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Influence of a plant-based surfactant on improving the stability of iron ore particles for dispersion and pipeline transportation

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A B S T R A C T

This investigation addresses the study of the effects of the saponin isolated from the fruits of *Sapindus laurifolia* (*S. laurifolia*) as a dispersing and stabilizing agent in the pipeline transportation of iron ore (IO) particles. Two types of IO samples named S1 and The purpose of this study was to investigate the effect of saponins isolated from the fruits of Sapindus laurifolia (S. laurifolia) as dispersants and stabilizers in pipeline transport of iron ore (IO) particles. Two types of IO samples, called S1 and S2, mainly composed of hematite (Fe2O3), are collected for study. The rheological behavior of iron ore water slurries (IOWS) was studied as a function of saponin dosage, IO concentration, pH, temperature, and the relationship between shear rate and shear stress. The isoelectric point of IOWS is calculated by changing the zeta potential with pH. A suitable mechanistic model is given to explain the interaction between S. laurifolia and IO particles. The economic effectiveness of dispersants is investigated based on slurry pressure drop, solids throughput, hydraulic energy demand, and specific power consumption (SPC) for the proposed His IOWS pipeline to enter commercial operation. I was. S2, which are primarily constituted of hematite (Fe_2O_3) are taken for the study. The rheological behavior of iron ore water slurry (IOWS) has been studied as a function of saponin dosages, IO concentration, pH, temperature, and the shear rate-shear stress relationship. The isoelectric point of IOWS is calculated by the variation of zeta potential with pH. A suitable mechanism model is given to describethe interaction between *S. laurifolia* and IO particles. The economic effect of the dispersant has been examined based on slurry head loss, solids conveying rate, hydraulic power need, and specific power consumption (SPC) for the proposed IOWS pipeline to be introduced into commercial operation.

1. Introduction

The industrialization of today's civilization has resulted in a scarcity of mineral resources, and this has led to a crisis in infrastructure development. The advanced processing methodologies of mineral sources, as well as their potential developed technologies, contribute in a greater way to addressing the challenges posed by the crisis in the use of minerals. In the field of mineral processing technology, the IO in slurry form and its stabilization have emerged as an innovative research focus [1]. The conventional transportation process of IO causes serious environmental pollution. Slurry pipeline transportation is a sustainable approach that is widely used in numerous studies. Before transferring the bulk slurry through pipelines, it is necessary to prepare a highly dispersed, homogeneous suspension of IO particles in water as the carrier medium. The rheological behavior of the concentrated slurry must be properly evaluated in terms of viscosity and other slurry flow characteristics to negotiate the pumping power with the least specific energy consumption [2]. The literature mentions some small research on the rheological behavior of a concentrated IOWS. According to Jones and Horsley [3], chemical dispersants improve the flowability of slurries, allowing them to be pumped at considerably greater solid concentrations and thereby reducing water usage. As a result, selecting the proper additives should be one of the most critical factors to consider when preparing slurries for transportation. Several chemical agents have been used in the mining industry at various stages of processing to change the rheological properties of IO. Among other things, these chemicals might have served as dispersants, flocculants, surfactants, or anti-settling agents. Vieira and Peres [4] examined that adding chemical reagents such as polyacrylic acids, silicone acrylate copolymer, citric acid, and sodium hexametaphosphate to aqueous IO samples decreased the apparent viscosity and fluid consistency index. Abroet al [5] investigated the stability of ultrafine IOWS at low solids concentrations (7.5%) as well as the optimum dose of chemical dispersants concerning slurry pH, stirring speed, and time. In a slurry concentration range of 18.8–25.8% by volume, Malorie, and Kaushal et al. [6], found that various dosages of sodium hexametaphosphate lowered the shear stress and viscosity values of IO fine slurry. The magnitude of the surface charge of the particle and the pH of the medium were shown to have a significant impact on the adsorption of dispersant on the IO surface. The electrostatic attractive force between the positively charged magnetite particle and anionic Sodiumdodecylbenzenesulphonate causes a considerable quantity of adsorption at pH levels below the isoelectric point [7]. Polymeric dispersant (DP001) was implemented at varying volume concentrations [8] to lower the viscosity of ferrosilicon and magnetite dense medium dispersion. It was observed that a small amount of polymer lowered the viscosity of the medium dense slurry by roughly 20% and up to a 50% reduction being possible for certain gravities and slime concentrations. Although commercial additives showed potential for IOWS stabilization, the detrimental impact on the ecosystem owing to their chemical action could not be avoided.

Natural additives, on the other hand, might be a viable option for IOWS stability, taking into account both the economy and the environment. Senapati et al. utilized low amounts (1% *w*/w of total solids) of two natural additives derived from Indian spinach (botanical name *Basella alba*) and Bellyache bush (botanical name *Jatropha gossypifolia-Linn*) to minimize Bingham viscosity and yield stress values via chemical modifications of the iron particle surface. The natural additives increased the fluid mobility between particles by decreasing the flocs' frictional resistance among the iron particles. and enabling slurry flow with a much-reduced shearing force. According to literature evaluations, the majority of the chemicals or dispersants employed in IOWS stabilization are synthetic in origin and not environmentally acceptable. As a result, in this study, an attempt has been made to use a natural dispersant, saponin derived from the *S. laurifolia* plant in IOWS stabilization. The fruits of this plant are tiny, and spherical, with a leathery-skinned pericarp that measures 1.0 to 2.0 cm in diameter and contains a considerable amount of saponin. Das et al. [9], studied the stabilization of high concentrated coal water slurry by using the saponin extracted from the plant, *Sapinduslaurifolia*. The enhanced stabilizing tendency of saponin is due to the presence of both hydrophilic (sugar chain) and hydrophobic (triterpene) rings. The mechanism of stabilization showed that due to hydrophobic interaction among coal surface and triterpene ring a stable dispersion of coal water slurry is formed. Similarly, a saponin from *Sapindus mukorossi,* another member of the *Sapindus* family has been used as an alternative to synthetic surfactant in many industrial applications such as dye solubilization [10], dye degradation [11], nanoparticle synthesis [12], and enhanced oil recovery [13]. Moreover, there are numerous applications of other surfactantsin various applications such as industrial applications [14–16] and medical applications [17].

The sources of surfactant from the fruit of *S. laurifolia* were selected because of its excellent stabilizing characteristics based on earlier studies relevant to slurry stabilization [18,19]. Saponin comprises a hydrophilic glyconic constituent made up of polysaccharides including rhamnose, pentose, galactose, and glucose, attached to a hydrophobic aglyconic component. An aglycon is a macromolecule made up of tri- terpenes that are connected to a polysaccharide unit by an oxygen atom(Fig. 1).

We investigated the potential of utilizing a natural surfactant, saponin extracted from *S. laurifolia* through two different processes one is the aqueous extraction process and the other is the chem. Extractionprocess as a stabilizing agent in the IOWS stabilization and trans- portation. The study revealed the significant role of key factors such as *S. laurifolia* concentration, IO concentration, zeta potential, and the surface tension of the IO particle in the formulation of and dispersion of high concentration IOWS. A qualitative interaction model was given between IO particle sand saponin molecules to establish the dispersion and sta- bilization of IOWS.

2. Materials and methods

Iron ore sample

IO sample-1 (S1) and sample-2 (S2) were supplied by Gandhamardan iron Ore mines, Odisha Mining Corporation, Keonjhar, Odisha, India, and Gua Iron Ore Mines, Jharkhand, India, respectively. Table.1, describes the chemical composition of IO as determined by XRF (Zentium, Malvern Pan analytical). A laser scattering analyzer (LA-960, HORIBA) was used to measure the particle size distribution (PSD) of the IO sam- ple, as shown in Fig. 2. The mineral characteristics of IO were studied using X-ray diffraction (XRD) diffractometer (Ultima IV, Rigaku), and the peak pattern is shown in Fig. 3. The IO sample's SEM analysis was studied (Fig. 4) using the instrument JEOI, JSM-7100F.

Extraction of S. laurifolia

Saponin is extracted from *S. laurifolia* by two processes (Aq. & chem. Extraction processes), which were reported in our previous studies[18,20,21].

Aqueous extraction of Saponin

Fruit of *S. laurifolia* was obtained from the Koraput district situated in the southern forest zone of India. About 100 g of fruit were taken, and the pericarps were removed, sun-dried, and chopped into minute frag- ments before being pulverized and mixed in 1 L of water at a solid-to- liquid ratio of 1:10 (0.1 g/cc). The obtained solution was stirred continuously for 3 h using a magnetic stirrer. After that, the supernatantwas centrifuged and filtered to recover the aqueous phase saponinsolution.

Chemical extraction of Saponin

Similar to the aq. extraction approach, the pericarps of *S. laurifolia* fruits were cut into minute pieces, and the extraction procedure was performed in 1 L of water at room temperature for 24 h under static conditions. The same procedure was repeated three times with the treated pericarps and finally by 1 L of hot water (90–95 °C) at static conditions. The extract was evaporated by heat to maintain a 1:3 solid-liquid ratio. The reduced sample was treated with ammonium sulphate

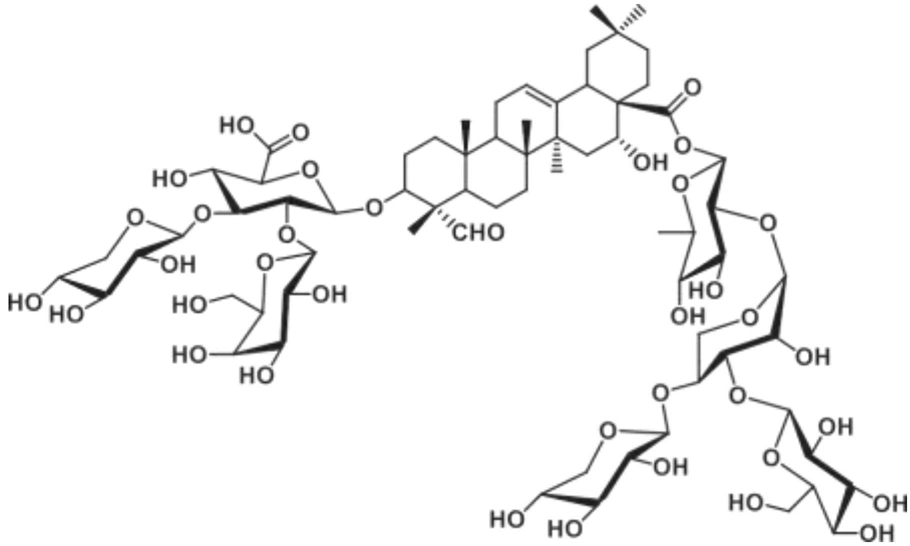


Fig. 1. Structure of saponin.

Table 1
Chemical component analysis of IO (XRF).

Chemical constituents	Fe_2O_3(%)	Al_2O_3(%)	SiO_3(%)	Others (%)
% Of OXides(S1)	80.23	6.24	6.33	7.20
% Of OXides(S2)	78.47	7.19	8.37	5.93

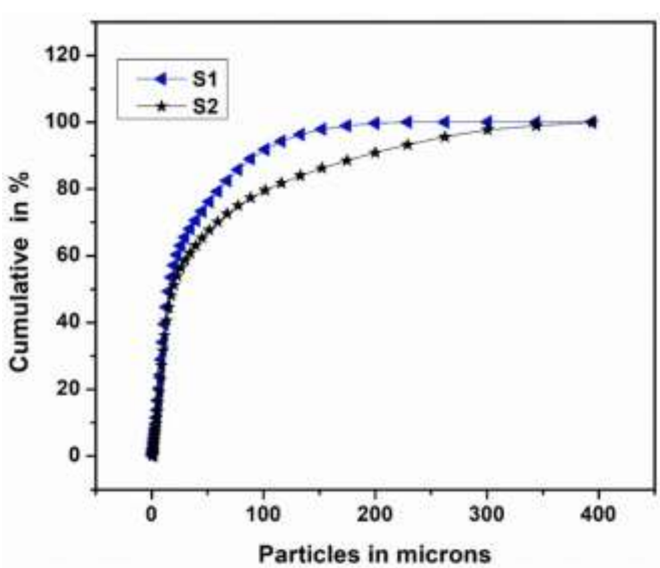
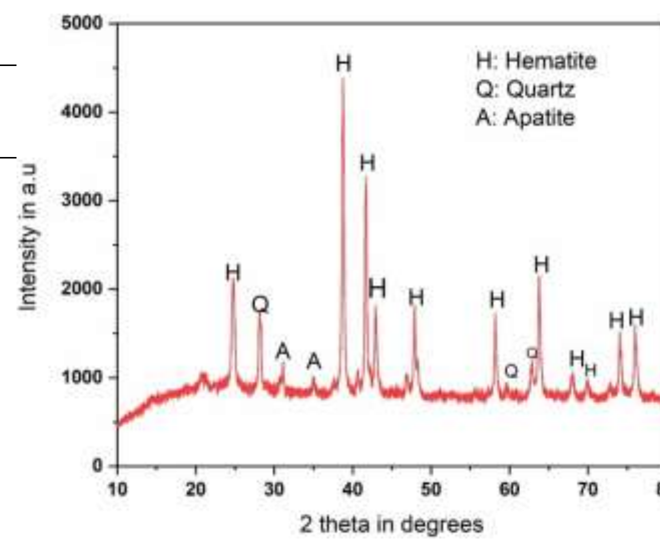


Fig. 2. Particle size distribution of iron ore sample.



until saturation was reached, after which the floating solid mass was separated. The solid mass was then dissolved in n-butanol and thread-like mass saponin was isolated using the rotary evaporator heating technique. Saponin was detected using a thin layer chromatogram (TLC) of a silica gel with hexane and chloroform in a 1:3 ratio as eluants [9].

Surface tension measurement of IOWS

The critical micellar concentration(CMC) of saponin isolated by the aq. and chem. Process was found to be 0.017 g per cc and 0.008 g per cc respectively as reported in our previous paper [9,18]. The surface tension of the IOWS was measured with a surface tensiometer by using the

Fig. 3. XRD pattern of iron ore sample.

William plate method (Kyowa-350, Japan). The value of CMC of saponin in IOWS was determined by the varying trend of the surface tension of IOWS with saponin dosage at a particular IO concentration for both samples S1& S2. The CMC of saponin with and without IO was compared.

Zeta potential measurement

The zeta potential of the IOWS sample was measured using a zeta potential analyzer (Nano ZS 90, Malvern). At a temperature of 25 °C, 10 g of IO sample were mixed with 100 mL of demonized water-containing and stirred at 500 rpm for 30 min. After that, 1 mL of the resulting sample was collected for a zeta potential analysis. The majority of the
tests were carried out in triplicate, with the mean data taken into account and reported.

Rheological study

A HAAKE RHEOSTRESS 1(Thermo Scientific Rheometer) was used to conduct an IOWS rheological investigation with an MV I sensor system.

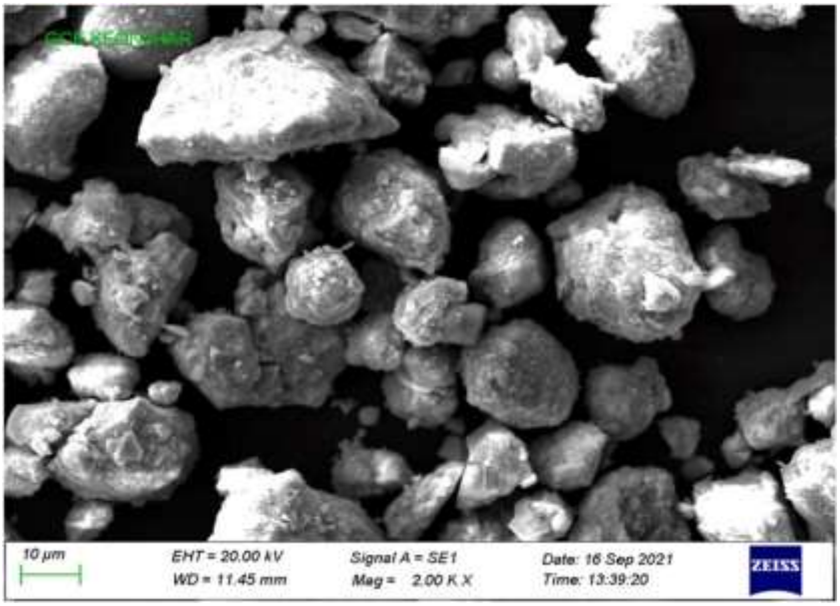


Fig. 4. SEM image of untreated IO.

The shear rate was varied from 10 to 200 s^{-1} to examine the relationship between viscosity and shear stress. The slurry was placed through a viscometer, connected to a constant temperature circulating bath, which ensured a temperature variation of 0.1 °C. With continual stirring for 10 to 15 min, 100 mL of the slurry of different concentrations of IOWS, ranging from 50 to 74%, were prepared using different proportions of IO and *S. laurifolia.* After it was made, the suspension was wrapped in aluminum foil to prevent evaporation. A slurry sample of 30 mL was put in a cleaned rheology cup for rheological study. Each experiment was repeated three times, and the average value was taken.

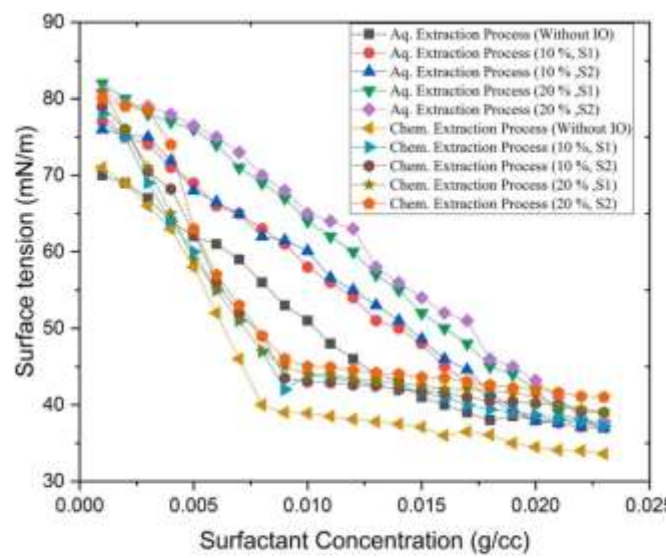
3. Result and discussion

Effect of saponin concentration on the surface tension of IOWS

Dispersants are surface-active molecules that reduce the surface tension of the fluids and enhance the wettability of solid materials. This minimizes the interfacial tension between solid particles and the liquid in a slurry system. The ability of the dispersant (in this case saponin) to attach to the IO surface is vital for the stability of the IOWS. Therefore, the study of the solution behavior of the dispersant in the IOWS mixture is essential. The surface tension value decreases with the increase in the saponin concentration in the pure saponin solution and the IOWS mixture containing 10% and 20% IO of both the samples S1&S2 (Fig. 5). It has been examined from the figure that the lowest value of surface tension (40 mN/m) was achieved at 0.017 g/cc and 0.008 g/cc of saponin isolated by the aq. and chem. Extraction methods without IO. A similar trend is observed for the IOWS mixture. With increasing IO concentration, the surface tension of the IOWS mixes increased. This is primarily due to the increase in interfacial surfaces. This caused the lowering of the active surfactant concentration in the bulk of the IOWS mixture. CMC of saponin in IOWS mixtures is significantly greater than that of saponin solution in the absence of IO owing to surfactant absorption by IO particles [22].

Effect of saponin concentration on the viscosity of IOWS

Due to their great affinity for one another rather than the surrounding medium, preferential dispersion of particles in a solvent is



challenging, resulting in flocculation and settling of the particles [23]. As a result, developing areas in IO particles that promote IO-water

Fig. 5. Variation of Saponin concentration with the surface tension of IO samples S1&S2.

contact, restrict IO-IO interaction, or both are necessary and fundamental for IOWS stabilization. Surfactants are chemical reagents that promote the stabilization of solid–water dispersion by lowering the hydrophilicity of solid particles or forming a film around each particle. Fig. 6. shows the influence of saponin concentration on the apparent viscosity of IOWS. It was examined from the figure that the slurry vis- cosity was significantly reduced by the addition of saponin solution which may be due to the improved dispersion of scattered IO particles. This could be owing to the saponin molecule coating on the surface of the IO particle, which creates an effective barrier between the particles, resulting in better dispersion. Saponin isolated via two different routes was used as a dispersant in the concentration range of 0.001–025 g/cc with an IO content of 70%. The viscosity value was reduced sharply from around 1400 to 400 mPa.s. by increasing the dispersant concentration from 0.001 to 0.021 g/cc (Aq. extraction) and 0.001 to 0.012 g/cc (Chem. extraction). These surfactant concentration values (0.021 and 0.011 g/cc) are referred to be optimum concentrations for maximum

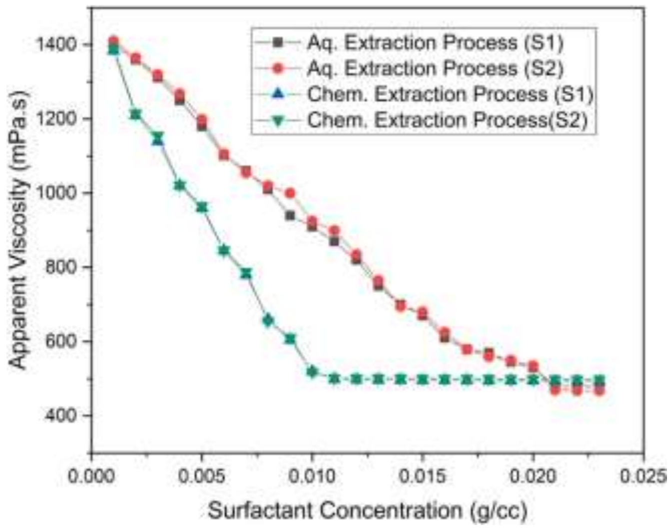


Fig. 6. Variation of saponin concentration with apparent viscosity at IO concentration 70%.

viscosity reduction of IOWS, and they are above their CMC [24]. There was no further substantial reduction in viscosity beyond these concentrations (0.021 and 0.011 g/cc), indicating that the interface segregation and surfactant partitioning stops [25,26]. It can be predicted that increasing the concentration of saponin in the slurry increased the number of saponin-coated IO particles which resulted in an improved dispersion of IO particles. Both the IO samples exhibit similar types of behavior towards the developed dispersant.

Effect of iron ore concentration on viscosity at optimized dispersant concentration

The viscosity of the slurry is the result of the agglomeration of the solid particle at a higher concentration. By altering the percentage of iron in the slurry, the apparent viscosity of the slurry can be controlled. It is vital to increase the concentration of IO while keeping the viscosity at a minimum for cost-effective pipeline transportation of IOWS. Fig. 7 shows the viscosity of the IOWS containing different solid contents ranging from 50% to 80% in the presence of an optimized concentration of *S.laurifolia* (0.021 for aq. and 0.011 g/cc for chem. Extraction

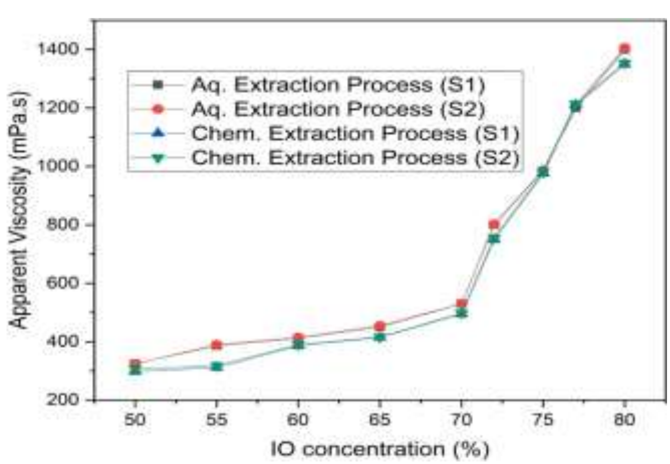


Fig. 7. Effect of IO concentration with apparent viscosity at optimized saponin concentration.

process). With the increase in IO concentration, the apparent viscosity gradually increases and it was examined that the apparent viscosity value becomes more than 1000 mPa.s for solid concentration above 72% which may not suitable for pipeline transportation [27]. When the solid quantity of the slurry is more, the dispersion velocity of the particles in the slurry is slower than the re-aggregation speed, and so it cannot be well dispersed, resulting in the formation cluster. From Fig. 7 it is also observed that slurries with solid content between 50% to 72% possess good fluidity whereas fluidity fades as the solid content increases to 74%, due to high viscosity value. The slurries have poor flow characteristics and appear hard as the solid component is increased to 78% [28].

Effect of shear rate on the apparent viscosity of IOWS

The shear force or rate existing between the different layers of a flowing liquid controls the apparent viscosity of the slurry. Accordingly, it is essential to know its effect on the apparent viscosity of IOWS and to make the slurry to be economically viable for application, shipping as well as storage. Fig. 8 explains the variation of shear rate (10 to 200 s^{-1}) with apparent viscosity at different concentration ranges (50 to 72%) of IO. The graph shows that when the shear rate of the IOWS increased, the viscosity of the slurry is reduced exponentially indicating a Non-Newtonian fluid material irrespective of the amount of IO content [18,28]. Particle size and SEM examination (Section 2.1) reveal that IOWS is made up of a variety of IO particle sizes and shapes. The size, shape, and cohesiveness of the molecules will determine how much force is necessary to induce motion as they pass by each other using applied force [29]. The viscosity of the slurry hardly changes at higher shear rate region and non-Newtonian behavior diminishes for all the studied range of IO concentration.

Shear rate-shear stress relationship of IOWS

IOWS transportation by pipeline needs a free-flowing tendency, therefore understanding the nature of flow behavior and viscosity variations during flow is vital. To determine the rheological properties of IOWS, the variation of shear stress with the shear rate was studied at an optimized concentration of saponin and different IO concentrations (60% and 72%). It is investigated (Fig. 9.) that the shear stress in the Y-intercept of the plot is sustained by IOWS up to a certain value (initial

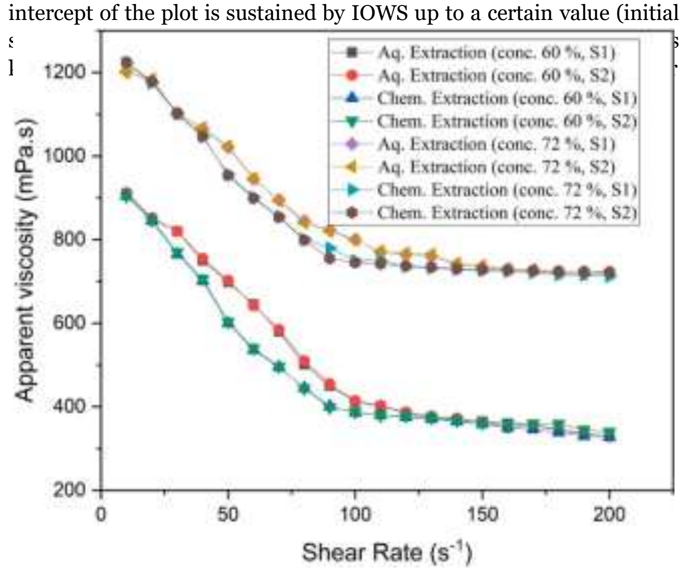


Fig. 8. Effect of shear rate on apparent viscosity at different IO concentrations.

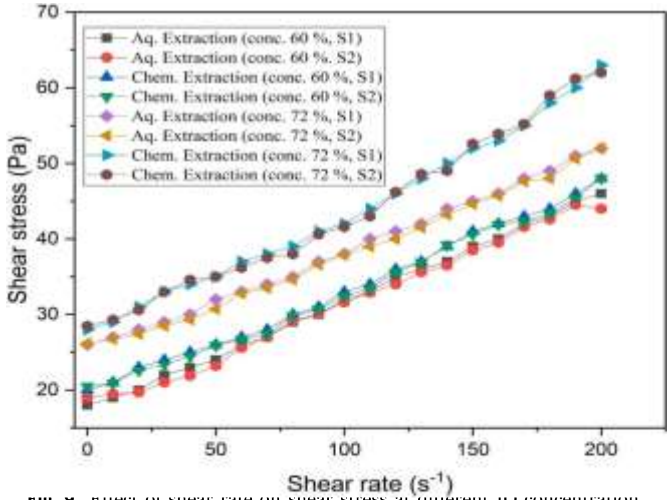


Fig. 9. Effect of shear rate on shear stress at different IO concentration.

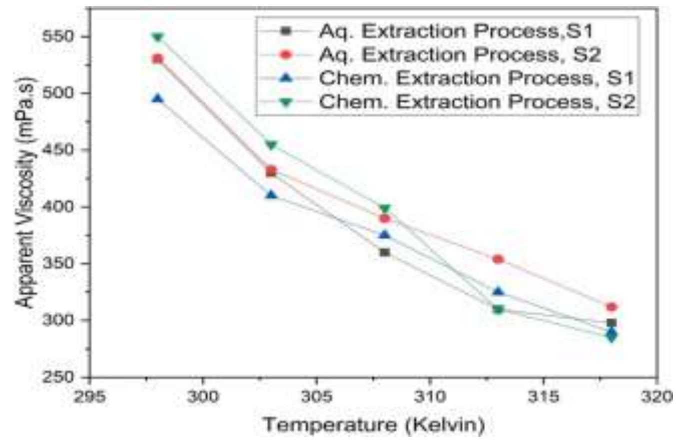


Fig. 10. Effect of temperature on apparent viscosity at 70% IO.

rate should overcome this yield stress value [30]. Only after the yield stress point, the shear rate is linearly proportional to shear stress. The plot of shear stress versus shear rate with an initial threshold gives a straight line (Fig. 9), indicating that IOWS follows non-Newtonian Bingham plastics fluids obeying the equation as given below.

$$\sigma = a.\gamma + b \tag{1}$$

where a denotes dynamic viscosity, b denotes yield stress, and γ denotes applied shear rate.

It has also been observed that (Fig. 8) with the increase in IO concentration from 60% to 72% there is a significant increase of Y-intercept in the plot (yield stress value) which may be due to strong agglomeration of IO at higher concentration [25]. The yield stress of IOWS was determined by the intercept of these linear plots, and yield stress increases as the amount of IO increases in the IOWS at the optimized concentration of saponin. Values of yield stress and regression coefficient at different IO concentrations are given in Table 2.

Effect of temperature on apparent viscosity of IOWS

The effect of temperature on apparent viscosity is particularly important when evaluating materials that will be transported under different atmospheric conditions. It has been established that fluidity and temperature have an inverse relationship [28]. In the present study, the temperature was varied in the range of 298 K to 318 K at 70% IO and optimized saponin concentration to study its effect on apparent viscosity value (Fig. 10). The kinetic energy of the IO particles increases as the temperature rises, lowering the cohesive force among the IO particles and increasing the mobility of IOWS. Arrhenius's expression as presented in Eqs. (1) & (2) gives the relation between temperature and viscosity.

$$\eta = Aexp^{E/RT} \tag{2}$$

$$ln(\eta) = ln(A) + E/RT \tag{3}$$

where “η” is the viscosity at a particular shear rate, “E” is the fluid flow activation energy, “T” is the temperature in Kelvin, “A” is a fitting parameter and “R” is the Universal gas constant.

Zeta potential and isoelectric point (IEP) of IOWS

Electrokinetic effects have a significant impact on particle-particle or particle-solvent interaction in the slurry. The Zeta potential (ζ) can be used to quantify these electrokinetic effects. When all of the particles in dispersion have a substantial negative or positive zeta potential, they will resist agglomeration and flocculation and will not stick together. Generally, particles having a magnitude of zeta potentials greater than 30 are regarded as stable [31]. The surface charge of hematite (IO) particles determines the processing of hematite ores such as selective flocculation, froth flotation, thickening, and filtration and transportation [32]. Proton uptake and release by surface-exposed oxygen atoms or dissociative water sorption cause the surface of hematite to become charged [33]. Metal oxides, and therefore hematite, have pH-dependent surface characteristics. The surface charge of IO particles is evaluated by measuring the magnitude of attractive or repulsive interaction among the ore particle by keeping them in an electrolytic cell. Fig. 11 represents the plot of ζ of the IO sample as a function P^H.

It is observed from Fig. 11 that increasing the pH of the solution ζ value decreases from around 28 mV and becomes zero around pH 6.8. It can be predicted that maximum agglomeration of IO particles occurs at

Table 2
Yield stress and R-square at different IO concentration.

Iron concentration (%)	Aq. extraction, S_1		Aq. extraction, S_2		Chem. extraction, S_1		Chem. extraction, S_2	
	Yield stress (Pa)	R-square	Yield stress (Pa)	R-square	Yield stress (Pa)	R-square	Yield stress (Pa)	R-square
50	9.259	0.99	8.259	0.99	10.65	0.98	09.65	0.983
55	10.10	0.99	10.70	0.98	11.5	0.99	12.5	0.99
60	12.41	0.998	13.41	0.99	13.30	0.995	12.30	0.98
65	17.54	0.995	16.54	0.995	15.41	0.995	14.41	0.990
70	20.20	0.98	18.20	0.983	19.10	0.99	19.60	0.993
72	22.16	0.99	21.16	0.99	22.77	0.98	21.56	0.987
80	32.21	0.98	30.21	0.98	31.52	0.99	30.32	0.991

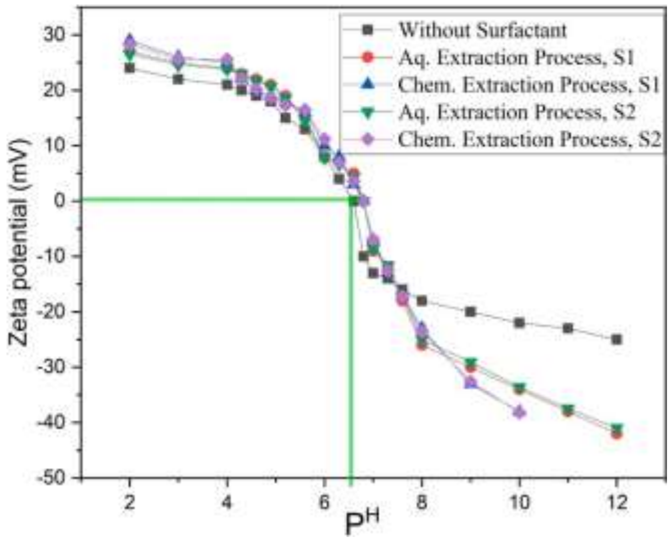
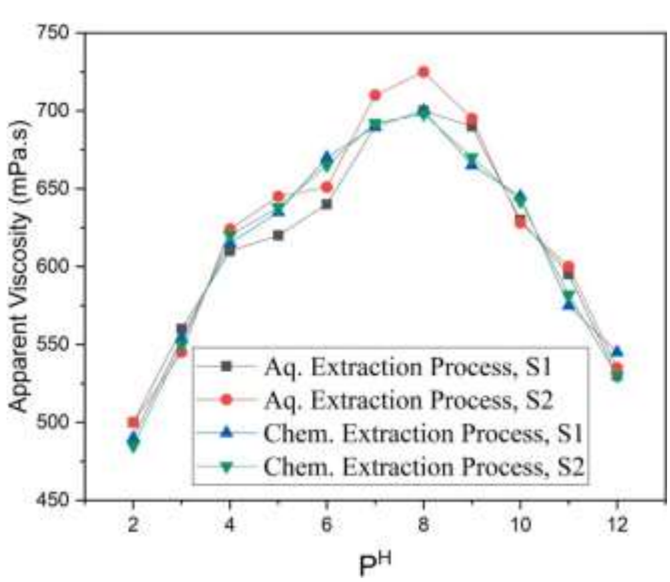


Fig. 11. Effect of pH on zeta potential.

this pH value. With a further increase in pH of the solution more negative ions (OH¯) appear on the surface of IO particles resulting in more surface hydroxylation thereby increasing the magnitude of electrostatic repulsion between IO particles.

3.8. Effect of pH on apparent viscosity IOWS

The plot of apparent viscosity with the variation of pH containing 70% IO and the optimized surfactant concentration is shown in Fig. 12. It is seen from the figure that the apparent viscosity of IOWS increases from 510 to 770 mPa.s with increasing pH up to the isoelectric point (pH 6.8). This could be due to the decrease in zeta potential, which promotes particle-particle agglomeration. After passing through IEP, it was noticed that with a further increase in the pH value, the apparent viscosity reduced. The electrostatic repulsion between IO surfaces increases because of the increased surface hydroxylation around each IO particle as the pH of the slurry increases after IEP. At this pH that is nearly equal to the isoelectric point, the maximum viscosity is attained. As a result, IO particles settle down relatively quickly at IEP. At this pH, more pumping is required to make the slurry flow [9].



Mechanism of stabilization IOWS

The surface of an IO particle is mostly hydrophilic. Considering the hydrophilicity of the IO surface, the most likely mechanism of saponin adsorption at the IO surface is that the hydrophilic residue (sugar) of saponin is adsorbed on the IO particle surface while the hydrophobic triterpenoid group is away from the IO particle (Fig. 13). When the surfactant molecule adheres to the IO surface, the water molecules are likely to be desorbed from the mineral surface owing to the presence of the hydrocarbon chain. This process is repeated until the surfactant concentration (CMC) is optimum. As a result, a well-dispersed IOWS is generated, preventing IO-IO interaction [34].

Prediction of pressure drop (head loss), slurry flow rate, solids flow rate, hydraulic power, and SPC of IOWS

Slurry head loss, solid conveying rate, hydraulic power demand, and specific power consumption (SPC) must be calculated for the projected iron ore slurry pipeline to be implemented into operation to evaluate the economic impact of the surfactants [35]. At a slurry flow rate of 2 m/s, nominal bores of 200, 250, and 300 mm NB (nominal bore) was used. The mass concentration of IOWS was maintained at 60%. The Dar- by–Melson combined equation, valid for all flow conditions, was applied to quantify the head loss of iron ore slurry [36]. Solids flow rate (tons/h) is a function of pipe diameter, transport velocity, slurry density, and concentration. Consequently, the iron ore solids flow rate (tons/h) was determined using the following formula:

$$W_S = \frac{Q \times \rho_m \times C_w}{1000} \tag{4}$$

Where ρ_m (Kg/m^3) is the slurry density, Q (m^3/h) the slurry flow rate, and C_w the solids mass concentration (infraction).

Using the formula, the required hydraulic power PH in kW for slurry flow was calculated.

$$P_H = \frac{Q \times \rho_m \times g \times \Delta H}{3.6 \times 10^{-6}} \tag{5}$$

where ΔH is the head loss of slurry in a meter of water per kilometer.

Regardless of the pipe flow conditions, the SPC is expected to be a minimum to provide the most effective and economical slurry transfer possible. To move a ton of material 1 km through a pipeline, a hydraulic power (kW) of 1 kW is needed.

The following equation was used to estimate the SPC for iron ore slurry at a slurry concentration of 60% mass in three different pipes with and without surfactants:

$$SPC = \frac{P_H}{W_S} \tag{6}$$

Fig. 12. Effect of pH on apparent viscosity at 70% IO.

Assuming a 60% mass concentration of iron ore slurry in 200, 250 and 300 mm NB pipes, Table 3. shows the calculated values for head loss, solids conveying rate, hydraulic power need, and SPC. When the surfactant was added to iron ore slurry, shows that the head loss, hy- draulic power consumption, and SPC were all significantly influenced [37]. Hydraulic power decreased when the different concentrations of
S. laurifolia were added to iron ore slurry. When dealing with slurry headloss, this means that pump power will be lowered by nearly half to overcome it. The SPC values for the three pipelines were likewise reduced with the addition of the surfactant at different concentrations. Accordingly, iron ore can be transported affordably via a slurry disposalpipeline system with a cheap initial expenditure.

4. Conclusion

Saponin is a natural non-ionic surfactant isolated from the plant *S. laurifolia* fruit by aq. and chem. Extraction method. The isolated saponin was applied as a viscosity reducing agent in stabilization and pipeline

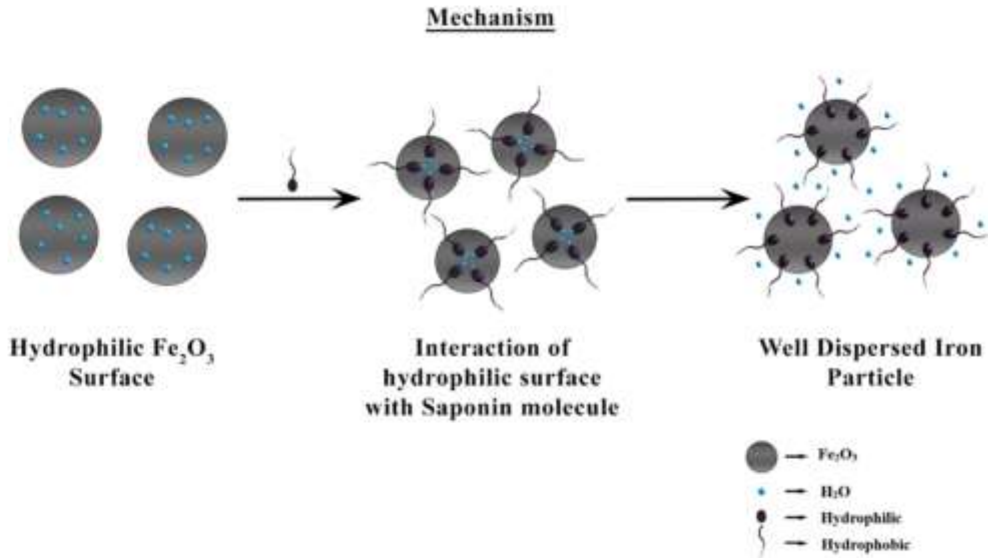


Fig. 13. Mechanism of transportation of IOWS.

Table 3
IO pipeline hydraulic and operational parameters without and with *S.laurifolia* (C_w = 60%).

Nominal bore of a pipe	*S. laurifolia* concentration		Head loss (m of water/km)		Slurry flow rate (m^3/h)	Solids flow rate (tons/h)	Hydraulic power (Kw/km)		SPC (kWh/ton-km)	
	Aq. extraction process	Chem. extraction process	Aq. extraction process	Chem. extraction process			Aq. extraction process	Chem. extraction process	Aq. extraction process	Chem. extraction process
200 mm NB pipe	0	0	385.1	385.1	155.04	146.21	216.30	216.30	1.479	1.479
	0.005	0.005	320.4	265.3	155.04	146.21	188.44	158.92	1.289	1.087
	0.010	0.010	255.6	199.6	155.04	146.21	173.22	136.00	1.185	0.930
	0.015	0.015	215.3	170.6	155.04	146.21	152.68	130.52	1.044	0.893
	0.021	0.021	190.8	164.3	155.04	146.21	138.34	124.35	0.946	0.850
	0.025	0.025	186.3	162.9	155.04	146.21	135.18	122.39	0.925	0.837
250 mm NB pipe	0	0	150.6	150.6	240.92	225.65	162.82	162.82	0.722	0.722
	0.005	0.005	131.2	110.65	240.92	225.65	151.07	144.06	0.669	0.638
	0.010	0.010	120.6	94.69	240.92	225.65	129.76	109.42	0.575	0.485
	0.015	0.015	106.3	90.87	240.92	225.65	123.85	99.38	0.549	0.440
	0.021	0.021	96.32	86.58	240.92	225.65	82.67	83.66	0.366	0.371
	0.025	0.025	94.12	85.21	240.92	225.65	82.05	72.10	0.364	0.320
300 mm NB pipe	0	0	80.98	80.98	337.25	321.15	355.95	355.95	1.108	1.108
	0.005	0.005	75.14	71.65	337.25	321.15	296.14	245.22	0.922	0.764
	0.010	0.010	64.54	54.42	337.25	321.15	236.25	184.49	0.736	0.574
	0.015	0.015	61.6	49.43	337.25	321.15	199.00	157.69	0.620	0.491
	0.021	0.021	41.12	41.61	337.25	321.15	176.36	151.86	0.549	0.473
	0.025	0.025	40.81	35.86	337.25	321.15	172.20	150.57	0.536	0.469

transportation of high concentration IOWS. The viscosity of the slurry and the yield stress value dropped as the saponin concentration was increased. The highest reduction in viscosity (1200 to 398 mPa.s) occurred at 0.021 g per cc (Aq. Extraction process) and 0.011 g per cc (Chem. Extraction process) of saponin. Agglomeration of IO particles occurred at the IEP of IOWS, which was around pH 6.8. Apparent viscosity, as well as yield stress of the IOWS, was maximum at IEP. The investigation demonstrates the suitable and effective utilization of a natural dispersant, *S.* laurifolia, for enhancing pipeline transportation of IOWS. Based on slurry head loss, solids conveying rate, hydraulic power requirement, and SPC the economic impact of the dispersant on the transport cost of the IOWS pipeline is estimated. The addition of *S.* laurifolia to IOWS significantly reduced the head loss, hydraulic power, and SPC.

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CRediT authorship contribution statement

Mandakini Behari: Conceptualization, Validation, Data curation, Visualization, Writing – original draft. **A.M. Mohanty:** Conceptualization, Supervision, Formal analysis. **Debadutta Das:** Conceptualization, Methodology, Investigation, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influencethe work reported in this paper.

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