Synthesis of Disaccharide-Based Xanthates for the Removal of Some Heavy Metals from Aqueous Solutions

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ABSTRACT: *Two samples of lactose xanthates (LX1 and LX2) have been synthesized by the reaction of lactose (La), and carbon disulfides (CS_2) in the basic medium using NaOH/KOH. The synthesized products were extracted with diethyl ether and dried in the air resulting in the formation of yellow-colored liquid products. The formation of synthesized xanthates has been confirmed by FT-IR spectroscopy and elemental analysis. The synthesized xanthates were utilized for the removal of heavy metal ions (Cu^{II} and Ni^{II}) and turbidity from wastewater. It was found that LX1, LX2, and pure lactose (La) remove 94.9%, 95.4%, 93.8%, &95.4%, 73.3%, 70.98% of Cu^{II} ions and Ni^{II} ions respectively. These results show improved metals and turbidity removal with LX1, LX2 in comparison to many other coagulants reported in the literature.*

KEYWORDS: *Lactose xanthates; Turbidity; Wastewater; Flocculation; Heavy metal ion; Kinetics model.*

INTRODUCTION

Environmental pollution happens due to the contamination of the environment by a variety of organic, inorganic (heavy metal and other ions), and biological pollutants. A variety of inorganic pollutants are released in the environment through various domestic, agricultural, mining, and other industrial activities. Among the inorganic pollutants, heavy metals persist in the environment because of their non-biodegradable nature. Therefore,

the removal of heavy metals has been an area of high importance for researchers [1-4].

Several heavy metals such as copper, nickel, chromium, lead, cadmium, etc. are released into the environment at high concentrations *via* industrial activities [5-7]. Commonly heavy metals are present in a combined form with the organic and stable metal ion in industrial effluents, which creates many difficulties for their removal [8-10]. Several heavy metals cause an adverse effect on human health causing various disorders and diseases even at low concentrations [11-13]. It means that the aquatic ecosystem can be adversely affected by wastewater having high concentrations of heavy metals. Metal ions in the aqueous solution are easily absorbed by living organisms and can be easily transmitted to animals through food and water [14]. Therefore, the treatment of heavy metal-containing wastewater is essential before its discharge into the environment [15]. A large number of processes such as chemical neutralization, precipitation, ion exchange, redox reaction, sulphides precipitation, adsorption, and flocculation have been used for the treatment of heavy metal-containing wastewater [16-18]. Among this flocculation, sulphides precipitation and adsorption have been used commonly because these processes are simple, cost-effective, and required a short duration [9].

Precipitation of the heavy metal removal depends upon many factors such as the selection of heavy metals, operating parameters, and types of material used. Heavy metal contamination depends upon the types of industrial effluent, the operating parameter can be generated via process modification, but the selection of materials used needs a detailed study for their application. There are various grades of chemicals and chemically modified substances such as the tunics of the Corm of the Saffron [19] and (CS-MgONPy) [20] were used in the removal of dyes from wastewater. Some other substances such as carbon enriched material [21], polysaccharides-based substances, carboxymethyl polysaccharides [22], chitosan flocculants [23], chitosan-based hydrogels [24-25], crosslinked hydrogels [26], polymers [27-30], cross-linked resins [32], Schiff bases [32], modified textile waste [33] and some xanthates [34-37], carboxymethyl chitosan xanthates [38] have already been used for the removal of heavy metals and also for the treatment of industrial water.

Several saccharides and polysaccharides have been reported for various applications including wastewater treatment and heavy metal removal. However, the application of lactose and its xanthate derivatives has rarely been reported in the literature. The current study covers the synthesis of lactose xanthates (two different xanthates) from lactose, (a naturally occurring, low-cost, and eco-friendly saccharide) and their application for the removal of hazardous heavy metals like Cu^{II}, Ni^{II}, and turbidity from a synthetic wastewater sample. In addition, pseudo-first-order, and second-order kinetic studies have been performed to validate the experimental results.

EXPERIMENTAL SECTION
Materials

All reagents *viz* lactose, carbon disulphide, sodium hydroxide/ Potassium hydroxide, and solvents were obtained from S. D. Fine Chemicals Ltd., India. Kaolin powder was obtained from Adhipathi Minerals & Chemicals Private Limited Hyderabad, India.

Preparation of Lactose xanthates

The synthetic scheme of two lactose xanthates (LX1 and LX2) has been given below in Scheme 1. The xanthates have been synthesized using the method reported for the synthesis of poly(vinyl alcohol xanthates) [39-40]. In a round bottom flask equipped with a magnetic stirring bar, 7.2 g (20 mmol) lactose and sodium hydroxide (20 mmol) or potassium hydroxide (40 mmol) (for the respective grade of xanthates as given in Table 1) were taken and 25 mL deionized water was added to dissolve all the chemicals with constant stirring at room temperature for about 1.5h. After that carbon disulphide (as Table 1) was added dropwise with constant stirring at room temperature for 24h and a saffron-colored product was obtained. The synthesized product was extracted with diethyl ether and dried in the air. A yellow-colored liquid product was obtained.

Turbidity and heavy metal ions removal from water

Kaolin suspension 5% (w/v) and stock solution of metal ions (Cu^{2+} and Ni^{2+}) of 1000 ppm concentration were prepared from their respective sulphate salts by dissolving in the distilled water. After that, 5 mL of kaolin suspension and 50mL metal ions solution were placed into six different

Table 1: Synthetic details of lactose xanthates.

S.N.	Xanthates	Lactose (mmol)	NaOH/KOH (mmol)	CS$_2$ (mmol)	%Yields
1	LX1	20	20	20	90.4
2	LX2	20	40	40	92.6
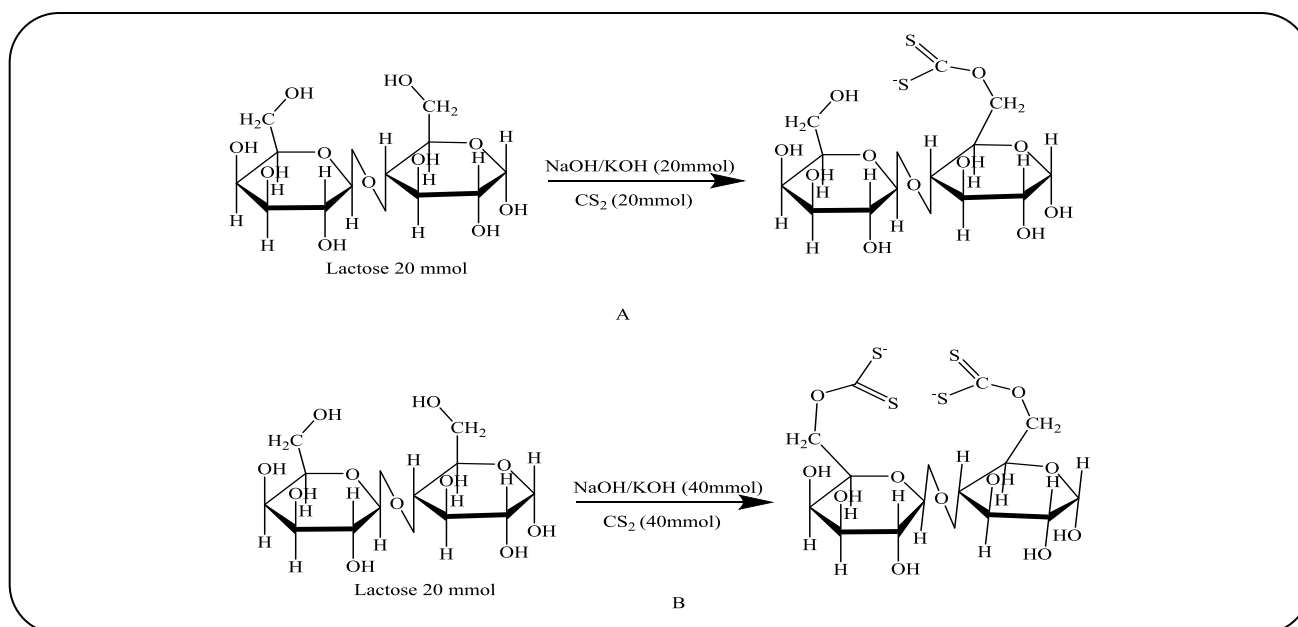
Scheme 1: Synthesis of lactose xanthates.

100mL beakers containing varying lactose xanthates dosage 10, 15, 20, 25, 30, 35 mg respectively. Each mixture was stirred at room temperature with a uniform speed of 120 rpm for 15 minutes after that the solution was stirred at the reduced speed of 60 rpm for 120 minutes. After completion of the reaction, stirring was stopped and the mixture was allowed to settle down. The turbidity of supernatant liquids was measured using a turbidity meter, and the concentration of metal ions in the supernatant solution was measured with the help of a UV-Visible spectrophotometer. The percentage removal of turbidity (Tr) and the percentage removal of metal ions (Mr) were calculated with the help of Equations (1) and (2) respectively [41-42].

$$\% \, T_r = \frac{T_0 - T_1}{T_0} \times 100 \tag{1}$$

Where *Tr, T$_o$* and *T$_1$* are turbidity removal, turbidity of initial suspension, and supernatant liquid respectively.

$$\% \, M_r = \frac{C_o - C_e}{C_o} \times 100 \tag{2}$$

Where *%Wr* = percentage removal of *M^{II}* ion (M^{II} = Cu^{II} and Ni^{II}), *Co* and *Ce* = initial and equilibrium concentration of metal ions respectively).

Simultaneous removal of both turbidity and metal ions

50mL stock solutions of metal ions were taken into a series of 100 mL beakers and added to 5mL of kaolin suspension in each beaker and the pH was adjusted to the desired level with the help of 1N HCl. The experimental process used was the same as described above turbidity and metal ion removal. The removal rate of turbidity percentage (%T$_{rd}$), removal rate percentage of metal ion (%M$_{rd}$), and adsorption capacity of xanthates (*q$_e$* in mg/g) was calculated by using Eqs. (3), (4), and (5) respectively.

$$\% \, T_{rd} = \frac{T_0' - T_1'}{T_0'} \times 100 \tag{3}$$

Here *T'$_0$* and *T'$_1$* are the initial turbidities of suspension and supernatant liquid respectively.

$$\% \, M_{rd} = \frac{C_0' - C_1'}{C_0'} \times 100 \tag{4}$$

Where C'_0 and C'_1 initial concentration of metal ion solution and metal ion concentration of the supernatant solution, respectively.

$$q_e = \frac{C_0 - C_t}{w} \times V \tag{5}$$

Here, q_e = adsorption capacity of lactose xanthates, C_0 and C_t are the initial and final metal ion concentrations at time t respectively V= solution in liter and w = amount of xanthates in gram.

Characterization

The formation of lactose xanthates and their complexes with copper and nickel ions was confirmed with the help of spectroscopic and micro-analytical data. FT- IR spectra (liquid thin film in the 400-4000 cm^{-1} wavenumbers range) were recorded on Bruker FT-IR spectrophotometer, US. Elemental analyses of C, H, S, and O were obtained from elemental analyzers Euro-E 3000, Italy. Turbidity of suspended wastewater was recorded with the help of turbidity meter TL2350 Tungsten Lamp Turbidity meter, EPA, 0-10000 NTU, India. UV-visible absorption of metal ion solutions was recorded by Microprocessor UV-visible double beam spectrophotometer L1-2700, India at the wavelength of 380 nm for Cu (II) and 590 nm for Ni(II) respectively.

RESULTS AND DISCUSSION
Elemental analysis and FT-IR spectra

The elemental percentage obtained through elemental analysis of lactose xanthates confirmed the attachments of CS_2 molecules with lactose molecules. FT-IR spectra of lactose xanthates and their copper and nickel ion complexes are summarized in Table 2, and Figs. 1 and 2. The observed peak in lactose xanthates at 3402-3381 cm^{-1}, stretching frequency has been assigned to –OH vibrations. Peaks between frequencies 2937-2925 cm^{-1} are due to the presence of –CH stretching. The absorption peaks between 1092-1088 cm^{-1} and 1018-1014 cm^{-1} stretching vibration frequencies have been assigned to –C-O-C- group in the synthesized xanthates, peaks between 1358-1356 cm^{-1} are due to the out-of-plane bending vibrations of the –OH groups. The presence of a pyranose ring has been confirmed by observed vibrational frequencies between 945-933cm^{-1}, 762-754 cm$^{-1,}$ and

710-706 cm^{-1} respectively [43-45]. Stretching frequency observed between 1165-1153 cm^{-1} and 1115-1103 cm^{-1} indicates the presence of xanthate –(C=S)-SH, group, 2565-2563 cm^{-1} corresponds to the stretching vibration of –SH group in xanthates[43-45]. In LX1 xanthate the presence of IR frequency at 1066 cm^{-1} is due to –C-O- group of primary alcohol while in LX2 xanthate this frequency is absent this clearly indicates that in LX1 xanthates all –CH$_2$OH groups are not converted into –CH$_2$-O-(C=S)S- groups while in LX2 all primary alcoholic groups are converted into xanthates.

In the FTIR spectra of the xanthate complexes of copper and nickel, IR frequencies found at 2563 & 2565 cm^{-1}, 1153 & 1165 cm^{-1} and 1103-1115cm^{-1} (in LX1 and LX2) show considerable reduction to 2522-2528 cm^{-1}, 1118-1120cm^{-1} and1068-1080-cm^{-1} respectively. This confirmed that the sulphur atoms of xanthate (Scheme 2A and 3B) act as a donor group for the formation of metal complexes with a heavy metal ion (LX1Cu^{II}, LX1Ni^{II}, LX2Cu^{II,} and LX2Ni^{II}) [42,45].

Chemical Reaction of xanthate

A number of chemical reactions take place in the heavy metal–xanthate–water system at different pH and oxidation-reduction potentials. For the determination of dominant reaction products, chemical reaction equilibria of the species were measured. Consequently, it should be noted that during the assessment of chemical reactions, the processes, such as hydrolysis of metal ions and precipitation of metal xanthates can take place. Redox reactions in the solutions may also be concerned with some chemical reactions [46]. Some key chemical reactions are illustrated as

$$M^{2+} + 2X \Leftrightarrow MX_{2(s)} \tag{6}$$

M^{2+}= heavy metal ions X= xanthate. This reaction is the principal chemical reaction in the process of the formation of metal–xanthate. At pH 6.5 the heavy metal ions are mixed with xanthate ions, and the precipitation takes place immediately. At the higher solution pH, considerable competition of hydroxide ions to xanthates takes place for heavy metal ions, and most of the metal ions are precipitated following hydrolysis reaction as is Eq. (7) [46,47].
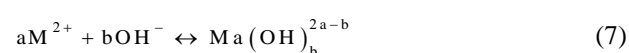
$$aM^{2+} + bOH^- \leftrightarrow Ma(OH)_b^{2a-b} \tag{7}$$

Table 2: Elemental percentage and IR frequency of Lactose xanthates and IR frequency of xanthates heavy metal (Cu^{II} and Ni^{II}) complex.

Xanthates (MW)	Yield (%)	Elemental (%)					IR frequency (cm^{-1})
		C	H	S	O	Cu/Ni	
LX1 (417)	90.24	37.2 o 37.4 c	5.0o 4.91c	15.0 o 15.3 c	42.0 o 42.2 c		3381, 2937. 2563, 1421, 1358, 1153, 1103, 1092, 1066, 1014, 945, 762, 706, 656.
LX2 (492)	92.46	33.9 o 34.1c	4.0 o 4.1 c	13.1 o 13.3 c	35.7 o 35.8 c		3402. 2925, 2565, 1425. 1356, 1165, 1115, 1088. 1045. 1018. 933. 754, 710. 650
LX1 Cu(II) (480.5)		32.4 o 32.5 c	4.3 o 4.4 c	13. 1o 13.3 c	36.4 o 36.6 c	13.0 o 13.2 c	3398, 2931, 2536, 1410. 1356, 1120, 1090, 1080, 1026, 1016, 943, 762, 714, 644.
LX2Cu(II) (555.5)		30.0 o 30.2 c	3.5 o 3.6 c	22.8 o 23.0 c	31.5 o 31.7 c	11.3 o 11.4 c	3395, 2922, 2548, 1420, 1348, 1160, 1118, 1080. 1075, 1014, 940, 761, 711, 650
LX1Ni(II) (475.7)		32.7 o 32.8 c	4.2 o 4.4 c	13.2 o 13.5 c	36.8 o 36.9 c	12.1 o 12.3 c	3419, 2932, 2530, 1423, 1360, 1122, 1082, 1072, 1020, 1016, 941, 762, 715, 654
LX2Ni(II)		30.4 o 30.5 c	3.4 o 3.6 c	23.3 o 23.2 c	31.8 o 32.0 c	10.5 o 10.7 c	3410, 2926, 2522, 1420, 1355, 1121, 1080, 1068, 1018, 1014, 939, 760, 713, 650,

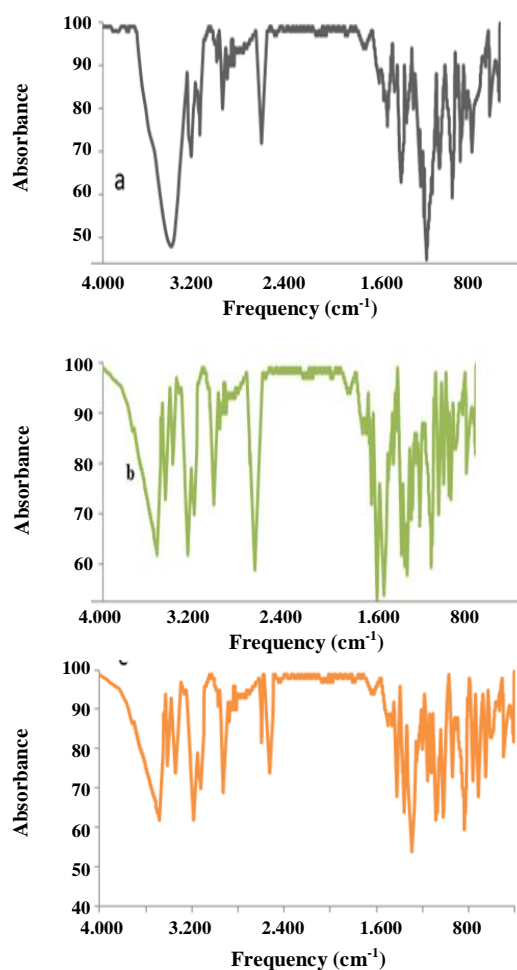*Remark: o & c observed and calculated percentage value.*

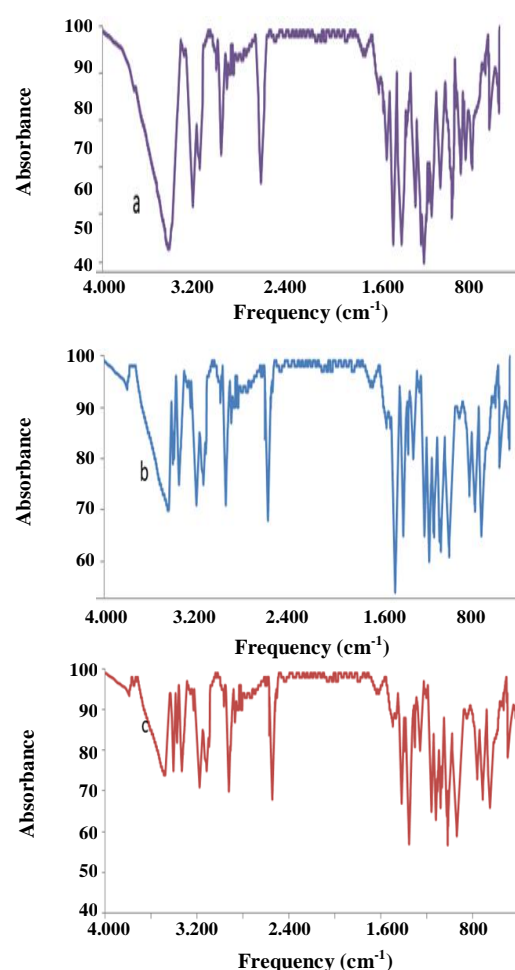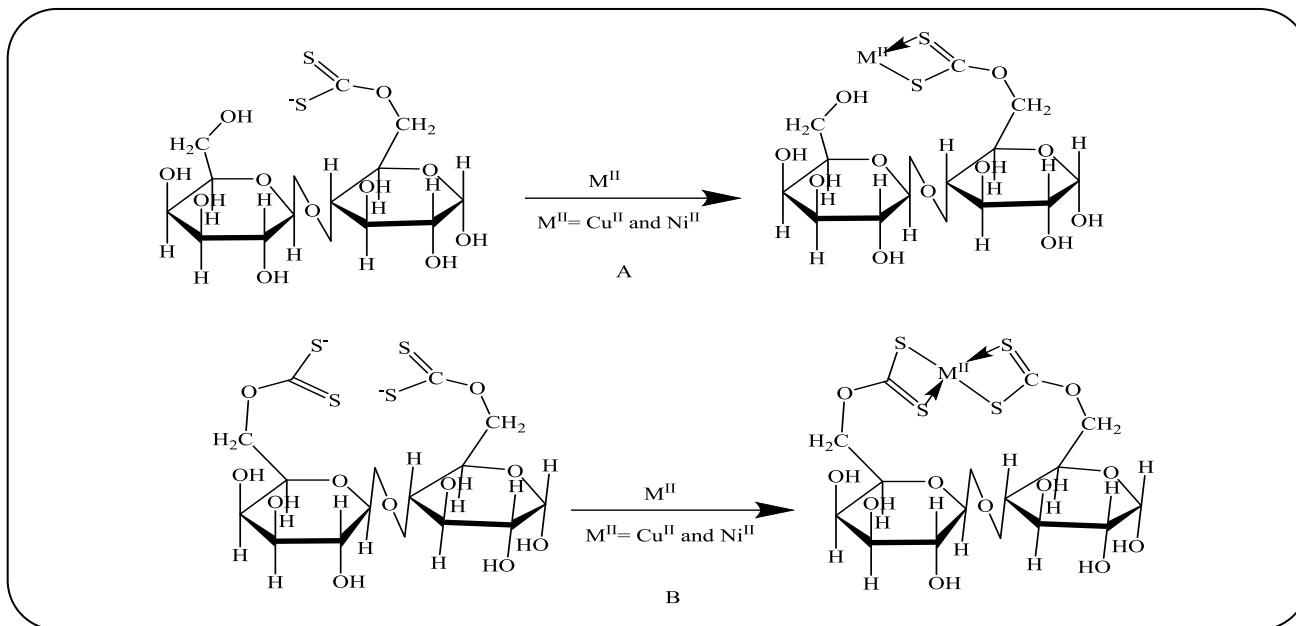**Fig. 1: IR spectra (a) LX1 (b) LX1Cu^{II} (c) LX1Ni^{II}.**

Fig. 2: IR spectra (a) LX2 (b) LX2Cu^{II} (c) LX2Ni^{II}.

Scheme 2: Lactose metal complexes formation during the metal ion removal process.

Where a and b are the number of moles of metal ions and OH ions.

Application of Lactose Xanthates (LXs) in wastewater treatment

The application of LXs in wastewater treatment was evaluated using a flocculation procedure for the removal of turbidity and metal ions (Cu^{II} and Ni^{II}) from the synthetic wastewater. The effect of LXs on individual removal of turbidity, metal ions, and combined turbidity and metal ions are described as follows.

Effects of LX1, LX2, and La dosages on the removal of turbidity and metal ion from water.

The effective removal of turbidity, copper, and nickel ion were evaluated with two samples of lactose xanthates and pure lactose. The experimental results are presented in Figs. 3, 4a & 4b and 5a & 5b for turbidity, Cu^{II}, and Ni^{II} respectively. From these Figures, it can be observed that the turbidity and metal ion removal increases with xanthate doses and at 30 mg dose the turbidity and metal ion percentage removal become constant. The maximum turbidity removal 52.2%, 61.3%, and 62.4% were observed with La, LX1, and LX2 respectively. The maximum Cu^{II} removal of 73.3%, 94.9%, and 95.4% was observed with La, LX1, and LX2 respectively. The maximum Ni^{II} removal of 70.98%, 93.8%, and 95.4% was observed
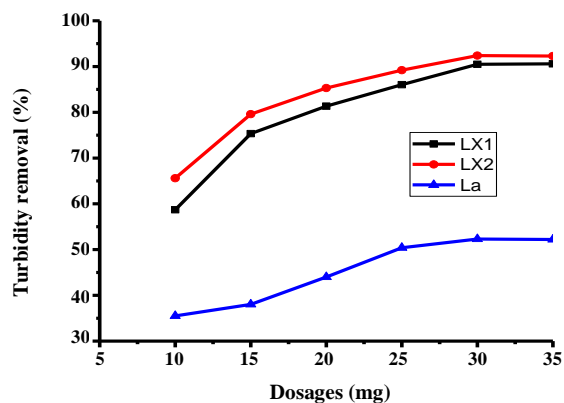

Fig. 3: % Removal of turbidity with xanthate dose [initial turbidity: 1000 ppm, initial pH: 6.5.

With La, LX1, and LX2 respectively. The metal ion reduction increases with increased xanthate loading because the number of available active sites for capturing metal ions increases. Since, xanthates contain both sulphur and oxygen atoms they can donate lone pairs of electrons and therefore can easily capture metal ions from the bulk solution [42, 45].

Effect of time on the removal of metal ions from water with xanthates.

Experiments were performed under a constant dosage of xanthates (20 mg) with varying time intervals (30-120 minutes)
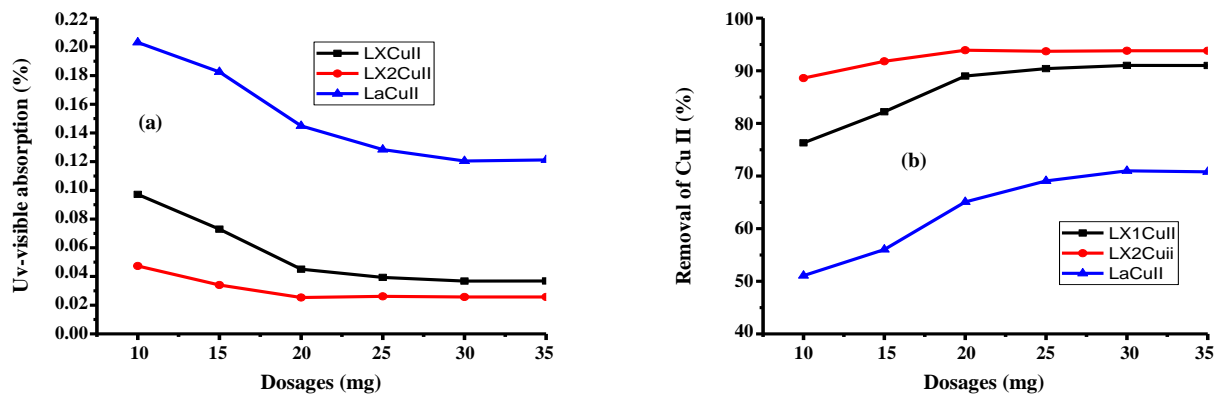
Fig. 4: Influence of xanthates dosage (a) UV-visible absorption of supernatant Cu^{II} ion solution (b)% Removal of Cu^{II} ion.[initial Cu^{II} concentration: 1000 ppm, initial pH: 6.5].
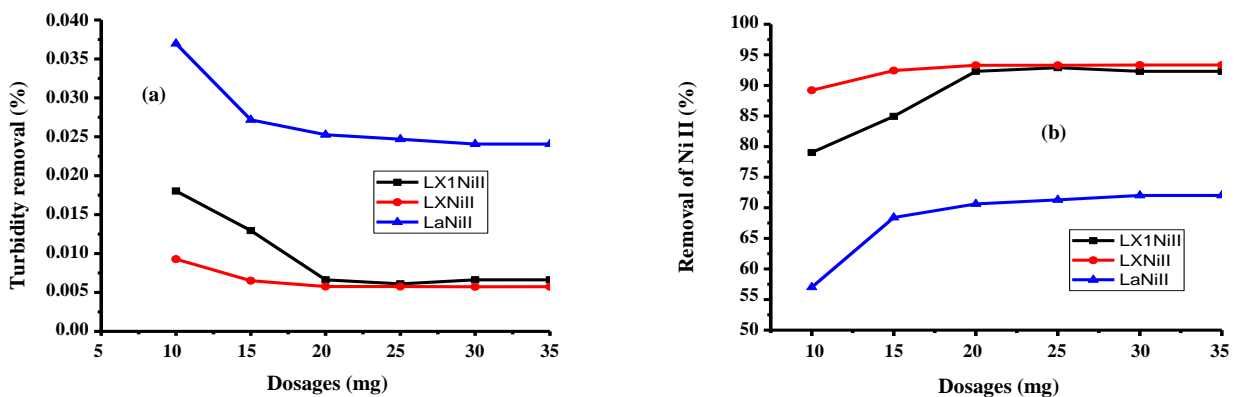

Fig. 5: (a)UV-visible absorption of supernatant Ni^{II} ion solution (b)% Removal of Ni^{II} ion.[initial Ni^{II} concentration: 1000 ppm, initial pH: 6.5].

and the results are illustrated in Fig. 6 a&b, and 7 a&b for Cu(II) and Ni(II) metal ions respectively. From Figs. 6 and 7 it can be observed that the rate of metal ion removal increases rapidly up to 60 minutes and then slow removal of these ions takes place up to 90 minutes. It is obvious the initial metal ion concentration of 1000 ppm decreases with time and initially all the active sites of the xanthate is available for coordination with metal ions. The density of the active sites decreases with time due to the coordination of metal ions on the active sites. So, a fast reduction in metal ion concentration is observed initially and the rate of metal removal decreases with time.

Effect of pH on removal of Cu^{II} and Ni^{II} ion

The experiments were performed by using 50 mL of 1000 ppm copper and nickel ion water solution with varying pH (2 to 5) maintained using 1N HCl. In this experiment uniform dosage (20 mg) of lactose xanthates (LX1, LX2) and parent lactose were used in each set. The experimental results are represented in Figs. 8 a&b, 9 a&b.

Results clearly show that the UV-visible absorption decreases and the percentage of metal ion removal increase with increasing pH of the solution and after pH 5 their removal become constant. It can be described by the –C(C=S)S$^-$ groups present in xanthate salts which are easily converted into -C(C=S)SH (xanthatanic acid) group in the acidic medium at a lower pH zone which is easily ionized in alkaline medium at higher pH and produces more negatively charge –C(C=S)S$^-$ groups [43,48]. The overall effect of these competing reactions is that the electron donor properties of xanthates towards complex formation with metal ions are optimum around neutral medium including slightly acidic and basic regions. In the highly acidic lower pH zone, the xanthates lose the ability
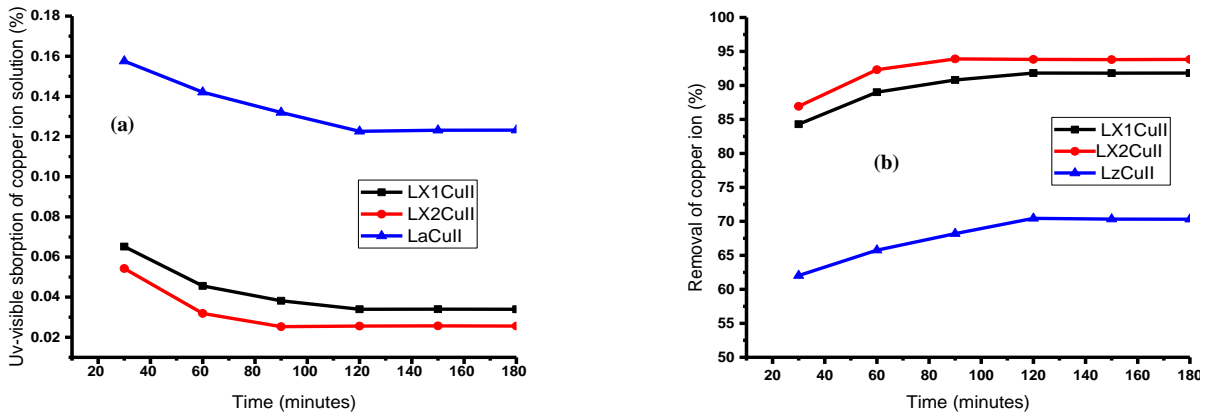
Fig. 6: Influence of time (a) UV-visible absorption of supernatant Cu^{II} ion solution (b)% Removal of Cu^{II} ion.[initial Cu^{II}concentration:1000 ppm, 6.5 solution pH].
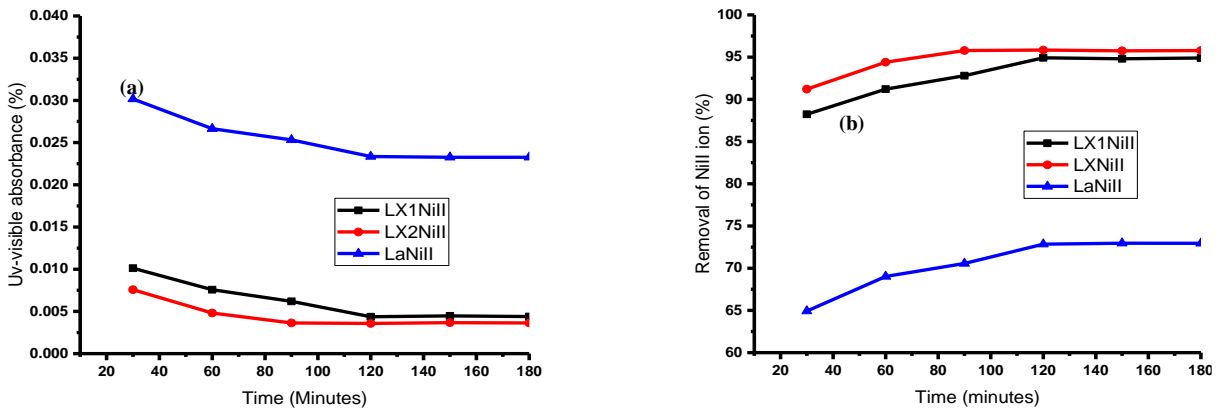

Fig. 7: (a) UV-visible absorption of supernatant Ni^{II} ion solution (b) % Removal of Ni^{II} ion.[initial 1000 ppm concentration of Ni^{II}:, at pH: 6.5].
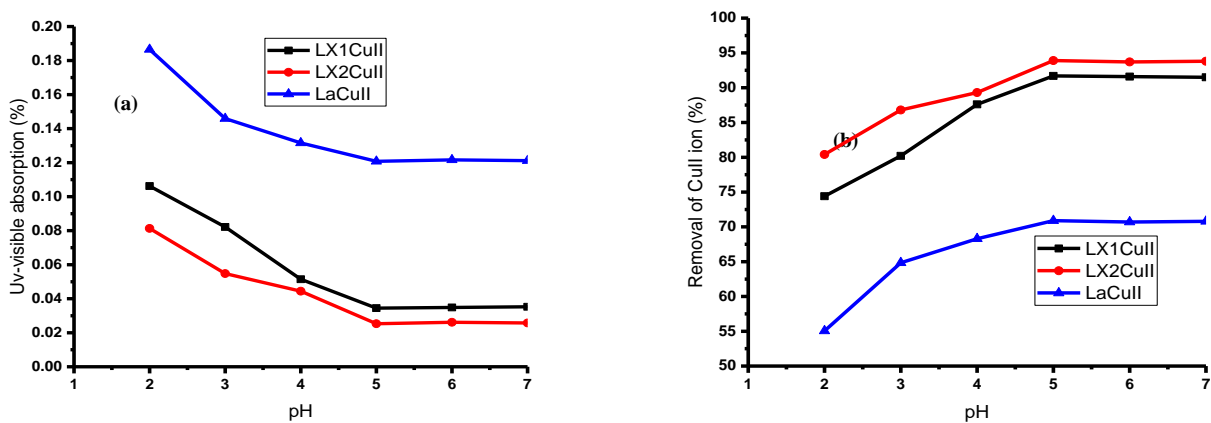

Fig. 8: Influence of pH (a) UV-visible absorption of supernatant Cu^{II} ion solution (b)% Removal of Cu^{II} ion. (initial concentration of Cu^{II}ion is 1000ppm and Xanthates dosages = 20 mg).
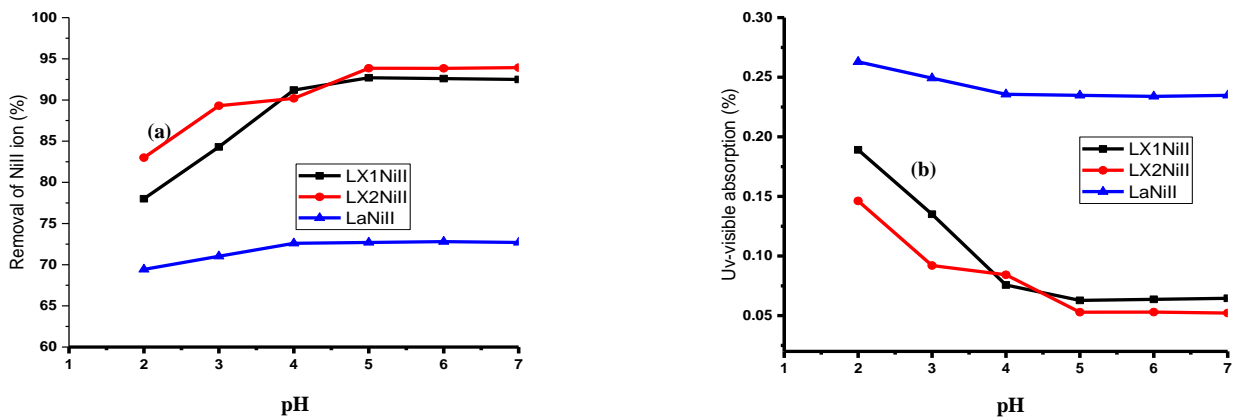
Fig. 9: Influence of pH (a) % Removal of Ni^{II} ion (b) UV-visible absorption of supernatant Ni^{II} ion solution. [initial Ni^{II} concentration: 1000 ppm, initial pH: 6.5].
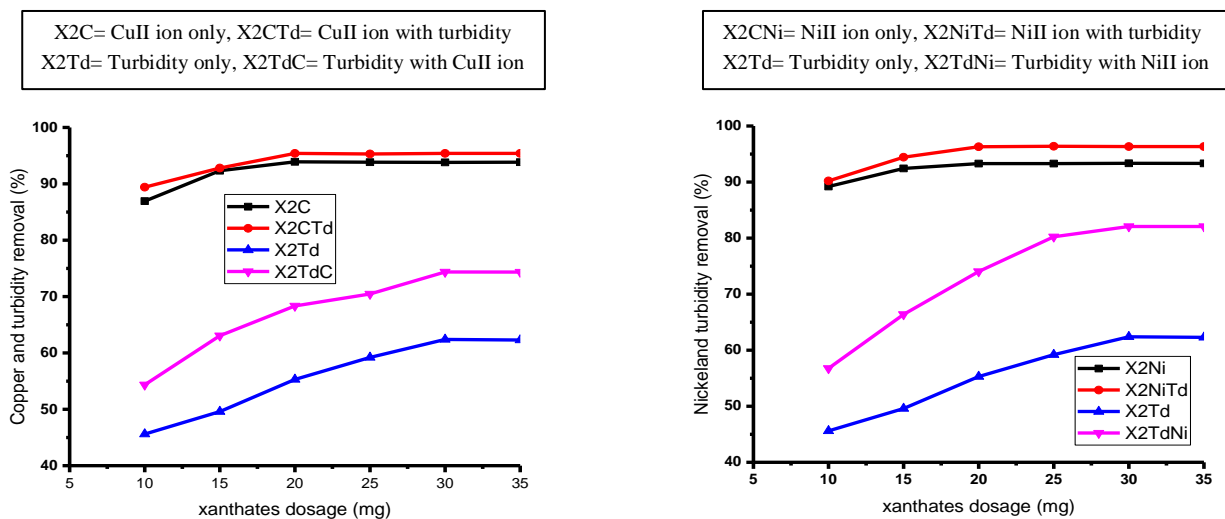
X2C= CuII ion only, X2CTd= CuII ion with turbidity
X2Td= Turbidity only, X2TdC= Turbidity with CuII ion

X2CNi= NiII ion only, X2NiTd= NiII ion with turbidity
X2Td= Turbidity only, X2TdNi= Turbidity with NiII ion

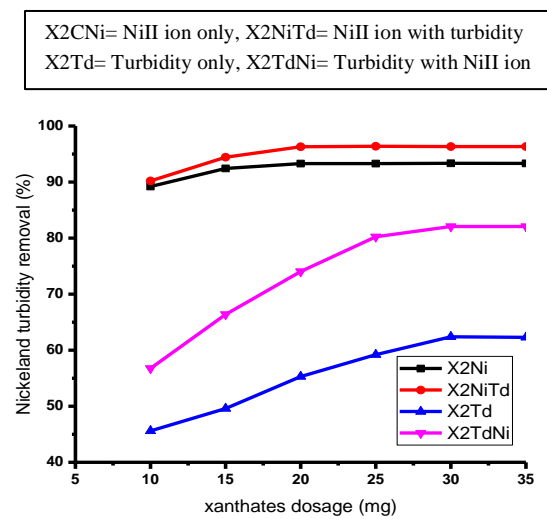*Fig. 10: Removal of Cu^{II} and Turbidity together.*

Fig. 11: Removal of Ni^{II} and Turbidity together.

to form strong complexes with metal ions because of the conversion of xanthate ions to the xanthinic acid form. So, both metal ions show maximum removal at pH 5.

Simultaneous removal of Cu^{II}/Ni^{II} ion and turbidity by LX2

In these experiments varying loading of LX2 (10-35 mg) was used for 50 mL,1000 ppm metal ion (M^{II} = Cu^{II} and Ni^{II}) solution at initial pH of 5. The turbidity of the same solution was adjusted 100 NTU.

The effect of xanthate loading on the simultaneous removal of Cu^{II}, Ni^{II,} and turbidity removal are presented in Figs. 11 & 12 respectively. From the figure, the elimination rate of metal ions in presence of turbidity is higher than the metal ions without turbidity. This result

shows a considerable difference for Ni metal ions. This fact can be explained that the removal of turbidity involved the flocculation process and formed flocs. These flocs enhanced the "sweep" coagulation mechanism towards colloidal pollutant particles of metal ions xanthates, and insoluble chelates and also generate a weak adsorption mechanism for soluble metal ions [43,49].

Kinetics of metal ion removal

The metal ion removal kinetics was determined with the help of two kinetics models [50-51] viz. pseudo-first-order and pseudo-second-order model.

Pseudo–first-order kinetics was studied using the Lagergren equation [52-53] :

Table 3: The values of K₁,K₂, and their respective R² for the removal of Mⁱⁱ ion(Mⁱⁱ = Cuⁱⁱ and Nⁱⁱ)
by LX1 and LX2 at 1000ppm initial concentration.

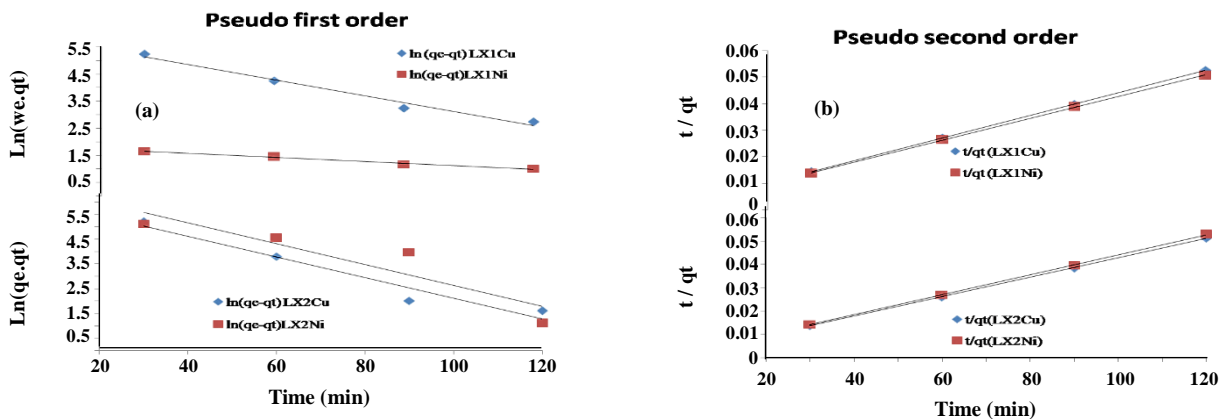| Xanthates	Metal ion	Pseudo-first order			Pseudo-second order		
	(M^{II})	qe (mg/g)	K_1(min⁻¹)	R^2	qe (mg/g/min)	K_2(g/mg/min)	R^2
LX1	Cu	399.81	-0.028	0.979	2500	1.33×10^{-4}	0.998
LX2	Cu	534.75	-0.007	0.992	2500	1.14×10^{-4}	0.999
LX1	Ni	6.52	-0.041	0.951	2500	1.14×10^{-4}	0.999
LX2	Ni	931.22	-0.042	0.834	2500	1.14×10^{-4}	0.999

Fig. 12: Kinetics model (a. Pseudo-first order, b. Pseudo-second order) for removal of Cuⁱⁱan Niⁱⁱion with LX1 and LX2,
at initial concentration 1000ppm.(0.20g adsorbent amount and 0.05g (50 mL)solution used)..

$$\ln(q_e - q_t) = \ln q_e - k_1 t \tag{8}$$

Where q_e= Concentration of metal ion at equilibrium and q_t = metal ion concentration at time (t min), k_1 is rate constant (min⁻¹).

The value of k_1 was obtained with the help of drawing a linear graph $ln(q_e–q_t)$ v/s t.

Pseudo-second order model explained the dependency of metal ions removal capacity of xanthates with respect to time. It can be obtained by using equation 9 as follows:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{9}$$

Where q_e and q_t are the amounts of metal ions at equilibrium and at time t respectively, k_2 is the rate constant (g/mg/min). By drawing a linear plot of t/q_t w.r.t., time the values of q_e and k_2 can be easily determined by determining the slope and intercept respectively.

The rate constant (K_1 and K_2) and R^2 values for the metal ion removal by LX1 and LX2 are given in Table 3. The R^2 values for the pseudo-second-order reaction model are greater than the pseudo-first-order, which indicates that the pseudo-second-order model is better than the pseudo-first-order model for the modeling of metal ion removal [50-51].

Determination of Lactose xanthates loading capacity (q_e mg/g) heavy metal ion

The loading capacity of lactose xanthates was calculated with the help of equation 5. The loading capacity of LX1 with copper metal and nickel ion 229.55, 237.5 LX2 234.78, and 239.35 respectively which was found better with another adsorbent used by different researchers shown in table 4.

CONCLUSIONS

The process used for the synthesis of xanthates is very easy to carry out. Water has been utilized as an eco-friendly green solvent. Lactose used for the synthesis of xanthates is a naturally occurring disaccharide that is biodegradable in nature. The synthesized lactose xanthates were found too involved in complexation with heavy metal ions.

Table 4: Use of several adsorbents for metal ions removal.

Adsorbent	Adsorption capacity (mg/g)	Metal ions	Reference
Zirconium oxide immobilized alginate beads	69.9	Cu(II)	[54]
Polycarboxylated starch-based hydrogel	128.26	Cu(II)	[55]
Chitosan and starches-g-PAN cryobeads	100.6	Cu(II)	[56]
Cross-linked graft copolymers of cellulose	112.74	Ni(II)	[57]
Cellulose and gelatine-based composite hydrogels	49.1	Cu(II)	[58]
Cellulose-based hydrogel	142.7	Cu(II)	[59]
Chitosan-coated PVC beads	120.5	Ni(II)	[60]
Magnetic hydroxyapatite/chitosan composite	112.36	Ni(II)	[61]
Lactose xanthate 1 (LX1)	229.55	Cu(II)	Present Study
-Do-	237.5	Ni(II)	,, ,,
Lactose xanthate 2(LX2)	234.78	Cu(II)	,, ,,
-Do-	239.35	Ni(II)	,, ,,

The complexes formed are precipitated in water and can be easily removed through filtration. As compared to parent lactose, the efficiency of lactose xanthates LX1 and LX2 is higher towards the removal of heavy metal ions and turbidity. These materials have shown excellent results in their plausible use on an industrial scale for the treatment of heavy metal ion-containing wastewater. The kinetics study revealed that the pseudo-second-order model can be utilized for obtaining better results in the industrial use of these xanthates.

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