Concentration-Dependent Changes in the Critical Turbidity and Rheology of Power-Law Non-Newtonian Liquids

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ABSTRACT

The turbidity of liquid is very important in high speed camera applications used to record the movement of accelerated solid spherical particles with rotation falling in Newtonian and non – Newtonian liquids. Measurements of turbidity, density, apparent viscosity and fluid rheological properties (flow behavior index n & consistency index K) were taken for different concentrations (0.15, 0.2, 0.25, 0.3 and 0 .4) % w/v of Carboxy methyl Cellulose (CMC), poly – vinyl alcohol (PVA) and CMC – PVA. Two types of CMC were used (industrial and laboratorial products). The results show that laboratorial CMC is the least turbidity (more transparent) than PVA and industrial CMC, PVA is less turbidity than industrial CMC and adding 0.5 gm of PVA to laboratorial CMC for the first three concentrations decreases the apparent viscosity and increase turbidity, while the apparent viscosity and turbidity were increased for the last two concentrations. The rheological properties of industrial CMC were unmeasurable because of the vibrational and unsteady records when they were measured by the viscometer. Different water turbidities were used to determine the critical turbidity suitable for this study which was 17.6 NTU and the corresponding critical concentrations were (0.25, 0.4, 2.25, 2.4 and 2.7) % w/v for (industrial. CMC + 0.5 gm PVA, industrial CMC, laboratorial CMC + 0.5 gm PVA, PVA and laboratorial CMC) respectively.

INTRODUCTION

Turbidity, which can make water appear cloudy or muddy, is caused by the presence of suspended and dissolved matter, such as clay, silt, finely divided organic matter, plankton and other microscopic organisms, organic acids, and dyes [1]. The color of water, whether resulting from dissolved compounds or suspended particles, can affect a turbidity measurement [2]. Chhabra et al., [3] used CMC (0.5, 0.75, 0.9 & 1.5) % w/v as non-Newtonian power law liquids ($0.2 \leq n \leq 1.8$) to describe experimentally the accelerating motion of rigid sphere. Matijasic & Glasnovic [4] used CMC (1-4) % w/v with optical method (IR rays between photo diode/photo receiver pairs) to measure the drag coefficient experimentally of different spherical particles in materials and diameters. They measured density, n and K, they show the importance of transparency of fluids in the optical method which is inapplicable for opaque fluids. Kelessidis and Mpandelis [5] and [6] used CMC (0.7, 0.9&1.1) % w/v as pseudoplastic liquids in measuring terminal velocity of solid spherical particles of different diameters and materials. Rheological properties were measured in their studies and take the density of liquid the same as for water at the experiment temperature. Al bermany and Jabbar [7] studied the effect of adding PVA on the optical properties of (0.1-0.8) % w/v concentrations of CMC; the rheological properties weren't measured in their study. Mahmood [8] choose 0.2 % w/v CMC as a non-Newtonian liquid to study experimentally the effect of surface roughness of different diameters of spherical stainless steel accelerated particles in Newtonian and non-Newtonian liquids using a high speed digital camera of (1000 frame/sec). Sulaymon et al., [9] investigated experimentally using high speed digital camera of (25000 f/s) the settling behavior of two stainless steel spheres of different diameters and different separation distances between the two spheres in CMC for the same concentrations of Kelesidis [5]. Aina et al., [10] studied the dissolution behavior of (0.1-1) % w/v concentrations of PVA in water and showed the non-ideal behavior of PVA dissolution in water and recorded the dissolution time for each PVA concentration (30-70) minutes, the rheological properties weren't measured in their study. The aim of the current article is to study the effect of turbidity on different concentrations of transparent non-Newtonian, power law liquids (CMC, PVA and CMC-PVA) to choose the most transparent (less turbidity) liquid and its best concentration to prepare 50 liters of it to be used with a high speed digital camera (1000 frame/sec) to measure experimentally the stainless steel spherical particles rotation's rate of different diameters in Newtonian and non-Newtonian liquids. Calculation of the critical turbidity and the corresponding liquid's concentration for the used liquids in this study are also one of this study's aims.

EXPERIMENTAL PROCEDURE

Chemical Materials

Industrial CMC is a commercial product used as a food thickener ,it has a white color with shape like sugar, it can be get from the local markets and it is low cost than laboratorial CMC. It was purchased from CPKelco, 3100 Cumberland Boulevard suit 600 Atlanta, Georgia, U.S.A. Laboratorial CMC is a white powder was purchased from Keshi Company, Chengdu area at the industrial development zone zindu mulan, China. PVA is a laboratorial white powder produced by Shanghai Guanghua technology co. ltd, 1798 West Tianshan Street, Shanghai, China. Distilled water was used as a solvent liquid. The reason of choosing CMC and PVA is their non-toxic nature [5] and [10] respectively.

Preparation Of Non-Newtonian Liquids

The weights of (0.75, 1, 1.25, 1.5 and 2) gm of each material were dissolved in 500 ml of distilled water using a small mixer NSF Hamilton Beach at 500 rpm to get the concentrations of (0.15, 0.2, 0.25, 0.3 and 0.4) % w/v.

Industrial CMC Solution

One of the selected weights was added gradually in 500ml of cold distilled water and it was mixed for 5 minutes [8], a dense and viscose solution was gotten.

Laboratorial CMC Solution

One of the selected weights was added gradually in 500 ml of hot distilled water (70°C) and it was mixed for 10 minutes, a completely dissolved solution was gotten. Al-Bermany and Jabbar [7] depended 30 minutes as a mixing time because they used a CMC from different chemical company.

Laboratorial PVA Solution

According to [10], the resulted concentrations (0.15, 0.2, 0.25, 0.3 and 0.4) % w/v need (35, 40, 45, 60 and 70) minutes respectively as a mixing time, see Figure 1 [10]:

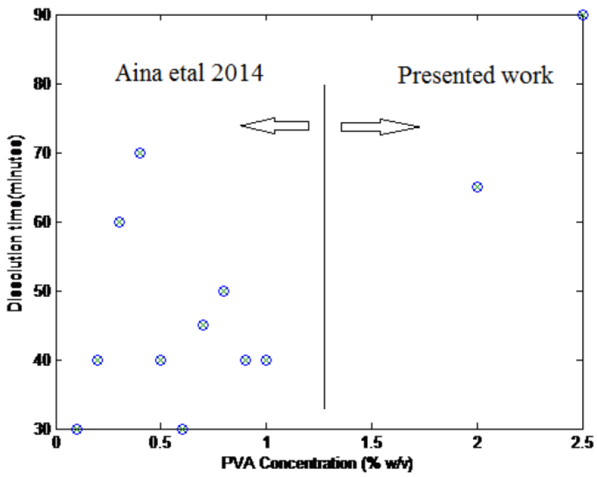


Figure 1. Plot of dissolution time versus PVA concentration

PVA was added to 500 ml of distilled water pre-heated to 40 °C, under continuous stirring. The resulting solution is then stirred and heated (up to 65 °C) without any interruption until the PVA is completely dissolved [10]. In this study 90 °C was attained (prevent boiling because liquid level decreases) so the PVA completely dissolved.

CMC-PVA Solution

The industrial CMC and the laboratorial CMC were prepared for the selected weights as previously described and they were cooled to the ambient temperature then the measurements (density, turbidity and rheological properties) can be taken immediately [7] or after 24 hours [6]. Then the CMC solution was heated to 70°C and 0.5 gm of PVA was added gradually to the solution for 30 minutes until PVA dissolved completely [7].

MEASUREMENTS

The previous works [3, 4, 6 and 9] considered the density of the product non-Newtonian liquid the same as water density at the experiment temperature. In the present work, the density was computed by dividing the liquids mass to its volume. All measurements were done at room temperature. The Turbidity was measured using a turbidimeter (HACH 2100N). Fanning viscometer type OFITE (model 800) which has eight speeds (600, 300, 200, 100, 60, 30, 6 and 3 rpm) was used to find the viscosity of the solution. To calculate the power law constants, the following equations were used [11]:

$$n = 3.32 \times \log \frac{600 \cdot rpm \cdot reading}{300 \cdot rpm \cdot reading} \quad (1)$$

$$K = \frac{600 \cdot rpm \cdot reading}{(1022)^{n}} \quad (2)$$

$$\mu_a = \frac{600 \cdot rpm \cdot reading}{2} \quad (3)$$

Where: n = Flow behavior index.

K = Consistency index in ($pa.s^n$).

μ_a = Apparent viscosity in (c.p.).

RESULTS AND DISCUSSION

The results of measurements are listed in Tables 1 and 2. The results will be presented in the following order: non-Newtonian behavior of different liquids concentrations, the optimum turbidity, and effect of adding PVA to CMC.

NON-NEWTONIAN BEHAVIOR

From Figures 2, 3 (a, b, c) and 4, it is clear that laboratorial CMC, PVA and laboratorial CMC-PVA are non-Newtonian power law type liquids for the used concentrations in this study. The industrial CMC and the industrial CMC-PVA (for all concentrations) gave unsteady and vibrational readings when their viscosities were measured, for this reason μ_a, n and K are not available (see Table 1). The reason of this behavior is that industrial materials are less purity than laboratorial materials.

OPTIMUM TURBIDITY

The results show that liquid's turbidity increases (transparency decreases) with increasing liquid's concentration for all liquids types used in this study except PVA (see Table 1). The turbidity of distilled water is less than tap water's turbidity (see Table 2). To get less liquid turbidity, it is better to prepare the solutions by distilled water. Mahmood [8] used tap water of turbidity 5 NTU to prepare 0.2 % w/v of laboratorial CMC, the resulted sample turbidity was 66 NTU, while 0.914 NTU (see table 1) was resulted when mixing the same material concentration with distilled water. Laboratorial CMC has less turbidity than other liquids, followed by PVA. The industrial CMC-PVA liquid has higher values of turbidity than other used liquids. When measuring solid particles rotation's rate using a high digital speed camera the turbidity becomes very important factor (see Figure.5 (a, b and c)) which represent different water's turbidity samples were taken from experimental cases using a glass cylinder of 1.5m length, 0.22m inner diameter and 0.5 cm thick . The critical turbidity is 17.6 NTU so as the particle's rotation can be seen well (see Figure.5.b.1). The critical corresponding concentrations of the used liquids (that gave 17.6 NTU liquid's turbidity value) can be evaluated from Figure.6 and they are listed in Table 1.

Table 1. Measurements results.*N.A. not available

Liquids Type	Concentration % w/v	Density gm/cm^3	Turbidity NTU	Critical Concentration % w/v	Apparent Viscosity (c.p.)	N	K ($Pa.s^n$)
Industrial CMC	0.15 0.2 0.25 0.3 0.4	0.988 0.968 0.991 1.00 1.097	3.92 7.64 10.7 11.6 16.6	0.4	*N. A.	N. A.	N. A.

Laboratorial CMC	0.15 0.2 0.25 0.3 0.4	0.9885 0.9917 0.9928 0.9973 0.9995	0.850 0.914 1.25 1.42 1.85	2.7	7.75 9.5 12.25 14.25 19.5	0.7059 0.6626 0.7074 0.7032 0.6703	0.1164 0.1926 0.1821 0.2181 0.3748
Laboratorial PVA	0.15 0.2 0.25 0.3 0.4	0.95 0.961 0.979 0.971 1.020	2.26 2.02 1.07 1.6 3.62	2.4	2 2.35 2.5 2.5 2.5	0.1925 0.4251 0.5143 0.3217 0.3217	1.0535 0.2471 0.1417 0.5379 0.5379
Industrial CMC + 0.5 gm PVA	0.15+0.5 0.2+0.5 0.25+0.5 0.3+0.5 0.4+0.5	1.0230 0.9960 0.9987 0.9527 0.9286	12.3 13.4 17.9 21.8 24.4	0.25	N. A.	N. A.	N. A.
Laboratorial CMC + 0.5 gm PVA	0.15+0.5 0.2+0.5 0.25+0.5 0.3+0.5 0.4+0.5	0.9869 0.9906 0.9969 0.9986 0.9989	1.45 3.65 4.65 5.89 6.72	2.25	7 9.25 11.5 14.5 23.25	0.8069 0.6855 0.6652 0.7283 0.6319	0.0522 0.1600 0.2290 0.1865 0.5831

Table 2. Different water's turbidity results

Water type	Turbidity NTU	Figure number
Distilled water	0.318	5.a
Tap water	1.14	5.b.2
Turbid water 1	17.6	5.b.1
Turbid water 2	21.65	5.c.2
Turbid water 3	25.5	5.c.1

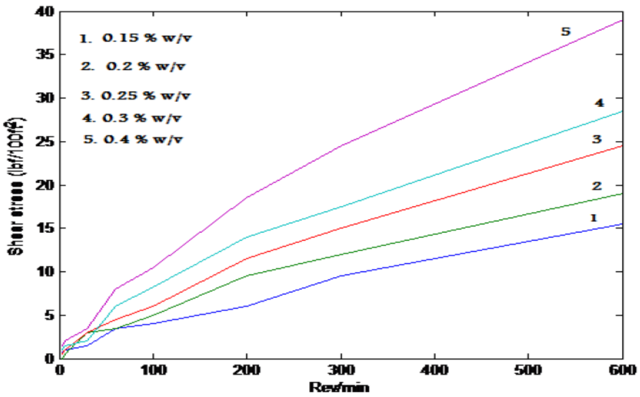
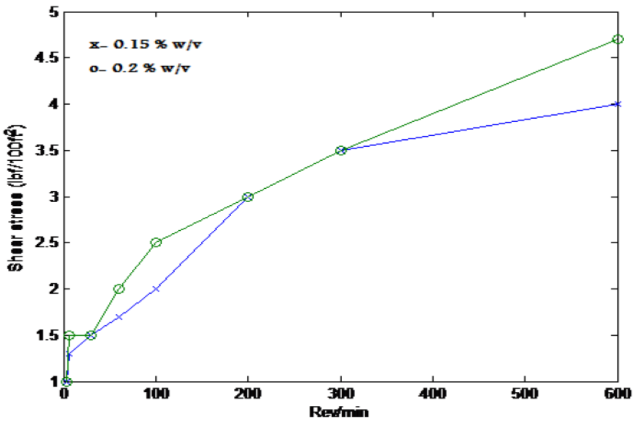
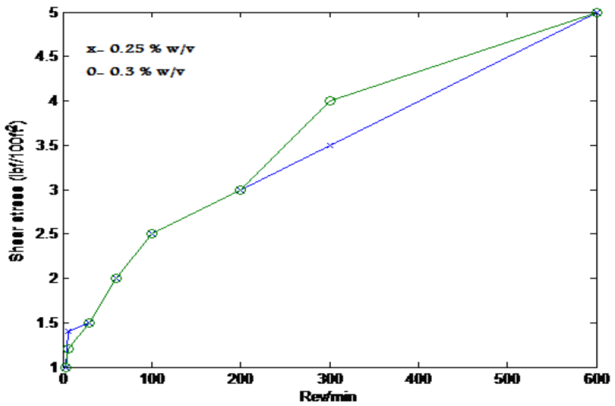


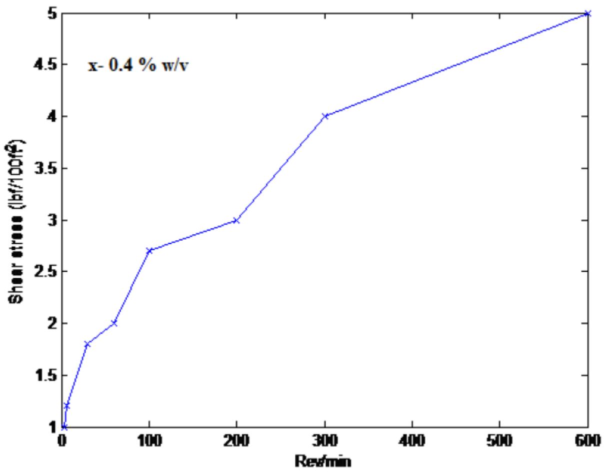
Figure 2. Laboratorial CMC non-Newtonian behavior



(a)



(b)



(c)

Figure 3. Laboratorial PVA non-Newtonian behavior with different concentrations

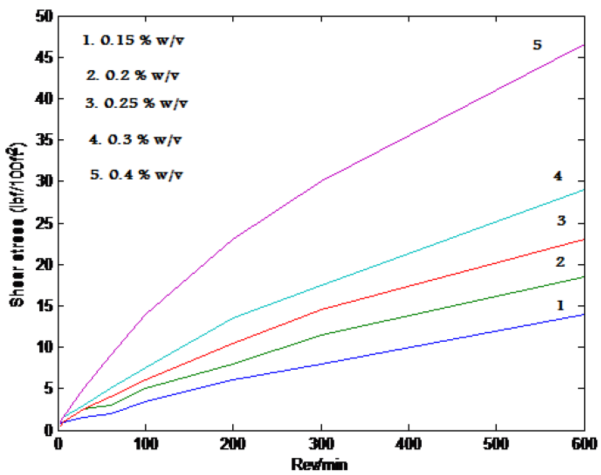


Figure 4. Laboratorial CMC-PVA non-Newtonian behavior

RHEOLOGICAL PROPERTIES

Generally the apparent viscosity increases with increasing liquids concentration. PVA has less apparent viscosity than other used liquids. The values of n are less than 1, which means that the used concentrations gave a shear thinning liquids (for n > 1 shear thickening liquids) [3]. Mahmood [8] rheological properties results (for 0.2 % w/v laboratorial CMC) were n=0.4147, k= 0.4519295 (pa.s^n), μ_a = 4 (c.p) and ρ = 1041.70 (Kg/m^3). From Table 1, this study's results for the same concentration is less dense and more viscouse.

EFFECT OF ADDING PVA TO CMC

Adding 0.5 gm of PVA to industrial CMC and laboratorial CMC increases turbidity for all concentrations and decreases apparent viscosity for the concentrations (0.15, 0.2 and 0.25) % w/v of laboratorial CMC while it increases with the concentrations (0.3 and 0.4) % w/v.

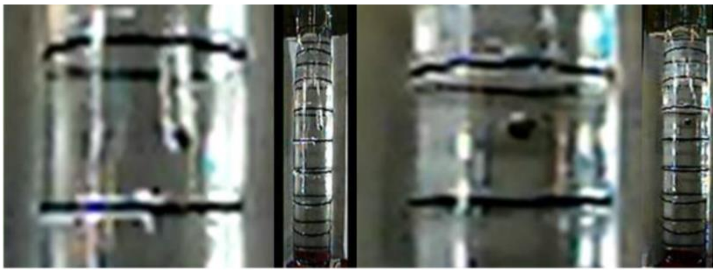
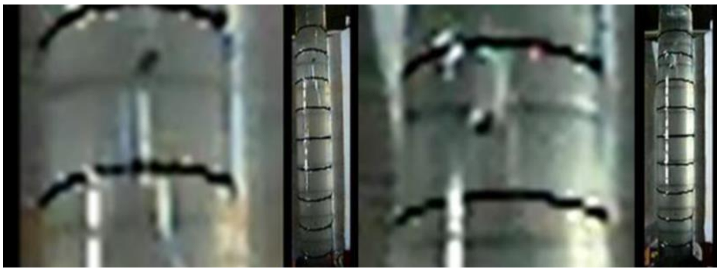
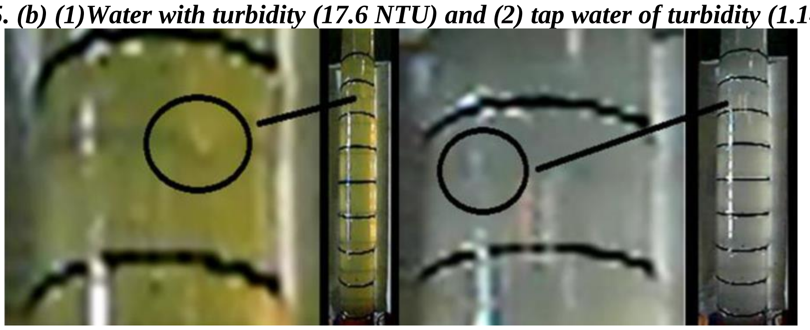


Figure 5. (a) Distilled water with turbidity 0.318 NTU



(1) (2)

Figure 5. (b) (1)Water with turbidity (17.6 NTU) and (2) tap water of turbidity (1.14 NTU)



(1) (2)

Figure 5. (c) (1) Water with turbidity (25.5NTU) and (2) water of turbidity (21.65 NTU).

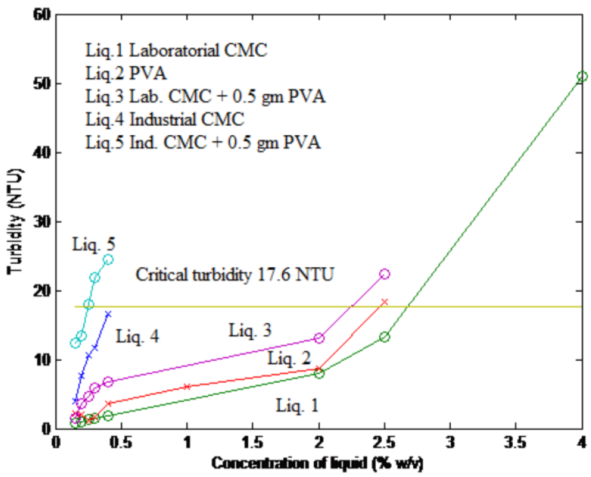


Figure 6. Turbidity of different liquids versus liquid's concentration

CONCLUSION

1. All the concentrations of this study (0.15, 0.2, 0.25, 0.3 and 0.4) % w/v gave non-Newtonian behavior for laboratorial CMC, PVA and laboratorial CMC-PVA. The industrial CMC rheological properties were unmeasurable because of the vibrational and unsteady records when measuring them by the viscometer.
2. PVA has the least viscosity among other used liquids in this study.
3. Laboratorial CMC has the least turbidity among other used liquids in this study for the same concentrations followed by PVA and laboratorial CMC-PVA respectively.
4. Using distilled water in solutions gives liquid's turbidity and density less than them by using tap water but more apparent viscosity.
5. Generally the lowest concentration gives the lowest turbidity. The critical liquid's turbidity was 17.6 NTU and the corresponding critical concentrations were (0.25, 0.4, 2.25, 2.4 and 2.7) % w/v for (industrial CMC + 0.5 gm PVA, industrial CMC, laboratorial CMC + 0.5 gm PVA, PVA and laboratorial CMC) respectively.
6. Adding 0.5 gm of PVA to:

- Laboratorial CMC increases turbidity for all concentrations and decreases apparent viscosity for concentrations (0.15, 0.2 and 0.25) % w/v while it increases for concentrations (0.3 and 0.4) % w/v.
- Industrial CMC increases turbidity for all concentrations.

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