EFFECT OF TEMPERATURE ON FLOW PROPERTIES OF DIGESTED WASTE WATER SLUDGE

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ABSTRACT

The digested waste water sludge from the Zeinein station, North of Cairo was characterized for its physical and chemical properties. The flow properties of this sludge were followed at different temperatures, for different levels of solid content. The yield strength of the sludge was found to increase linearly with temperature. The apparent viscosity was related to absolute temperature by an equation in the form $\eta = A.e^{b/T}$. While the constant A varies with both solid content and strain rate, the activation energy at constant strain rate is independent of solid volume fraction. The effect of temperature has to be taken in consideration when the experimental data are used to design the pipeline that is to transport the sludge to the next treatment plant.

Key Words: Waste water sludge – Rheology – Temperature – Viscosity

INTRODUCTION

The effect of solid concentration on the flow properties of digested wastewater sludge (From the Zeinein station North of Cairo) was investigated, Maha et al. [1]. In view of the fact that seasonal as well as diurnal variations in temperature can be very drastic in this region, the present part deals with the effect of temperature on the flow properties of the sludge. The average temperatures experienced by the sludge range from 10^{o}C in "cold" winter reaching 60^{o}C in the sun in summer. This has determined the choice of temperatures used in this investigation.

The temperature dependence of viscosity has been studied by a number of investigators. This has been mostly done by fitting the data by an Arrhenius type equation: $\eta = A.e^{E/RT}$. In this equation, E denotes the "activation energy", the temperature. For Non-Newtonian fluids, the value of E can be evaluated for data at constant strain rate E_γ or at constant shear stress E_τ. Generally $E_\gamma \neq E_\tau$, Jinescu [2]. In a more detailed study, Weymann et al. [3] presented a numerical analysis for data on clay-water mixtures and showed that the viscosity is related to both concentration and temperature. On the other hand, Yamagushi et al. [4] studied the effect of temperature on viscosity and divided the value of E into two terms: Ep which is the energy required for floc separation and E_v which is the viscous energy. They were able to show that the former term is independent of both shear rate and solid concentration. More recently, Atsushi and Yoshida [5] were able to relate the viscosity of the suspension to that of the solvent at any temperature using a single master curve, provided the particle - particle and the particle - solvent interactions did not change with temperature.

The rheological properties of sludge, as affected by temperature, were not extensively studied. Perhaps the work of Battistoni et al. [6], [7] is the only positive contribution in this respect. Also, Battistoni [8] has studied the effect of temperature on water sludge in the range 50 – 55^{o}C. He concluded by calculating the activation energies that the dispersion of solid aggregate is easier than the shearing of material.

EXPERIMENTAL TECHNIQUE

Characterization of the sludge

In the Zeinein plant, excess secondary sludge is mixed with at the plant entrance with raw sewage. The sludge collected from the primary settling tank is thus a mixture of secondary and primary sludge. It is to be pumped to another treatment plant before its final disposal. Part of this sludge is first thickened and then anaerobically digested. This constitutes the raw material of the present study.

The solid volume fraction of this sludge ranges from 0.015 to 0.036. The sludge was first characterized for humidity, BOD, pH, total suspended solids (TSS) Volatile suspended solids (VSS) and conductivity. Standard methods suggested by APHA et al. [9] were used. Table 1 shows the results obtained as well as the chemical characteristics of the sludge.

Table (1) Physico-chemical characteristics of sludge

Item	Value	Unit
Humidity %	97.46	%
BOD	7000	ppm
COD	48000	ppm
PH	6.8	-
TSS	31634	ppm
VSS	20610	ppm
TDS	1670	ppm
TS	33304	ppm
Conductivity	1940	µS
Chloride	1030	ppm
Sulphate	1578	ppm
Nitrate	64	ppm
Ammonia	470	ppm
Phosphorus	162	ppm

Rheological Measurements

The rheological properties of the sludge were investigated using a Brookfield type digital viscometer (Model DV-II). In this type of viscometer, a spindle is allowed to rotate within the fluid at pre-determined speeds and two readings are digitally recorded: the viscosity and the shear stress. From these, the strain rate can be obtained. Temperature was varied by placing the flask containing the suspension over a water bath and recording the temperature of the suspension. Measurements were begun when a steady state was reached. The error in the readings was ± 1^{o}C.

RESULTS AND DISCUSSION

Figure 1 shows the stress-strain rate behavior of sludge suspensions of solid volume fraction = 0.01524 at various temperatures. As shown, the Bingham pattern was obtained at all temperatures, with both the slopes and intercepts of the lines decreasing with increased temperature. This behavior was observed at all solid fractions although the curves are not reported. The effect of temperature on the yield strength (intercept) is shown in Fig. 2. This curve shows that there is a general decrease in the yield strength with increasing temperature, although this decrease is more accentuated at higher solid levels. It was possible to correlate the yield strength to temperature and solid fraction by a linear equation in the form:

$$\tau_o = A.t + B \qquad (1)$$

where: A and B are functions in the solid fraction C, and t is the temperature in ^{o}C.

$$A = -8.37\,C^2 + 0.64\,C - 0.0075 \qquad (2)$$

$$B = 37\,C - 0.51 \qquad (3)$$

On the other hand, Fig. 3 shows the relation between the apparent viscosity and temperature (K) at a solid volume fraction of 0.01524. The curves show a decrease in viscosity following an increase in temperature, the effect being more pronounced at lower strain rates. This behavior was observed at all solid fractions although the curves are not reported. The Arrhenius correlation relating $\ln \eta$ to 1/T (T in K) is shown in Fig. 4 . In this figure it is clear that at a constant shear rate of 3.5 sec^{-1}, the straight lines obtained were parallel, indicating that the activation energy is independent of solid fraction. The value of E/R = 1286 irrespective of the solid fraction.

The relation between viscosity and temperature at that strain rate takes the form:

$$\eta = K.e^{1286/T} \qquad (4)$$

where K is related to solid volume fraction by :

$$K = e^{107\,C\ -\ 9.1} \qquad (5)$$

Similar results were obtained at all other strain rates (7, 17 and 35 sec^{-1}) although the curves are not reported. It was possible to correlate the value of E/R (K) to the strain rate through the generalized equation:

$$E/R = 910 + 1433\, \gamma^{-1.17} \tag{6}$$

This result shows that as the strain rate increases the value of E decreases to reach a limiting value of 910 K at infinite strain rate. Practically, this implies that at high sludge velocities, the sensitivity of viscosity to temperature fluctuations becomes very low.

APPLICATION

The sludge produced from the Zeinein station is to be pumped to the next treatment plant 14 km away for further treatment. Its solid volume fraction is about 0.036 corresponding to a density of 1058 kg/m^3. The pipe used is to be 760 mm in diameter and the flow rate is 240 dm^3/sec. In the following is shown the calculation procedure to obtain the pressure drop along the pipe at the two extreme temperatures of 10^oC and 60^oC.

Velocity of flow = $240 \times 10^{-3} / \pi.(0.38)^2 = 0.53$ m/sec.

Corresponding strain rate $8.v / D = 8.(0.53) / 0.76 = 5.58\ sec^{-1}$

At that strain rate, from equation (6), E/R = 1102

The equation corresponding to (5), at a strain rate of 5.58 sec^{-1} is $K = e^{100\,C - 8.8}$

For C = 0.036 , K = 0.0055 and at a temperature of 10^oC, $\eta = 0.0055\ e^{1102/283}$

$\eta = 0.27$ Pa.sec

Performing the same calculations at 60^oC, we get;

$\eta = 0.15$ Pa.sec

The effect of these changes in viscosity on the pressure drop across the pipeline can be assessed by getting the Reynolds number in each case and calculating the friction factor from the generalized relation f = 16/Re.

Calculations show that: At 10^oC, Re = 1580 , f = 0.01 and Δp = 1.1 MPa

At 60^oC, Re = 2840 , f = .0056 and Δp = .617 MPa

This shows that the seasonal and diurnal variations in temperature highly affect the pressure drop, and hence the power required for the transportation of sludge.

The previous analysis is not a quantitative result. It has only been made to set up a methodology for the calculations of the pressure drop along a line at different temperatures. It is obvious that, when dealing with different sludge types, the calculations will have to rely on the corresponding experimental data.

CONCLUSION

The digested sludge from the Zeinein plant, North of Cairo, was characterized for its physical and chemical properties. Its rheological behavior was followed at different temperatures ranging from $10^{o}C$ to $60^{o}C$ using a Brookfield viscometer, for different solid concentrations. It was found that the sludge followed a Bingham fluid law for all solid contents and at all temperatures. The yield strength was linearly correlated to temperature. Also, the apparent viscosity was correlated to temperature using an Arrhenius type equation. It was found that the activation energy at constant strain rate is independent of solid fraction. The value of this activation energy was found to approach a limiting value corresponding to E/R = 910 K at very high strain rates. From the experimental results, it was possible to predict the effect of temperature on the pressure drop along the pipeline that is to transport the sludge to the next treatment plant.

LIST OF SYMBOLS

A	Empirical parameter, function in solid volume fraction	
B	Empirical parameter, function in solid volume fraction	
C	Volumetric fraction of solids	
D	Diameter of pipe	m
E	Activation energy at constant γ	J/g mole
f	Friction factor	
K	Empirical parameter, function in solid volume fraction	
R	General gas constant	J/g mole .K
Re	Reynolds Number	
t	Temperature	^{o}C
T	Temperature	K
v	Velocity of fluid	m/sec
γ	Strain rate	sec^{-1}
Δp	Pressure drop	MPa
η	Apparent viscosity	Pa.sec
τ_o	Yield stress	Pa

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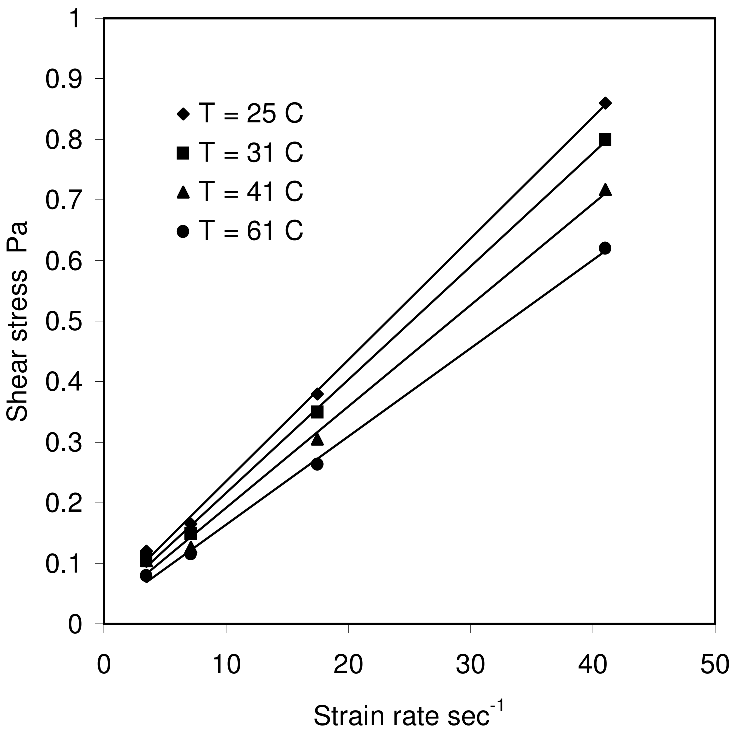

Fig.1 Effect of temperature on the stress-strain rate relation for suspensions containing a solid fraction = 0.01524

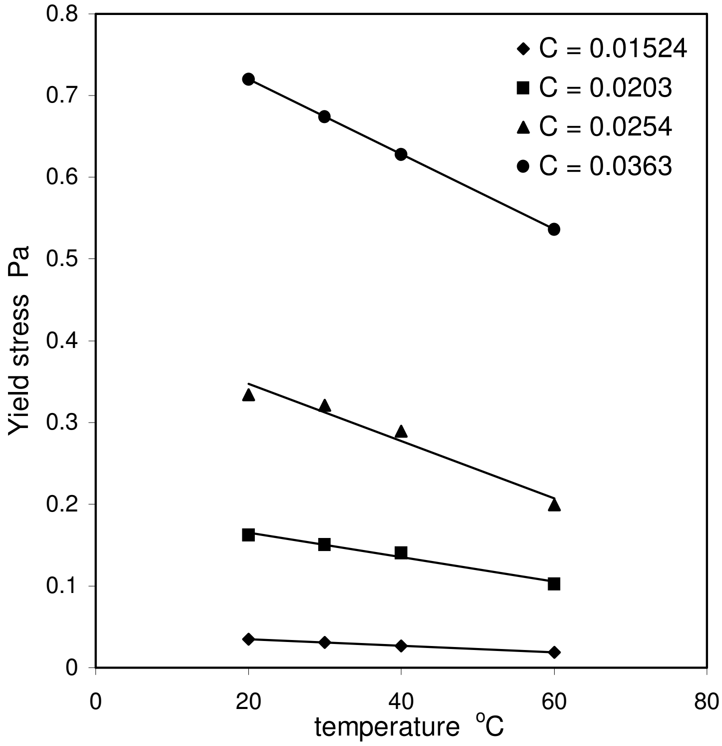

Fig.2 Effect of temperature on the yield stress of sludge suspensions at different volume fractions

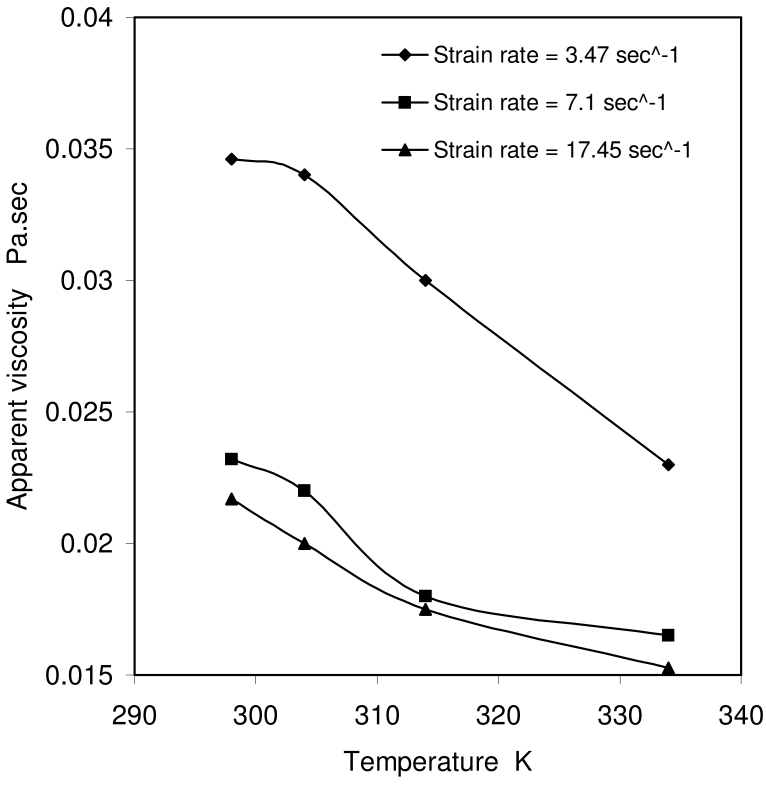

Fig.3 Effect of temperature on the apparent viscosity of sludge suspensions containing 0.01524 volume fraction

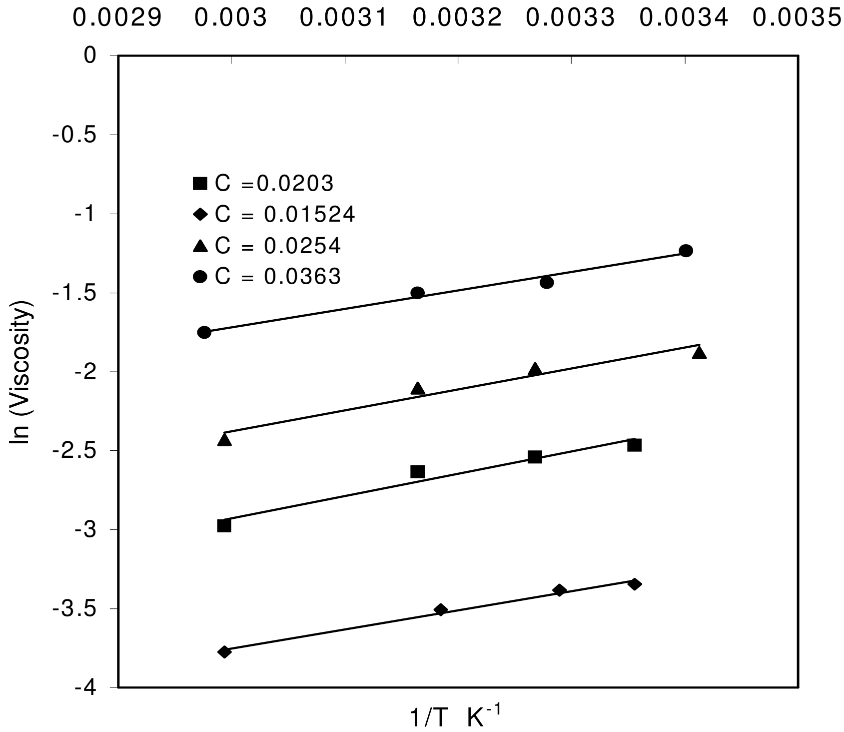

Fig. 4 Linearized plots of viscosity against temperature for sludge suspensions at constant strain rate = 3.5 sec^{-1}