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Beneficiation of Talc Ore

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1. Introduction

Talc is an industrial mineral, which is composed of hydrated magnesium sheet-silicates with theoretical formula of $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$ that belongs to the phyllosilicate family (Fuerstenau and Huang, 2003; Ozkan, 2003; Yehia and AL-Wakeel, 2000; Boghdady et al, 2005). Talc may have white, apple green, dark green or brown colors, depending on its composition. Talc is the softest one in all minerals, which has Mohs hardness ranges from (1–1.5) and a greasy feel (Boghdady et al, 2005). The specific gravity of talc is about 2.75; it is relatively inert, and water repellent (Engel and Wright, 1960). Talc is formed by the alteration of serpentine. The resulting talc contains magnesia and water but relatively more silica than serpentine (Andrews, 1985).

Talc surface is comprised of two types of surface area, the basal cleavage faces and the edges. The faces surface has no charged group, therefore, it is believed that the talc faces are non-polar and hydrophobic, whereas the edges are hydrophilic due to the presence of charged ions (Mg^{2+} and OH^-) (Kusaka, et al, 1985; Sarquis and Gonzalez, 1998). The major gangue minerals of talc are carbonates, magnesite, dolomite, serpentine, chlorite and calcite, which contribute to the production of undesirable characteristics. The trace minerals in talc include magnetite, pyrite, quartz and tremolite (Andrews, 1985; Sarquis and Gonzalez, 1998; Simandle and Paradis, 1999; Al-Wakeel, 1996; Schober, 1997).

1.1 Petrographical and geochemical characterization of talc

Talc is an extremely versatile mineral which is composed of hydrated magnesium sheet-silicates with a theoretical chemical formula of $\text{Mg}_3(\text{Si}_2\text{O}_5)_2(\text{OH})_2$ that belongs to the phyllosilicate family (Ozkan, 2003; Yehia and AL-Wakeel, 2000; Shortridge, et al 2000). It is formed by the alteration of serpentine. The resulting talc contains magnesia and water with a relatively more silica than serpentine (Andrews, 1985). The talc particles are composed of hydrophobic and hydrophilic surfaces, faces and edges; the former are created by cleavage whereas the latter ones are created by a spontaneous hydrolysis to form oxides sites (Boghdady et al, 2005; Kusaka, et al, 1985). Talc edges consist of charged ions (Mg^{2+} and OH^-) and therefore, number of bonding possibilities exist between water molecules and talc edges. Hence the edges of talc are likely to be hydrophilic and the talc surface is hydrophobic (Khraisheh, et al 2005). Commercial talc may contain related sheet silicates

such as chlorite and serpentine, as well as, carbonates, such as magnesite, dolomite and calcite (Ozkan, 2003; Sarquis and Gonzalez, 1998).

Okunlola et. al. (2003) worked at Baba talc occurrence (Nigeria) with preliminary quantities estimation of 3 million tons. By the aid of a thin section examination, they showed that talc, tremolite and chlorite are the main minerals. Talc content ranged from 14% to 72% and occurred as fibrous aggregates and sometimes as a platy.

Gondim and Loyola (2002) mentioned that talc deposits of the Parana district (Brazil) occurred as layers, lenses and veins. They attributed the formation of two types of talc mineralization processes in the deposit of Parana district to the regional dynamo-thermal metamorphism (organic metamorphism) and hydrothermalism.

Simandle and Paradisi (1999) stated that the age of talc mineralization (Ontario, Canada and New York State, USA) is mainly Precambrian. Most carbonate hosted talc deposits are believed to be formed of dolomite with silica and water.

The origin of talc deposits and their associated minor sulfide occurrences in Eastern Desert of Egypt has been a controversy topic from the time of their discovery (Schandl, et al 2002, 1999a, 1999b; Helmy and Kaindl, 1997; El Bahariya and Arai, 2003). El Sharkawy (2000) has reported that, the majority of talc occurrences in Egypt may be derived and hosted by ultramafic rocks, mainly serpentinite. Serpentinite bodies characteristically occur in belts of low- grade metamorphic sedimentary and volcanic rocks. Talc deposits are widely variable in shape and are mostly pod-shaped, lenticular, thin shells and irregular masses.

The majority of talc exploitation in Egypt is wadi El-Allaqi, Derhib, wadi El-Atshan, Gabal El-Angoria and wadi Eggat (Kamel, et al 2001).

Nasr and Masoud (1999) investigated the area which lies between latitude $22^{\circ} 30' 00''$ - $22^{\circ} 37' 30''$ N and longitudes $33^{\circ} 22' 30''$ - $33^{\circ} 32' 30''$ E, covering about 190km². They found that talc deposit lies between latitude $22^{\circ} 30' 00''$ and longitude $33^{\circ} 29' 50''$, and talc occurred as lenses along the shear zone which were affected by hydrothermal solution rich in magnesium or as pockets enclosed within the shear zones. X-ray diffraction of twelve representative samples of talc lenses in wadi El-Allaqi area showed that the talc mineral represented 99% of the samples with rare carbonate and illite but other samples showed that the talc mineral represented 95% of the samples with traces of carbonate, illite, magnesium, iron, aluminum clinchlore and manganese.

Attia (1960) have studied the talc deposits in Aswan district, which occurred in a metamorphic schist area at the head of wadi Um Guruf, a tributary of wadi Abu Agag. The working area (Latitude $24^{\circ} 02' N$ and longitude $33^{\circ} 05' E$) is East of El-Shallal railway station at a distance of 17 km. The schist in this area is dominantly plagioclase-quartz-biotite schist. Talc exists beneath the ground surface and is found in the form of bands or lenses in the schist. It seemed evident that the talc of this locality is an alteration product of the schist.

Yousef (2003) studied the characterization of the talc varieties in El-Allaqi and Abu-Dahr areas. Firstly, El-Allaqi samples were characterized with white to white-grey talc flakes and spherulitic structure intersected with the carbonate crystals. The X-ray diffraction revealed the presence of dolomite, kaolinite, chlorite and quartz in these samples. The chemical analysis indicated that carbonates are the main gangue minerals in the samples (the percent of CaO is equal to 4.64% and the percent of loss on ignition equal to 12.22%). Abu-Dahr samples showed a formation of vein of chlorite talc and highly pyritized talc; the X-ray diffraction of samples showed the presence of chrome and chlorite. The chemical analysis of samples showed that, iron oxide was the main gangue mineral in samples (the percent of Fe₂O₃ = 4.96%).

Boulos et. al. (2004) have performed X-ray diffraction (XRD) of Shalatin samples, which showed a higher percentage of loss on ignition and CaO but for El-Allaqi samples showed higher quality with minor amount of carbonates and traces of quartz. The presence of chlorite in both samples was also confirmed by X-ray diffraction. The total amount of exposed talc in wadi El-Allaqi is more than 165000 tons of very high grade talc quality, but no accurate estimation of talc reserves has been calculated for shalatin locality.

1.2 Processing of talc

Boulos et. al. (2004) have applied the wet attritioning technique as a substitution of the conventional ball or rod milling in talc beneficiation plants because of the friable nature of talc. The objective of this process was to achieve preconcentration of talc by differential grinding from harder carbonate impurities. Optimization of this process included verification of some parameters such as; attritioning time, attritioning speed, and pulp density. Attritioning was carried out on two samples obtained from Shalatin and El-Allaqi regions.

For Shalatin sample, an attritioning scrubbing of -11 mm crushed talc ore was carried out at 60% solids, 1500 rpm motor speed and an attritioning time of 60 minutes. The product has 8.4% loss on ignition with 74.7% mass recovery.

For El-Allaqi sample, an attritioning scrubbing was executed at 60% solids, 2100 rpm motor speed and an attritioning time of 60 minutes. The product has 5% loss on ignition and about 87.5% mass recovery (Boulos et. al. 2004).

Piga and Maruzzo (1992) tried the attritioning of talc-carbonates. Because the carbonates are harder than talc, they are used as a grinding medium for the slurry formed of the ore to be treated. So the fine fraction should be enriched in talc and the coarser fraction enriched in carbonates. A selective attritioning carried out with 76% pulp density, at 20 minutes attritioning time, and a 1 kg/t sodium hexametaphosphate as a dispersant gave a concentrate grading of 82% talc-chlorite and 18% carbonates. The recovery of talc-chlorite was around 74% from a crude ore containing 67% talc-chlorite and 33% carbonates. This product may be sent to flotation for further removal of carbonates and separation of talc from chlorite.

Yousef (2003) used attritioning scrubber as a preconcentrator for talc of El- Allaqi locality. The selective attrition executed with a 50% solid/liquid ratio and an attritioning time of 20 minutes to obtain a concentrate with 9.1% loss on ignition, the percent of CaO was 1.07% and the whiteness increased from 74% in the original ore to 80% in the concentrate.

Flotation is the preferred concentration technique to remove impurities from talc Kho and Sohn, 1989). Various factors that control the flotation process of talc include particle size, pH values, collector dosage, depressant dosage, pulp density and frother dosage which were studied by many authors (Fuerstenau and Huang, 2003; Boulos et. al. 2004; Kho and Sohn, 1989; Andrews, 1989; Feng and Aldrich, 2004).

When adjusting the pH values of the system this can enhance or prevent the flotation of a mineral. Thus, the point of zero charge (ZPC) of the mineral is an important mineral property in such systems (Wills, 1992).

The critical pH is a value below which any given mineral can float, and above which it will not float. This critical pH value depends on the nature of the mineral, the particular collector, its concentration, and temperature (Wills, 1992).

Chang (2002) beneficiated talc at the Gouverneur district in New York. Talc was crushed firstly by jaw crushers, and then by gyratory crushers, conveying to the plant, storage of wet ore, the ore was ground to minus 0.95 cm, tertiary crushing, grinding of coarse product by using a pebble mill in a closed circuit with Raymond mill, and finally grinding of the fine product with fluid energy mill. Concentrating tables were installed to remove high-gravity product containing Ni, Co and iron minerals. He used a flotation plant for the production of high-grade talc. Combination of froth flotation and high intensity magnetic separation has been studied for the removal of iron-bearing minerals.

Wills (1992) reported that increasing concentration of collector tends to float other minerals and reduce selectivity. It is always difficult to eliminate a collector already adsorbed. An excessive concentration of a collector has also an adverse effect on the recovery of valuable minerals; this fact may be due to the development of collector multi-layers on the particles or by reducing the proportion of hydrocarbon radicals oriented into the bulk solution. The hydrophobicity of the particles is thus reduced, and hence their floatability. The flotation limit can be extended without loss of selectivity by using a collector with a longer hydrocarbon chain, which produces greater water-repulsion, rather than by increasing the concentration of a shorter chain collector.

It is common to add more than one collector to the flotation system. A selective collector may be used at the head of the circuit, to float the highly hydrophobic minerals, then after a more powerful, but less selective one is added to promote recovery of the slower floating minerals (Wills, 1992).

Fuerstanaue and Pradip (2005) have revealed that; adsorption of collectors in the flotation of silicate minerals is controlled by the electrical double layer at the mineral-water interface. In the systems where the collector is physically adsorbed, the flotation process with anionic or cationic collectors depends on the mineral surface which is being charged oppositely.

In beneficiation of Egyptian talc-carbonate ore, Yehia and Al-Wakeel (2000) applied flotation process at 25% solids, airflow rate = 1000 L/min., pH value = 7, using 0.1 kg/ton of polypropylene glycol as a frother. They obtained concentrate with 90% recovery and 60% grade of talc. The final product was treated by using diluted hydrochloric acid of 10% and 300 ppm of Tin chloride (SnCl_2). This product may be suitable one for cosmetic, paint and paper industries.

Al-Wakeel (1996) treated talc ore from wadi El-Baramiya having a size fraction of (-50+45 μm). A selective flotation of talc was applied at a pH value = 6, a frother dosage of polypropylene glycol (AF65) = 0.1 kg/t and an impeller speed = 1100 rpm. The pH value of the pulp was adjusted before the addition of frother which in turn is followed by aeration. The grade of talc was about 72.5%. By applying another cleaning stage using 0.075 kg/t a frother dosage at a pH = 7, the grade of talc was increased to 93.5% with a recovery of 70%.

Yousef (2003) has applied more than one technique for the flotation of -75 μm scrubbed talc obtained from attritioning process. The obtained results showed that:

1. Using natural floatability of talc, the final product obtained has loss on ignition about 6.85% and a recovery of 50%.
2. With the addition of 0.05 kg/t of frother (Aerofroth 73), increased the recovery to 65.8% with a slight decreasing in grade is observed.
3. The best result was achieved by using 1 kg/t oleic acid as a collector in the presence of 0.4 kg/t hexametaphosphate as a depressant and at pH value = 10. The final concentrate having 6.6% loss on ignition and a recovery of 61.8%.

Andreola et. al., (2006) have reported that more increasing of sodium hexametaphosphate (used as a depressant) may lead to an increase in the final percent of CaO. This trend can be interpreted to the ability of sodium hexametaphosphate (SHMP) to sequester the calcium cations (Ca^{+2}) forming with the calcium a strong hydrophilic complex compound. But the effect of sodium hexametaphosphate towards aluminum is weak to sequester the aluminum sites. This may be interpreted to the interaction of sodium hexametaphosphate (SHMP) anions with the exposed atoms of Al giving complexes anions.

Khraisheh et. al. (2005) revealed that the adsorption of carboxymethyl cellulose (CMC) depressant onto talc can be increased by increasing the molecular weight of CMC depressant and by the addition of magnesium, potassium and calcium to carboxymethyl cellulose.

Derco and Nemeth (2002) treated three types of talcose rocks (Slovakia): talc-magnesite, talc-dolomite, and talc-magnesite-dolomite. The flotation process was applied for talc-magnesite rock at pH value = 6, pine oil was used as a frother by an amount of 0.5 g/L, and Na_2CO_3 (0.2 g/L) was used as a depressant. The product fulfilling the requirements of pharmaceutical usage. Then the product was treated with polygradient electromagnetic mud separator to decrease the percent of Fe_2O_3 from 1.38% to 1.00% which is suitable for electro ceramic technology. The flotation of talc-dolomite rock was carried out using sodium hexametaphosphate to depress dolomite. This gave a product is used for pharmaceutical purpose. Dressing of talc-magnesite-dolomite rocks produced talc suitable for electro ceramic technology.

Leaching process with diluted acid solutions has some advantages over the other techniques. It is cheap and the acid can be easily recovered from the beneficiated solid ores by filtration (Rizk, et al 2001).

Sarquis and Gonzalez (1998) have reported that the chemical treatments using acids may be applied for further increasing of the grade of concentrate. The basis of the proposed technique lies in the fact that talc is inert with most chemical reagents. The final concentrate of flotation process was leached with diluted hydrochloric acid having a concentration of 10%. The residues of leaching process were washed first with acidulated hot water and then with pure water. The obtained results showed that the whiteness increased from 65.5% to 70.2% at 60 °C., while the loss on ignition decreased from 18% to 6.3% at the same temperature and the assays of CaO, MgO and Fe_2O_3 also decreased.

Al-Wakeel (1996) and Roe (1983) have treated the final cleaned product with a diluted hydrochloric acid having a concentration of 10% and SnCl_2 (300 ppm) to produce talc free from carbonates. The iron content was nearly removed and the whiteness increased to 93%. Their last product was suitable for different purposes for paper, cosmetic, paint, roofing, ceramic and rubber filling industries.

Aim of the work

1. Evaluation of the petrographical properties and geochemical characteristics of the talc samples. This evaluation was carried out on four representative samples of different types of talc carbonates to determine the possibility of improving the talc quality.
2. The possibility to improve talc quality by using flotation and determination of the optimum values of operating variables of flotation process such as pH value, depressant dosage, collector dosage and pulp density.
3. The possibility of using leaching process to improve the quality of talc to increase its suitability for different industrial purposes.

2. Experimental

2.1 Materials

2.1.1 Talc ore sample

The head sample used in the present work is a mixing of four samples obtained from different sites in the Eastern Desert of Egypt (Shalatin area). Petrographically, the talc samples are classified into four different types. From the geochemical point of view, the samples are correlated together with high percentages of aluminum oxide and iron oxide. The details and characteristics of these samples were discussed in a previous published paper (Boghdady, et al. 2005). The petrographical types and chemical analysis of the samples, showing the major constituents of talc (MgO and SiO₂) and some associated minerals which constitute the gangue (Fe₂O₃, Al₂O₃ and CaO) are tabulated in Table 1. Mixing of the four samples was carried out to achieve a minimum percent of main wastes in talc (Fe₂O₃, Al₂O₃ and CaO), and a maximum percent of talc constituents (SiO₂ and MgO). Equal mixing of samples did not result any improvement of constituents in the head sample. The percentage of constituents was improved by mixing 5% of sample 1, 5% of sample 2, 45% of sample 3 and 45% of sample 4. The percentage of magnesium oxide and silicon dioxide increased compared with the equal mixing; the percentage of calcium oxide decreased from 2.2% to 0.8%; the percentage of aluminum oxide decreased from 7% to 5.5% and the percentage of iron oxide decreased from 8.6% to 8.2%. The final head sample was crushed to minus 35 mm in a semi-industrial jaw crusher, then to minus 4.75 mm in a laboratory jaw crusher. A wet attrition scrubbing was used owing to the friable nature of talc. The attrition scrubbing conditions were as follows: pulp density = 50%, motor speed = 1720 rpm and attrition time = 45 minutes. A particle size of minus 75 µm (the desired size for flotation process) was obtained (Boulos, 2004). The flowsheet of crushing and attritioning processes is shown in Fig 1. The final product was collected, filtered and dried. The chemical analysis of the studied head sample is given in Table 2. The particle size distribution of the flotation feed is shown in Table 3.

Sample No.	Petrographically	Constituent, %				
		MgO	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO
1	Tremolite-talc-chlorite-schist	29.0	50.8	9.67	6.95	2.05
2	Antigorite-serpentine	28.5	45.2	8.68	10.6	5.81
3	Talc-schist	30.4	58.2	7.04	3.02	0.18
4	talc-chlorite-schist	29.6	51.3	9.12	7.35	0.81

Table 1. The petrographical types and chemical analysis of different samples

Head Sample

Semi-industrial
jaw crusher (set = 35 mm)

Screen (35 mm)

Laboratory jaw crusher
(set = 4.75 mm)

Screen (4.75 mm)

Wet attritioning
scrubbing

+
Wet screen (0.075 mm)

Flotation

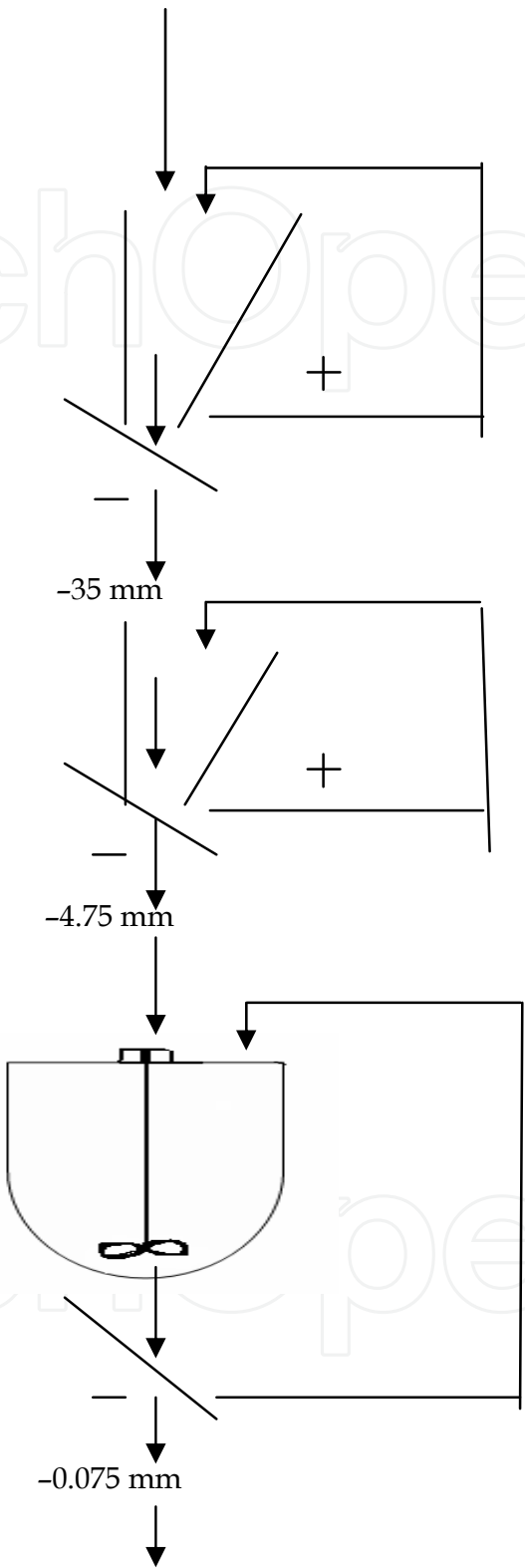


Fig. 1. Flowsheet of crushing and attritioning processes

Assay (A _f), %									
SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃	P ₂ O ₅	Na ₂ O	K ₂ O	MnO	SO ₃
54.10	29.90	0.80	5.50	8.20	0.52	0.12	0.15	0.16	0.43

Table 2. Chemical analysis of the studied head sample

Size fraction, μm	wt. ret., %	cum. wt. ret., %
-75+53	10.0	10.0
-5.3+45	42.0	52.0
-45+38	8.0	60.0
-38	40.0	100.0
Σ	100.0	

Table 3. The particle size distribution of the flotation feed

2.1.2 Reagents

The flotation tests were carried out using oleic acid (in an equal mixture with kerosene) as a pure collector (iodine value 85-95, acid value 196-204 and molecular weight 282.47). The dosage was varied from 0.6 to 1.4 kg/t (Boulos, 2004). Sodium hexametaphosphate (SHMP) were employed as a selective depressant of carbonates. It was changed from 0.4 to 1.2 kg/t (Boulos, 2004; Andreola et al. 2006a, 2006b). The frother agent used for all tests was pine oil (a dosage of 0.1 kg/t). Sodium hydroxide and hydrochloric acid (30%-34%) were used to adjust the pH of the medium. Tap water was used to maintain the flotation pulp level. All other conditions were kept constant.

2.2 Apparatus

Laboratory flotation tests were carried out in a 2800 cm³ Wemco Fagergren cell. The impeller speed was fixed at 1100 rpm. An aeration rate of 6 L/min was used. A water Perspex tank was used to maintain the pulp level at a constant value. Hand skimming was used to collect the froth overflow.

Leaching test was executed in a glass reactor of 1000 cm³ capacity situated on a heater. A thermometer was used for adjusting the required temperature. The pulp was stirred with a mechanical stirrer fitted with a stainless steal impeller.

The chemical analysis of the samples was done by XRF analysis carried out at the central laboratories sector of the Egyptian Mineral Resources Authorities, Giza, Egypt. Whiteness of talc was determined by the apparatus of Dr Lang Micro Color V2.0 (Kho and Sohn, 1989; Boulos, 2004; Al-Wakeel, 1996).

2.3 Procedure

All flotation tests were carried out at room temperature. The total conditioning time was 10 min. The talc sample was added slowly and conditioned with water for five min. Further water was then added to bring the liquid level to 10 mm below the overflow lip. The pH modifiers were added to adjust the required pH. The depressant dosage (sodium hexametaphosphate) was added at the end of the initial conditioning period and was

allowed to condition for 2 min. with the pulp. The collector dosage (oleic acid and kerosene mixture) was added at the end of the previous period and was allowed to condition for 2 min. with the pulp. The frother dosage was then added and a further 1 min. of conditioning was allowed prior to aeration. The air supply was gradually opened. The required pulp level was maintained constant.

In each experiment, after allowing 15 seconds for froth to form, a hand skimmer was used to collect the froth over until the froth is stopped. After the process being finished, the products (concentrate and tailings) were dried, weighed and chemically analyzed.

The final concentrate of flotation was leached with a diluted hydrochloric acid having a concentration of 10% using a solid liquid ratio of (1:2) and at a temperature of 60 °C for a period of 30 min. The residues of leaching process were washed with acidulated hot water and then with pure water. After the process being finished, the concentrate was dried, weighed, and chemically analyzed.

3. Results and discussions

3.1 Calculations of experimental mass and component recoveries of flotation products

Using the mass percent and assays of different constituents in the feed, concentrate, and tailings, the experimental values of mass and component recoveries of the flotation products can be calculated as follows:

$$\text{Mass recovery of concentrate} = R_m(c) = 100 \cdot \frac{C}{F} \quad (1)$$

$$\text{Mass recovery of tailings} = R_m(t) = 100 \cdot \frac{T}{F} \quad (2)$$

$$\text{Component recovery in concentrate} = R_c(c) = 100 \cdot \frac{C \cdot c}{F \cdot f} \quad (3)$$

$$\text{Component recovery in tailings} = R_c(t) = 100 \cdot \frac{T \cdot t}{F \cdot f} \quad (4)$$

3.2 Effect of pH

Table 4a includes the chemical analysis of constituents in flotation products of experiments carried out at different pH values. These tests were carried out at collector dosage = 1.0 kg/t, depressant dosage = 0.8 kg/t, and pulp density = 200 g/L. This table showed that the percentages of SiO₂ and MgO (the major constituents of talc) decreased in the concentrate product with increasing pH value from 4 to 12. Conversely, the percentages of CaO, Al₂O₃ and Fe₂O₃ (the main wastes in talc) increased.

These results are illustrated also in Figures 2a through 2e. From Figures 2a and 2b, it can be seen that, the SiO₂ assay decreased from pH 4 to pH 12 (57.02% to 54.30%), as well as, MgO assay decreased from pH 4 to pH 12 (34.0% to 31.8%). This may be interpreted due to the tendency of magnesium to precipitate or hydrolysis with increasing pH, which leads to

decrease its content, especially at the alkaline values (Rath et al. 1995; Bremmell and Addai-Mensah, 2005).

Figures 2c through 2e showed that with increasing the value of pH from 4 to 12, CaO increased (from 0.35% to 0.72%), Al₂O₃ increased (from 2.17% to 4.30%), and Fe₂O₃ increased (from 6.22% to 8.10%). This may be attributed to that, the carbonates content increase with increasing pH. These results are in agreement with the work of Al-Wakeel, 1996.

Exp. No.	pH	Concentrate					Tailings				
		Assay (A _c), %					Assay (A _t), %				
		SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃
1	4	57.02	34.00	0.35	2.17	6.22	50.81	25.28	1.31	9.26	10.43
2	7	56.15	33.39	0.42	2.62	6.53	50.41	23.61	1.48	10.69	11.21
3	9	55.9	33.03	0.44	2.78	6.85	50.45	23.55	1.53	11.02	10.94
4	11	55.71	32.92	0.50	3.03	7.14	45.32	13.44	2.44	18.97	13.98
5	12	54.3	31.81	0.72	4.3	8.10	53.40	23.24	1.08	9.68	8.55

Table 4a. The chemical analysis of constituents in flotation products of experiments carried out at different pH values

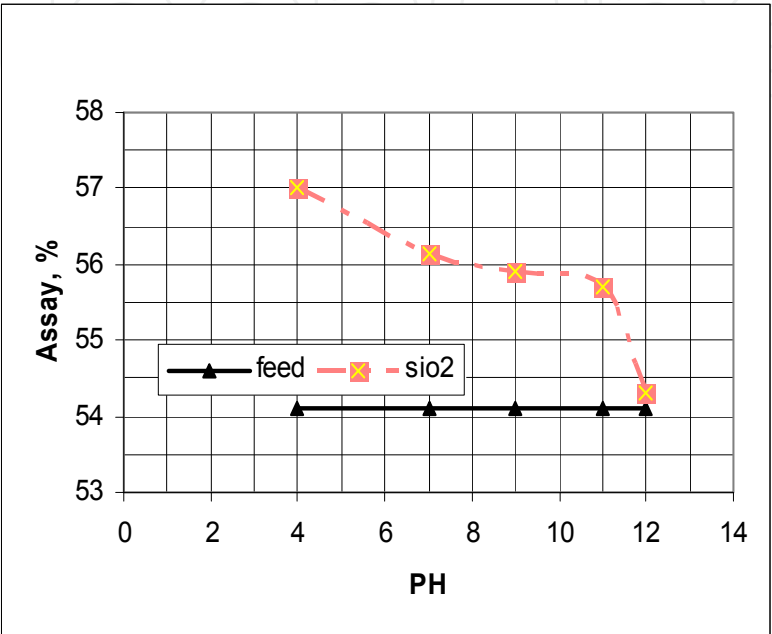
The percentage of iron oxide is still high due to the association of iron oxide with all mineral components of the sample, which sometimes appearing as yellowish brown threads along its schistose structure and in other cases, associating with the banded talc- chlorite structure (Boulos, 2004).

The effect of pH values on the mass recovery of concentrate is shown in Table 4b and Fig. 2f. From this figure, it can be revealed that, the mass recovery increased from 53% to 84.5%, as the value of pH increased from pH 4 to pH 11. More increase of the pH value, above 11, decreased the mass recovery.

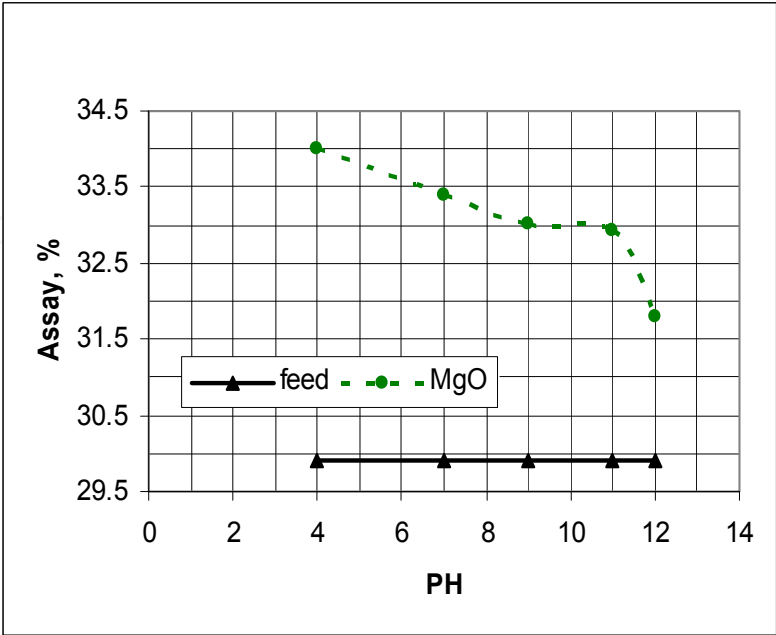
pH	Concentrate						Tailings					
	Component recovery R _c (c), %					R _m (c), %	Component recovery R _c (t), %					R _m (t), %
	SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃		SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃	
4	55.9	60.3	23.2	20.9	40.2	53.0	44.1	39.7	76.8	79.1	59.8	47.0
7	66.7	71.8	33.8	30.6	51.2	64.3	33.3	28.2	66.2	69.4	48.8	35.7
9	69.2	74.0	36.9	33.9	56.0	67.0	30.8	26.0	63.1	66.1	44.0	33.0
11	87.0	93.0	52.8	46.6	73.6	84.5	13.0	7.0	47.2	53.4	26.4	15.5
12	78.0	82.7	69.9	60.7	76.8	77.7	22.0	17.3	30.1	39.1	23.2	22.3

Table 4b. The mass recoveries of flotation products and the component recoveries of constituents of experiments carried out at different pH values

The effect of pH values on the component recoveries of constituents in concentrate is illustrated also in Table 4b and Fig. 2f. From this figure, it can be shown that, the component recovery of SiO₂ increased from 56% to 87%, as well as, the component recovery of MgO increased from 60% to 93% as the pH value increased from pH 4 to pH 11. Any increase of pH value (above pH 11) decreased the component recoveries of these two constituents. On the other hand, the component recoveries of CaO, Al₂O₃ and Fe₂O₃ increased with increasing the pH value.

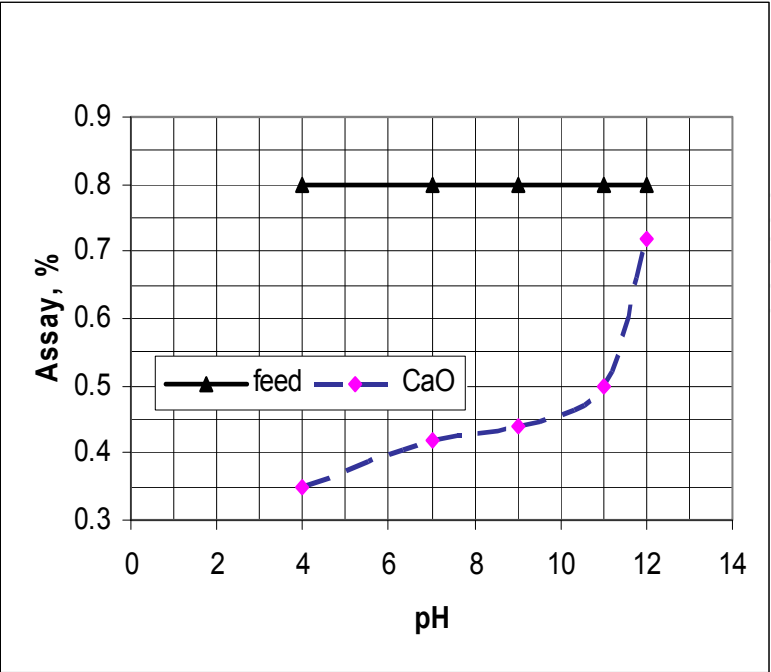


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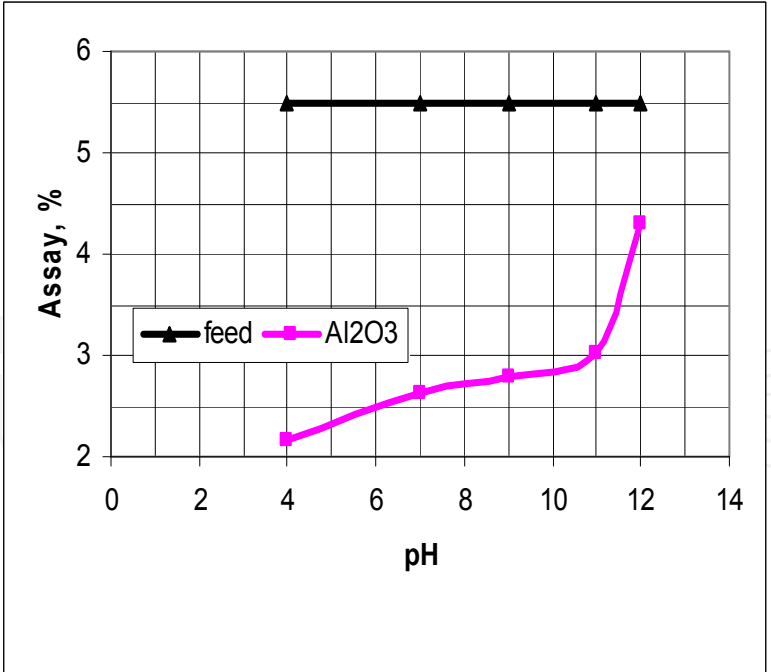


b

Fig. 1. a. SiO₂ assay with pH b. MgO assay with pH

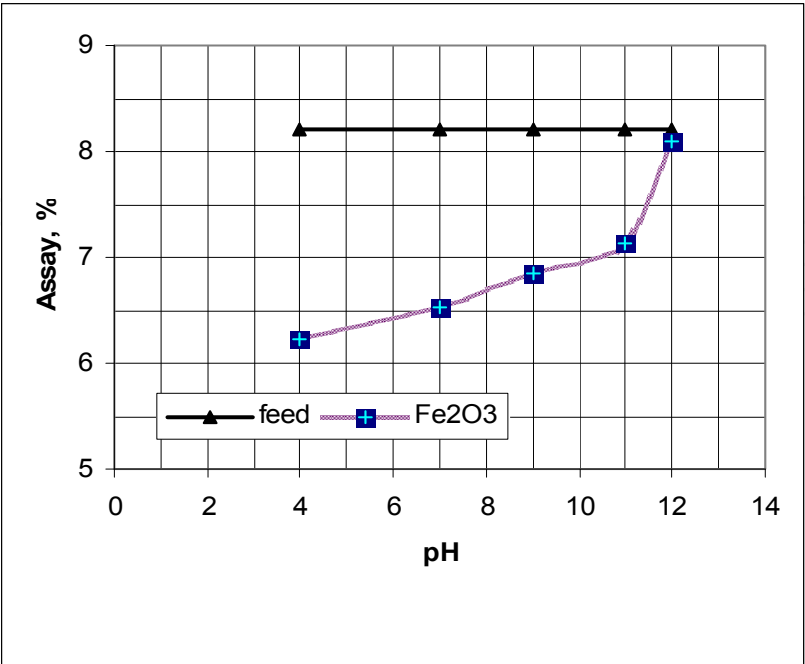


c

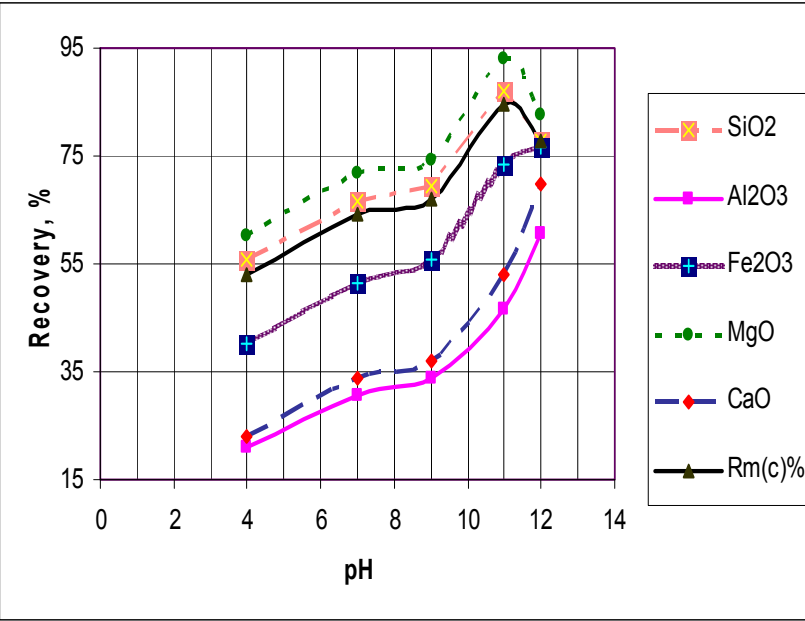


d

Fig. 1. c. CaO assay with pH , d. Al₂O₃ assay with pH



e



f

Fig. 1. e. Fe₂O₃ assay with pH, f. Mass and component recoveries with pH
Fig. 1. Effect of pH values on the mass recovery, as well as, on the assays and component recoveries of different constituents in concentrate

The above results can be interpreted such that, by increasing the pH, the effective coverage by the collector is enhanced and the resulting talc surface therefore becomes more hydrophobic leading to greater talc recovery. The native talc surface does not become more hydrophobic (Fuersrenau and Huang, 2003) but in fact above pH 9 becomes more hydrophilic and the recovery drops as pH goes up. The recovery of the oleic acid treated talc was shown to increase as the pH increased from 2 to 11 however the rate of increase from pH 7 to 11 was much greater than the rate of increase from 2 to 7 (see Fig 2f) (Al-Wakeeel, 1996). The anisotropy nature of talc revealed that their crystals consist of faces, which are being hydrophobic and not charged, and edges being hydrophilic and charged. The bubbles will attach to the hydrophobic faces where they are not affected by the edge charge. At a higher pH value, over 11, the overall charge on the particle may give a rise to a high repulsion of air bubbles. This may be due to that some dissolution of particles takes place at high pH and adsorption of hydrolyzed species may contribute to increase of hydrophilicity (Fuerstenau and Huang, 2003). Although the talc has a point of zero charge (PZC) at pH 1.8 (Al-Wakeeel, 1996), the using of oleic acid, as an anionic collector, will change zeta potential of talc from a negative to a positive value at pH 11 (Xu et al. 2004).

From Table 4a, it can be seen that the assays of SiO_2 and MgO were at their lowest values in tailings, as well as, the assays of CaO , Al_2O_3 and Fe_2O_3 were at their highest ones at the same value of pH 11. This assures that the optimum conditions of these experiments can be obtained at pH 11.

3.3 Effect of depressant dosage

Table 5a contains the chemical analysis of constituents in flotation products of experiments executed at different depression dosages of sodium hexametaphosphate (SHMP). These experiments were executed at pH 11, collector dosage = 1.0 kg/t, and pulp density = 200 g/L. The table showed that the percentages of SiO_2 and MgO (the major constituents of talc) decreased in the concentrate product with increasing the depression dosage from 0.4 to 1.2 kg/t. Conversely, the percentages of CaO , Al_2O_3 and Fe_2O_3 (the main wastes in talc) increased. These results are also revealed in Figures 3a through 3e. From Figures 3a and 3b, it can be shown that, SiO_2 decreased (from 57.23% to 54.46%) with increasing the depression dosage from 0.4 to 1.2 kg/t, as well as MgO decreased (from 34.13% to 31.29%) with the same dosage. Figure 3c shows that CaO decreased (from 0.72% to 0.42%) if the depression dosage was increased from 0.4 Kg/t to 1.0 Kg/t. More increasing of the dosage will lead to increase the final percent of CaO . This trend can be explained due to the ability of sodium hexametaphosphate (SHMP) to sequester the calcium cations (Ca^{2+}) and forming with the calcium a strong hydrophilic complex compound (Andreola et al. 2006a, 2006b). Figures 3d and 3e showed that with increasing the depression dosage from 0.4 to 1.2 kg/t, Al_2O_3 increased (from 1.98% to 4.21%), as well as, Fe_2O_3 increased (from 5.88% to 8.07%). This could possibly be due to the interaction of SHMP anions with the exposed Al atoms to give complexed anions but, as Andreola et. al. (2006a) has shown, SHMP is too weak to sequester the aluminum sites.

The effect of depression dosages on the mass recovery of concentrate is shown in Table 5b and Fig. 3f. From this figure, it can be seen that, the mass recovery increased from 71.2% to 88.0%, as the value of depression dosage increased from 0.4 to 1.0 kg/t. More increase of the depression dosage, above 1.0 kg/t, decreased the mass recovery. The effect of depression dosages on the component recoveries of constituents in concentrate is illustrated also in Table 5b and Fig. 3f. From this figure, it can be revealed that, the component recovery of

SiO₂ increased (from 75.3% to 89.4%), as well as, the component recovery of MgO increased (from 81.3% to 93.9%) as the depression dosage increased from 0.4 to 1.0 kg/t. Any increase of depression dosage above this value decreased the component recoveries of these two constituents. From Fig. 3f, it can be also shown that the component recovery of CaO decreased (from 64.0% to 46.2%) as the depression dosage increased from 0.4 to 1.0 kg/t and then increased by increasing of depression dosage above 1.0 kg/t. On the other hand, the component recoveries of Al₂O₃ and Fe₂O₃ increased with increasing the depression dosage value.

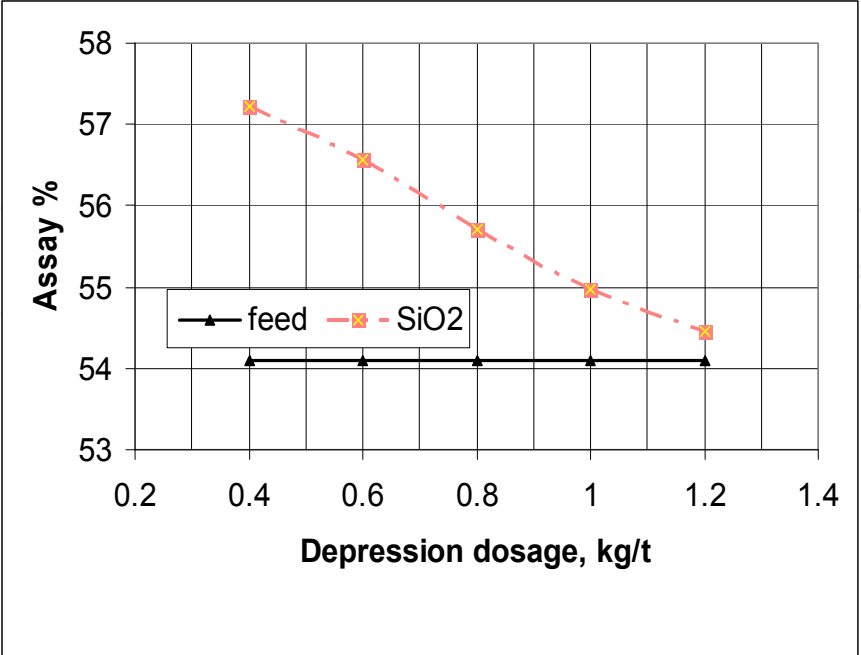
Exp. No.	Depression dosage, kg/t	Concentrate					Tailings				
		Assay (A _c), %					Assay (A _t), %				
		SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃
1	0.4	57.23	34.13	0.72	1.98	5.88	46.36	19.44	1.00	14.20	13.94
2	0.6	56.57	33.67	0.63	2.14	6.35	45.59	16.91	1.39	17.07	14.57
3	0.8	55.71	32.92	0.50	3.03	7.14	45.32	13.44	2.44	18.97	13.98
4	1.0	54.97	31.89	0.42	3.08	7.21	41.36	15.31	3.59	23.25	15.46
5	1.2	54.46	31.29	0.68	4.21	8.07	52.96	25.5	1.18	9.59	8.61

Table 5a. The chemical analysis of constituents in flotation products of experiments carried out at different depression dosages

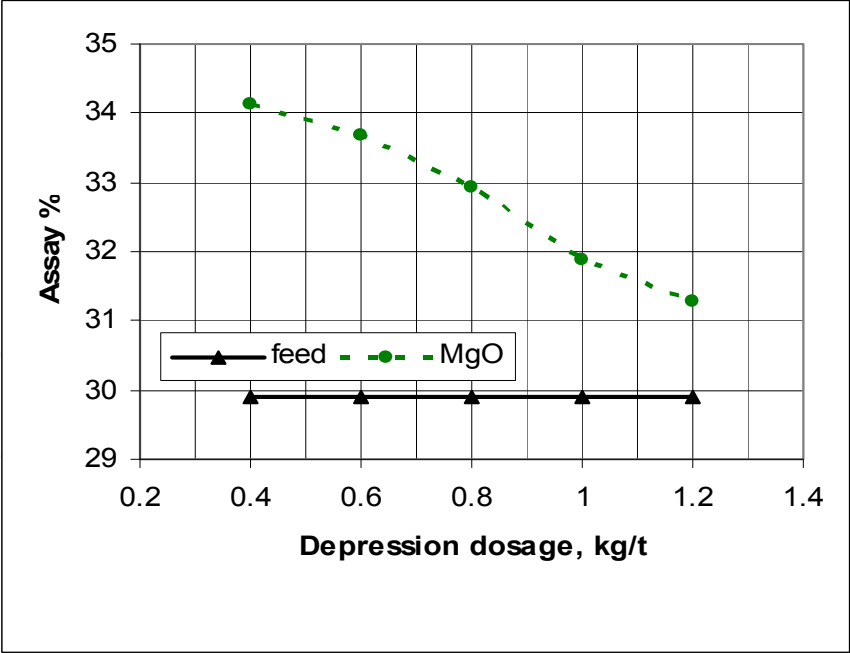
Depression dosage, kg/t	Concentrate						Tailings					
	Component recovery R _c (c), %					R _m (c), %	Component recovery R _c (t), %					R _m (t), %
	SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃		SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃	
0.4	75.3	81.3	64.0	25.6	51.1	71.2	24.7	18.7	36.0	74.4	48.9	28.8
0.6	81.0	87.3	61.0	30.2	60.0	77.5	19.0	12.7	39.0	69.8	40.0	22.5
0.8	87.0	93.0	52.8	46.6	73.6	84.5	13.0	7.0	47.2	53.4	26.4	15.5
1.0	89.4	93.9	46.2	49.3	77.4	88.0	10.6	6.1	53.8	50.7	22.6	12.0
1.2	76.5	79.5	64.6	58.2	74.8	76.0	23.5	20.5	35.4	41.8	25.2	24.0

Table 5b. The mass recoveries of flotation products and the component recoveries of constituents of experiments executed at different depression dosages

From Table 5a, it can be seen that the assays of SiO₂ and MgO were at their lowest values in tailings, as well as, the assays of CaO, Al₂O₃ and Fe₂O₃ were at their highest ones at the same value of depression dosage (1.0 kg/t). This assures that the optimum conditions of these experiments may be obtained at a depression dosage of 1.0 kg/t.

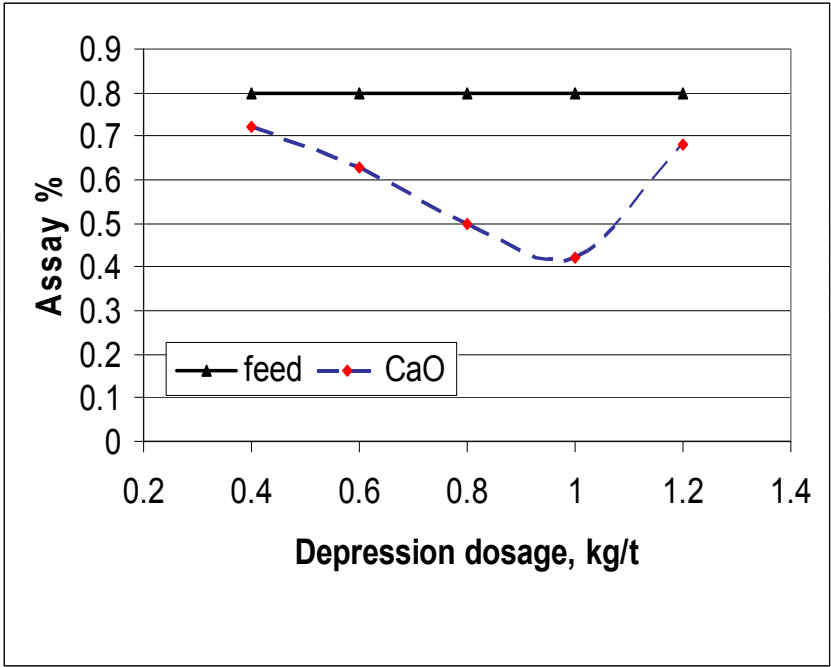


a

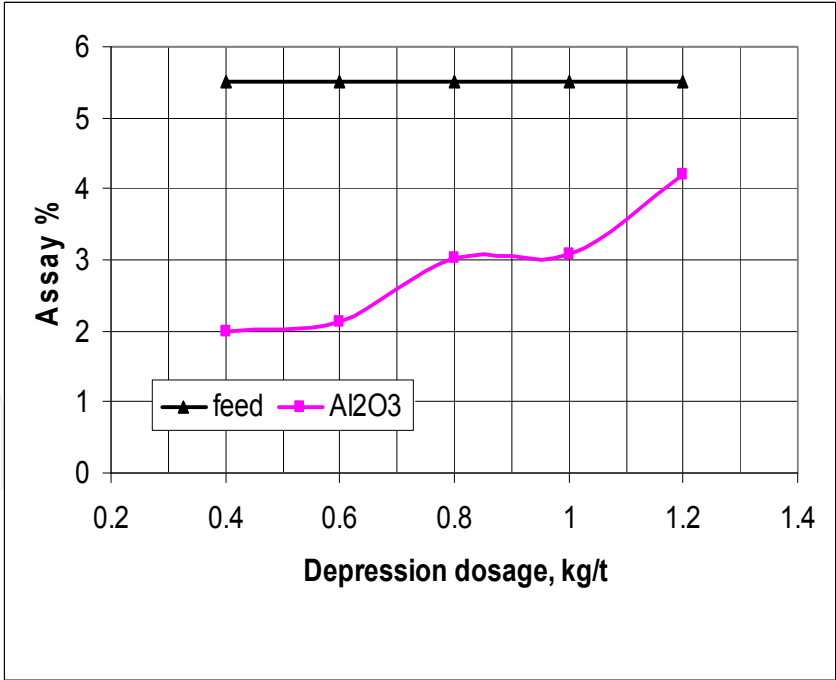


b

Fig. 2. a. SiO₂ assay with depression dosage , b: MgO assay with depression dosage

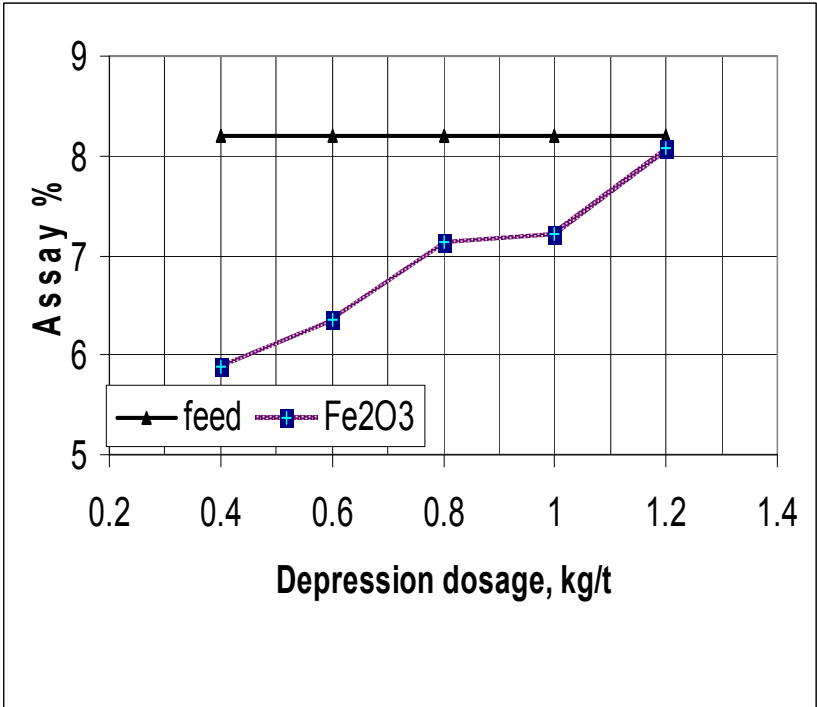


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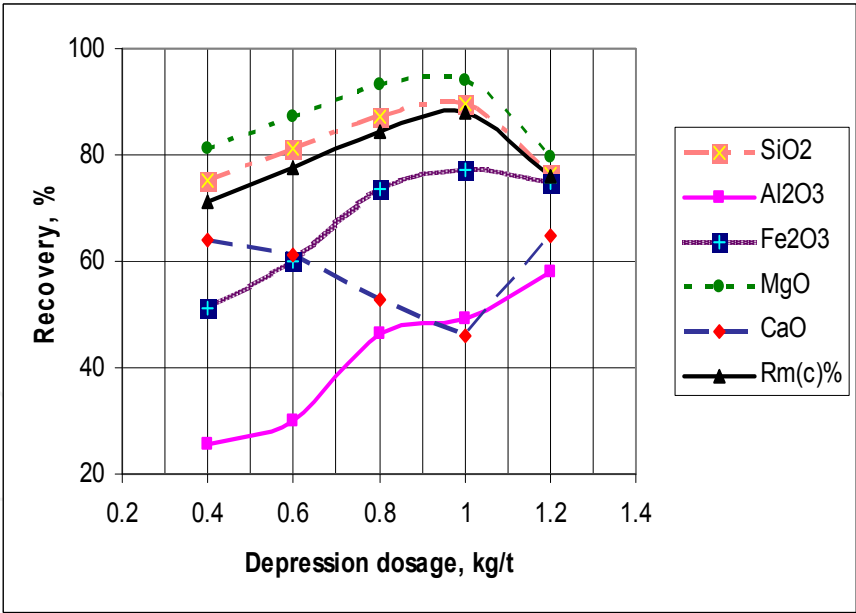


d

Fig. 2. C. CaO assay with depression dosage , d. Al₂O₃ assay with depression dosage



e



f

Fig. 2. E. Fe_2O_3 assay with depression dosage, f. Mass and component recoveries with depression dosage

Fig. 2. Effect of depression dosage on the mass recovery, as well as, on the assays and component recoveries of different constituents in concentrate

3.4 Effect of collector dosage

The experiments of collector dosage parameter were carried out at pH 11, depressant dosage of 1.0 kg/t, and pulp density of 200 g/L. Table 6a included the chemical analysis of constituents in flotation products of experiments carried out at different collector dosages of oleic acid (in an equal mixture with kerosene). The table showed that the percentages of SiO₂ and MgO (the major constituents of talc) decreased in the concentrate product with increasing the collector dosage from 0.6 to 1.4 kg/t. Conversely, the percentages of CaO, Al₂O₃ and Fe₂O₃ (the main wastes in talc) increased. These results are illustrated also in Figures 4a through 4e. From Figures 4a and 4b, it can be shown that, SiO₂ decreased (from 57.46% to 54.15%) at increasing of the collector dosage from 0.6 to 1.4 kg/t, as well as MgO decreased (from 34.22% to 30.69%) at the same collector dosage. This may be attributed to the power of oleic acid (anionic collector) to produce a water-repulsion and monomolecular layer on particle surfaces (starvation level), thereby imparting hydrophobicity to the particles (Wills and Napier-Munn, 2006).

Exp. No.	Collector dosage, kg/t	Concentrate					Tailings				
		Assay (A _c), %					Assay (A _t), %				
		SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃
1	0.6	57.46	34.22	0.30	2.09	5.90	45.42	18.74	2.09	14.31	14.14
2	0.8	55.78	32.83	0.36	2.75	6.78	47.16	17.80	2.62	16.85	14.06
3	1.0	54.97	31.89	0.42	3.08	7.21	41.36	15.31	3.59	23.25	15.46
4	1.2	54.94	31.76	0.42	3.11	7.24	41.35	7.29	5.42	24.20	19.87
5	1.4	54.15	30.69	0.54	3.95	7.97	49.13	24.98	2.14	13.52	8.05

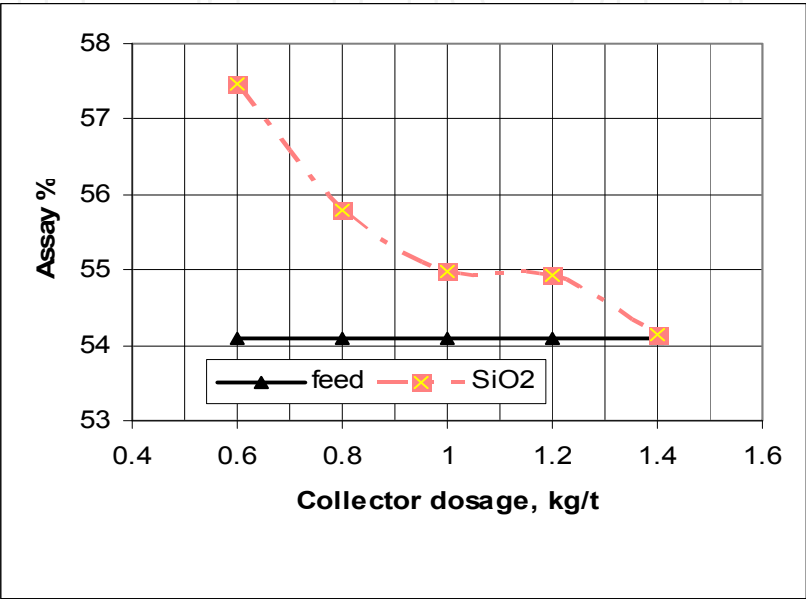
Table 6a. The chemical analysis of constituents in flotation products of experiments carried out at different collector dosages

Collector dosage, kg/t	Concentrate						Tailings					
	Component recovery R _c (c), %					R _m (c), %	Component recovery R _c (t), %					R _m (t), %
	SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃		SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃	
0.6	76.6	82.5	27.0	27.4	51.9	72.1	23.4	17.5	73.0	72.6	48.1	27.9
0.8	83.0	88.4	36.2	40.3	66.6	80.5	17.0	11.6	63.8	59.7	33.4	19.5
1.0	89.4	93.9	46.2	49.3	77.4	88.0	10.6	6.1	53.8	50.7	22.6	12.0
1.2	93.8	98.2	48.5	52.3	81.6	92.4	6.2	1.8	51.5	47.7	18.4	7.6
1.4	83.9	86.0	56.6	60.2	81.5	83.8	16.1	14.0	43.4	39.8	18.5	16.2

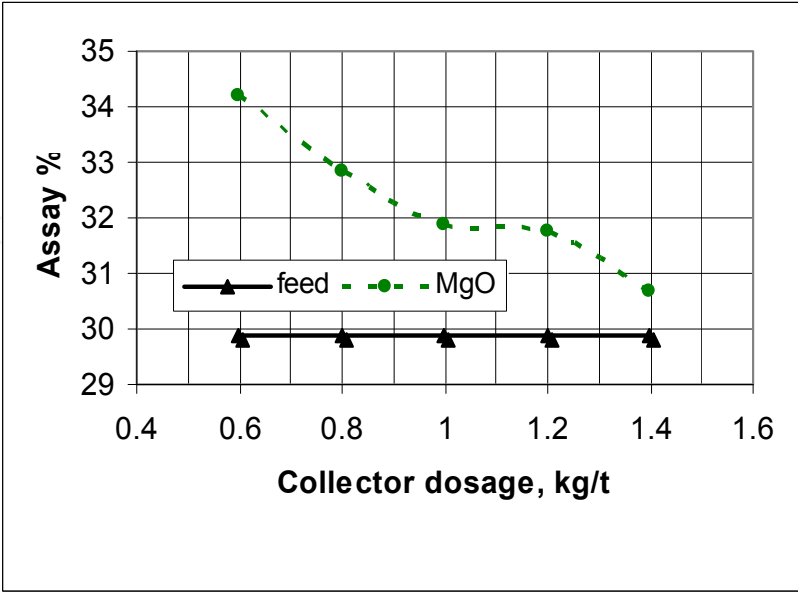
Table 6b. The mass recoveries of flotation products and the component recoveries of constituents of experiments carried out at different collector dosages

Figures 4c through 4e showed that as the collector dosage increased from 0.6 to 1.4 kg/t, CaO increased (from 0.30% to 0.54%), Al₂O₃ increased (from 2.09% to 3.95%), and Fe₂O₃ increased (from 5.90% to 7.97%).

The effect of collector dosages on the mass recovery of concentrate is shown in Table 6b and Fig. 4f. From this figure, it can be revealed that, the mass recovery increased from 72.1% to 92.4%, as the collector dosage increased from 0.6 to 1.2 kg/t. More increase of the collector dosage above 1.2 kg/t decreased the mass recovery.

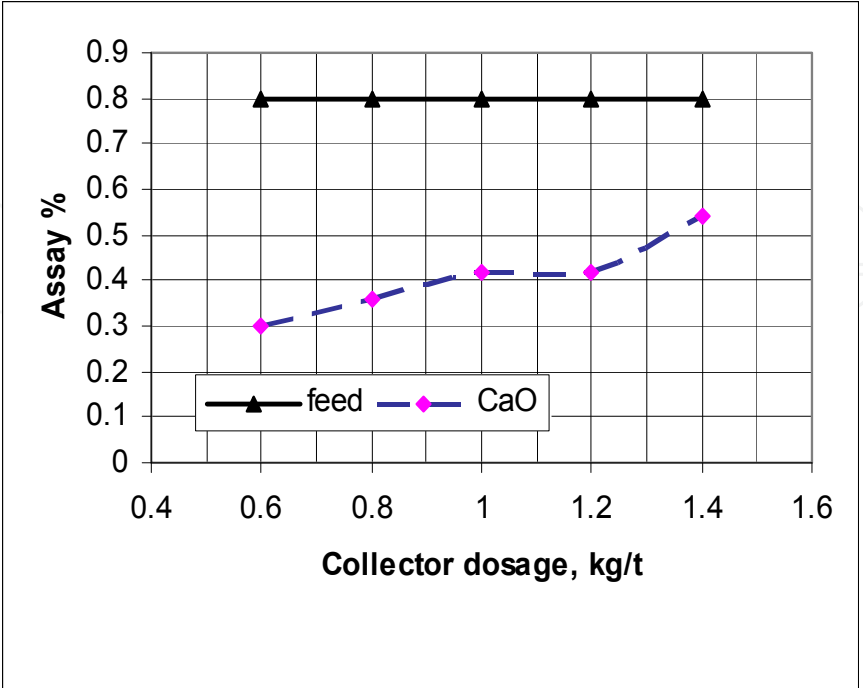


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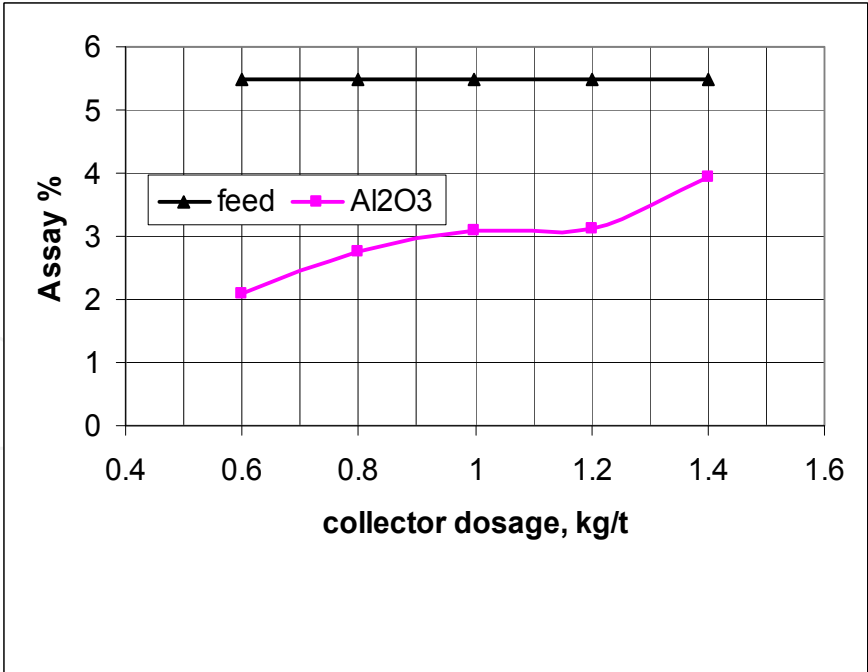


b

Fig. 3. a. SiO₂ assay with collector dosage, b. MgO assay with collector dosage

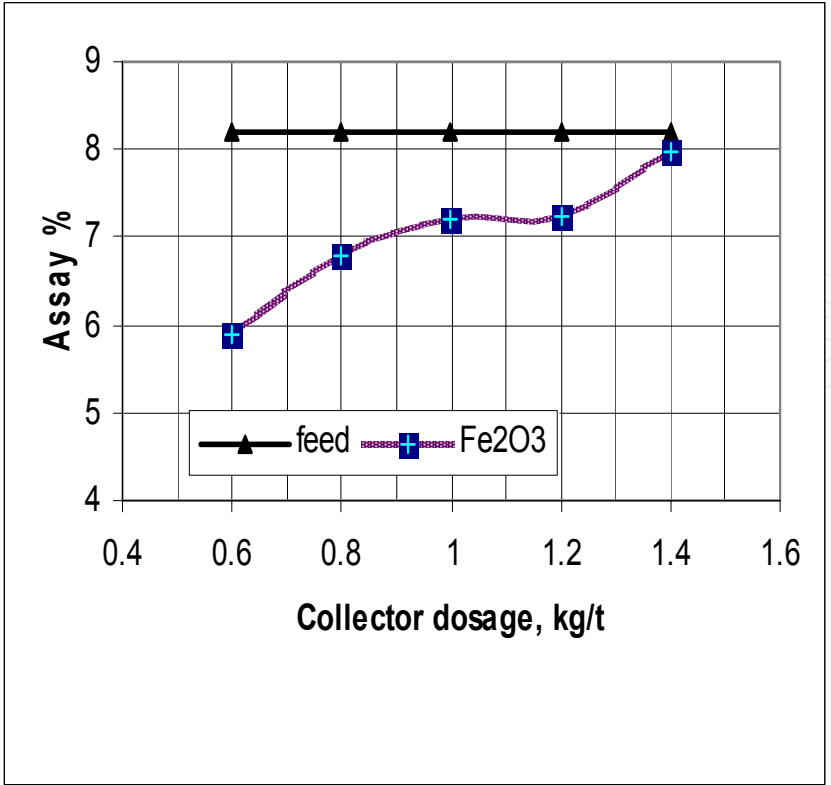


c

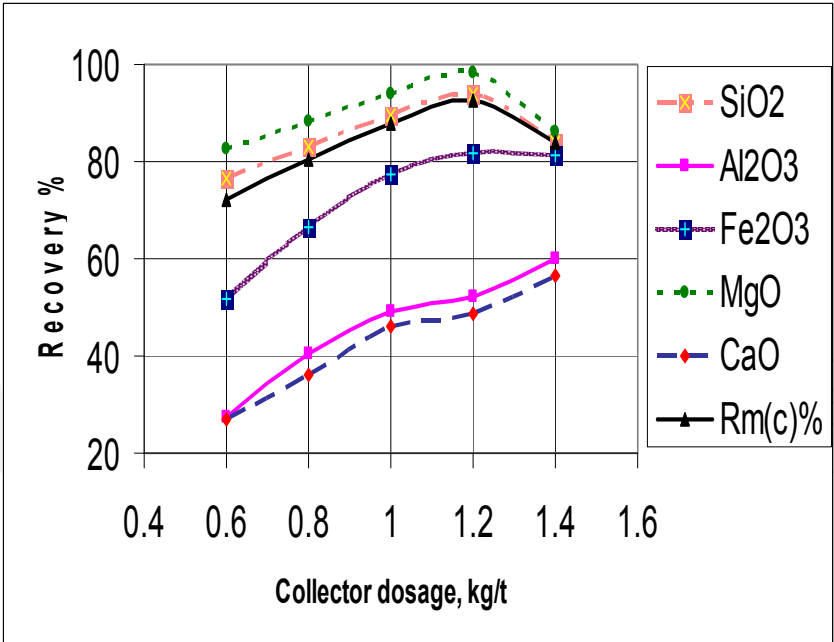


d

Fig. 3. C. CaO assay with collector dosage , d. Al₂O₃ assay with collector dosage



e



f

Fig. 3. e. Fe_2O_3 assay with collector dosage, f. Mass and component recoveries with collector dosage

Fig. 3. Effect of collector dosage on the mass recovery, as well as, on the assays and component recoveries of different constituents in concentrate

The increase of the flotation recovery with the collector dosage may be explained due to the more rapid reaction at higher concentration or due to more rapid approach of the exchanger adsorption equilibrium at higher concentration. This trend can be explained also due to the displacement of the exchange-adsorption equilibrium more and more toward complete collector adsorption as concentration of the collector is increased (Ahmed, 1995). The effect of collector dosages on the component recoveries of constituents in concentrate are illustrated also in Table 6b and Fig. 4f. From this figure, it can be shown that, the component recovery of SiO_2 increased (from 76.6% to 93.8%), as well as, the component recovery of MgO increased (from 82.5% to 98.2%) as the collector dosage increased from 0.6 to 1.2 kg/t. This may be interpreted due to that, the faces of the talc are mildly hydrophobic and thus contribute largely to the floatability of the talc. At low collector concentration, only the faces are covered making them more hydrophobic leading to an increase in recovery (Ahmed, 1995). At higher dosages, the hydrophilic edges start to be covered and recovery is further enhanced (Fuerstenau and Huang, 2003). At dosages higher than 1.2 kg/t recovery begins to decrease possibly due to a build up of multilayers of collector on the surface. At these high dosages collector starts to build up on the other minerals leading to a reduction in selectivity and a lowering of the grade (Wills and Napier-Munn, 2006).

On the other hand, the component recoveries of CaO , Al_2O_3 and Fe_2O_3 increased with increasing the collector dosages.

From Table 6a, it can be seen that the assays of SiO_2 and MgO were at their lowest values in tailings, as well as, the assays of CaO , Al_2O_3 and Fe_2O_3 were at their highest ones at the same value of collector dosage (1.2 kg/t). This assures that the optimum conditions of these experiments are obtained at a collector dosage of 1.2 kg/t.

3.5 Effect of pulp density

Table 7a contains the chemical analysis of constituents in flotation products of experiments executed at different pulp densities. These experiments were carried out at pH 11, 1.0 kg/t depressant dosage and a collector dosage of 1.2 kg/t. The table showed that the percentages of SiO_2 and MgO (the major constituents of talc) decreased in the concentrate product with increasing the pulp density from 100 to 300 g/L. Conversely, the percentages of CaO , Al_2O_3 and Fe_2O_3 (the main wastes in talc) increased. These results are illustrated also in Figures 5a through 5e.

Figures 5c through 5e revealed that CaO increased (from 0.29% to 0.68%), Al_2O_3 increased (from 2.02% to 4.86%), and Fe_2O_3 increased (from 5.59% to 8.04%) as the pulp density increased from 100 to 300 g/L.

The effect of pulp density on the mass recovery of concentrate is shown in Table 7b and Fig. 5f. From this figure, it can be shown that, the mass recovery increased from 70.0% to 92.4%, as the value of pulp density increased from 100 to 200 g/L. More increase of the pulp density, above 200 g/L, decreased the mass recovery.

The effect of pulp density on the component recoveries of constituents in concentrate is illustrated also in Table 7b and Fig. 5f. From this figure, it can be revealed that the component recovery of SiO_2 increased from 74.5% to 93.8%, as well as, the component recovery of MgO increased from 80.3% to 98.2% as the pulp density increased from 100 to 200 g/L. Any increase of pulp density above 200 g/L decreased the component recoveries of these constituents. Feng and Aldrich, (2004) stated that an 8% solids concentration was optimal with respect to the lowest recovery of talc. Higher pulp concentrations had a detrimental effect on flotation. Wills, (2006) has reported that the denser the pulp, the less

cell volume is required in the commercial plant and fewer reagents are required, since the effectiveness of most reagents is a function of their concentration in solution. The optimum pulp density is of great important, as in general the more dilute the pulp, the cleaner the separation.

Exp. No.	Pulp density, g/L	Concentrate					Tailings				
		Assay (A _c), %					Assay (A _t), %				
		SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃
1	100	57.60	34.30	0.29	2.02	5.59	45.93	19.63	1.99	13.62	14.29
2	150	56.24	33.07	0.34	2.63	6.49	43.43	14.09	3.09	19.82	16.73
3	200	54.94	31.76	0.42	3.11	7.24	41.35	7.29	5.42	24.20	19.87
4	250	54.75	31.65	0.52	3.69	7.83	50.56	20.36	2.33	15.37	10.22
5	300	54.23	30.88	0.68	4.86	8.04	53.62	26.26	1.25	7.88	8.79

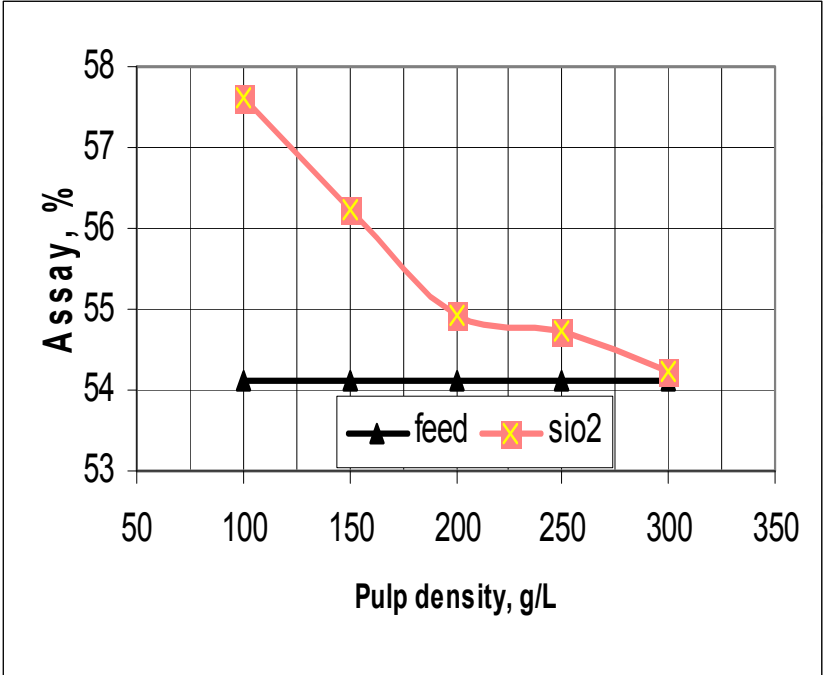
Table 7a. The chemical analysis of flotation products of different experiments carried out at different pulp densitiesFrom Figures 5a and 5b, it can be revealed that, as the pulp density increased from 100 to 300 g/L, SiO₂ decreased (from 57.60% to 54.23%), as well as, MgO decreased (from 34.30% to 30.88%).

Pulp density, g/L	Concentrate						Tailings					
	Component recovery R _c (c), %					R _m (c), %	Component recovery R _c (t), %					R _m (t), %
	SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃		SiO ₂	MgO	CaO	Al ₂ O ₃	Fe ₂ O ₃	
100	74.5	80.3	25.4	25.7	47.7	70.0	25.5	19.7	74.6	74.3	52.3	30.0
150	86.6	92.1	35.4	39.8	65.9	83.3	13.4	7.8	64.6	60.2	34.1	16.7
200	93.8	98.2	48.5	52.3	81.6	92.4	6.2	1.8	51.5	47.7	18.4	7.6
250	85.5	89.5	54.9	56.7	80.7	84.5	14.5	10.5	45.1	43.3	19.3	15.5
300	78.0	81.4	67.0	69.6	77.3	78.8	22.0	18.6	33.0	30.4	22.7	21.2

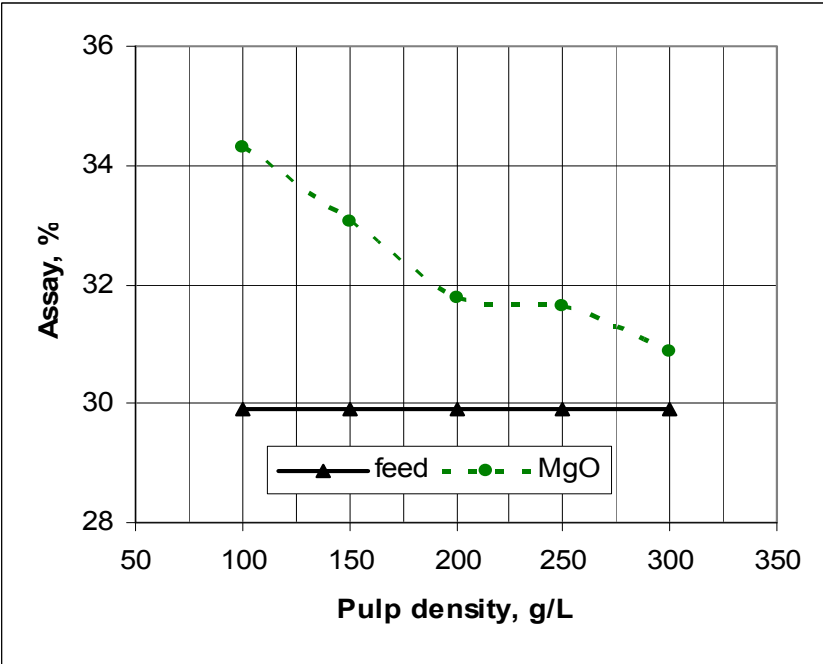
Table 7b. The mass recoveries of flotation products and the component recoveries of constituents of experiments executed at different pulp densities

From Figure 5f, it can be seen that the component recoveries of CaO, Al₂O₃ and Fe₂O₃ increased with increasing pulp densities. From Table 7a, it can be shown that the assays of SiO₂ and MgO were at their lowest values in tailings, as well as, the assays of CaO, Al₂O₃ and Fe₂O₃ were at their highest ones at the same value of pulp density (200 g/L). The whiteness improved from 75.4% to 83.7% and the

loss on ignition decreased from 6.64% to 5.21% in the final product. This assures that the optimum condition of these experiments is obtained at a pulp density of 200 g/L.

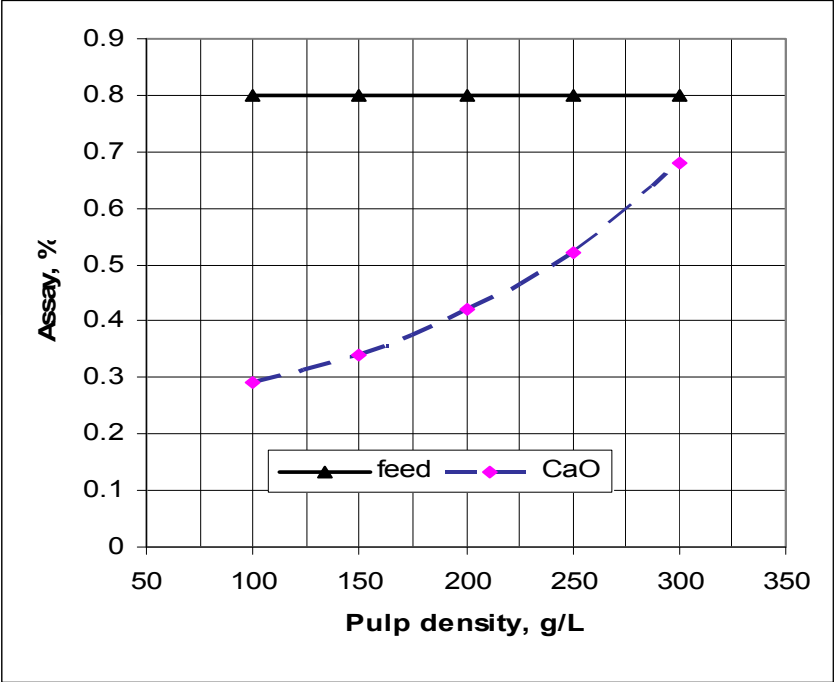


a

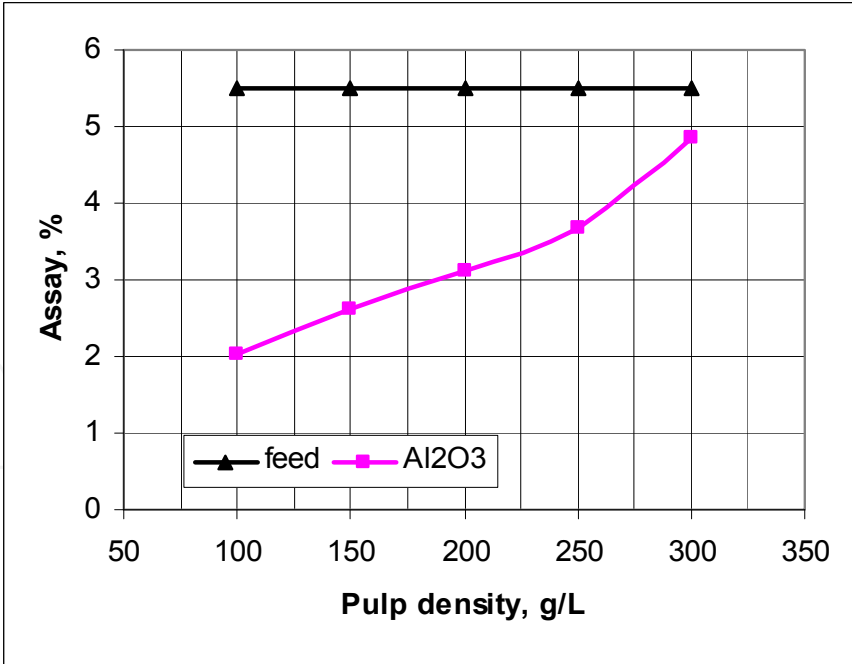


b

Fig. 4. a. SiO₂ assay with pulp density , b. MgO assay with pulp density

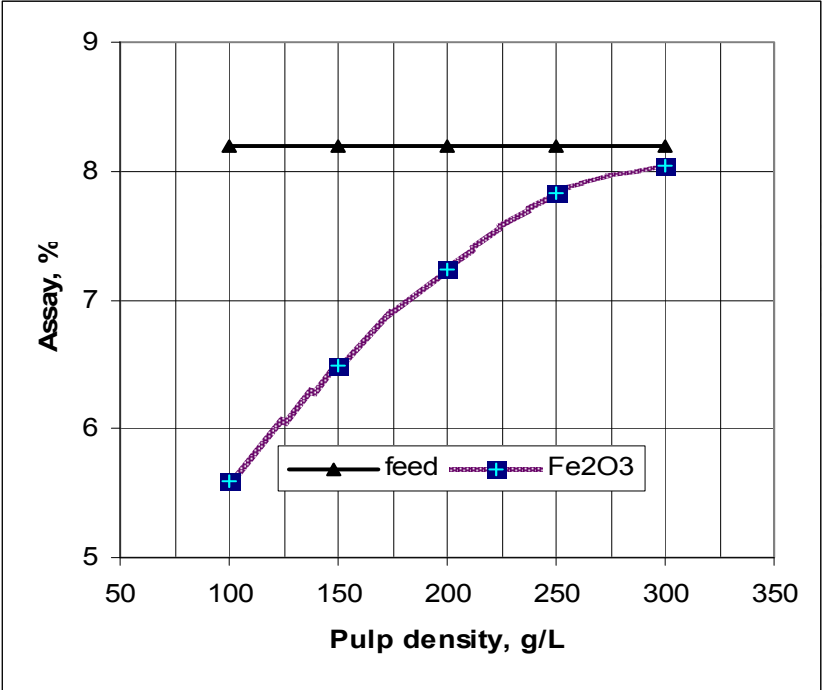


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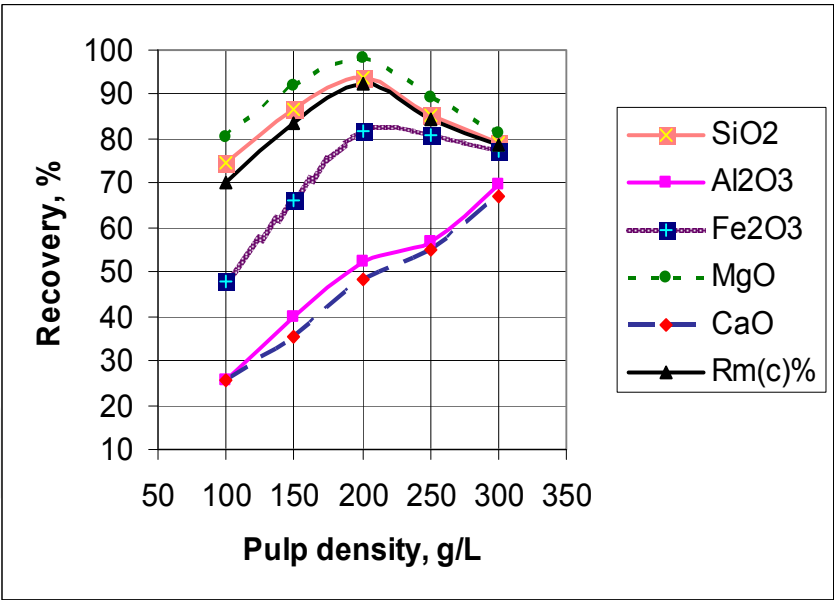


d

Fig. 4. c. CaO assay with pulp density , d. Al₂O₃ assay with pulp density



e



f

Fig. 4. e. Fe₂O₃ assay with pulp density, f. Mass and component recoveries with pulp density
Fig. 4. Effect of pulp density on the mass recovery, as well as, on the assays and component recoveries of different constituents in concentrate

From Table 7 and Fig. 5, it can be revealed that there are another operating conditions, which give better result of the characteristics of talc in concentrate but with lower mass recovery. This conclusion was obtained at a pulp density of 100 g/L. At this condition, the assays of SiO₂ (57.60%) and MgO (34.30%) were at their highest values in concentrate, as well as, the assays of CaO (0.29%), Al₂O₃ (2.02%) and Fe₂O₃ (5.59%) were at their lowest ones. The mass recovery was the lowest one (70%), as well as, the component recovery of talc constituents were also the lowest ones (74.5% and 80.3% respectively).

3.6 Leaching of final concentrate of flotation

More improvement of talc quality was obtained by leaching of final concentrate of flotation with a dilute hydrochloric acid having a concentration of 10%, solid-liquid ratio (1:2), at a temperature of 60° C for a period of 30 minutes using a mechanical stirrer. The residues of leaching process were washed with acidulated hot water and then with pure water. After the process being finished, the concentrate was dried, weighed and chemically analyzed. The final results of chemical analysis of talc constituents, mass recovery, whiteness, and loss on ignition in feed, final concentrate of flotation, and leaching product are shown in Table 8. The mass recovery of final product was about 85% of initial feed. In this final product, Fe₂O₃ decreased to 3.12%, CaO decreased to 0.38%, and Al₂O₃ decreased to 3.01%. The assay of SiO₂ increased to 58.96%, MgO percent was nearly the same, the whiteness increased to 88.5%, and the loss on ignition decreased to 4.03%. The improvement of whiteness may be attributed to the reduction of iron content in the final product (Hassan, 2007 and Ahmed, et al 2007). The experimental errors of all experiments were within the permissible limits, i.e. lesser than 5%.

		Feed	Final concentrate of flotation	Leaching product
Assay, %	SiO ₂	54.10	54.94	58.96
	MgO	29.90	31.76	31.73
	CaO	0.80	0.42	0.38
	Al ₂ O ₃	5.50	3.11	3.01
	Fe ₂ O ₃	8.20	7.24	3.12
Mass recovery, %		100	92.40	85.00
Whiteness, %		75.4	83.7	88.5
Loss on ignition, %		6.64	5.21	4.03

Table 8. The final results of chemical analysis of talc constituents, mass recovery, whiteness, and loss on ignition in feed, final concentrate of flotation, and leaching product

4. Conclusions

- From the results of this investigation, the following conclusions can be drawn:
1. The floatability of talc increased as the pH increased up to a value of 11. Above this value, the floatability of talc decreased.
 2. The CaO and Al₂O₃ can be partially sequestered using sodium hexametaphosphate as a selective depressant at a certain limit. The optimum value was found at 1.0 kg/t.
 3. Using oleic acid in conjunction with kerosene resulted in an increase in talc recovery up to a maximum of 1.2 kg/t after which recovery decreased.

4. The recovery of talc increased as the pulp density increased up to 200 g/L, above which the recovery of talc decreased.
5. The final concentrate of flotation was leached with a dilute hydrochloric acid (10%). In the final product, SiO_2 assay increased to 58.96%, and Fe_2O_3 decreased to 3.12%. The mass recovery was about 85% of the initial feed, and whiteness improved to 88.5%.
6. The final talc product of this research is suitable for many industrial uses such as low-loss electronics (a type of ceramics), paints, rubber, plastics, roofing, textiles, refractories, insecticides and coating of welding rods.

5. Nomenclature

C	=	mass of concentrate, g
T	=	mass of tailings, g
F	=	mass of feed, g
c	=	assay of constituent in concentrate, %
t	=	assay of constituent in tailings, %
f	=	assay of constituent in feed, %
Rm(c)	=	mass recovery of concentrate, %
Rm(t)	=	mass recovery of tailings, %
Rc(c)	=	component recovery in concentrate, %
Rc(t)	=	component recovery in tailings, %

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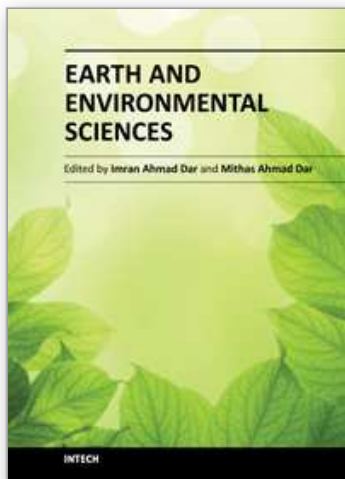
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