

# Rheological Behavior of Fresh Activated Sludge

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**Abstract**—Despite of few research works on municipal sludge, still there is a lack of actual data. Thus, this work was focused on the conditioning and rheology of fresh activated sludge. The effect of cationic polyelectrolyte has been investigated at different concentrations and pH values in a comparative fashion. Yield stress is presented in all results indicating the minimum stress that necessary to reach flow conditions. Connections between particle-particle is the reason for this yield stress, also, the addition of polyelectrolyte causes strong bonds between particles and water resulting in the aggregation of particles which required higher shear stress in order to flow. The results from the experiments indicate that the cationic polyelectrolytes have significant influence on the sludge characteristic and water quality such as turbidity, SVI, zone settling rate and shear stress.

**Keywords**—Rheology, Polyelectrolyte, Settling volume index, Turbidity.

## I. INTRODUCTION

SLUDGE of waste water is conditioned with polymers to enhance the efficiency of dewatering with presses and centrifuges, but the relationship between fluid dynamics and the polymer/sludge interaction has been shown to be critical in mixing and conditioning performance. In addition to that, the cost effective design, sizing or selection of equipment for sludge pumping, transportation, handling, mixing, thickening, de-watering, heat exchanging and other processing depends on reliable measurements of sludge rheology [1].

Since sludge comes from different sources and undergoes different treatments prior to experiments, the task of correlating the sludge conditioning and flocculation to its rheological behavior is usually overlooked or improperly addressed. Furthermore, the development of new sewage and sludge processes has resulted in a growing number of various types of sludge whose properties cannot be accurately predicted. For controlling and design processes such as piping scaling of aeration tanks in waste water plant in which sludge flows have a sufficiently large of solid contents [1] - [4].

Chemical coagulations such as polyelectrolytes, are very important phenomenon for the sludge conditioning in waste water treatment. All coagulants are used in order to reduce the electrical charge of the particles breaking the stability of the colloids and thus affecting the flocculated microbial aggregates [5].

## II. RHEOLOGICAL THEORIES

Due to the non-uniform of sludge operation conditions, wastewater shows different rheological characteristics, especially in empirical correlation [6]. Shear yield stress may

be defined as the minimum shear stress required initiating flow [7]. An elastic solid behavior would be shown by sludge sample during tests of shear stress ramp measurements; this act forces the viscosity to increase as more stress is applied. At the point of reaching yield stress, sludge sample starts to flow and hence the viscosity starts falling accordingly [8]. Measurement of the shear yield stress provides valuable information regarding the handleability of the filter and thickener output as a function of the solids concentration of flocculated sludge. There are many ways to evaluate the yield stress for fluid-like substances and no single “best” technique can be defined.

There are many ways to evaluate the yield stress for fluid-like substances and no single “best” technique can be defined. Different applications require different methods. The most popular techniques are based on the extrapolation of shear stress versus shear rate. The traditional method of determining the shear yield stress of a particulate suspension is through the extrapolation of shear stress versus shear rate data to a zero shear rate. The most used model by the investigators [1], [3], [6] is Bingham plastic model (1) for obtaining the value for the yield stress. This model assumes a linear relationship between shear stress and shear rate with the stress intercept being the Bingham yield value:

$$\tau = \tau_o + k\gamma \quad (1)$$

where,  $\tau$  is the shear stress ( $N/m^2$ ),  $\tau_o$  is the yield stress ( $N/m^2$ ),  $\gamma$  ( $sec^{-1}$ ) is the shear rate and  $k$  is the consistency index that represents the cohesiveness of the fluid, the higher value reflect higher viscosities.

## III. CONDITIONING AGENTS

In order to improve the solid-liquid separation of the sludge, conditioning agents shall be used due to the large effect of these agents on the dispersed particles. There are two types of agents, inorganic and organic chemicals. Both are used to change the electrical potential of the suspended particles and reduce the repelling force. These agents form polymeric charged hydroxide and are adsorbed on the dispersed particles and thus modify their surface charge [9].

The overall objective of this study is to investigate the role of polyelectrolytes such as Polyacrylamide (PAM) as flocculating and conditioning agents for sewage sludge at the Nizwa waste water treatment plant.

## IV. MATERIALS AND METHODS

The sludge samples used for experimental tests come from the waste water treatment plant at Nizwa city in the Sultanate of Oman. The considered sludge samples were taken from the

aeration tank in order to obtain the optimum solid concentration in the digester. The considered sludge samples were taken from the aeration tank in order to obtain the optimum solid concentration in the digester. The solid contents of the collected one sample has TSS=7.31 g/l, VSS=5.51g/l, and FSS=1.8 g/l. These values reveal that organic content in the sample is about 75%.

#### A. Chemical Preparations

One type of polyacrylamide was used as flocculants; CPAM-80, provided by Cytec Industries Ltd., UK. This solution of this chemical was prepared by mixing 1 g with one liter of deionized water and stirring with a magnetic stirrer for 24 hours. Ten different concentrations of polyacrylamide were used in order to cover range from 0.05 to 100 mg of chemical per one gram of total suspended solid (TSS) of the activated sludge. The pH for each solution was adjusted by adding sulfuric acid or sodium hydroxide solutions.

#### B. Microscopic Analysis

Optical microscope was performed using HORNET Micro Zoom 1280 to photo fresh sludge sample; Untreated and treated with Polyacrylamide. The adopted magnification 6x-50x. The photos have been done with a digital camera MICROS CAM 320 "Advanced". Fig. 1 (a) shows a sample of sludge without polyelectrolyte and Fig. 1 (b) shows clearly how the polyelectrolyte carries out the function of separating solids particles of sludge in comparison with a normal sludge. Also, these photos show the complexity of the sludge and most of the sludge particles are heterogeneous in shapes.

#### C. Rheology Tests

Rheological measurements were conducted using TA-Rheometer (HR-2 Discovery Hybrid Rheometer). The used geometry is Peltite plate which is used for low viscosity liquids. As no much water remaining in the solid sample, thus, no water is rejected during tests even at imposing a high share rate.



Fig. 1 (a) Photo of fresh sludge without Polyelectrolyte, Diluted 50 times with water

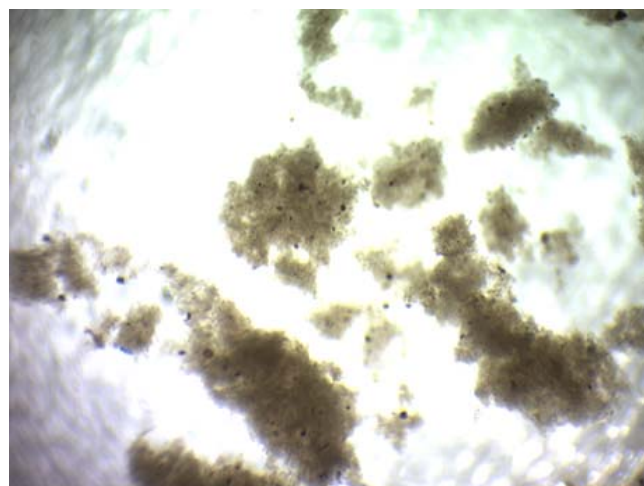


Fig. 1 (b) Photo of fresh sludge conditioned with polyelectrolyte (13 g poly/g solid/l) Diluted 50 times with water

#### D. Turbidity

The turbidity was measured in NTU (Nephelometric Turbidity Unit) using a turbidity meter (CL 52D NEPHELOMETER). Flocculation was carried out on a six multiple stirring unit with a stainless steel paddle (Jar test) using rapid mixing (200rpm) for 2 minutes and then followed by slower mixing (90rpm) for 30 minutes. Short and fast mixing helps in binding the polyelectrolyte molecules and dispersed particles.

#### E. Settling Property

The measurement of the settling properties was characterized by the sludge volume index (SVI) using Imhoff cone. The position of the interface between the supernatant liquor and sludge zone was observed and recorded. Total suspended solids (TSS) for each fresh sludge sample were analyzed using method 2540D that issued by the 1998 APHA standard [10].

## V. RESULTS AND DISCUSSIONS

#### A. Turbidity

Fig. 2 shows that the turbidity of the supernatant depends on the polyelectrolyte concentration and pH level. Turbidity was measured for the supernatant liquor of all samples including samples with and without the addition of the polyelectrolytes. The results showed that the polyelectrolyte CPAM-80 had improved the turbidity and also, it can be observed that the turbidity was improved immediately after first and small dosage of CPAM-80 and reaches 1 NTU at 2 mg CPAM-80/g soild/l and kept the turbidity at value of 1 NTU. For samples at pH=5.6 and pH=9, there were a less improvement in turbidity compared to that under pH near neutrality (pH=6.8).

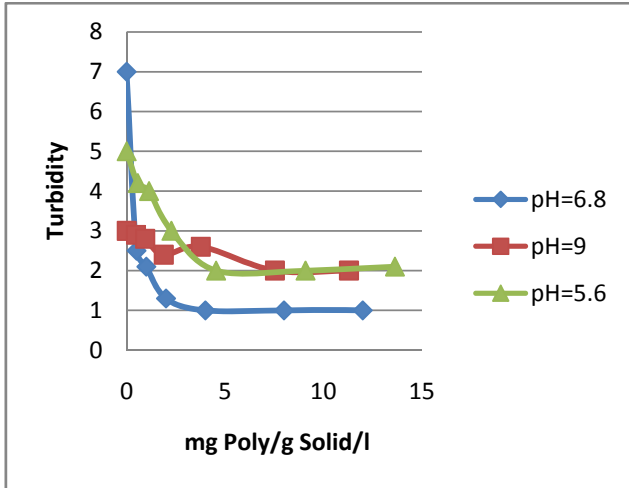


Fig. 2 Effect of Polyelectrolyte concentration on turbidity after 2 hours of settling using different pH values

**B. Settling Behavior**

All samples collected within three months from Nizwa waste water treatment plant had a high SVI (e.g. in thousands). This behavior may also be due to the high organic contents in the waste water. Also, this unhealthy biomass content may be a result of fungi, algae, worms and virus organisms found in the waste water feed [4].

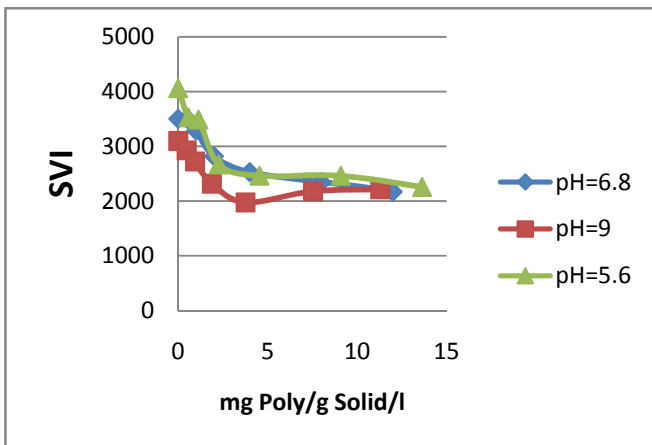


Fig. 3 SVI at different dosage of chemicals and different pH values

**C. Rheology Tests**

In order to analyze the rheological behavior of sludge with and without conditioning, typical test is the ramp shear stress. Results are shown in Figs. 4-6. The non-Newtonian behaviors are clearly shown. Yield stress is presented in all results indicating the minimum stress levels that are necessary to reach flow condition. Connections between particle-particle are the reason for this yield stress. The higher the concentrations of polyelectrolyte caused strong bonds between particles and water and resulting aggregation of particles which required higher shear stress in order to flow. The formation of these aggregates with certain of strength of bonding causes stress overshoot due to the structure broken down. The results showed that the larger concentration of the

polyelectrolyte offered larger overshoot size. After this disruption, the effect of the polyelectrolyte was vanished and shear stress rapidly decreased and when reached a share rate of 150 1/s, all samples behaved similarly to those without conditioning and had the same trend. However, solutions with higher pH value caused lager yield stress. All samples of sludge under stress are followed Bingham model. Different k values that satisfy (1) has been obtained for each test with different pH values. However, the difference between these k values is very small as shown Table I below.

TABLE I  
 K VALUES IN BINGHAM MODEL

K value	pH
$6.9 \times 10^{-3}$	6.8
$6.2 \times 10^{-3}$	5.6
$5.5 \times 10^{-3}$	9

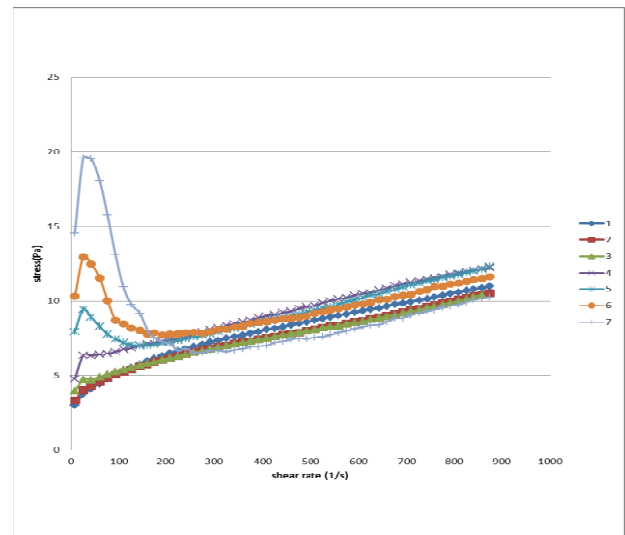


Fig. 4 Share stress vs. share rate at different concentration of polyelectrolyte and pH=6.8

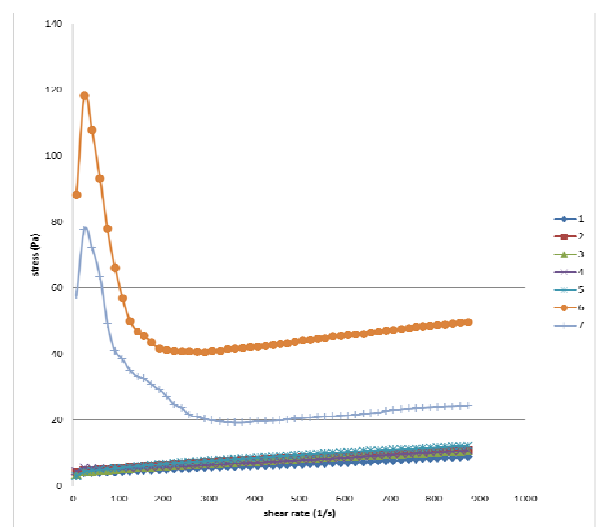


Fig. 5 Share stress vs. share rate at different concentration of polyelectrolyte and pH=5.6

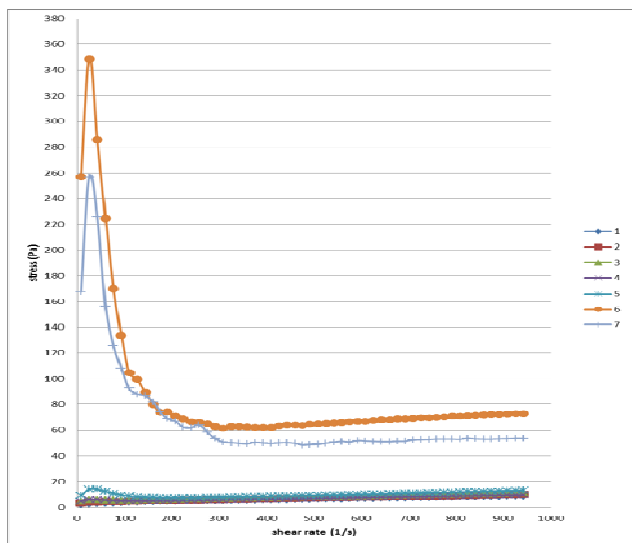


Fig. 6 Share stress vs share rate at different concentration of polyelectrolyte and pH=9.0

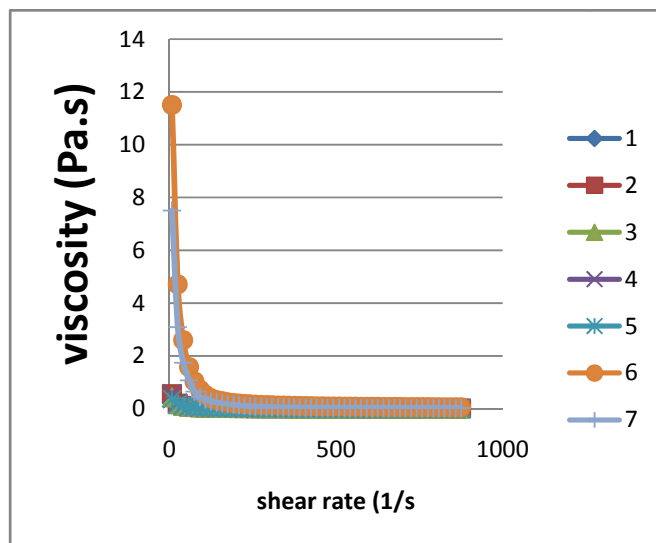


Fig. 8 Viscosity vs. share rate at different concentration of polyelectrolyte and pH=5.6

Also, it was found that despite of the increase of concentration of polyelectrolyte; the viscosities of all samples decreased rapidly within 5 seconds of shearing then slowly become nearly constant as shown in Figs. 7-9. The results showed that higher initial values of viscosities were obtained at higher concentration of polyelectrolyte for all types of solutions. However, the ranges of these viscosities were higher for solution with pH=9 than that of other solutions.

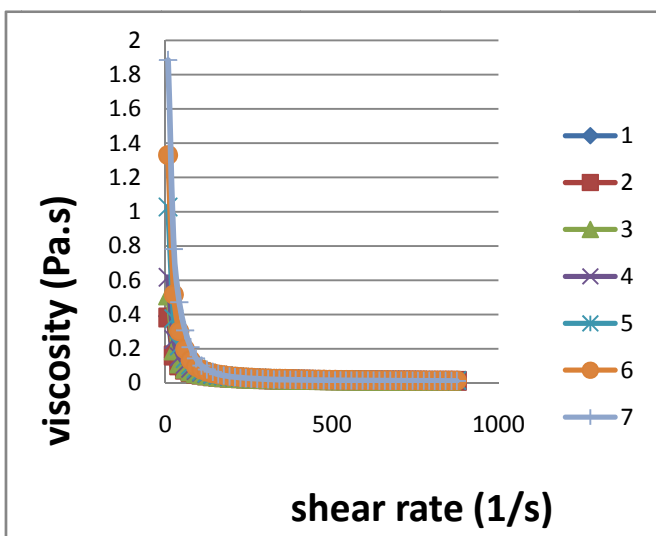


Fig. 7 Viscosity vs. share rate at different concentration of polyelectrolyte and pH=6.8

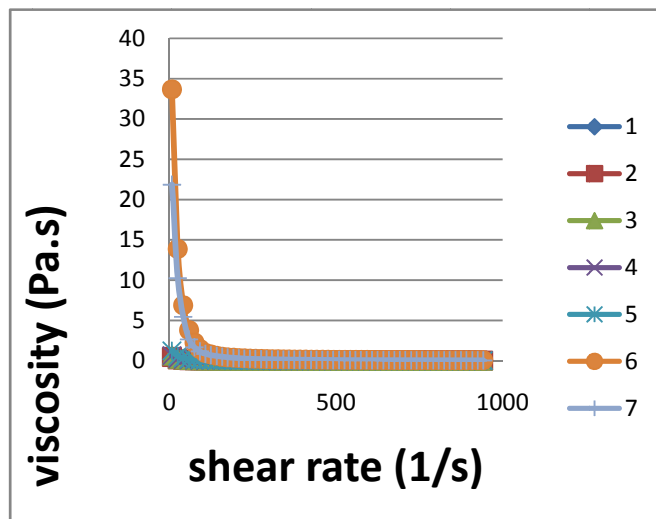


Fig. 9 Viscosity vs. share rate at different concentration of polyelectrolyte and pH=9

## VI. CONCLUSIONS

The use of the polyelectrolyte PAM-80 showed a significant effect on improving turbidity and reduction of sediment thickness. The following conclusion can be drawn:

1. The fresh activated sludge collected from the Nizwa waste water treatment plant has a high SVI and unhealthy biomass content which caused slow settling.
2. The effect of pH on the sludge characteristics displayed a negative profile in the case of increasing the yield stress, especially with pH value higher or lower than neutrality.
3. The results showed that the polyelectrolyte CPAM-80 improved the turbidity.
4. The share stress–share rate relation was modeled by Bingham model with average  $k$  value of  $6 \times 10^{-3}$ .

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