



# IJEAST

INTERNATIONAL JOURNAL  
OF ENGINEERING APPLIED SCIENCE  
AND TECHNOLOGY



VOLUME : 4    ISSUE : 05    Print / Issue Publication Date: 09-Nov-2019



ISSN : 2455-2143



DOI : 10.33564/IJEAST.2019.v04i05.043

Indexed In



[WWW.IJEAST.COM](http://WWW.IJEAST.COM)

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# STUDIES ON SORPTION PROPERTIES OF SOME BIO-POLYMERS IN THE ABSORPTION OF TOXIC METAL ION

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**ABSTRACT:** Toxic metal ions such as Fe (II) and Hg (II) present in industrial waste water can be absorbed by certain biopolymers in parts per milligrams. Biopolymers like Guar Gum, Xanthan Gum, Acacia Gum, Gum Tragacanth, Sodium Alginate, Carboxymethyl Cellulose, Methyl Cellulose and Hydroxypropyl Methyl Cellulose were tested for the same. We found Hg (II) metal ion can be absorbed only by Xanthan Gum and Gum Tragacanth whereas Fe (II) metal ion absorbed by all these biopolymers from waste water. Maximum possible absorption of metal ions determined using minimal quantity of bio-polymer sample. Sorption kinetics and solution property studies of biopolymers conducted also sorption of Fe, Hg metal ions characterized at different temperature and concentrations of biopolymers. Absorption maximum for all these mixtures obtained through spectrophotometric study.

**KEYWORDS:** Absorption, Biopolymers, Sorption Property, Temperature effect.

## I. INTRODUCTION

Sorption is a physical and chemical process whereas Biosorption is a physico-chemical process that occurs naturally. In these days treating industrial waste water is a challenge since it contains toxic metal ions, pesticides and other organic compounds. Certain existing methods for the treatment of industrial waste water are expensive and ineffective. So we can go for biosorption method which is environment friendly filtering technique. Biopolymers are produced by living organisms also they are renewable, compostable and biodegradable [10]. In order to remove these metal ions, waste water can be treated with some biopolymers which have hydrogel properties. Hydrogels are crosslinked polymers, hydrophilic in nature, able to swell in water [1, 4, 9]. Heavy metals are naturally occurring but various activities of human have altered the balance of the same. Once it enters into the environment or to the aquatic system heavy metals cannot be degraded or destroyed easily since they are stable. They tend to accumulate in nature [3]. They move from one ecological trophic level to another by damaging the ecosystem. Due to

biomagnifications or multiplication process they accumulate in living tissues, causing several health issues in humans [12]. Many metallic elements like Zinc, Iron, Copper, etc. are essential for living organisms. Although they are necessary, they become toxic at high concentrations [11]. When present above threshold concentrations, all heavy metals can be toxic. Geological weathering, solid waste dump, leaching of metals, industrial processing of metals are some sources through which metal pollution occurs. Metals used in electroplating, tanning and textile industry are highly toxic to humans [6]. Existing biosorption methods for removal of metal ions from waste water like ion-exchange, reduction, precipitation, etc. are expensive and inefficient in treating large quantities. New trends in removing heavy metals from industrial waste water are being processed [2]. The natural affinity of biological compounds for metallic elements could contribute to the purification of metal loaded waste water [8]. Thus biosorption is a beneficial option because it is both efficient and cheap [5].

## II. EXPERIMENTAL

### 2.1 Materials and Methods

Biopolymers selected based on availability and price. Guar gum (GG), Xanthan gum (XG), Acacia gum (Ac.G), Gum tragacanth (GT), Sodium alginate (Na Alg), Carboxymethyl Cellulose (CMC), Methyl Cellulose (MC), Hydroxypropyl methyl cellulose (HPMC) were obtained from Himedia laboratories, Mumbai, India and used without additional purification. All chemicals were of Analytical reagent grade. Mohr's salt,  $K_2Cr_2O_7$  and  $ZnSO_4 \cdot 7H_2O$  obtained from Merck India, Ammonium thiocyanate obtained from Himedia. BaDS (Barium diphenylamine Sulfonate) indicator,  $HgSO_4$ , Dithizone (1, 5-Diphenylthiocarbazone) and 1, 4-dioxane solution obtained from Loba chemie. Distilled water used wherever necessary. Digital pH meter (Systronics, MK-IV) used for pH study. Ultrasonic Interferometer for liquids F-81 (Mittal Enterprises) used for the estimation of ultrasonic sound velocity. Spectrophotometric analysis performed using Vis Double Beam Spectro 1203, Systronics.



## 2.2 Polymer sample preparation

1000ppm Stock solution of Fe and Hg metal ions were prepared by Mohr's salt (Ferrous Ammonium Sulphate) and  $\text{HgSO}_4$  respectively. Crystals of Mohr's salt and  $\text{HgSO}_4$  were dissolved with dil.  $\text{H}_2\text{SO}_4$ . Bio-polymers such as Guar gum, Xanthan Gum, Acacia gum, Gum tragacanth, Sodium Alginate, CMC, Methyl cellulose and HPMC are taken with different quantities that are 20%(200mg), 15%(150mg), 10%(100mg), 5%(50mg), 1%(10mg), 0.5%(5mg), 0.1%(1mg), 0.05%(0.5mg) and 0.01%(0.1mg). Each bio-polymer mixtures taken in different beakers, to that separately added 10ml of 1000ppm Fe (II) and Hg (II) metal ion solution. Then for all the mixtures 10ml of waste water was added. These biopolymer- metal ion mixtures along with waste water mixed thoroughly with the help of magnetic stirrer. After proper mixing, the resulting mixture taken for further studies.

## 2.3 Sample preparation for Spectrophotometric study

For all biopolymer mixtures containing Fe (II) metal ion, ammonium thiocyanate solution and  $\text{HNO}_3$  were added. Whereas to the mixtures containing Hg (II) metal ion, equal volumes of Dithizone and 4.5M sulphuric acid were added. To this 1, 4-dioxane solution was added later.

## III. RESULTS AND DISCUSSIONS

### 3.1 Interaction of bio-polymer mixtures with toxic metal ions

#### 3.1.1 Study of absorption of Fe and Hg metal ions

Initially we applied simple titration method to determine the absorption properties of bio-polymers. Solution containing 10ml of 1000ppm Fe (II) metal ion was titrated against 0.003N  $\text{K}_2\text{Cr}_2\text{O}_7$  solution using BaDS (Barium diphenylamine Sulfonate) indicator at lab temperature ( $30^\circ\text{C}$ ).  $\text{K}_2\text{Cr}_2\text{O}_7$  standardised with 0.003N Hypo solution. Solution containing 10ml of 1000ppm Hg (II) metal ion was titrated against 0.02M  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  solution using EBT indicator at lab temperature ( $30^\circ\text{C}$ ). Initially  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  standardized with 0.02M EDTA. Strength of Mohr's salt ( $N_{\text{Mohr's}}$ ) and Strength of  $\text{HgSO}_4$  ( $N_{\text{HgSO}_4}$ ) calculated using formula

$$N_1 V_1 = N_2 V_2 \quad (1)$$

Where  $N_1$  is the strength and  $V_1$  is volume of Mohr's salt solution,  $N_2$  is the strength and  $V_2$  is volume of  $\text{K}_2\text{Cr}_2\text{O}_7$  solution in case of Fe (II) analysis and  $N_1$  is the strength and  $V_1$  is volume of  $\text{HgSO}_4$  solution,  $N_2$  is the strength and  $V_2$  is volume of  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  solution in case of Hg (II) analysis. By this, amount of only Fe and Hg can be calculated as

$$N_{\text{Mohr's}} \times \text{Molar weight of Fe} \times 1000 \text{ in ppm.} \quad (2)$$

$$N_{\text{HgSO}_4} \times \text{Molar weight of Hg} \times 1000 \text{ in ppm.} \quad (3)$$

Where  $N_{\text{Mohr's}}$  is the strength of Mohr's salt solution and  $N_{\text{HgSO}_4}$  is the strength of  $\text{HgSO}_4$ . Titration of 10ml of 1000ppm Mohr's salt solution against 0.003N  $\text{K}_2\text{Cr}_2\text{O}_7$ , considered as blank titration. Similarly titration of 10ml of 1000ppm  $\text{HgSO}_4$  solution against 0.02M  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  solution considered as blank titration. Solution which contains only 1000ppm of Mohr's salt, considered as blank solution of Fe and solution

contains only 1000ppm of  $\text{HgSO}_4$ , considered as blank solution of Hg. By titration method, amount of only Fe present in 1000ppm of Mohr's salt solution (blank solution of Fe) was found to be 201ppm and amount of only Hg present in 1000ppm of  $\text{HgSO}_4$  solution (blank solution of Hg) found to be 782ppm at lab temperature. Sorption properties of the metal ions are characterized by different concentrations of bio-polymer mixtures. Then different concentrations of bio-polymer mixtures along with corresponding metal ion solution were tested for absorption of Fe (II) and Hg (II) metal ions in the same way at lab temperature. It was observed that Guar gum, Xanthan gum, Acacia Gum, Gum tragacanth, Na Alginate, CMC, MC and HPMC mixtures could effectively absorb Fe (II) metal ion, only Xanthan gum and Gum tragacanth mixtures could absorb Hg (II) metal ion. Thus we can use corresponding bio-polymer mixtures for the effective removal of Fe (II) and Hg (II) metal ions from industrial waste water. Details of the observations have given in the Table 1.

Table 1. a.) Absorption of Fe (II) metal ion by different biopolymer mixtures (ppm) at  $30^\circ\text{C}$ .

| Concentrations | Amount of Fe (ppm) |                    |                    |                  |                  |                   |                   |                      |                      |
|----------------|--------------------|--------------------|--------------------|------------------|------------------|-------------------|-------------------|----------------------|----------------------|
|                | 20%<br>(200<br>mg) | 15%<br>(150<br>mg) | 10%<br>(100<br>mg) | 5%<br>(50<br>mg) | 1%<br>(10<br>mg) | 0.5%<br>(5m<br>g) | 0.1%<br>(1m<br>g) | 0.05%<br>(0.5<br>mg) | 0.01%<br>(0.1<br>mg) |
| GG             | 114                | 121                | 129                | 134              | 137              | 140               | 144               | 147                  | 151                  |
| XG             | 117                | 130                | 147                | 150              | 154              | 157               | 159               | 163                  | 167                  |
| Ac.G           | 114                | 120                | 127                | 131              | 134              | 137               | 139               | 142                  | 144                  |
| GT             | 107                | 116                | 122                | 128              | 134              | 140               | 144               | 146                  | 149                  |
| Na Alg.        | 134                | 137                | 141                | 145              | 147              | 150               | 154               | 157                  | 159                  |
| CMC            | 95                 | 105                | 115                | 119              | 124              | 129               | 131               | 136                  | 139                  |
| MC             | 117                | 126                | 134                | 136              | 139              | 141               | 144               | 146                  | 149                  |
| HPMC           | 119                | 128                | 139                | 143              | 149              | 152               | 156               | 159                  | 162                  |

1. b.) Absorption of Hg (II) metal ion by XG and GT mixtures (ppm) at  $30^\circ\text{C}$ .

| Concentrations | Amount of Hg (ppm) |                    |                    |                  |                  |                   |                   |                      |                      |
|----------------|--------------------|--------------------|--------------------|------------------|------------------|-------------------|-------------------|----------------------|----------------------|
|                | 20%<br>(200<br>mg) | 15%<br>(150<br>mg) | 10%<br>(100<br>mg) | 5%<br>(50<br>mg) | 1%<br>(10<br>mg) | 0.5%<br>(5m<br>g) | 0.1%<br>(1m<br>g) | 0.05%<br>(0.5<br>mg) | 0.01%<br>(0.1<br>mg) |
| XG             | 538                | 572                | 610                | 644              | 678              | 690               | 702               | 715                  | 722                  |
| GT             | 702                | 714                | 726                | 738              | 750              | 757               | 762               | 766                  | 770                  |

At  $30^\circ\text{C}$  since the polymer concentration is high maximum absorption of Fe (II) and Hg (II) metal ions has observed for 20% each bio-polymer. According to the intension of this study we found that, minimal amount i.e., 0.01% (0.0001gms) of biopolymer mixtures could absorb Fe metal ion as; 151ppm



using Guar gum, 167ppm using Xanthan gum, 144ppm using Acacia gum, 149ppm using GT, 159 ppm using Sodium Alginate, 139 ppm using CMC, 149 ppm using MC and 162 ppm using HPMC mixture out of 201ppm (blank solution of Fe). Also 0.01% mixtures of XG and GT could absorb 722ppm of Hg metal ion and 770ppm of Hg metal ion respectively out of 782 ppm (blank solution of Hg) at lab temperature. The absorption of Fe, Hg metal ions goes on increased as biopolymer concentrations decreased since concentration getting closer to blank concentration. i.e., 20% < 15% < 10% < 5% < 1% < 0.5% < 0.1% < 0.05% < 0.01%. Experiment has stopped at 20% (0.2gms) of each bio-polymer mixture because it is difficult to carry out the experiment since the thickness of mixture becomes too high after 0.2gms.

### 3.1.2 pH study

pH of blank Fe, Hg solution and different concentrations of biopolymer mixtures were noted at lab temperature (30°C). Acidic pH range of 2-3 has observed in blank solution of both Fe and Hg metal ion as well as in every bio-polymer mixtures with corresponding metal ion. pH of blank solution of Fe was found to be 3.81 and that of Hg was 3.10 at lab temperature. pH values of various biopolymer mixtures along with corresponding metal ion at lab temperature are mentioned in Table 2.

Table 2. a.) pH values of different biopolymer mixtures contain Fe (II) metal ion.

| Concentration | 20% (200 mg) | 15% (150 mg) | 10% (100 mg) | 5% (50 mg) | 1% (10 mg) | 0.5% (5mg) | 0.1% (1mg) | 0.05% (0.5 mg) | 0.01% (0.1 mg) |
|---------------|--------------|--------------|--------------|------------|------------|------------|------------|----------------|----------------|
| GG            | 3.78         | 3.63         | 3.85         | 3.80       | 3.74       | 3.71       | 3.80       | 3.83           | 3.81           |
| XG            | 3.37         | 3.58         | 3.34         | 3.21       | 3.33       | 3.29       | 3.03       | 3.06           | 3.07           |
| Ac. G         | 2.80         | 2.79         | 2.78         | 2.88       | 2.80       | 2.82       | 2.84       | 2.75           | 2.76           |
| GT            | 2.87         | 2.85         | 2.88         | 2.89       | 2.78       | 2.80       | 2.88       | 2.79           | 2.89           |
| Na Alg.       | 3.55         | 3.48         | 3.33         | 3.39       | 3.22       | 3.25       | 3.22       | 3.19           | 3.20           |
| CMC           | 3.33         | 3.17         | 3.10         | 3.07       | 2.94       | 3.00       | 2.91       | 2.96           | 2.90           |
| MC            | 2.90         | 2.91         | 2.86         | 2.89       | 2.86       | 2.95       | 2.85       | 2.93           | 2.85           |
| HPMC          | 3.15         | 3.12         | 3.15         | 3.16       | 3.11       | 3.10       | 3.12       | 3.15           | 3.10           |

2. b.) pH values of XG and GT mixtures contain Hg (II) metal ion.

| Concentration | 20% (200 mg) | 15% (150 mg) | 10% (100 mg) | 5% (50 mg) | 1% (10 mg) | 0.5% (5mg) | 0.1% (1mg) | 0.05% (0.5 mg) | 0.01% (0.1 mg) |
|---------------|--------------|--------------|--------------|------------|------------|------------|------------|----------------|----------------|
| XG            | 2.91         | 3.03         | 2.91         | 2.98       | 3.07       | 3.10       | 3.05       | 2.98           | 2.81           |
| GT            | 3.08         | 3.07         | 3.10         | 2.79       | 2.98       | 2.88       | 2.94       | 3.08           | 2.82           |

### 3.1.3 Density and Viscosity studies of biopolymer mixture

Density and viscosity measurements were carried out for both Fe and Hg blank solution and also for different concentrations of biopolymer mixtures with corresponding metal ions at lab temperature. At 30°C we found density of Fe blank was  $0.3950 \times 10^3$  (kg/m<sup>3</sup>) and its viscosity was 0.2805mm<sup>2</sup>/sec, density of Hg blank was  $0.3950 \times 10^3$  (kg/m<sup>3</sup>) and its viscosity was 0.3189mm<sup>2</sup>/sec. Density and viscosity values of various concentrations of biopolymer mixtures along with respective metal ions at are shown in Table 3 and 4 respectively. Both the parameters decreased as we move from higher concentration (20%) to lower concentrations (0.01%) of each biopolymer mixture. Mass of the substance goes on decreases from 20% to 0.01%. As a result value of density decreases.

Thickness of the substance decreases from higher concentrations (20%) to lower concentrations (0.01%). Therefore internal resistance of the mixture decreases. We know that, a liquid with high internal resistance to flow is described as having high viscosity [7]. A liquid with low internal resistance to flow is described as having low viscosity. Therefore decrease in viscosity has observed from higher concentrations (20%) to lower concentrations (0.01%).

Table 3. a.) Density values of different biopolymer mixtures contain Fe (II) metal ion.

| Concentration | Density values [ $10^3$ (kg/m <sup>3</sup> )] at 30°C |              |              |            |            |            |            |                |                |
|---------------|-------------------------------------------------------|--------------|--------------|------------|------------|------------|------------|----------------|----------------|
|               | 20% (200 mg)                                          | 15% (150 mg) | 10% (100 mg) | 5% (50 mg) | 1% (10 mg) | 0.5% (5mg) | 0.1% (1mg) | 0.05% (0.5 mg) | 0.01% (0.1 mg) |
| GG            | 0.3970                                                | 0.3969       | 0.3968       | 0.3967     | 0.3966     | 0.3965     | 0.3964     | 0.3963         | 0.3961         |
| XG            | 0.3978                                                | 0.3970       | 0.3963       | 0.3962     | 0.3961     | 0.3960     | 0.3959     | 0.3958         | 0.3957         |
| Ac. G         | 0.3975                                                | 0.3973       | 0.3969       | 0.3965     | 0.3961     | 0.3959     | 0.3957     | 0.3955         | 0.3954         |
| GT            | 0.3974                                                | 0.3971       | 0.3969       | 0.3965     | 0.3962     | 0.3961     | 0.3960     | 0.3959         | 0.3958         |
| Na Alg.       | 0.3980                                                | 0.3974       | 0.3969       | 0.3967     | 0.3966     | 0.3964     | 0.3962     | 0.3961         | 0.3960         |
| CMC           | 0.3973                                                | 0.3971       | 0.3968       | 0.3965     | 0.3963     | 0.3962     | 0.3961     | 0.3958         | 0.3955         |
| MC            | 0.3971                                                | 0.3966       | 0.3962       | 0.3961     | 0.3960     | 0.3959     | 0.3958     | 0.3957         | 0.3956         |
| HPMC          | 0.3972                                                | 0.3968       | 0.3963       | 0.3961     | 0.3959     | 0.3957     | 0.3956     | 0.3955         | 0.3953         |

3. b.) Density values of XG and GT mixtures contain Hg (II) metal ion.

| Concentration | Density values [ $10^3$ (kg/m <sup>3</sup> )] at 30°C |              |              |            |            |            |            |                |                |
|---------------|-------------------------------------------------------|--------------|--------------|------------|------------|------------|------------|----------------|----------------|
|               | 20% (200 mg)                                          | 15% (150 mg) | 10% (100 mg) | 5% (50 mg) | 1% (10 mg) | 0.5% (5mg) | 0.1% (1mg) | 0.05% (0.5 mg) | 0.01% (0.1 mg) |
| XG            | 0.3973                                                | 0.3971       | 0.3968       | 0.3965     | 0.3963     | 0.3962     | 0.3961     | 0.3958         | 0.3955         |
| GT            | 0.3972                                                | 0.3968       | 0.3963       | 0.3961     | 0.3959     | 0.3957     | 0.3956     | 0.3955         | 0.3953         |



| Concentration | 20% (200 mg) | 15% (150 mg) | 10% (100 mg) | 5% (50 mg) | 1% (10 mg) | 0.5% (5 mg) | 0.1% (1 mg) | 0.05% (0.5 mg) | 0.01% (0.1 mg) |
|---------------|--------------|--------------|--------------|------------|------------|-------------|-------------|----------------|----------------|
| GG            | 0.4041       | 0.4016       | 0.4003       | 0.3993     | 0.3989     | 0.3980      | 0.3974      | 0.3970         | 0.3965         |
| GT            | 0.3980       | 0.3976       | 0.3973       | 0.3970     | 0.3968     | 0.3967      | 0.3966      | 0.3964         | 0.3962         |

Table 4. a.) Viscosity values of different biopolymer mixtures contain Fe (II) metal ion.

| Concentration | 20% (200 mg) | 15% (150 mg) | 10% (100 mg) | 5% (50 mg) | 1% (10 mg) | 0.5% (5 mg) | 0.1% (1 mg) | 0.05% (0.5 mg) | 0.01% (0.1 mg) |
|---------------|--------------|--------------|--------------|------------|------------|-------------|-------------|----------------|----------------|
| GG            | 14.4142      | 9.9878       | 4.8055       | 2.1818     | 0.6942     | 0.5665      | 0.3496      | 0.3214         | 0.2906         |
| XG            | 36.6945      | 25.4141      | 13.8747      | 8.3135     | 2.3279     | 1.1763      | 0.8996      | 0.5043         | 0.2902         |
| Ac. G         | 0.4325       | 0.4151       | 0.4037       | 0.3956     | 0.3748     | 0.3604      | 0.3466      | 0.3282         | 0.3182         |
| GT            | 0.6486       | 0.4848       | 0.3473       | 0.3365     | 0.3280     | 0.3161      | 0.3091      | 0.3003         | 0.2949         |
| Na Alg.       | 0.4142       | 0.4008       | 0.3849       | 0.3654     | 0.3471     | 0.3353      | 0.3280      | 0.3133         | 0.3091         |
| CMC           | 2.2555       | 1.8645       | 0.7698       | 0.5587     | 0.3890     | 0.3511      | 0.3232      | 0.3156         | 0.3087         |
| MC            | 7.6177       | 5.6730       | 1.5910       | 0.7756     | 0.3512     | 0.3245      | 0.2950      | 0.2934         | 0.2901         |
| HPMC          | 1.2165       | 0.9989       | 0.5625       | 0.449      | 0.3044     | 0.2993      | 0.29        | 0.2886         | 0.2816         |

4. b.) Viscosity values of XG and GT mixtures contain Hg (II) metal ion.

| Concentration | 20% (200 mg) | 15% (150 mg) | 10% (100 mg) | 5% (50 mg) | 1% (10 mg) | 0.5% (5 mg) | 0.1% (1 mg) | 0.05% (0.5 mg) | 0.01% (0.1 mg) |
|---------------|--------------|--------------|--------------|------------|------------|-------------|-------------|----------------|----------------|
| XG            | 28.453       | 17.313       | 8.45         | 4.0654     | 2.347      | 0.7653      | 0.4331      | 0.3875         | 0.3283         |
| GT            | 0.3907       | 0.364        | 0.3571       | 0.3421     | 0.3332     | 0.3308      | 0.3284      | 0.3208         | 0.3199         |

### 3.1.4 Study of Ultrasonic sound velocity of biopolymer mixtures

Determination of ultrasonic sound velocity carried out as a part of solution property studies of biopolymers with heavy metal ions. Study conducted for blank solution of Fe and Hg also for various concentrations of biopolymer mixture with corresponding metal ion at lab temperature using Ultrasonic Interferometer for liquids F-81 (Mittal Enterprises). Ultrasonic sound velocity of blank solution of Fe was 1609m/s and for blank Hg solution it was 1605m/s. The obtained values of ultrasonic sound velocity for various concentrations of

biopolymer mixtures with respective metal ions are given in Table 5. No characteristic changes observed in the values of ultrasonic velocity for different concentrations of biopolymer mixtures.

Table 5. a.) Ultrasonic sound velocities of different biopolymer mixtures contain Fe (II) metal ion.

| Concentration | 20% (200 mg) | 15% (150 mg) | 10% (100 mg) | 5% (50 mg) | 1% (10 mg) | 0.5% (5 mg) | 0.1% (1 mg) | 0.05% (0.5 mg) | 0.01% (0.1 mg) |
|---------------|--------------|--------------|--------------|------------|------------|-------------|-------------|----------------|----------------|
| GG            | 1724         | 1655         | 1646         | 1612       | 1708       | 1688        | 1630        | 1661           | 1645           |
| XG            | 1609         | 1588         | 1607         | 1613       | 1594       | 1595        | 1604        | 1611           | 1616           |
| Ac. G         | 1575         | 1581         | 1565         | 1579       | 1590       | 1588        | 1566        | 1587           | 1597           |
| GT            | 1621         | 1645         | 1630         | 1616       | 1636       | 1604        | 1639        | 1626           | 1620           |
| Na Alg.       | 1584         | 1596         | 1599         | 1579       | 1595       | 1575        | 1569        | 1591           | 1588           |
| CMC           | 1602         | 1598         | 1600         | 1621       | 1603       | 1597        | 1591        | 1616           | 1594           |
| MC            | 1586         | 1593         | 1601         | 1603       | 1585       | 1590        | 1607        | 1587           | 1605           |
| HPMC          | 1619         | 1624         | 1594         | 1612       | 1599       | 1587        | 1602        | 1579           | 1601           |

5. b.) Ultrasonic sound velocities of XG and GT mixtures contain Hg (II) metal ion.

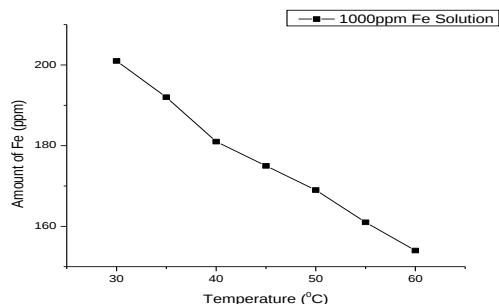
| Concentration | 20% (200 mg) | 15% (150 mg) | 10% (100 mg) | 5% (50 mg) | 1% (10 mg) | 0.5% (5 mg) | 0.1% (1 mg) | 0.05% (0.5 mg) | 0.01% (0.1 mg) |
|---------------|--------------|--------------|--------------|------------|------------|-------------|-------------|----------------|----------------|
| XG            | 1610         | 1595         | 1605         | 1607       | 1613       | 1616        | 1594        | 1610           | 1607           |
| GT            | 1607         | 1604         | 1603         | 1600       | 1605       | 1608        | 1604        | 1602           | 1607           |

## 3.2 Sorption kinetics studies (Temperature Study)

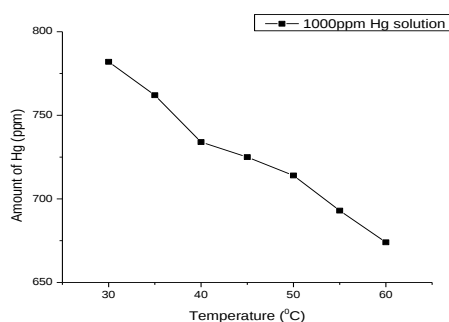
### 3.2.1 Effect of temperature on absorption of toxic metal ion

Study of effect of temperature on absorption of Fe (II) and Hg (II) by biopolymers, their pH values, density, viscosity and ultrasonic sound velocity were conducted. Both blank solution of Fe, Hg and various concentrations of biopolymer mixtures containing corresponding metal ions were tested for the same. Temperature increased starting from lab temperature to slight higher temperatures. That was from 30°C to 60°C. Absorption of Fe (II) and Hg (II) from industrial waste water was found to decrease with increasing temperature for all the biopolymer mixtures even for blank solutions of metal ion. As we increase the temperature the rate of reaction increases. Particles can

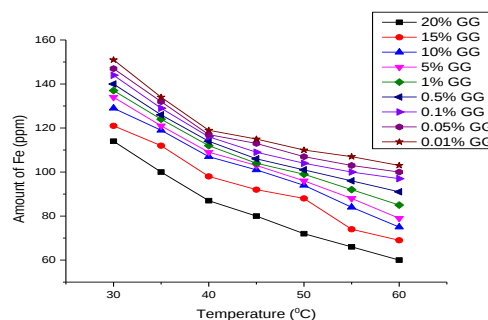
react only when they collide. By heating, particles move faster and collide more frequently. That will speed up the rate of reaction. Fig.1 and 2 represent the effect of temperature on absorption of Fe and Hg blank solutions respectively. Effect of temperature on absorption of Fe (II) metal ion by different concentrations of Guar gum mixtures (Fig.1.a), Xanthan gum mixtures (Fig.1.b), Acacia gum mixtures (Fig.1.c), Gum tragacanth mixtures (Fig.1.d), Sodium alginate mixtures (Fig.1.e), CMC mixtures (Fig.1.f), MC mixtures (Fig.1.g) and HPMC mixtures (Fig.1.h) have given below. Temperature effect on absorption of Hg (II) by Xanthan gum (Fig.2.a) and Gum tragacanth (Fig.2.b) also mentioned. Absorption curves of Fe, Hg blank (Fig.1 & 2) taken as reference curve. Remaining curves of all biopolymer mixtures with corresponding metal ion when compared with respective reference curve, lesser absorption values obtained. From graph it is clear that temperature has greater effect on reaction rate of biopolymer mixtures resulting in, decreasing temperature curve. After 60°C, absorption found to be constant also there was negligible difference in absorption values. Hence temperature study has stopped at 60°C for all the mixtures.



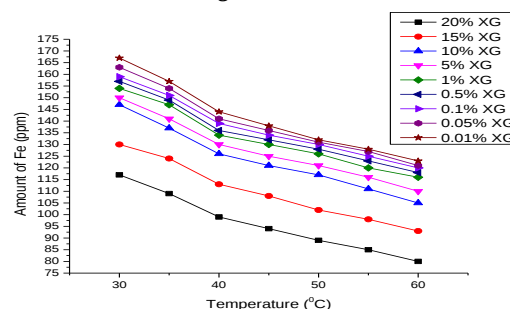
**Fig.1** Effect of temperature on absorption of Fe blank



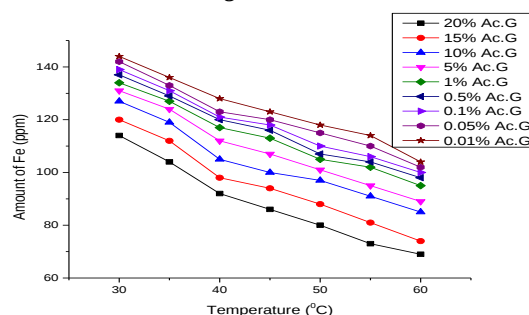
**Fig.2** Effect of temperature on absorption of Hg blank



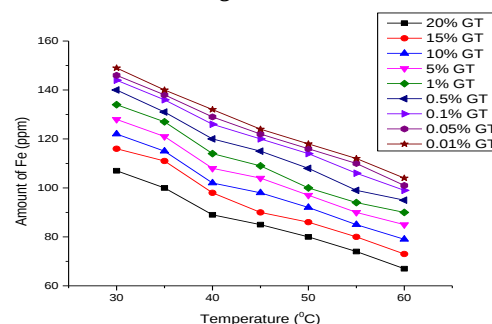
**Fig.1.a** Effect of temperature on absorption of Fe using GG mixtures



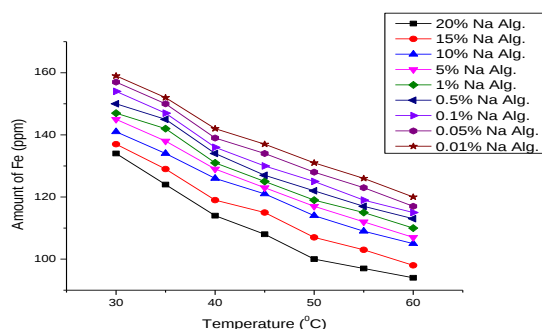
**Fig.1.b** Effect of temperature on absorption of Fe using XG mixtures



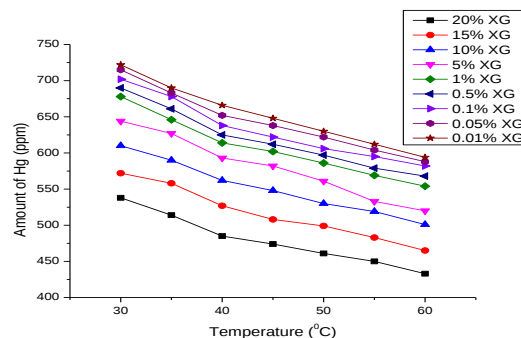
**Fig.1.c** Effect of temperature on absorption of Fe using Ac.G mixtures



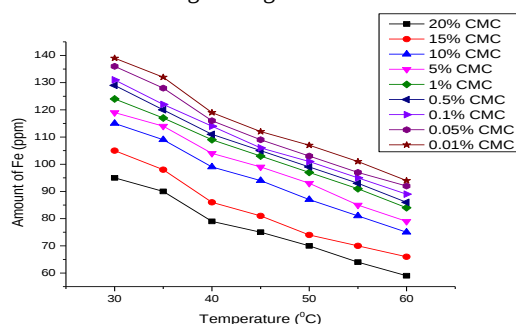
**Fig.1.d** Effect of temperature on absorption of Fe using GT mixtures.



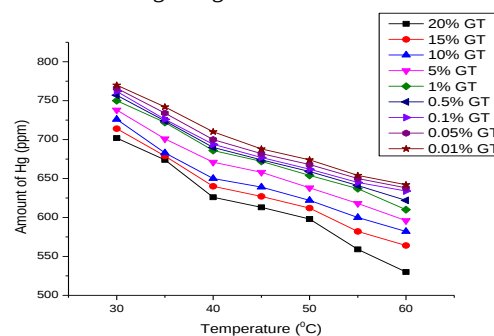
**Fig.1.e** Effect of temperature on absorption of Fe using Na Alg. mixtures



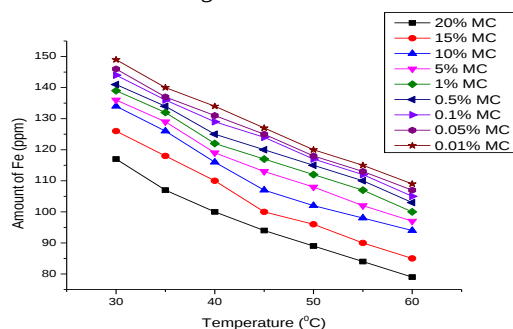
**Fig.2.a** Effect of temperature on absorption of Hg using XG mixtures



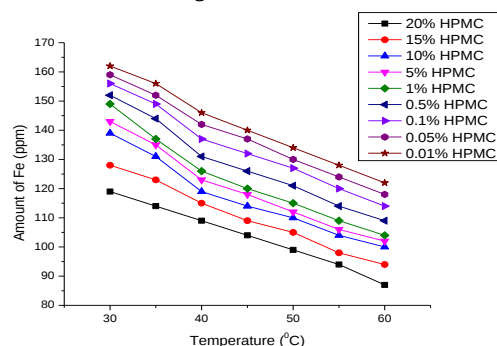
**Fig.1.f** Effect of temperature on absorption of Fe using CMC Mixtures



**Fig.2.b** Effect of temperature on absorption of Hg using GT Mixtures



**Fig.1.g** Effect of temperature on absorption of Fe using MC mixtures



**Fig.1.h** Effect of temperature on absorption of Fe using HPMC mixtures

### 3.2.2 Effect of temperature on pH values

pH of both blank solutions and their corresponding biopolymer mixtures were slightly decreased with increase in temperature. Acidic pH range (2-3pH) noticed in every mixture even though the pH values decreased. Temperature plays a significant role on pH measurements. As the temperature rises, molecular vibrations increase which results in the ability of water to ionize and form more hydrogen ions. As a result, the pH will drop. pH values of blank solutions of metal ion at different temperatures and effect of temperature on pH values of different concentrations of biopolymer mixtures are given in Table 6.

Table 6. a.) Effect of temperature on pH of Fe and Hg blank solutions

| Temperature °C | 30   | 35   | 40   | 45   | 50   | 55   | 60   |
|----------------|------|------|------|------|------|------|------|
| pH of Fe blank | 3.81 | 3.66 | 3.14 | 3.06 | 2.98 | 2.88 | 2.68 |
| pH of Hg blank | 3.10 | 3.06 | 2.96 | 2.86 | 2.83 | 2.79 | 2.77 |



6. b.) Effect of temperature on pH of different biopolymer mixtures containing Fe metal ion

| Temperature °C | GG mixtures   |      |      |      |      |       |       |         |        |
|----------------|---------------|------|------|------|------|-------|-------|---------|--------|
|                | 20 %          | 15 % | 10 % | 5 %  | 1 %  | 0.5 % | 0.1 % | 0.0 5 % | 0.01 % |
| 30             | 3.78          | 3.63 | 3.85 | 3.80 | 3.74 | 3.71  | 3.80  | 3.83    | 3.81   |
| 35             | 3.70          | 3.50 | 3.55 | 3.63 | 3.53 | 3.59  | 3.58  | 3.76    | 3.49   |
| 40             | 3.64          | 3.26 | 3.04 | 3.45 | 3.16 | 3.48  | 3.12  | 3.51    | 3.11   |
| 45             | 3.46          | 3.11 | 2.98 | 3.29 | 3.04 | 3.31  | 3.01  | 3.28    | 3.02   |
| 50             | 3.06          | 2.95 | 2.91 | 3.13 | 2.89 | 3.19  | 2.96  | 3.17    | 2.90   |
| 55             | 2.94          | 2.88 | 2.88 | 3.01 | 2.86 | 3.06  | 2.91  | 3.09    | 2.84   |
| 60             | 2.85          | 2.79 | 2.83 | 2.91 | 2.84 | 2.88  | 2.80  | 2.87    | 2.75   |
| Temperature °C | XG mixtures   |      |      |      |      |       |       |         |        |
|                | 20 %          | 15 % | 10 % | 5 %  | 1 %  | 0.5 % | 0.1 % | 0.0 5 % | 0.01 % |
| 30             | 3.37          | 3.58 | 3.34 | 3.21 | 3.33 | 3.29  | 3.03  | 3.06    | 3.07   |
| 35             | 3.28          | 3.44 | 3.25 | 3.14 | 3.28 | 3.18  | 2.88  | 3.02    | 2.98   |
| 40             | 3.06          | 3.32 | 3.02 | 3.05 | 3.09 | 3.11  | 2.83  | 2.95    | 2.86   |
| 45             | 2.99          | 3.16 | 2.95 | 2.96 | 3.01 | 3.04  | 2.79  | 2.88    | 2.79   |
| 50             | 2.94          | 3.07 | 2.88 | 2.88 | 2.93 | 2.97  | 2.76  | 2.81    | 2.75   |
| 55             | 2.90          | 2.97 | 2.81 | 2.81 | 2.85 | 2.90  | 2.71  | 2.74    | 2.73   |
| 60             | 2.85          | 2.86 | 2.77 | 2.77 | 2.71 | 2.82  | 2.64  | 2.70    | 2.69   |
| Temperature °C | Ac.G mixtures |      |      |      |      |       |       |         |        |
|                | 20 %          | 15 % | 10 % | 5 %  | 1 %  | 0.5 % | 0.1 % | 0.0 5 % | 0.01 % |
| 30             | 2.80          | 2.79 | 2.78 | 2.88 | 2.80 | 2.82  | 2.84  | 2.75    | 2.76   |
| 35             | 2.74          | 2.73 | 2.75 | 2.81 | 2.77 | 2.76  | 2.80  | 2.69    | 2.73   |
| 40             | 2.73          | 2.66 | 2.72 | 2.77 | 2.73 | 2.70  | 2.77  | 2.64    | 2.68   |

| 45               | 2.71 | 2.64 | 2.70 | 2.74 | 2.71 | 2.67  | 2.76  | 2.58    | 2.67   |
|------------------|------|------|------|------|------|-------|-------|---------|--------|
| 50               | 2.70 | 2.51 | 2.69 | 2.69 | 2.70 | 2.65  | 2.74  | 2.45    | 2.66   |
| 55               | 2.68 | 2.41 | 2.65 | 2.63 | 2.68 | 2.63  | 2.71  | 2.42    | 2.63   |
| 60               | 2.66 | 2.36 | 2.64 | 2.58 | 2.66 | 2.58  | 2.69  | 2.39    | 2.61   |
| GT mixtures      |      |      |      |      |      |       |       |         |        |
| Temperature °C   | 20 % | 15 % | 10 % | 5 %  | 1 %  | 0.5 % | 0.1 % | 0.0 5 % | 0.01 % |
| 30               | 2.87 | 2.85 | 2.88 | 2.89 | 2.78 | 2.80  | 2.88  | 2.79    | 2.89   |
| 35               | 2.86 | 2.81 | 2.86 | 2.83 | 2.75 | 2.74  | 2.85  | 2.73    | 2.84   |
| 40               | 2.84 | 2.74 | 2.82 | 2.72 | 2.70 | 2.70  | 2.81  | 2.66    | 2.81   |
| 45               | 2.82 | 2.70 | 2.80 | 2.66 | 2.68 | 2.65  | 2.80  | 2.55    | 2.80   |
| 50               | 2.80 | 2.66 | 2.78 | 2.63 | 2.66 | 2.61  | 2.77  | 2.48    | 2.78   |
| 55               | 2.78 | 2.51 | 2.76 | 2.58 | 2.64 | 2.55  | 2.74  | 2.41    | 2.74   |
| 60               | 2.76 | 2.46 | 2.74 | 2.50 | 2.61 | 2.50  | 2.72  | 2.32    | 2.72   |
| Na Alg. Mixtures |      |      |      |      |      |       |       |         |        |
| Temperature °C   | 20 % | 15 % | 10 % | 5 %  | 1 %  | 0.5 % | 0.1 % | 0.0 5 % | 0.01 % |
| 30               | 3.55 | 3.48 | 3.33 | 3.39 | 3.22 | 3.25  | 3.22  | 3.19    | 3.20   |
| 35               | 3.46 | 3.36 | 3.28 | 3.31 | 3.17 | 3.20  | 3.15  | 3.15    | 3.12   |
| 40               | 3.42 | 3.18 | 3.22 | 3.25 | 3.12 | 3.15  | 3.11  | 3.11    | 3.05   |
| 45               | 3.33 | 3.11 | 3.20 | 3.17 | 3.07 | 3.13  | 3.08  | 3.06    | 3.02   |
| 50               | 3.29 | 3.05 | 3.18 | 3.11 | 3.05 | 3.06  | 3.06  | 3.04    | 2.98   |
| 55               | 3.18 | 2.96 | 3.15 | 3.08 | 3.02 | 3.00  | 3.02  | 2.99    | 2.93   |
| 60               | 3.08 | 2.88 | 3.10 | 3.03 | 2.99 | 2.95  | 2.98  | 2.94    | 2.86   |
| CMC mixtures     |      |      |      |      |      |       |       |         |        |



| Tem<br>pera<br>ture<br>°C | 20<br>%  | 15<br>%  | 10<br>%  | 5%       | 1%       | 0.5<br>% | 0.1<br>% | 0.0<br>5% | 0.01<br>% |
|---------------------------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|
| 30                        | 3.3<br>3 | 3.1<br>7 | 3.1<br>0 | 3.0<br>7 | 2.9<br>4 | 3.0<br>0 | 2.9<br>1 | 2.9<br>6  | 2.90      |
| 35                        | 3.3<br>0 | 3.1<br>1 | 3.0<br>4 | 3.0<br>3 | 2.8<br>8 | 2.9<br>3 | 2.9<br>0 | 2.9<br>1  | 2.86      |
| 40                        | 3.2<br>4 | 3.0<br>2 | 3.0<br>0 | 2.9<br>8 | 2.8<br>4 | 2.8<br>4 | 2.8<br>6 | 2.8<br>0  | 2.81      |
| 45                        | 3.2<br>0 | 2.8<br>8 | 2.9<br>8 | 2.9<br>2 | 2.8<br>0 | 2.7<br>7 | 2.8<br>3 | 2.7<br>3  | 2.79      |
| 50                        | 3.1<br>8 | 2.8<br>3 | 2.9<br>4 | 2.8<br>6 | 2.7<br>8 | 2.6<br>1 | 2.8<br>0 | 2.5<br>5  | 2.77      |
| 55                        | 3.1<br>1 | 2.6<br>9 | 2.9<br>0 | 2.8<br>1 | 2.7<br>5 | 2.5<br>0 | 2.7<br>6 | 2.4<br>9  | 2.72      |
| 60                        | 3.0<br>8 | 2.6<br>4 | 2.8<br>9 | 2.7<br>7 | 2.7<br>2 | 2.4<br>6 | 2.7<br>4 | 2.4<br>0  | 2.69      |
| <b>MC mixtures</b>        |          |          |          |          |          |          |          |           |           |
| Tem<br>pera<br>ture<br>°C | 20<br>%  | 15<br>%  | 10<br>%  | 5%       | 1%       | 0.5<br>% | 0.1<br>% | 0.0<br>5% | 0.01<br>% |
| 30                        | 2.9<br>0 | 2.9<br>1 | 2.8<br>6 | 2.8<br>9 | 2.8<br>6 | 2.9<br>5 | 2.8<br>5 | 2.9<br>3  | 2.85      |
| 35                        | 2.8<br>8 | 2.8<br>6 | 2.8<br>2 | 2.8<br>3 | 2.8<br>3 | 2.9<br>0 | 2.8<br>3 | 2.8<br>8  | 2.82      |
| 40                        | 2.8<br>4 | 2.8<br>4 | 2.7<br>5 | 2.7<br>5 | 2.7<br>6 | 2.8<br>1 | 2.7<br>7 | 2.7<br>7  | 2.76      |
| 45                        | 2.8<br>0 | 2.7<br>4 | 2.7<br>3 | 2.6<br>6 | 2.7<br>5 | 2.6<br>6 | 2.7<br>4 | 2.6<br>3  | 2.75      |
| 50                        | 2.7<br>6 | 2.6<br>6 | 2.7<br>2 | 2.5<br>1 | 2.7<br>4 | 2.6<br>3 | 2.7<br>3 | 2.6<br>0  | 2.73      |
| 55                        | 2.7<br>3 | 2.6<br>1 | 2.7<br>0 | 2.4<br>8 | 2.7<br>1 | 2.5<br>9 | 2.7<br>1 | 2.5<br>4  | 2.70      |
| 60                        | 2.7<br>1 | 2.5<br>3 | 2.6<br>8 | 2.3<br>5 | 2.6<br>9 | 2.5<br>5 | 2.6<br>9 | 2.4<br>9  | 2.68      |
| <b>HPMC mixtures</b>      |          |          |          |          |          |          |          |           |           |
| Tem<br>pera<br>ture<br>°C | 20<br>%  | 15<br>%  | 10<br>%  | 5%       | 1%       | 0.5<br>% | 0.1<br>% | 0.0<br>5% | 0.01<br>% |
| 30                        | 3.1<br>5 | 3.1<br>2 | 3.1<br>5 | 3.1<br>6 | 3.1<br>1 | 3.1<br>0 | 3.1<br>2 | 3.1<br>5  | 3.10      |
| 35                        | 3.1<br>0 | 3.0<br>8 | 3.1<br>0 | 3.1<br>1 | 3.1<br>0 | 3.0<br>8 | 3.1<br>1 | 3.1<br>4  | 3.09      |
| 40                        | 3.0<br>8 | 3.0<br>7 | 3.0<br>6 | 3.0<br>9 | 3.0<br>8 | 3.0<br>4 | 3.0<br>7 | 3.1<br>0  | 3.06      |
| 45                        | 3.0<br>5 | 3.0<br>6 | 3.0<br>5 | 3.0<br>5 | 3.0<br>6 | 3.0<br>0 | 3.0<br>5 | 3.0<br>8  | 3.05      |

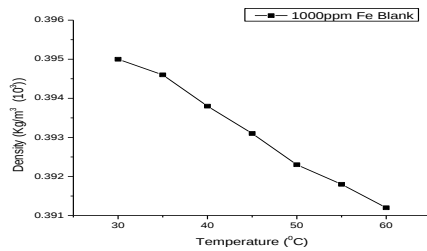
|    |          |          |          |          |          |          |          |          |      |
|----|----------|----------|----------|----------|----------|----------|----------|----------|------|
| 50 | 3.0<br>2 | 3.0<br>3 | 3.0<br>4 | 3.0<br>3 | 3.0<br>5 | 2.9<br>9 | 3.0<br>2 | 3.0<br>4 | 3.07 |
| 55 | 3.0<br>1 | 3.0<br>0 | 3.0<br>3 | 3.0<br>0 | 3.0<br>3 | 2.9<br>5 | 3.0<br>1 | 3.0<br>0 | 3.03 |
| 60 | 3.0<br>0 | 2.9<br>7 | 3.0<br>2 | 2.9<br>7 | 3.0<br>2 | 2.9<br>3 | 3.0<br>0 | 2.9<br>3 | 2.99 |

6. c.) Effect of temperature on pH of XG and GT mixtures containing Hg metal ion

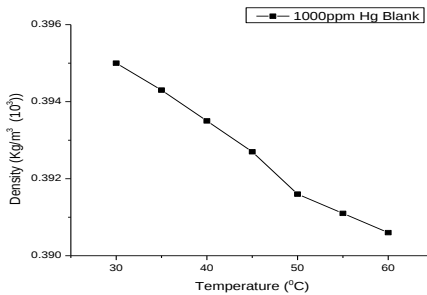
| <b>XG mixtures</b>        |          |          |          |          |          |          |          |           |           |
|---------------------------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|
| Tem<br>pera<br>ture<br>°C | 20<br>%  | 15<br>%  | 10<br>%  | 5%       | 1%       | 0.5<br>% | 0.1<br>% | 0.0<br>5% | 0.01<br>% |
| 30                        | 2.9<br>1 | 3.0<br>3 | 2.9<br>1 | 2.9<br>8 | 3.0<br>7 | 3.1<br>0 | 3.0<br>5 | 2.9<br>8  | 2.81      |
| 35                        | 2.8<br>6 | 3.0<br>1 | 2.8<br>8 | 2.9<br>5 | 3.0<br>3 | 3.0<br>7 | 3.0<br>1 | 2.9<br>1  | 2.78      |
| 40                        | 2.7<br>7 | 2.9<br>6 | 2.7<br>7 | 2.9<br>0 | 2.9<br>8 | 3.0<br>5 | 2.9<br>6 | 2.8<br>5  | 2.73      |
| 45                        | 2.6<br>1 | 2.9<br>2 | 2.6<br>4 | 2.8<br>8 | 2.9<br>1 | 3.0<br>4 | 2.9<br>0 | 2.7<br>7  | 2.66      |
| 50                        | 2.5<br>3 | 2.8<br>8 | 2.5<br>9 | 2.8<br>4 | 2.8<br>7 | 3.0<br>0 | 2.8<br>6 | 2.6<br>3  | 2.62      |
| 55                        | 2.4<br>7 | 2.8<br>3 | 2.5<br>3 | 2.7<br>9 | 2.8<br>3 | 2.9<br>6 | 2.8<br>4 | 2.5<br>5  | 2.57      |
| 60                        | 2.4<br>0 | 2.7<br>7 | 2.4<br>0 | 2.7<br>5 | 2.6<br>9 | 2.9<br>4 | 2.7<br>7 | 2.4<br>2  | 2.55      |
| <b>GT mixtures</b>        |          |          |          |          |          |          |          |           |           |
| Tem<br>pera<br>ture<br>°C | 20<br>%  | 15<br>%  | 10<br>%  | 5%       | 1%       | 0.5<br>% | 0.1<br>% | 0.0<br>5% | 0.01<br>% |
| 30                        | 3.0<br>8 | 3.0<br>7 | 3.1<br>0 | 2.7<br>9 | 2.9<br>8 | 2.8<br>8 | 2.9<br>4 | 3.0<br>8  | 2.82      |
| 35                        | 2.9<br>6 | 3.0<br>3 | 3.0<br>2 | 2.7<br>4 | 2.8<br>4 | 2.8<br>5 | 2.8<br>8 | 3.0<br>3  | 2.78      |
| 40                        | 2.8<br>4 | 2.9<br>9 | 2.9<br>8 | 2.7<br>0 | 2.7<br>7 | 2.7<br>7 | 2.8<br>0 | 3.0<br>0  | 2.62      |
| 45                        | 2.7<br>9 | 2.9<br>1 | 2.8<br>6 | 2.6<br>5 | 2.7<br>4 | 2.7<br>6 | 2.7<br>8 | 2.9<br>7  | 2.56      |
| 50                        | 2.6<br>2 | 2.8<br>6 | 2.7<br>2 | 2.6<br>1 | 2.6<br>8 | 2.7<br>2 | 2.6<br>2 | 2.9<br>4  | 2.48      |
| 55                        | 2.6<br>0 | 2.8<br>1 | 2.6<br>2 | 2.5<br>5 | 2.6<br>6 | 2.6<br>9 | 2.5<br>0 | 2.8<br>6  | 2.45      |
| 60                        | 2.5<br>4 | 2.7<br>7 | 2.5<br>8 | 2.4<br>9 | 2.5<br>2 | 2.6<br>7 | 2.4<br>8 | 2.7<br>8  | 2.33      |

### 3.2.3 Effect of temperature on density

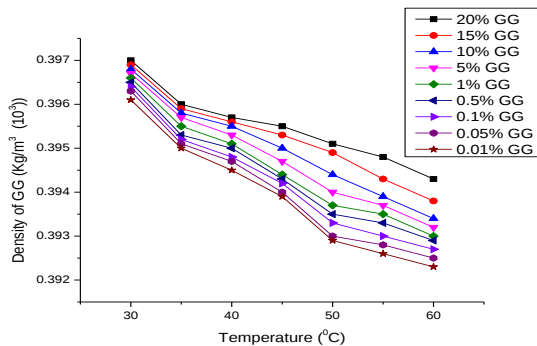
Density changes with temperature because volume changes with temperature. As temperature increases, the volume usually increases because the faster moving molecules are further apart. Thus increasing the volume decreases the density. Change in density values of Fe and Hg blank solutions with increasing temperature are given below in Fig.3 & 4 respectively. The temperature effect on density values for various concentrations of biopolymer mixtures containing Fe metal ion are given in Fig.3.a, 3.b, 3.c, 3.d, 3.e, 3.f, 3.g, 3.h for GG, XG, Ac.G, GT, Na Alg., CMC, MC, HPMC mixtures respectively. Similarly effect of temperature on density values of XG-Hg, GT-Hg mixtures are given in Fig.4.a, 4.b respectively. The density curves of Fe and Hg blank (Fig.3, 4)) taken as reference curve. Density curves of all biopolymer mixtures containing different metal ions when compared with corresponding reference curve, higher density values were obtained.



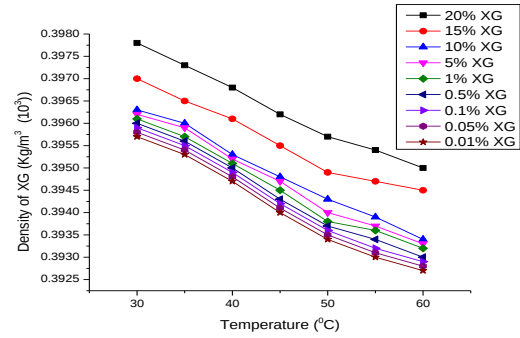
**Fig.3** Effect of temperature on density of Fe blank



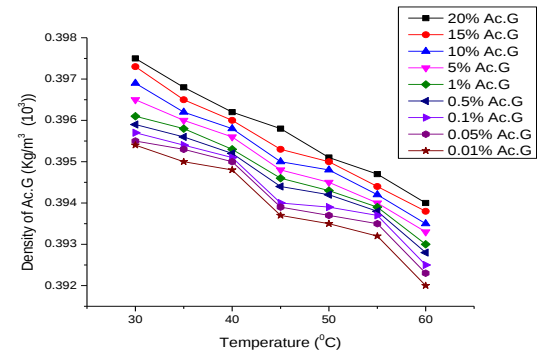
**Fig.4** Effect of temperature on density of Hg blank



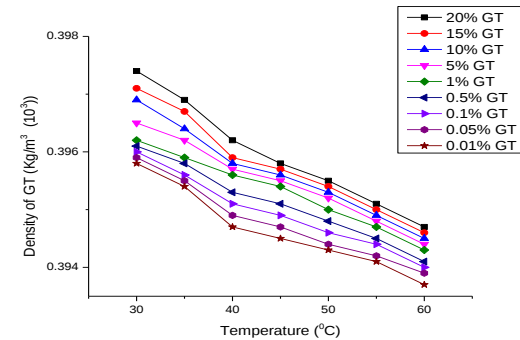
**Fig.3.a** Effect of temperature on density of GG-Fe mixture



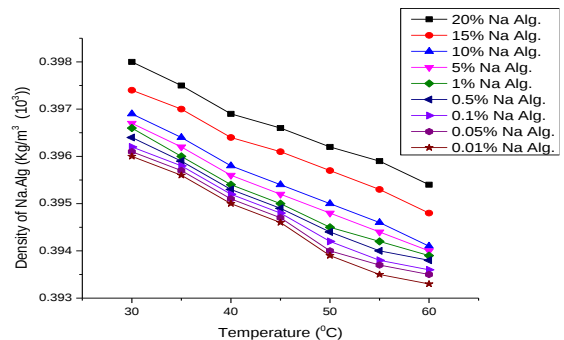
**Fig.3.b** Effect of temperature on density of XG-Fe mixture



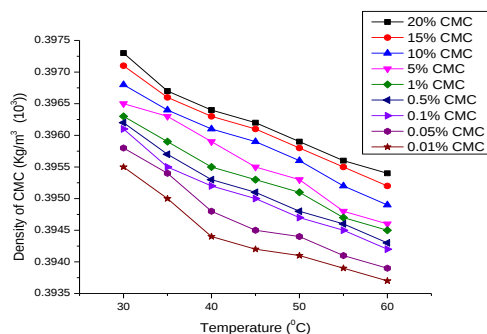
**Fig.3.c** Effect of temperature on density of Ac.G-Fe mixture



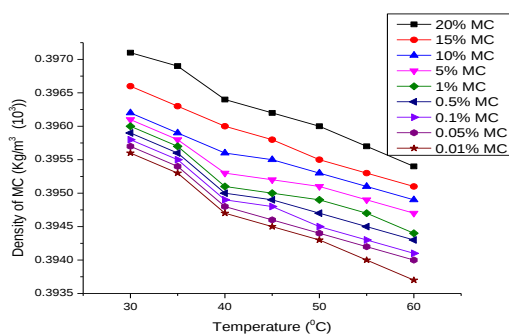
**Fig.3.d** Effect of temperature on density of GT-Fe mixture



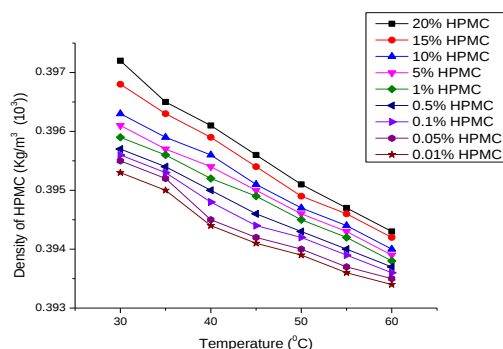
**Fig.3.e** Effect of temperature on density of Na Alg.-Fe mixture



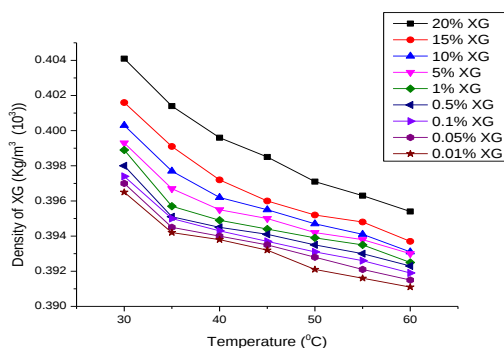
**Fig.3.f** Effect of temperature on density of CMC-Fe mixture



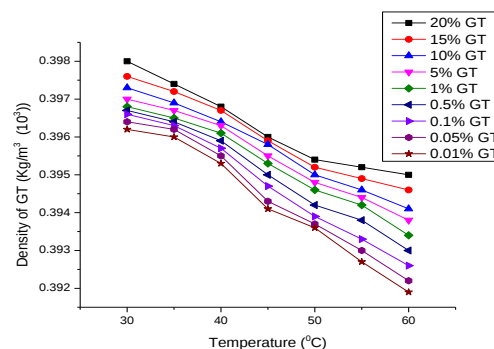
**Fig.3.g** Effect of temperature on density of MC-Fe mixture



**Fig.3.h** Effect of temperature on density of HPMC-Fe mixtures



**Fig.4.a** Effect of temperature on density of XG-Hg mixture



**Fig.4.b** Effect of temperature on density of GT-Hg mixture

As we move from higher to lower concentrations of the mixture, mass of the substance decreases density values become less. Density values of 20% and 15% mixtures of Xanthan gum-Fe (Fig.3.b), Sodium Alginate-Fe (Fig.3.e) and Methyl Cellulose-Fe (Fig.3.g) are very high. These biopolymers when mixed with Fe metal ion solution, form very thick mixture and Sodium alginate mixture becomes turbid too. Hence respective density curves lies at the top. All concentrations of Guar gum-Fe mixtures (Fig.3.a) are thick. Their initial density will be high. Later as temperature increases (after 35°C) density slightly decreases. Acacia gum-Fe (Fig.3.c) and Gum tragacanth-Fe (Fig.3.d) mixtures dissolve quickly with Fe metal ion solution. Hence they do not form compact solution. All the mixtures of Ac.G-Fe and GT-Fe showed good difference in density values. CMC-Fe (Fig.3.f) mixtures also become little bit thick. But all these mixtures exhibit good density differences. In case of Fig.3.h, all lines are close to each other this is because of negligible difference in density values between different concentrations of Hydroxypropyl methyl cellulose mixtures.

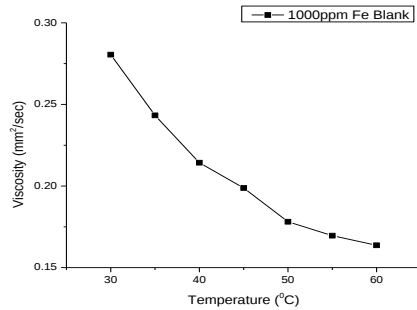
At higher concentrations Xanthan gum usually becomes thick when it mixes with Mercury metal ion solution. Therefore such mixture 20%, 15% and 10% of XG-Hg (Fig.4.a) will give large density values. After 10% (5% XG-Fe - 0.01% XG-Fe), density values found to be closer since these mixtures will not become that much thick. All GT (20% to 0.01%) mixtures are quickly soluble with Mercury metal ion solution. Also solution will not become thick. So differences between the density values are very less.

Sorption kinetics of change in density with respect to temperature also favors the absorption of metal ions from waste water.

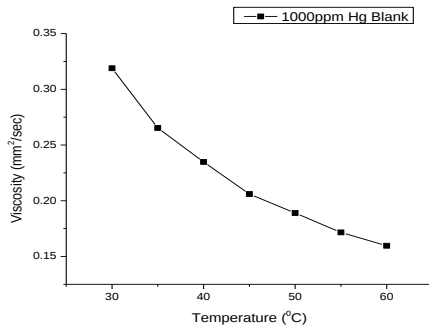
### 3.2.4 Effect of temperature on viscosity

The viscosity of liquids decreases with increase in temperature. The cohesive force between molecules of liquids decreases. At high temperature these molecules have high energy and overcome strong cohesive forces and move freely. Therefore viscosity of liquids decreases with increase in temperature. Change in viscosity values with temperature for

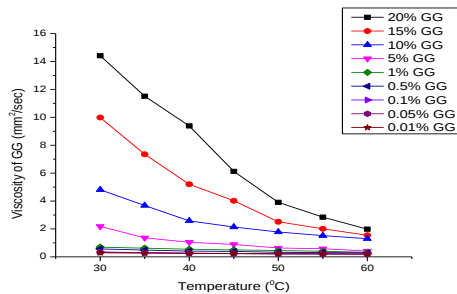
Fe and Hg blank are given below in Fig.5 & 6 respectively. Fig.5.a, 5.b, 5.c, 5.d, 5.e, 5.f, 5.g and 5.h represents the temperature effect on viscosity values for different Guar gum, Xanthan gum, Acacia gum, Gum tragacanth, Sodium alginate, CMC, MC and HPMC mixtures respectively which contain Fe metal ion. Similarly Fig.6.a and 6.b represents temperature effect on viscosity of XG-Hg and GT-Hg mixtures respectively. Fig.5, 6 considered as reference curve. Viscosity curves of all biopolymer mixtures containing different metal ions when compared with corresponding reference curve, higher viscosity values were obtained.



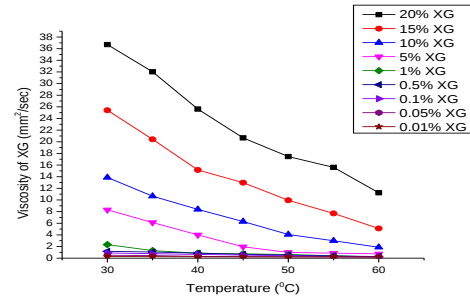
**Fig.5** Effect of temperature on viscosity of Fe blank.



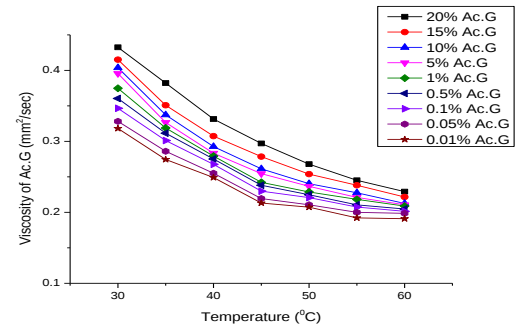
**Fig.6** Temperature effect on Viscosity of Hg blank



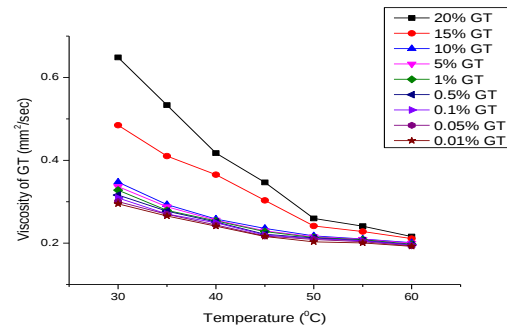
**Fig.5.a** Effect of temperature on viscosity of GG-Fe mixtures



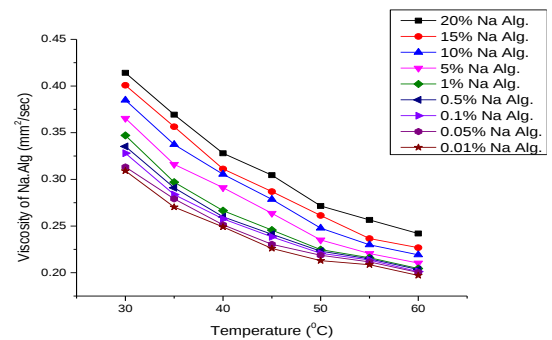
**Fig.5.b** Temperature effect on Viscosity of XG-Fe mixtures



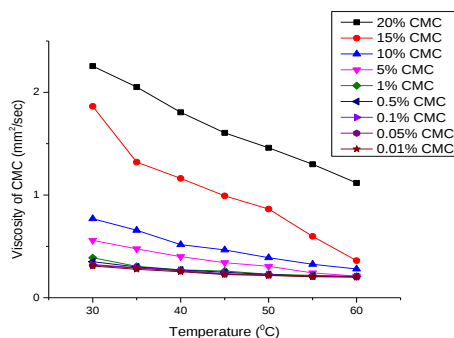
**Fig.5.c** Effect of temperature on viscosity of Ac.G-Fe mixtures



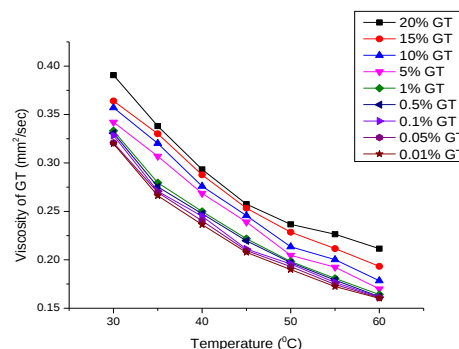
**Fig.5.d** Effect of temperature on viscosity of GT-Fe mixtures



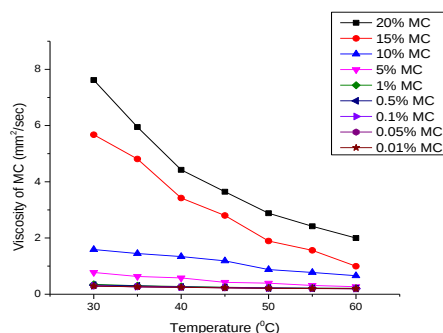
**Fig.5.e** Effect of temperature on viscosity of Na Alg.-Fe mixtures



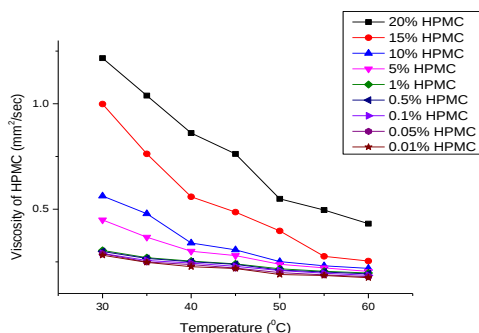
**Fig.5.f** Effect of temperature on viscosity of CMC-Fe mixtures



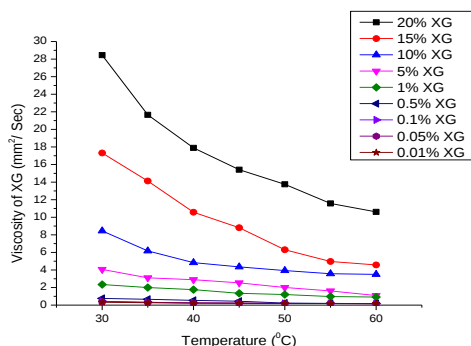
**Fig.6.b** Effect of temperature on viscosity of GT-Hg mixtures



**Fig.5.g** Effect of temperature on viscosity of MC-Fe mixtures



**Fig.5.h** Effect of temperature on viscosity of HPMC-Fe mixtures



**Fig.6.a** Effect of temperature on viscosity of XG-Hg mixtures

Out of all biopolymer thickness of Xanthan gum-Fe (Fig.5.b) and Xanthan gum-Hg (Fig.6.a) mixtures are very high. Its viscosity values also higher than other. Thickness remains high till 10% XG whereas after 10%, becomes less thick also viscosity curves of 1%-0.01% XG mixtures of both metal ions seem to be very close or overlapping. Mixtures which become too thick when mixed with Fe metal ion solution will give higher viscosity values. Respective viscosity curves lies at the top. Such observation we can see at 20% and 15% Fe metal ion mixtures of Guar gum (Fig.5.a), Gum Tragacanth (Fig.5.d), CMC (Fig.5.f), MC (Fig.5.g) and HPMC (Fig.5.h). As concentration of mixture decreases they lose their stiffness. Hence least concentrated mixtures almost occupy the same line in the curve. Viscosity values of all Acacia Gum-Fe (Fig.5.c) and Sodium alginate-Fe (Fig.3.e) mixtures showed good difference throughout. In Fig.6.b all GT-Hg mixtures (20% to 0.01%) are quickly soluble with Hg metal ion solution also it will not become thick. Hence their viscosity curves lies very close to each other, also 1% to 0.1% mixtures seem to be overlapping.

We observed that minimal amounts of 1% to 0.01% polymer mixtures are easy to handle for effective absorbance of Fe and Hg metal ions from industrial waste water. They dissolve quickly with metal ion solution. Thickness is also less.

### 3.2.5 Effect of temperature on Ultrasonic sound velocity

Sorption kinetics of ultrasonic sound velocity carried out as a part of solution property studies of biopolymers with heavy metal ions. Temperature is also a condition that affects speed of sound [13]. Molecules at higher temperature have more energy thus they can vibrate faster. In this experiment, velocity of ultrasonic sound decreases as temperature rises. Ultrasonic sound velocity of blank Fe and Hg solution at different temperatures and effect of temperature on ultrasonic sound velocity of various biopolymer mixtures with corresponding metal ion are given below (Table 7). All these values decreased with increasing temperature but no characteristic changes observed between the values of ultrasonic sound velocity for different concentrations of biopolymer mixtures.



Table 7. a.) Effect of temperature on ultrasonic sound velocity of Fe, Hg blank solutions

| Temperature (°C) | Ultrasonic Velocity of Fe blank (m/s) | Ultrasonic Velocity of Hg blank (m/s) |
|------------------|---------------------------------------|---------------------------------------|
| 30               | 1609                                  | 1605                                  |
| 35               | 1603                                  | 1602                                  |
| 40               | 1600                                  | 1600                                  |
| 45               | 1595                                  | 1593                                  |
| 50               | 1574                                  | 1589                                  |
| 55               | 1561                                  | 1576                                  |
| 60               | 1543                                  | 1557                                  |

7. b.) Effect of temperature on ultrasonic sound velocity of biopolymer mixtures contain Fe metal ion

| GG mixtures (m/s) |      |      |      |      |      |       |       |        |        |
|-------------------|------|------|------|------|------|-------|-------|--------|--------|
| Temperature °C    | 20 % | 15 % | 10 % | 5%   | 1%   | 0.5 % | 0.1 % | 0.0 5% | 0.01 % |
| 30                | 1724 | 1655 | 1646 | 1612 | 1708 | 1688  | 1630  | 1661   | 1645   |
| 35                | 1657 | 1623 | 1638 | 1609 | 1689 | 1659  | 1614  | 1638   | 1622   |
| 40                | 1606 | 1611 | 1619 | 1588 | 1655 | 1633  | 1601  | 1615   | 1608   |
| 45                | 1591 | 1596 | 1593 | 1570 | 1643 | 1611  | 1586  | 1593   | 1580   |
| 50                | 1586 | 1563 | 1577 | 1557 | 1618 | 1599  | 1570  | 1578   | 1566   |
| 55                | 1570 | 1541 | 1546 | 1546 | 1582 | 1574  | 1559  | 1563   | 1545   |
| 60                | 1536 | 1516 | 1531 | 1522 | 1563 | 1555  | 1541  | 1554   | 1521   |
| XG mixtures (m/s) |      |      |      |      |      |       |       |        |        |
| Temperature °C    | 20 % | 15 % | 10 % | 5%   | 1%   | 0.5 % | 0.1 % | 0.0 5% | 0.01 % |
| 30                | 1609 | 1588 | 1607 | 1613 | 1594 | 1595  | 1604  | 1611   | 1616   |
| 35                | 1603 | 1583 | 1601 | 1602 | 1590 | 1586  | 1598  | 1605   | 1608   |
| 40                | 1600 | 1576 | 1593 | 1593 | 1582 | 1571  | 1590  | 1597   | 1591   |
| 45                | 1597 | 1569 | 1586 | 1572 | 1560 | 1563  | 1579  | 1584   | 1583   |
| 50                | 1591 | 1550 | 1563 | 1566 | 1548 | 1548  | 1571  | 1572   | 1568   |
| 55                | 1584 | 1547 | 1555 | 1558 | 1522 | 1542  | 1556  | 1559   | 1554   |

| 60                     | 1578 | 1538 | 1541 | 1544 | 1504 | 1533  | 1547  | 1543   | 1539   |
|------------------------|------|------|------|------|------|-------|-------|--------|--------|
| Ac.G mixtures (m/s)    |      |      |      |      |      |       |       |        |        |
| Temperature °C         | 20 % | 15 % | 10 % | 5%   | 1%   | 0.5 % | 0.1 % | 0.0 5% | 0.01 % |
| 30                     | 1575 | 1581 | 1565 | 1579 | 1590 | 1588  | 1566  | 1587   | 1597   |
| 35                     | 1564 | 1577 | 1555 | 1563 | 1573 | 1574  | 1558  | 1579   | 1587   |
| 40                     | 1552 | 1562 | 1542 | 1545 | 1560 | 1558  | 1549  | 1569   | 1575   |
| 45                     | 1548 | 1548 | 1530 | 1538 | 1548 | 1549  | 1526  | 1547   | 1566   |
| 50                     | 1530 | 1530 | 1519 | 1515 | 1528 | 1529  | 1517  | 1531   | 1542   |
| 55                     | 1522 | 1522 | 1508 | 1506 | 1506 | 1515  | 1509  | 1525   | 1533   |
| 60                     | 1509 | 1516 | 1503 | 1494 | 1496 | 1502  | 1500  | 1514   | 1511   |
| GT mixtures (m/s)      |      |      |      |      |      |       |       |        |        |
| Temperature °C         | 20 % | 15 % | 10 % | 5%   | 1%   | 0.5 % | 0.1 % | 0.0 5% | 0.01 % |
| 30                     | 1621 | 1645 | 1630 | 1616 | 1636 | 1604  | 1639  | 1626   | 1620   |
| 35                     | 1613 | 1626 | 1622 | 1607 | 1625 | 1600  | 1622  | 1613   | 1611   |
| 40                     | 1608 | 1618 | 1614 | 1595 | 1618 | 1598  | 1610  | 1604   | 1602   |
| 45                     | 1594 | 1601 | 1608 | 1579 | 1610 | 1583  | 1604  | 1594   | 1591   |
| 50                     | 1587 | 1588 | 1601 | 1556 | 1602 | 1571  | 1591  | 1584   | 1579   |
| 55                     | 1564 | 1574 | 1596 | 1544 | 1593 | 1566  | 1586  | 1568   | 1573   |
| 60                     | 1545 | 1560 | 1583 | 1536 | 1589 | 1559  | 1577  | 1550   | 1568   |
| Na Alg. mixtures (m/s) |      |      |      |      |      |       |       |        |        |
| Temperature °C         | 20 % | 15 % | 10 % | 5%   | 1%   | 0.5 % | 0.1 % | 0.0 5% | 0.01 % |
| 30                     | 1584 | 1596 | 1599 | 1579 | 1595 | 1575  | 1569  | 1591   | 1588   |
| 35                     | 1564 | 1588 | 1586 | 1563 | 1575 | 1546  | 1547  | 1576   | 1568   |



|                                     |                 |                 |                 |           |           |                  |                  |                   |                   |
|-------------------------------------|-----------------|-----------------|-----------------|-----------|-----------|------------------|------------------|-------------------|-------------------|
| 40                                  | 154<br>7        | 15<br>67        | 15<br>66        | 15<br>42  | 15<br>44  | 15<br>23         | 15<br>36         | 15<br>64          | 1535              |
| 45                                  | 151<br>4        | 15<br>39        | 15<br>42        | 15<br>35  | 15<br>32  | 15<br>11         | 15<br>18         | 15<br>48          | 1514              |
| 50                                  | 149<br>4        | 15<br>28        | 15<br>33        | 15<br>28  | 15<br>15  | 15<br>06         | 15<br>09         | 15<br>37          | 1500              |
| 55                                  | 147<br>6        | 15<br>21        | 15<br>18        | 15<br>17  | 15<br>04  | 14<br>78         | 14<br>86         | 15<br>17          | 1490              |
| 60                                  | 146<br>6        | 15<br>09        | 15<br>07        | 15<br>06  | 14<br>86  | 14<br>64         | 14<br>73         | 15<br>01          | 1479              |
| <b>CMC mixtures (m/s)</b>           |                 |                 |                 |           |           |                  |                  |                   |                   |
| <b>Tem<br/>perat<br/>ure<br/>°C</b> | <b>20<br/>%</b> | <b>15<br/>%</b> | <b>10<br/>%</b> | <b>5%</b> | <b>1%</b> | <b>0.5<br/>%</b> | <b>0.1<br/>%</b> | <b>0.0<br/>5%</b> | <b>0.01<br/>%</b> |
| 30                                  | 160<br>2        | 15<br>98        | 16<br>00        | 16<br>21  | 16<br>03  | 15<br>97         | 15<br>91         | 16<br>16          | 1594              |
| 35                                  | 159<br>4        | 15<br>90        | 15<br>88        | 16<br>14  | 15<br>96  | 15<br>76         | 15<br>71         | 16<br>11          | 1588              |
| 40                                  | 159<br>1        | 15<br>84        | 15<br>79        | 16<br>04  | 15<br>88  | 15<br>49         | 15<br>62         | 16<br>04          | 1580              |
| 45                                  | 158<br>6        | 15<br>77        | 15<br>71        | 15<br>95  | 15<br>63  | 15<br>38         | 15<br>47         | 15<br>99          | 1577              |
| 50                                  | 157<br>5        | 15<br>60        | 15<br>63        | 15<br>80  | 15<br>41  | 15<br>26         | 15<br>36         | 15<br>91          | 1563              |
| 55                                  | 156<br>4        | 15<br>55        | 15<br>48        | 15<br>71  | 15<br>38  | 15<br>21         | 15<br>22         | 15<br>79          | 1544              |
| 60                                  | 156<br>0        | 15<br>43        | 15<br>35        | 15<br>62  | 15<br>26  | 15<br>17         | 15<br>18         | 15<br>62          | 1531              |
| <b>MC mixtures (m/s)</b>            |                 |                 |                 |           |           |                  |                  |                   |                   |
| <b>Tem<br/>perat<br/>ure<br/>°C</b> | <b>20<br/>%</b> | <b>15<br/>%</b> | <b>10<br/>%</b> | <b>5%</b> | <b>1%</b> | <b>0.5<br/>%</b> | <b>0.1<br/>%</b> | <b>0.0<br/>5%</b> | <b>0.01<br/>%</b> |
| 30                                  | 158<br>6        | 15<br>93        | 16<br>01        | 16<br>03  | 15<br>85  | 15<br>90         | 16<br>07         | 15<br>87          | 1605              |
| 35                                  | 157<br>4        | 15<br>86        | 15<br>91        | 15<br>87  | 15<br>73  | 15<br>80         | 15<br>90         | 15<br>67          | 1599              |
| 40                                  | 156<br>1        | 15<br>66        | 15<br>83        | 15<br>63  | 15<br>54  | 15<br>66         | 15<br>77         | 15<br>63          | 1588              |
| 45                                  | 154<br>5        | 15<br>47        | 15<br>76        | 15<br>51  | 15<br>38  | 15<br>44         | 15<br>61         | 15<br>45          | 1553              |
| 50                                  | 152<br>8        | 15<br>33        | 15<br>66        | 15<br>43  | 15<br>26  | 15<br>25         | 15<br>49         | 15<br>38          | 1563              |
| 55                                  | 151<br>2        | 15<br>18        | 15<br>53        | 15<br>28  | 15<br>14  | 15<br>11         | 15<br>39         | 15<br>21          | 1558              |
| 60                                  | 150<br>8        | 15<br>09        | 15<br>38        | 15<br>17  | 15<br>03  | 15<br>01         | 15<br>26         | 15<br>14          | 1542              |

|                                     |                 |                 |                 |           |           |                  |                  |                   |                   |
|-------------------------------------|-----------------|-----------------|-----------------|-----------|-----------|------------------|------------------|-------------------|-------------------|
| <b>HPMC mixtures (m/s)</b>          |                 |                 |                 |           |           |                  |                  |                   |                   |
| <b>Tem<br/>perat<br/>ure<br/>°C</b> | <b>20<br/>%</b> | <b>15<br/>%</b> | <b>10<br/>%</b> | <b>5%</b> | <b>1%</b> | <b>0.5<br/>%</b> | <b>0.1<br/>%</b> | <b>0.0<br/>5%</b> | <b>0.01<br/>%</b> |
| 30                                  | 161<br>9        | 16<br>24        | 15<br>94        | 16<br>12  | 15<br>99  | 15<br>87         | 16<br>02         | 15<br>79          | 1601              |
| 35                                  | 160<br>6        | 16<br>12        | 15<br>63        | 16<br>04  | 15<br>86  | 15<br>75         | 15<br>90         | 15<br>70          | 1589              |
| 40                                  | 158<br>6        | 16<br>01        | 15<br>40        | 15<br>84  | 15<br>74  | 15<br>45         | 15<br>79         | 15<br>58          | 1569              |
| 45                                  | 156<br>9        | 15<br>85        | 15<br>31        | 15<br>75  | 15<br>58  | 15<br>21         | 15<br>62         | 15<br>45          | 1533              |
| 50                                  | 155<br>5        | 15<br>73        | 15<br>20        | 15<br>53  | 15<br>33  | 15<br>09         | 15<br>46         | 15<br>29          | 1520              |
| 55                                  | 153<br>8        | 15<br>59        | 15<br>19        | 15<br>48  | 15<br>10  | 14<br>99         | 15<br>22         | 15<br>11          | 1503              |
| 60                                  | 151<br>4        | 15<br>46        | 15<br>07        | 15<br>21  | 14<br>96  | 14<br>76         | 15<br>03         | 15<br>00          | 1488              |

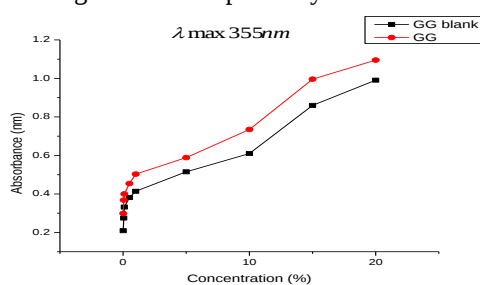
7. c.) Effect of temperature on ultrasonic sound velocity of biopolymer mixtures contain Hg metal ion

|                                     |                 |                 |                 |           |           |                  |                  |                   |                   |
|-------------------------------------|-----------------|-----------------|-----------------|-----------|-----------|------------------|------------------|-------------------|-------------------|
| <b>XG mixtures (m/s)</b>            |                 |                 |                 |           |           |                  |                  |                   |                   |
| <b>Tem<br/>perat<br/>ure<br/>°C</b> | <b>20<br/>%</b> | <b>15<br/>%</b> | <b>10<br/>%</b> | <b>5%</b> | <b>1%</b> | <b>0.5<br/>%</b> | <b>0.1<br/>%</b> | <b>0.0<br/>5%</b> | <b>0.01<br/>%</b> |
| 30                                  | 161<br>0        | 15<br>95        | 16<br>05        | 16<br>07  | 16<br>13  | 16<br>16         | 15<br>94         | 16<br>10          | 1607              |
| 35                                  | 160<br>3        | 15<br>89        | 16<br>04        | 15<br>84  | 16<br>07  | 16<br>00         | 15<br>93         | 16<br>05          | 1601              |
| 40                                  | 159<br>7        | 15<br>84        | 15<br>99        | 15<br>74  | 15<br>76  | 15<br>89         | 15<br>70         | 15<br>95          | 1600              |
| 45                                  | 158<br>6        | 15<br>75        | 15<br>96        | 15<br>67  | 15<br>43  | 15<br>76         | 15<br>65         | 15<br>82          | 1598              |
| 50                                  | 157<br>3        | 15<br>66        | 15<br>87        | 15<br>54  | 15<br>39  | 15<br>52         | 15<br>26         | 15<br>72          | 1584              |
| 55                                  | 156<br>0        | 15<br>48        | 15<br>62        | 15<br>43  | 15<br>26  | 15<br>43         | 15<br>08         | 15<br>68          | 1580              |
| 60                                  | 155<br>3        | 15<br>12        | 15<br>43        | 15<br>18  | 14<br>98  | 15<br>10         | 14<br>96         | 15<br>43          | 1575              |
| <b>GT mixtures (m/s)</b>            |                 |                 |                 |           |           |                  |                  |                   |                   |
| <b>Tem<br/>perat<br/>ure<br/>°C</b> | <b>20<br/>%</b> | <b>15<br/>%</b> | <b>10<br/>%</b> | <b>5%</b> | <b>1%</b> | <b>0.5<br/>%</b> | <b>0.1<br/>%</b> | <b>0.0<br/>5%</b> | <b>0.01<br/>%</b> |
| 30                                  | 160<br>7        | 16<br>04        | 16<br>03        | 16<br>00  | 16<br>05  | 16<br>08         | 16<br>04         | 16<br>02          | 1607              |

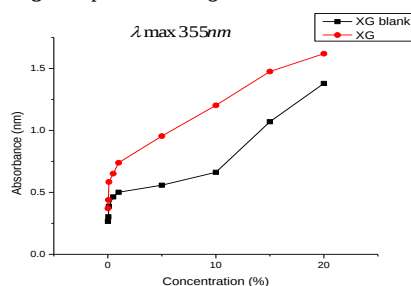
|    |          |          |          |          |          |          |          |          |      |
|----|----------|----------|----------|----------|----------|----------|----------|----------|------|
| 35 | 160<br>0 | 15<br>88 | 15<br>81 | 15<br>96 | 15<br>96 | 15<br>91 | 16<br>01 | 15<br>90 | 1604 |
| 40 | 159<br>6 | 15<br>77 | 15<br>73 | 15<br>85 | 15<br>89 | 15<br>81 | 15<br>96 | 15<br>70 | 1586 |
| 45 | 158<br>9 | 15<br>63 | 15<br>61 | 15<br>63 | 15<br>79 | 15<br>76 | 15<br>72 | 15<br>63 | 1583 |
| 50 | 158<br>0 | 15<br>53 | 15<br>37 | 15<br>46 | 15<br>43 | 15<br>57 | 15<br>29 | 15<br>52 | 1561 |
| 55 | 157<br>4 | 15<br>26 | 15<br>06 | 15<br>31 | 15<br>38 | 15<br>45 | 15<br>11 | 15<br>39 | 1553 |
| 60 | 156<br>7 | 15<br>04 | 14<br>98 | 15<br>20 | 15<br>20 | 15<br>30 | 14<br>98 | 15<br>01 | 1545 |

### 3.3. Spectrophotometric study

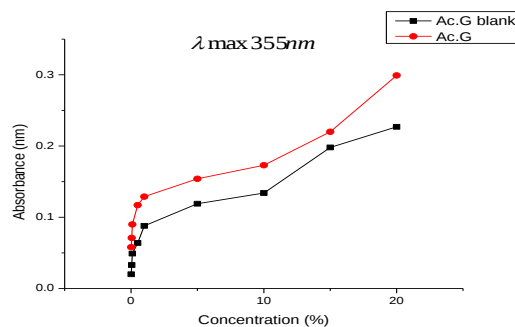
Solution containing Fe (II) and Hg (II) metal ions with different concentrations of bio-polymers analyzed using Visible Double Beam spectrophotometer. Absorption maximum obtained for different concentrations of biopolymer mixtures. Maximum absorption has obtained at 355nm for all the biopolymer mixtures containing Fe metal ion as well as for blank solution of Fe. Similarly maximum absorption obtained at 491nm for Hg blank also for its XG and GT mixtures. Absorption values, for Fe blank at 355nm is 0.051 and for Hg blank solution at 491nm is 0.504. For every mixture, respective blank reading has taken. Spectroscopic readings for Guar gum, Xanthan gum, Acacia gum, Gum tragacanth, Sodium alginate, CMC, Methyl Cellulose and HPMC mixtures which contain Fe metal ion are shown in Fig.7.a, 7.b, 7.c, 7.d, 7.e, 7.f, 7.g and 7.h respectively. Fig.8.a and 8.b represents spectral readings for XG-Hg and GT-Hg mixtures respectively.



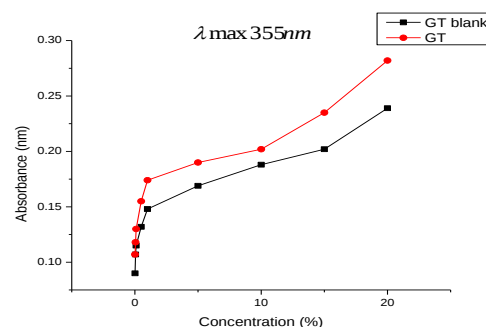
**Fig.7.a** Spectral readings for GG-Fe mixtures



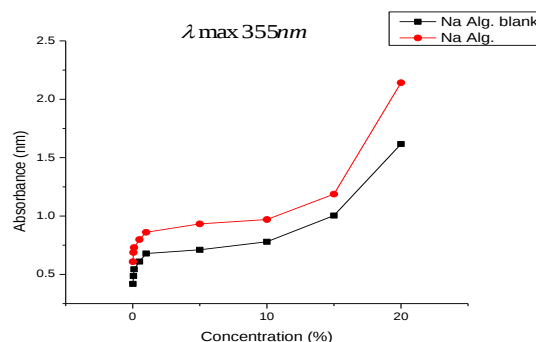
**Fig.7.b** Spectral readings for XG-Fe mixtures.



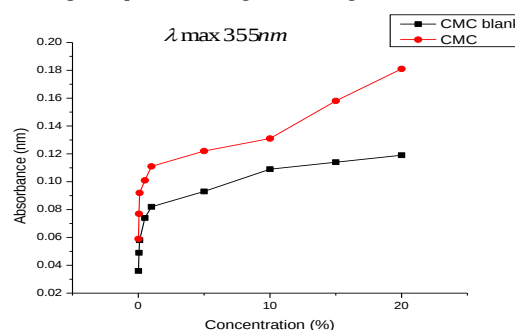
**Fig.7.c** Spectral readings for Ac.G-Fe mixtures



**Fig.7.d** Spectral readings for GT-Fe mixtures.



**Fig.7.e** Spectral readings for Na Alg.-Fe mixtures



**Fig.7.f** Spectral readings for CMC-Fe mixtures

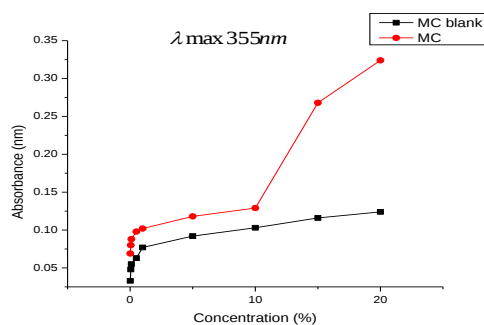


Fig.7.g Spectral readings for MC-Fe mixtures

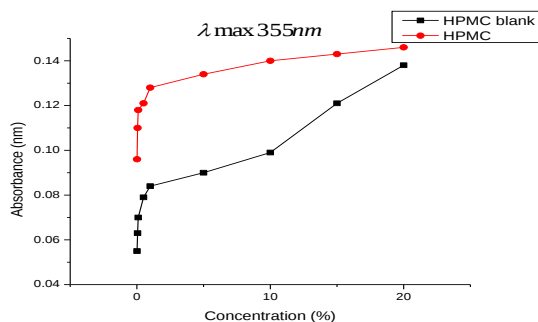


Fig.7.h Spectral readings for HPMC-Fe mixtures

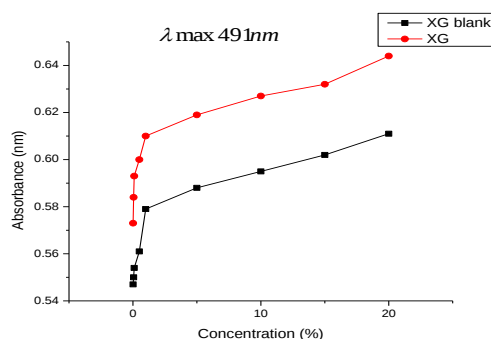


Fig.8.a Spectral readings for XG-Hg mixtures.

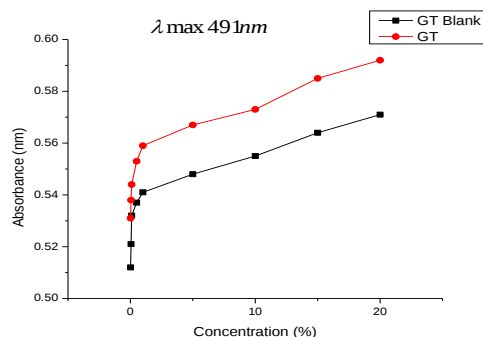


Fig.8.b Spectral readings for GT-Hg mixtures

#### IV. CONCLUSION

Study has shown that biopolymers such as Guar gum, Xanthan gum, Acacia gum, Gum tragacanth, Sodium alginate, Carboxymethyl cellulose, Methyl cellulose and HPMC

mixtures can absorb significant amount of Fe (II) metal ion whereas Xanthan gum and Gum tragacanth mixtures can absorb significant amount of Hg metal ion from industrial waste water. Minimal quantity of biopolymer mixture that is 0.01% or 0.1mg of biopolymer can effectively absorb Fe (II) and Hg (II) metal ions from waste water instead of using large quantity. Sorption kinetics of biopolymers studied at different concentrations at different temperatures. Study revealed that, solution property studies like change pH, viscosity, density, absorption capacity and ultrasonic sound velocity with and without the sorbed metal ions, decreases with increase in temperature. Acidic pH range of 2-3pH noticed throughout in every mixture. Biopolymer mixtures which form very thick with Fe and Hg metal ion solution will have greater density and viscosity values. Remaining mixtures either close to each other or seem to be overlapping. Maximum absorption observed at 355nm for all Fe related biopolymers also for Fe blank. For Hg blank solution, XG-Hg and GT-Hg mixtures absorption maximum obtained at 491nm.

#### V. ACKNOWLEDGMENT

This study is supported by Department of Chemistry and Research Centre, Sahyadri College of Engineering & Management, Adyar, Mangalore, India. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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