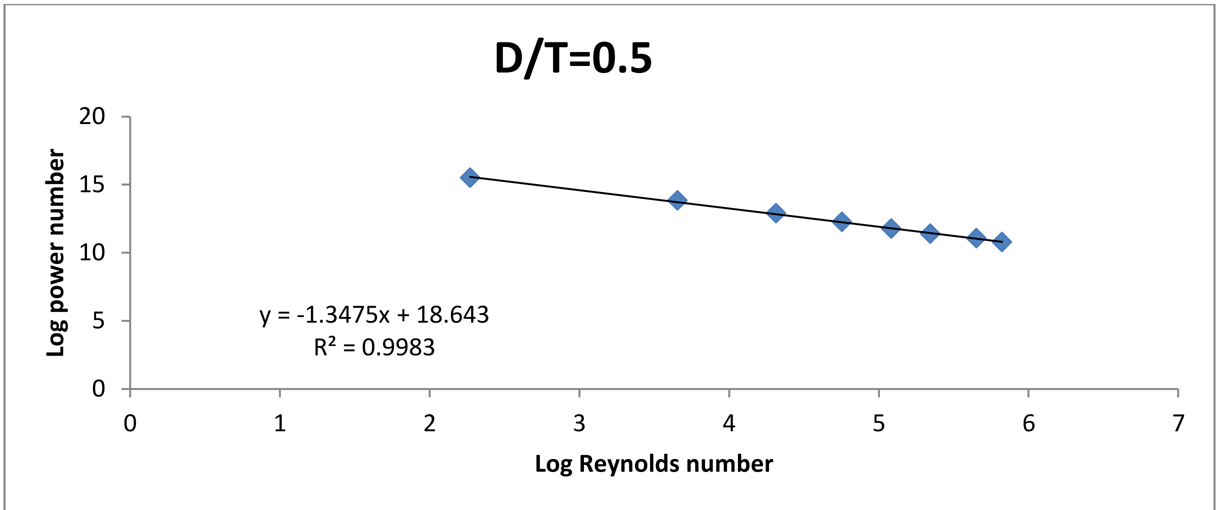

Fig. 3.5 Relation between log N_P and log Re of fig jam at 85°C

The relation between A and B constants in equation with temperature at different impeller to tank is shown in Table (3.1)

Table-3.1 The Relation between Constants (log A and B) in Equation and D/T

D/T	log A	Log B
0.2	-3.2711	14.234
0.3	-3.0189	10.861
0.4	-1.3475	19.158
0.5	-1.3475	18.643

3.2.2 Blend Number – Reynolds Number Plot

The relation between blend number (NB) and Reynolds number (Re) was shown in figure 6 (a,b). The results observed that as Reynolds number increase, the blend number increases at different ratio of (D/T).

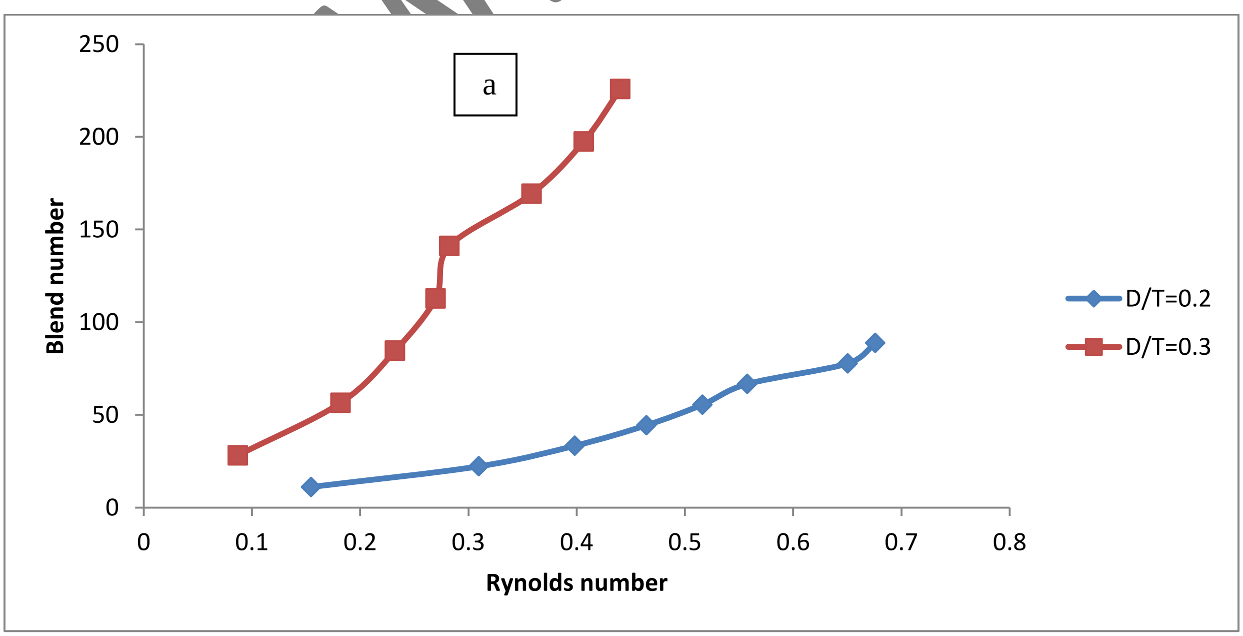

Fig. 3.6 Blend number (N_B) as function of Re at different D/T ratios

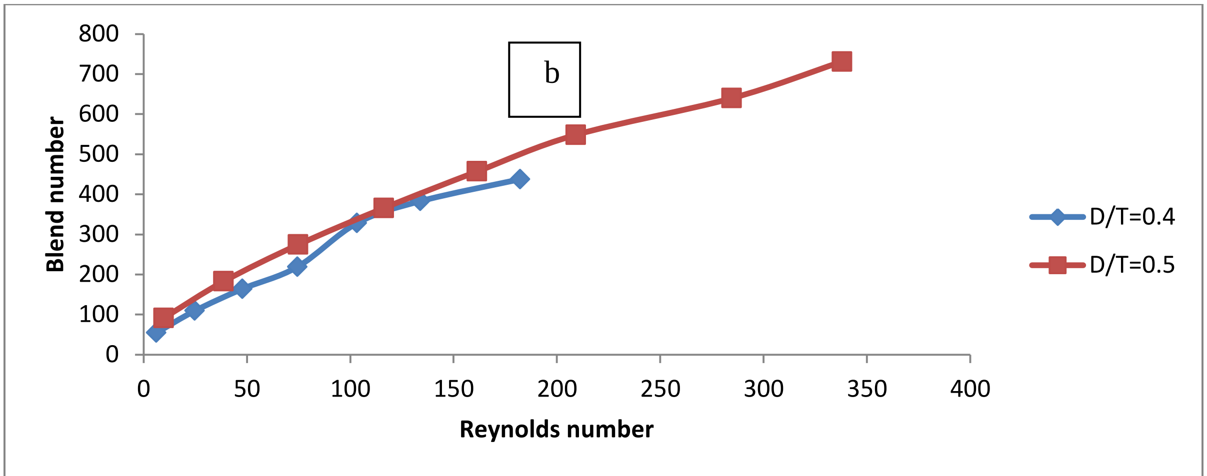

Fig. 3.6 Blend number (N_B) as function of Re at different D/T ratios

3.2.3 Pumping Number – Reynolds Number Plot

The effect of D/T ratio on pumping number was shown in Fig. 3.7. The results observed that increasing D/T ratios causes decrease in pumping number at the same Reynolds number. This may be due to the fact that constant volumetric flow rate of fluid leaving impeller, q, requires the decrease of pumping number with increase in impeller diameter.

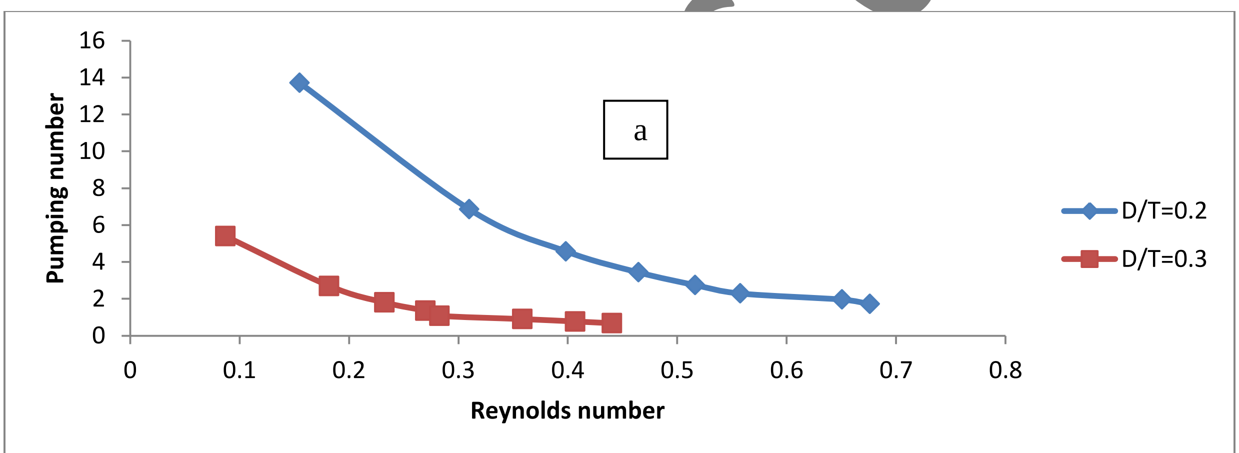

Fig. 3.7 (a) Pumping number (N_Q) as function of Re at different D/T ratios

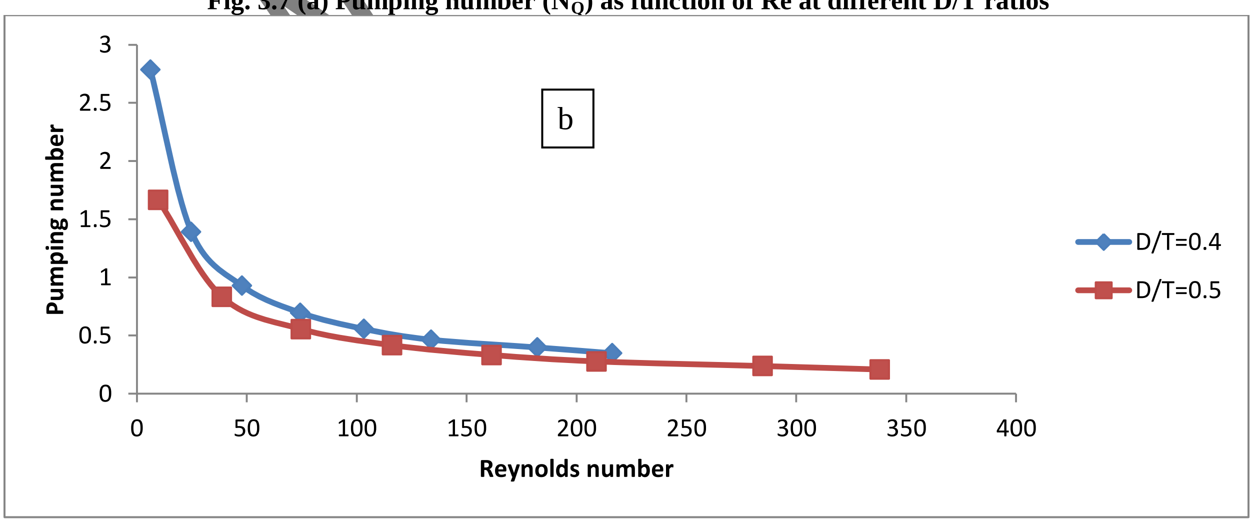

Fig. 3.7 (b) Pumping number (N_Q) as function of Re at different D/T ratios

CONCLUSION

Fig jam exhibition as non-Newtonian Bingham fluid at 85^oC and solid concentration 65% wt. An impeller mixer was used to predict the power number, blend number and pumping number as function of Reynolds number at different impeller to tank diameter ratios at 85^oC and 65% concentration. The effect of D/T on N_P, N_B and N_Q was explainable.

The design logic described in this paper depends on having reliable values of N_P, N_B and N_Q over the laminar flow regime for the impeller system being analyzed. it is recommended to use the previous data for selection of the appropriate scale-up criterion, ultimately leading to economic scale-up of Bingham fluid mixing.

NOTATION

A and B are constants in equation (8), dimensionless
D impeller diameter, m.
I current intensity, Ampere.
k consistency index, Pa.sec
n revolutions per second
N_P power number
N_B blend number
N_Q pumping number
P power of the mixer, watt
fr froud number
θ time in second
R_c radius of container, cm
R_b radius of spindle, cm
q volumetric flow rate of fluid leaving the impeller blades, m^3
Re Reynolds number
T tank diameter, m
V voltage, volt
V' volume, m^3
γ shear rate, sec^{-1}
μ viscosity, Pa.sec
ρ density, kg/m^3
τ shear stress, Pa
τ_o yield stress, Pa
m the mass of concentrates kg.
D_b the bulk density of concentrates kg/cm^3.

Appendix

The relation between Re and power number at different D/T

Re		Re		Re		Re	
	D/T=0.2		D/T=0.3		D/T=0.4		D/T=0.5
0.15492	5.25E+08	0.087143	69175931	6.1968	16415773	9.6825	5379120
0.30984	98494636	0.181863	12970487	24.7872	3077957	38.73	1008585
0.398366	38911461	0.23238	5124143	47.80389	1215983	74.69357	398453.4
0.46476	20519716	0.269861	2702185	74.3616	641241.1	116.19	210121.9
0.5164	12607313	0.282624	1660222	103.28	393978.5	161.375	129098.9
0.557712	8511882	0.358529	1120906	133.8509	265996.3	209.142	87161.67
0.650664	6126003	0.406665	806716.4	182.1859	191437.6	284.6655	62730.27
0.676015	4616936	0.440299	607991.6	216.3247	144279.3	338.0073	47277.43

REFERENCES

[1] Barnes H A 2001."Industrial Food Processing Experiments and Numerical Simulation" University of Plymouth, Institute of Non-Newtonian Fluid Mechanics and British Society of Rheology.
[2] M. A. Rao and J.F.Steffe, Viscoelastic properties of foods. London, 1992.
[3] Javanmard Marjan and Endan Johari (2010). A Survey on Rheological Properties of Fruit Jams (International Journal of Chemical Engineering and Applications, 1, 31-37.
[4] McCabe, W.L., Smith, J.C., "Unit Operations of Chemical Engineering", 6^{th} Ed., McGraw-Hill, New York, NY, 2001.
[5] Thakur, R.K., Vial, Ch., Djelveh, G., Labbafi, M., "Mixing of complex fluids with flat bladed impellers: effect of impeller geometry and highly shear thinning behavior". Chemical Engineering and Processing. Vol. 43, pp1211-1222, 2004.
[6] Chenxu Yu, Gunasekaran, S., “Performance evaluation of different model mixers by numerical simulation”, Journal of Food Engineering, Vol. 71, pp. 295-303, 2005.
[7] Kamienski, J.,"Mixing power of turbine mixers with divided angled blades". Industria; Chemical Processes. Vol 7, No 3, pp 417-431, 1986
[8] Yuji, S., Hiromoto, U., "Effects of paddle dimensions and baffle conditions on the interrelations among discharge flowrate, mixing power and mixing time in mixing vessels". Journal of Chemical Engineering of Japan. Vol. 20, No 4, pp 399-404, 1987.
[9] Masiuk, S., Kawecka,T.J., " Mixing energy measurements in liquid vessel with pendulum agitators". Chemical Engineering and Processing. Vol 43, No 2, pp 91-99, 2004.
[10] Mostafa, S.R. and Sorour, M.A. "Effect of impeller geometry on mixing of carrot concentrate". TESCE, Vol. 32, No. 3, pp. 1-13, 2006
[11] Geankoplis, C.J. "Transport processes and unit operations".Allyn and Bacon, Inc., 2nd Ed.,1983.
[12] Wilkens, R.J., Henry, C. and Gates,L. EChemical Engineering Progress. pp. 44-52, 2003.
[13] Sorour, M. A.; Mostafa S.R;. Abadir M. F and. Habash L. A (2006), 'Effect of temperature and concentration on the Rheological properties of fig jam puree.The third International Conference on Chemical and Environmental Engineering, Military Technical College, Kobry Elkobbah, Cairo, Egypt.
[14] Brookfield manual (1998), Brookfield manual No. M/98-211-B0104 Operating Instructions, Brookfield Engineering Laboratories, Inc. Middleboro, MA. USA.