EFFECT OF MIXING WATER TEMPERATURE AND OIL CONCENTRATION ON THE RHEOLOGICAL PROPERTIES OF COWPEA (*Vigna unguiculata*) SLURRY.

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Abstract

Cowpea (*vigna unguiculata*) flour was mixed with potable water at 70, 80 and 90 ^{0}C and 24, 28 and 28 ml of soybean oil to form a dispersion of 10% (w/v). The rheological properties of the slurry were studied using digital display viscometer (model NDJ-8S) at constant time interval with increasing shear rate of 0.1, 0.2, 0.5 and 1.0 S^{-1}. The flow of the dispersions was characterized by pseudoplastic behaviour ($0.317 \leq n \leq 0.720$) with shear thinning effect, and increasing shear stress and shear rates. The study shows that the consistency coefficient (k), of the cowpea slurry increased with increase in temperature and oil concentration and its value for the slurry mixed with water heated at 90 ^{o}C was higher (2.331-2.728 Ns/m^2) than the ones (0.934-2.314 Ns/m^2) mixed with water at other temperatures. The high correlation coefficient (r= 0.970-0.999) of log shear stress versus log shear rate data indicates that the power law adequately described the flow behaviour of the cowpea slurry. The apparent viscosity of the slurry increased with increase in temperature and oil concentration. However, the apparent viscosity generally decreased with increase in shear rate. The viscosity–temperature data fitted in Arrhenius equation yielded activation energy range of 40.72-51.0 KJ/mol and high correlation coefficient (r=0.897-0.956), which indicates that Arrhenius equation was suitable for describing the relationship between the temperature and viscosity of cowpea slurry within the mixing water temperature of 70-90 ^{o}C. The result of this study could be useful in process and equipment design and selection to produce moin-moin in industrial scale.

Key words: Arrhenius model, cowpea slurry, mixing, rheological properties; power law, pseudoplasticity, water temperature.

1 INTRODUCTION

Cowpea (*Vigna unguiculata)* are important grain legumes in East and West Africa[1] . Its flour which contains about 55-62% carbohydrate, 20-30 protein, 1.5-3.0% minerals and vitamins [2], [3] is a potential source of nutrients in a wide range of food products [4].

Viscosity is an important rheological property of fluid foods such as beverages and batters and for design of processing lines [5]. It is often important for quality control especially for product that is expected to be of a particular consistency in relation to mouth feel [6], [7]. Viscosity is a widely used rheological parameter and its relationship with shear rate has been to classify food into Newtonian and non Newtonian with distinguished sub classes such as pseudoplastic, dilatants and thixotropic [8]. Rheology is the study of flowing matter which describes a fluid's internal resistance to flow and may be thought as a measure of fluids friction. For good design of fluid handling equipment in food industry the knowledge of rheological behaviour is necessary in order to avoid over or under sized pumps and pipes [9].

Cowpea is used for the production of *akara* (a deep fried cowpea paste) and moin-moin, a steamed paste obtained by heating cowpea slurry beyond the protein transition temperature. These products are consumed in many parts of Nigeria. The production of moin-moin involves mixing the milled cowpea seed with oil and water at different temperatures. The rheological behaviour of different foods in Nigerian has been studied. Sopade and Kassum [8] studied the rheological characteristics of kunun zaki and kunun gyada and observed that kunun gyada exhibited pseudoplastic, while kunun zaki showed Newtonian characteristics. Akanbi[10] reported that drum dried cowpea slurry exhibited pseudoplastic behaviour when reconstituted into soup, while Ikegwu and Ekwu [11] observed that *Brachystegia spp,* (a traditional soup thickener) dispersions also showed pseudoplastic characteristics with shear thinning effect. Okechukwu [2] investigated the influence of peanut oil on the flow characteristics of cowpea slurry and found that the shear

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responses adequately fitted into the power law equation.

Although oil concentration provides a good parameter for controlling gel firmness in high energy moin-moin [2], its effect and the role of water temperature in mixing and energy requirements for slurry preparations deserve proper investigation for effective process design evaluation exercises. This aspect of rheological study of cowpea has not been fully exploited. The purpose of this study is to examine the influence of oil concentration and mixing water temperature on the flow characteristics of cowpea slurry.

1.1 Theoretical Consideration

For Newtonian fluids, the shear rate (γ) of flow is related to the applied shear stress (τ) expressed in a Newtonian law of internal friction [9] as (1)

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

μ = viscosity. Most fluid or semi fluid food materials deviate from the Newtonian behaviour. Assuming no plastic behaviour, the shear stress-shear rate relationship is approximated by power law model (2) as:

$$\tau = k\,\gamma^{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

k=consistency coefficient or index (N.s/m^2), n=flow behaviour index. In terms of apparent viscosity, (2) becomes

$$\mu_{app} = k\,\gamma^{n-1} \qquad 3$$

It has been observed that n=1 in Newtonian fluids, $0<n<1$ in pseudoplastic fluids, while in dilatant fluids, $1<n<\infty$ [12]. The main appeal of power law model is its simplicity and this explains why it is extensively used in both chemical and food engineering literatures [8].

Viscosity of fluids is temperature dependent [13] with the temperature decreasing as the temperature increases. For many fluids the change in viscosity, as a function of temperature can be represented over quite extensive temperature ranges by Arrhenius equation [14] as follows:

$$\mu = \mu_o \exp(-E_a/RT) \qquad 4$$

$$\text{or} \quad k = k_o \exp(-E_a/RT)$$

Where μ_o (k_o) = apparent viscosity (consistency index) at a reference temperature (T) in absolute value, k= consistency coefficient at absolute zero temperature. E_a = activation energy (KJ/mol), R= universal gas constant (8.314x 10^{-3} KJ/mol).

2 MATERIALS AND METHODS

Black eyed cowpea (*Virgna unguiculata)* seeds and soybean oil were purchased from Abakaliki main market in Ebonyi State Nigeria.

2.1 Sample preparation

The cowpea (*Vigna unguiculata*) seeds were sorted and cleaned. The dried seeds were soaked in potable water and manually dehulled by rubbing them between palms and removing the seed coat by floatation. The dehulled seeds were sun dried (32$\pm$ 2 ^{o}C, rh= 50 %) for 48 h and milled three times into flour in a locally fabricated commercial attrition mill. The flour produced was sieved with American standard sieve number 40 with aperture size of 435 μm. The flour that passed through the sieve was packaged in airtight polyethylene bag before analysis.

2.1 Viscosity measurements

The method of Sathe and Salunkhe [15] was adopted in determining the viscosity of the cowpea slurry. Carefully weighed 40 g of the flour was mixed with water (376 ml, 372 ml and 368 ml respectively) in 600 ml beaker. Each of the water volumes was heated to 70, 80, and 90 ^{o}C, respectively. Soybean oil (24 ml, 28 ml and 32 ml) was respectively gently added to the beaker and mixed to get a dispersion of 10 % (w/v), respectively. The slurry temperature was maintained using a thermostatically controlled calibrated Fisher's water bath (model 130) and hydrated for 30 minutes under a continuous stirring (British magnetic stirrer).

The viscosity readings of each slurry was measured using a digital display viscometer (model NDJ-8s) taken at 2 minutes interval with progressively increasing shear rate of 0.1, 0.2, 0.5, and 1.0 S^{-1}. Viscosity values were obtained by multiplying viscosity readings with appropriate factor (supplied by the viscometer manufacturer).

2.2 Flow characteristics and activation energy

Flow curves were plotted with the values obtained. From equation 3, log-log plot of μ_{app} against γ, a straight line of slope (n-1) and intercept, k, was obtained from which both the consistency coefficient and flow behaviour index were, respectively estimated. The relationship between temperature and viscosity of cowpea slurry was investigated using Arrhenius model (equation 4) for temperature range of 70-90 ^oC. From a semi log plot of k against 1/T (equation 4), the corresponding activation energy ratio (E_a/R), was obtained from the slope of each line, while the intercept was used to estimate the k_o.

2.3 Statistical Analysis:

Linear regression analysis was used to evaluate some of the data following the method of Steel and Torrie [16].

3 RESULTS AND DISCUSSIONS

The consistency coefficient (k), flow behaviour index (n) and associated correlation coefficient using the power law equation are presented in Table 1. The consistency coefficient, k, and flow behaviour index, n, ranged from 0.934 to 2.728, and 0.317 to 0.720 respectfully for the 10% w/v cowpea slurry mixed at water temperature of 70-90 ^oC and oil concentration of 24-32 ml. The consistency coefficient decreased with increase in oil concentration in all the water temperature used, while it increased as the mixing water temperature increased. The flow behaviour index did not show any defined trend with increase in water temperature and oil concentration. The result shows that flow behaviour index 'n' is not temperature dependent, which agrees with other published results [8]. However, the slurry indicates shear–thinning pseudoplasticity (n<1.0) in all the mixing water temperatures and oil concentrations. Shear thinning has been attributed to a progressive mechanical disentangling of chain within macromolecules as the rate of shearing increases [17]. The result in Fig 2-6 confirms this where the apparent viscosity decreases with increase in shear stress. The correlation coefficient (r) of log shear stress versus log shear rate data range between 0.970 and 0.999 indicates that the power law model adequately described the rheological behaviour of cowpea slurry mixed with water at temperature of 70-90 ^oC. Most Nigerian food dispersions have been found to be described by the power law [11,8].

Table 1: Effect of mixing water temperature and oil concentration on the rheological properties of cowpea slurry.

Temperature (^oC)	Oil concentration (ml)	Consistency coefficient, k,(Pas)	Flow behavior index n.	Correlation coefficient, (r)
70	24	0.981	0.626	0.970
	28	1.158	0.317	0.995
	32	0.934	0.554	0.988
80	24	2.314	0.666	0.999
	28	2.161	0.720	0.995
	32	2.252	0.672	0.992
90	24	2.728	0.436	0.979
	28	2.578	0.614	0.998
	32	2.331	0.520	0.991

Fig 1 shows the relationship between shear rate and shear stress. It shows that shear stress increased with increasing rate of shear. The shear tress also increased with increase with increase in the mixing water temperature. This is probably due to increase in gelatinization of some of cowpea slurry starch with increase in temperature. Cowpea starch exhibits a gelatinization thermal transition range of 66-86 °C when monitored with different instruments [2].

For the flow at water temperature of 70 °C at 0.1 Sec^{-1} and maximum shear rate of 1.0 Sec^{-1}, the shear tress (τ) were 5.11 and 40.56 N/m, respectively while the at 90 °C their values were 5.2 and 43.64 N/m respectively. This means that the samples mixed at water temperature of 70 °C and 80 °C requires less tress to flow. This is supported by the fact that apparent viscosity of the samples computed with equation 3 was higher when the flour was mixed with water at 90 °C (Fig 2). It also decreased with increase in shear rate. Ikegwu and Ekwu [11] made similar observations in their study of rheological characteristics of *achi* dispersions. The apparent viscosity of the cowpea slurry decreased with increase in shear rate (shear thinning), water temperature and oil concentration (Fig 4-6). This observation is similar to the findings of Alkali and Ijabo [1] for tomato paste, and Sopade and Kassum [8] for kunu zaki and kunu gyada. The shear thinning effect observed is expected because increase in rotation increases molecular alignment in the direction of flow, reducing resistance to flow and hence the viscosity. Awonorin [19] reported this phenomenon to be common with hydrocolloidal solutions and food paste with sensitive structure.

Table 2: Effect of oil concentration on the activation energy.

Oil concentration (ml)	Activation energy, E_a (KJ/mol)	Correlation coefficient (r)
24	51.42	0.938
28	41.77	0.956
32	40.72	0.891

The activation energy and correlation coefficient ranged from 40.76 to 51.46 KJ/mol and 0.891 to 0.956 respectively. From Table 2 the slurry mixed with 24 ml of oil appears to be more sensitive to temperature changes than that mixed with higher volume of 32 ml. It can therefore be inferred that temperature control will be more critical for sample mixed with 24 ml of oil during processing and quality control to, minimize variation in viscosity [8]. The results show that the activation energy decreased with increase in oil concentration. The high value of correlation coefficient, r, which is a measure of goodness of fit of experimental data to the Arrhenius equation, indicates that the model was adequate for describing the relationship between the temperatures and the viscosity of the cowpea slurry within the mixing water temperature (70-90 °C). These results would serve as useful purpose in proper design of flow system and in thermal processing of cowpea slurry. Rao and Ananthesaran [14] observed that rheological behaviour of foods play important role in thermal processing of food.

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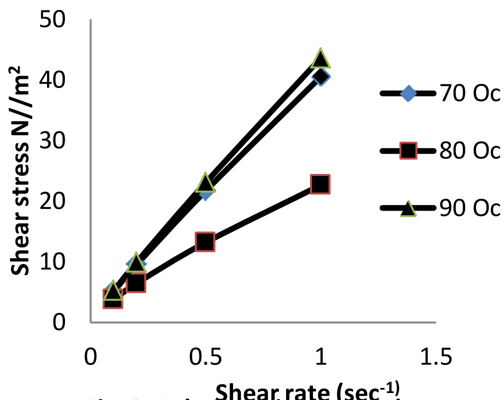

Fig 1: Relationship beteen shear rate and shear stress of cowpea slurry at different temperatures

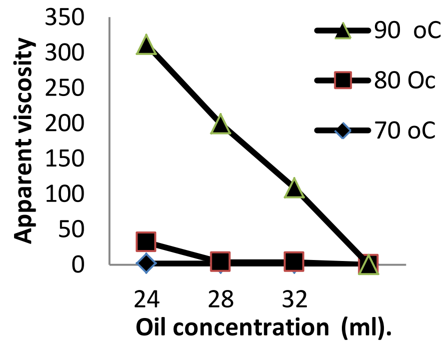

Fig 3: Effect of oil concentration on the apparent viscosity of the slurry at different temperatures

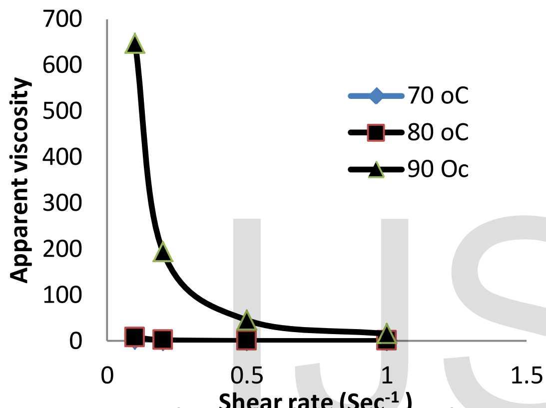

Fig 2 : Relationship between the shear rate and apparent viscosity at different temperatures

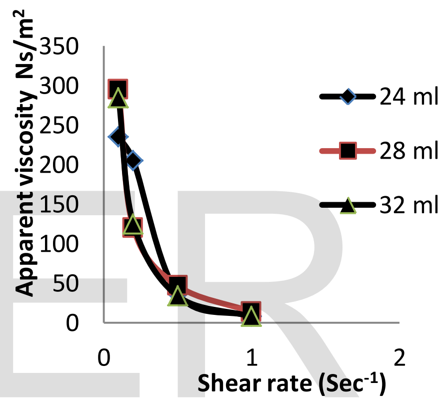

Fig 4 : Effect of oil concentration on the apparent viscosity of cowpea slurry at 70 °C

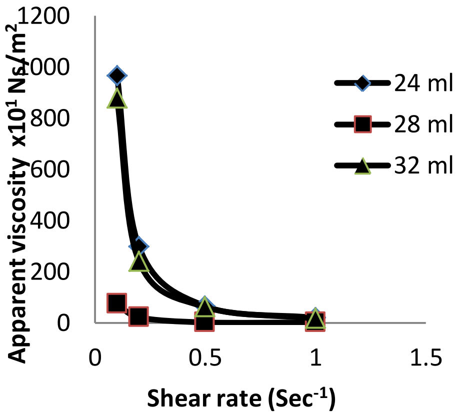

Fig 5 : Oil concentration on apparent viscosity of cowpea slurry at 80 °C

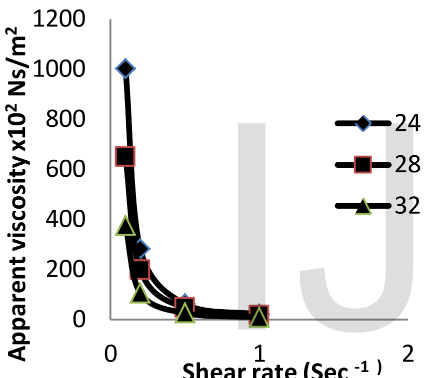

Fig 6 : Oil concentration on apparent viscosity of the copea slurry at 90 °C

CONCLUTIONS

The rheological responses of the cowpea slurry to changes in shear rate and temperature indicated pseudoplastic behaviour (0.317 < n< 0.720) and shear thinning effect. The apparent viscosity of the slurry increased with increase in temperature and oil concentration. The viscosity–temperature data fitted in Arrhenius equation yielded activation energy range of 40.72-51.0 KJ/mol and Arrhenius equation adequately described the relationship between the temperature and viscosity of cowpea slurry within the mixing water temperature of 70-90 °C. The result of this study could be useful in process and equipment design and selection to produce moin-moin in industrial scale.

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