Mining, Metallurgy & Exploration (2021) 38:2239–2247
https://doi.org/10.1007/s42461-021-00468-x

Purification and Removal of Hematite from Talc by Acid Leaching Assisted by Chlorination Techniques

Nisar Muhammad[1] · **Waqas Ahmad**[2] · **Mudassar Khan**[2] · **Muhammad Salman**[2] · **Arshad Ali**[1]

Received: 5 April 2021 / Accepted: 20 July 2021 / Published online: 9 August 2021

Abstract

Talc is an important industrial commodity due to its wide-ranging intrinsic properties; however, the presence of iron oxide hinders its industrial utilization. Herein, we report the purification of Pakistani talc through acid leaching assisted by chlorination techniques. Among various acids (i.e., HF, HCl, H_2SO_4, HNO_3, H_3PO_4, Aqua Regia, H_3BO_3, and CH_3COOH), HF was the most effectual, removing up to 67% of iron oxide at optimized conditions of temperature, 90–95 °C; time, 120 min; HF concentration of 5%; and at a pH of 1. In the second step, chlorination of the talc sample was performed separately by both wet chlorination and dry chlorination. Wet chlorination was carried out using $KMnO_4$ and HCl in slurry phase which shown about 52% removal of iron oxide, whereas dry chlorination with $CaCl_2$ at high temperature attained about 48% removal of iron oxide from talc sample. Further, the wet chlorination of HF leached samples was also performed under optimized conditions which showed up to 87% iron oxide removal. The original and treated talc samples were characterized by EDX and XRD analysis to monitor the changes in the elemental and mineralogical composition of the talc. It can be concluded that HF leaching followed by wet chlorination is an effective method for the upgradation of low-grade Pakistani talc ores.

Keywords Raw talc · Acid leaching · Wet chlorination · Dry chlorination · Iron analysis

1 Introduction

Talc is a magnesium-rich silicate in hydrated form having a formula $Mg_3Si_4O_{10}(OH)_2$. Owing to its outstanding inherent properties such as softness, chemical inertness, low electrical conductivity, thermal stability, high surface area, high density, good absorption, crystallinity, hydrophobicity, and adsorption properties, it is an important industrial commodity in paint, paper, pharmaceutical, and cosmetic industries [1, 2]. Talc is widely used as filler in rubber, paper, paint, and plastic; it is also used in cosmetic products, ceramics, roofing products, soap, textile, lubricants, pesticides, etc. Structurally, the talc crystals are arranged in two dimensions, i.e., the main cleavage faces and the edges. The basal faces are non-polar and hydrophobic due to the absence of charged groups; conversely, the edges are polar and hydrophilic due to the presence of charged groups (Mg and OH^{-1}) [3]. Based on its composition, talc can be found in various colors. It is a soft material and can be cut with a knife having a hardness of 1 as compared to diamond having a hardness of 10 on a Mohs scale. The talc comprises ingrained minerals and several impurities that describe its quality and consequently its market trade. The mainstream gangue minerals in talc are magnesite ($MgCO_3$), carbonates, dolomite ($CaMg(CO_3)_2$), calcite ($CaCO_3$), serpentine, and chlorite ($Mg_5(Al,Fe)(Al,Si)_4O_{10}(OH)_8$). The gangue minerals being hydrophilic in nature adversely affect the talc ore quality and hinder its industrial utilization [4, 5]. For instance, the occurrence of iron oxide both on the surface and entrenched inside talc refutes its ingrained properties and limits its exploitation as an industrial precursor material. It also reduces its whiteness which gives it an unattractive color specifically during calcination [6]. Therefore, talc deferrication before utilization is imperative economically and commercially.

To date, various techniques have been developed for the purification of talc ores such as floatation, magnetic separation, wet attrition, acid leaching, and chlorination [4, 7–9].

✉ Waqas Ahmad
waqasahmad@uop.edu.pk

[1] Department of Mining Engineering, University of Engineering and Technology, Peshawar, Khyber Pakhtunkhwa, Pakistan

[2] Institute of Chemical Sciences, University of Peshawar, Peshawar 25120, Khyber Pakhtunkhwa, Pakistan

Froth flotation is used for refining talc ore because of its low cost. In flotation, talc usually hydrophobic is concentrated at the top as froth, while the gangue minerals are collected at the bottom as tailings, using air bubbles and flotation reagents such as frothers and depressants [10]. However, the final concentrate often contains impurities that need further processing such as magnetic separation and acid leaching [4, 11]. Ahmad et al. used flotation for the up-gradation of Egyptian talc for industrial applications; however, it was not possible to extract iron and aluminum potentially. For the potential extraction of iron, flotation and magnetic separation were combined which showed good results [7, 12]. Also, acid leaching of talc ores for the exclusion of gangue minerals is an effective practice that involves the use of different acids such as HF, HCl, and H_2SO_4 [13–17]. Because of its effectiveness and economic feasibility, acid leaching is a potentially attractive process for the purification of talc ores [17]. It successfully eradicates carbonates as well as some amount of iron, yet it is inefficient in removing adsorbed iron in the clinochlore structure. To this effect, chlorination is suggested to be an effective approach for iron oxide removal from talc by volatilizing it in the form of $FeCl_3$ [6].

The current study accentuates acid leaching assisted by chlorination techniques to remove different gangue minerals from talc in general and iron oxide in specific. The talc sample used in this study is a host rock of emerald mines (from Swat, Pakistan). The removal of iron oxide from talc sample was initially studied by extraction with various acid solutions and then by wet and dry chlorination techniques. Wet chlorination was investigated by treatment of talc sample with $KMnO_4$ and HCl in slurry phase, while in dry chlorination, talc was roasted with $CaCl_2$. The sample was also treated by optimized leaching followed by chlorination. The changes in the talc sample during the leaching and chlorination treatment were investigated by EDX and XRD analysis.

2 Experimental

2.1 Materials

All the chemicals used were of analytical grade and were used as received. Sulfuric acid (97%) was supplied by Riedel-de-Haen. Hydrochloric acid (37%), nitric acid (65%), phosphoric acid (85%), and boric acid (99.95%) were purchased from BDH Chemicals. Hydrofluoric acid (38%), glacial acetic acid (100%), sodium hypochlorite solution, ammonium acetate, 1, 10 phenanthroline monohydrate, ammonium chloride, hydrogen peroxide, ammonia, potassium permanganate, ethyl alcohol, and calcium chloride were provided by Merck. Sample of talc was collected from Mingora emerald talc mine in District Swat, Khyber Pakhtunkhwa Province (Pakistan). The original ROM talc sample was crushed and ground to powder in a grinder, and then further to fine particles in a ball mill. The sample was sieved through a mesh to collect the sized fraction with average particle size of about 100 µm. The mineralogical composition of the original talc sample was analyzed by energy dispersive X-ray (EDX) analysis as given in Table 1. The average elemental composition by weight and atomic % of the original talc sample agrees with the literature reports [18]; additionally, it also contains about 6.07% of iron as iron oxide.

2.1.1 Removal of Iron Oxide from Talc by Acid Leaching

Purification of talc sample was investigated by leaching with various acids. In typical leaching experiment, 5 g of talc was taken in a 250-mL beaker, and 100 mL of leaching solution was added to it. The beaker was placed in an oil bath mounted on a magnetic stirring hot plate. The suspension was stirred for a definite time. After the reaction, the suspension was filtered. The residue was further washed with hot distilled water 3 times to neutralize its pH, filtered through Whatman 42 filter paper, and then dried in an oven for 5 h at 100 °C. The acid leaching experiment was initially carried out for 60 min at ambient temperature (about 30 °C), using 100 mL of 5% acid solution for a 5-g talc sample. However, leaching was later optimized under different conditions.

2.1.2 Removal of Iron Oxide from Talc by Chlorination

Removal of iron oxide from talc sample was also studied by chlorination treatment, during which the iron oxide in talc sample was converted into iron chloride, which could be removed from the talc by dissolution or by volatilization on heating at high temperature. Chlorination experiments were performed by both wet and dry methods.

Table 1 Elemental analysis of original talc sample through EDX

Element	Weight (%)	Atomic (%)
C K	8.47	14.05
O K	40.405	50.26
Mg K	19.99	16.36
Al K	0.74	0.55
Si K	21.57	15.29
K K	0.05	0.02
Ca K	2.34	1.16
Cr K	0.345	0.13
Fe K	6.07	2.16
Totals	100	100

Wet Chlorination In wet chlorination process, gaseous chlorine produced in the laboratory was bubbled through slurry of talc in ethanol. In a typical wet chlorination experiment, 5 g of talc sample was dispersed in ethyl alcohol in a conical flask. The opening of the flask was provided with a cork through which a glass tube carrying gaseous chlorine was inserted in the slurry. A long glass tube was also fixed in the cork of the flask to serve as reflux and exhaust. The flask was set in an oil bath placed on a hot plate to maintain the temperature of the slurry; chlorine gas was continuously bubbled through the talc suspension for 60 min, at a temperature 100 to 120 °C. The gaseous chlorine was supplied from another reaction assembly, in which chlorine gas was prepared by reaction of $KMnO_4$ and HCl or NaOCl and HCl.

For preparation of chlorine gas in the laboratory by the chemical reaction of HCl and $KMnO_4$, a close flask provided with dropping funnel and a tube for transport of Cl_2 was used. The flask was placed in an oil bath on a hot plate as shown in Fig. 1. About 4 g solid $KMnO_4$ was taken in the flask and heated up to 90–95 °C; to this 12 mL of HCl was added through the dropping funnel. $KMnO_4$ acts as an oxidizing agent, which reacts with HCl to form a yellow-green chlorine gas that was transferred by a delivery tube and bubbled through the talc alcoholic slurry in the conical flask.

$$2KMnO_4 + 16HCl \rightarrow 2MnCl_2 + 2KCl + 8H_2O + 5Cl_2$$

In an alternate procedure, gaseous Cl_2 was prepared by the reaction of NaClO and HCl in a similar reaction setup as described above. In a flask placed in an oil bath on a hot plate, NaClO was taken and heated. HCl was added from the dropping funnel; the reaction between NaOCl and HCl produced Cl_2 which was transferred through a delivery tube and bubbled through the talc slurry.

$$NaClO + 2HCl \rightarrow NaCl + Cl_2 + H_2O$$

After the experiment, the talc ethanol slurry was filtered. The residue was washed with hot distilled water. The pH of the talc filtrate was neutralized. The contents of chloride ions in the final talc product were analyzed by Argentometric titration. For chlorine contaminants, Mohr's method was used.

Dry Chlorination In a typical dry chlorination experiment, 5 g of talc sample was mixed thoroughly with 5 g of NH_4Cl, and the mixture was transferred into a 100-mL crucible. The crucible was then placed in a muffle furnace and heated to 250 °C for 120 min. After heating, the sample was removed from the furnace and cooled in a desiccator. The residue was then leached with deionized water at a temperature of 90 °C for about 120 min. The residue was transferred to a volumetric flask, then oxidized with a certain amount of H_2O_2, and again leached with deionized water. The pH values of the solutions were neutralized. The solution was cooled at room temperature and filtered. The residue was washed repeatedly with hot distilled water to neutralize its pH and then dried in an oven. In the same procedure, 5 g of talc sample was mixed thoroughly with 5 g of $CaCl_2$ instead of NH_4Cl. The iron contents in the filtrate were analyzed by spectrophotometer.

Removal of Iron Oxide from Talc by Acid Leaching Assisted Chlorination In these experiments, the talc sample was first subjected to acid leaching under optimized conditions, and

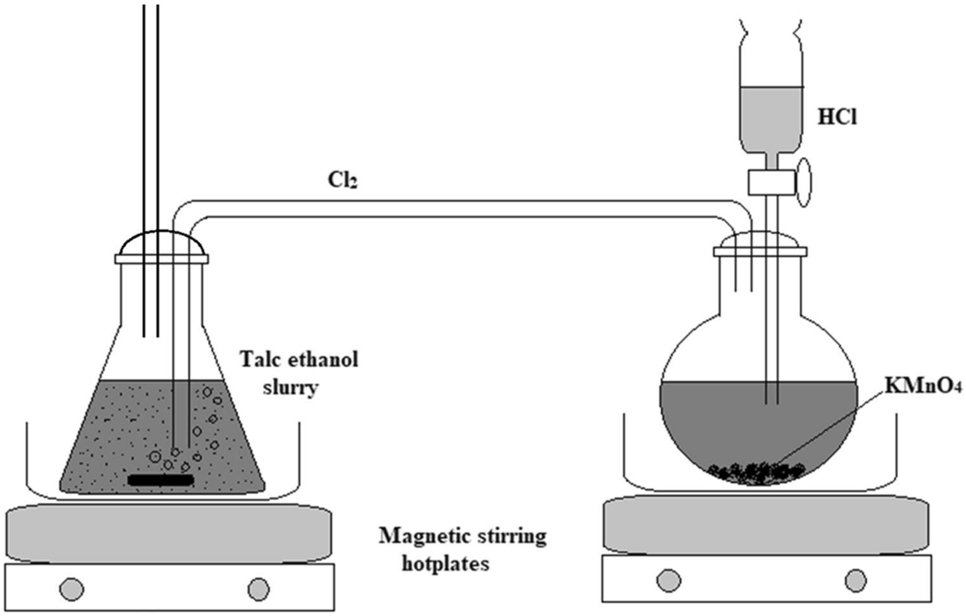


Fig. 1 Schematic representation of wet chlorination process

the leached sample was then treated by chlorination treatment as mentioned in procedure given above.

2.2 Characterization

The amount of iron removed from the talc sample was determined from the iron contents in the acidic leachate. The acid leachate was analyzed by colorimetric method or 1,10-phenonthroline method [19]. The iron standard solutions with different concentration was prepared, and its absorbance was recorded after the addition of a buffer solution and 1,10-phenonthroline on UV spectrophotometer at 510 nm, to construct the calibration curve. The absorbance of the filtrate sample was also determined similarly, and the concentration of Fe was calculated from the calibration curve. At the same time, the iron content in the powder samples was also analyzed by EDX. The elemental composition of the talc sample was analyzed by EDX through SEM equipped with X-ray detector (Model JEOL-JSM-5910; Japan). The mineral phases in the talc sample were investigated by XRD analysis over X-ray diffractometer (JDX-9C JOEL, Japan) using CuKα radiation at 1.54178 A° wavelength and a nickel filter. The whiteness of the original and treated talc samples was investigated by CR-300 Chroma Meter, Konica Minolta Color, Light, and Display, Japan.

3 Results and Discussions

3.1 Removal of Iron Oxide from Talc Sample by Leaching

The removal of iron oxide from the talc sample was initially studied by leaching with various acids. For effective removal of hematite (Fe_2O_3), the nature of acid plays a vital role; therefore, the role of different acid solutions was investigated on the removal of iron oxide from talc samples. The leaching of talc ore was investigated in the presence of various acids, i.e., HF, HCl, HNO_3, H_2SO_4, H_3PO_4, aqua regia, H_3BO_3, and CH_3COOH. The acid leaching experiment was initially carried out for 60 min at ambient temperature (about 30 °C), using 100 mL of 5% acid solution for a 5-g talc sample. However, leaching conditions were later optimized at different conditions. The acids used for leaching were of different strengths, including very weak acids (H_3BO_3 pKa 9.3, CH_3COOH pKa 4.5), moderately strong acids (H_3PO_4 pKa 2.12, HF pKa 3.2), and strong acids (HCl pKa -6, HNO_3 pKa -1.37, H_2SO_4 pKa -2). The acids with different strengths and natures were used to investigate their iron oxide leaching efficiency from talc. Figure 2 illustrates the removal of iron oxide from talc ore as a function of different acids. It is evident from the results that the removal of iron oxide increases in the order HF > HCl > H_2SO_4 > HNO_3 > H_3PO_4 > aqua regia > H_3BO_3 > CH_3COOH. Hydrofluoric acid shows higher removal of iron oxide up to 67% because HF being a strong acid preferentially dissolves a higher amount of minerals.

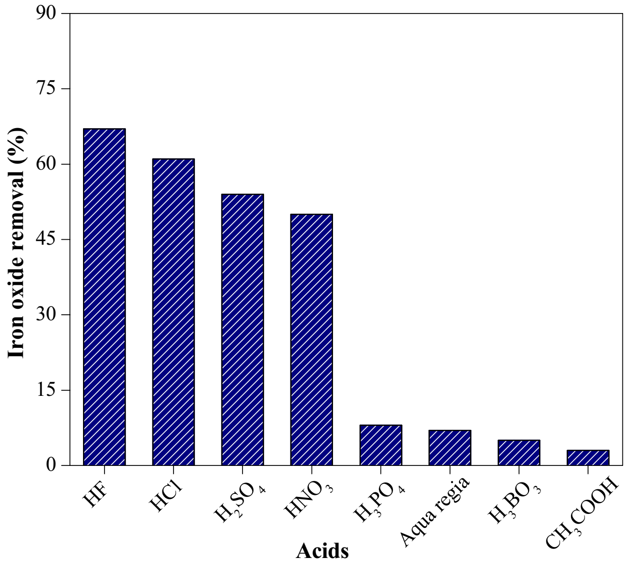


Fig. 2 Effect of acid leaching for iron oxide removal from talc

3.1.1 Process Parameters

The initial leaching experiments indicated that among various acid solutions, leaching with HF solution leads to maximum removal of the iron oxide; hence, further leaching experiments were carried out using HF solution. Leaching with HF was further studied under different varying process parameters, including the concentration of HF solution, initial pH of the talc slurry, leaching time, and leaching temperature; results are shown in Fig. 3a–d. The concentration of acid has a significant role in the removal of iron oxide; an upsurge in iron oxide removal is observed (Fig. 3a) as the concentration of hydrofluoric acid is increased from 1 to 5%. This may be attributed to the availability of increased H^+ ion which helps in dissolving a higher amount of iron oxide from the talc sample. Because of the increased in reactants specie due to increase in acid concentration, talc dissolution rate is higher [17]. High concentration of HF above 5% was not considered because of the corrosion and toxicity concern.

Additionally, the removal of iron oxide is also affected by fluctuations in pH; therefore, to observe the role of pH, different experiments were performed ranging from pH 1 to 7. As can be seen from Fig. 3b, the removal of Fe_2O_3 is higher at lower pH, following a decline as the pH reaches neutrality. The maximum removal of Fe_2O_3 at lower pH is because of the enhanced activity of H^+ ion which decreases at higher pH. Hence, higher iron oxide removal is favored at

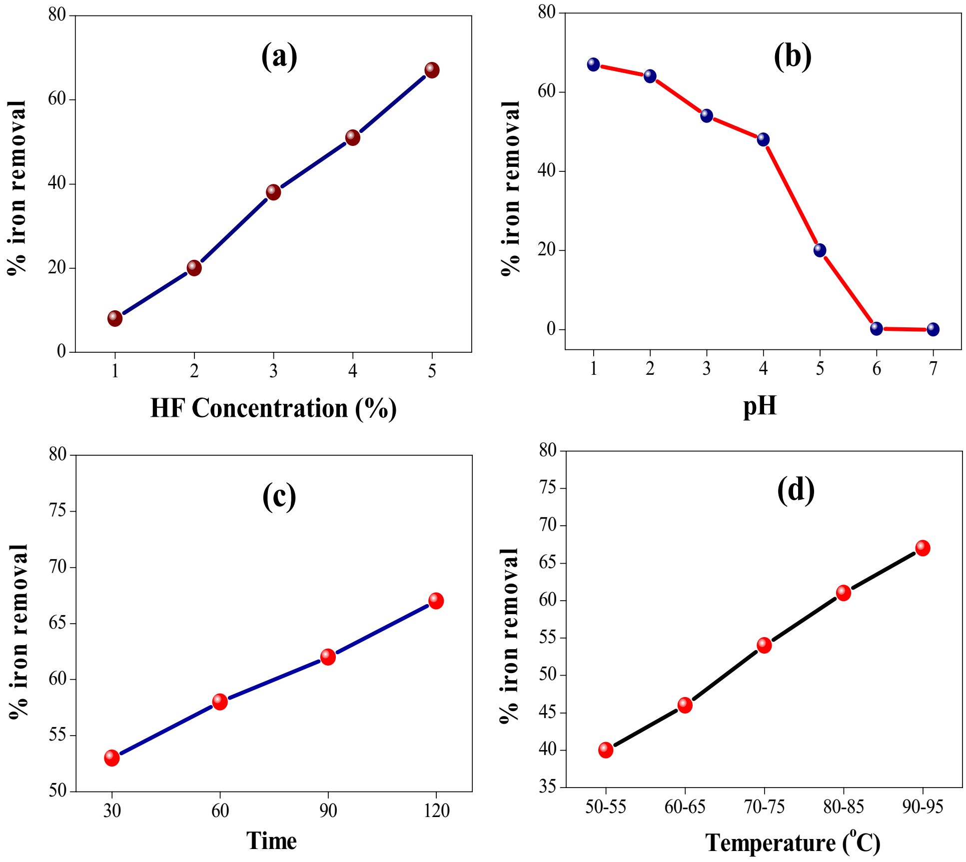


Fig. 3 Effect of HF % concentration (**a**), pH (**b**), leaching time (**c**), and temperature (**d**) on the removal of iron oxide from talc ore (initial leaching parameters: time 60 min, temperature 90 °C, acid concentration 5%, acid solution volume 100 mL, talc sample 5 g)

lower pH [20]. For the determination of optimum time and temperature, several experiments were carried out at varying times (30 to 120 min) and temperatures (50–95 °C), and its effect on the Fe_2O_3 removal was observed. The influence of an increase in leaching time (Fig. 3c) and temperature (Fig. 3d) has a positive effect on the removal of iron oxide from talc ore. Since iron oxide dissolution is predominantly reliant on the diffusion rate of HF which increases with an increase in time and temperature. Hence, it can be deduced that iron oxide removal is thermally activated process and is favored at longer reaction timing [20, 21].

3.2 Removal of Iron Oxide from Talc by Chlorination

Chlorination predominantly removes iron oxide by converting it into $FeCl_3$ which can be consequently volatilized or leached away [6]. Thereby, to explore the effect of chlorination on the removal of iron oxide from talc ore, both wet and dry chlorination were tried solely, and then the effective chlorinating route was applied to acid leached samples.

3.2.1 Effect of Wet Chlorination

The effect of wet chlorination on the removal of iron oxide from talc slurry in ethanol was explored in the presence of chlorinating agents, i.e., $HCl + KMnO_4$ and $NaOCl + HCl$. Figure 4 shows the spectrophotometric analysis for % iron oxide removal attained as a consequence of wet chlorination. As it is observed from the data, the removal of iron oxide up to 52% and 49% is achieved with $KMnO_4 + HCl$

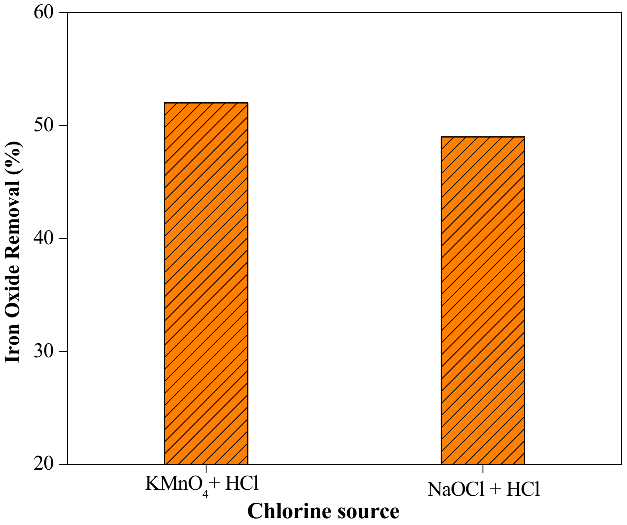


Fig. 4 Effect of wet chlorination on the removal of iron oxide from talc samples

and NaOCl + HCl respectively. As obvious from the results, increased iron oxide removal is observed with HCl + $KMnO_4$ which may be due to a larger volume of gaseous chlorine produced during this reaction, which effectively converted more iron into iron chloride.

3.2.2 Effect of Dry Chlorination

Removal of iron oxide from talc sample was also investigated through dry chlorination process, in which the talc sample was mixed with NH_4Cl or $CaCl_2$ and heated to about 250 °C for 120 min. The iron oxide converted into $FeCl_3$ is further removed by leaching. Since here two different chlorine precursors are used, i.e., NH_4Cl or $CaCl_2$, the % iron removal is displayed in Fig. 5. Results indicated that in case of NH_4Cl and $CaCl_2$, about 46% and 48% iron oxide removal are attained respectively. As it is evident from the results, wet chlorination leads to higher removal of iron oxide from talc; therefore, wet chlorination was preferentially applied to HF leached samples.

3.2.3 Effect of Simultaneous Leaching and Wet Chlorination

In these experiments, iron oxide removal from talc was studied via acid leaching followed by chlorination. The combined effect of acid leaching and chlorination was explored under optimized set of conditions. The talc sample was initially stirred with 5% HF solution for 120 min at 90 °C; this was followed by washing with distilled water and drying. The acid leached dried sample was divided into two portions; one part was subjected to wet chlorination using the chlorine produced by NaOCl + HCl process and the other portion by wet chlorination using $KMnO_4$ + HCl method. The results are displayed in Fig. 6. Samples 1 and 2 refer to HF leached followed by wet chlorination with NaOCl + HCl and $KMnO_4$ + HCl, respectively; it is evident from the results that in case of samples 1 and 2, about 83% and 87% removal of iron oxide was attained from talc sample respectively. This clearly shows the advantage of simultaneous leaching and chlorination in removal of iron oxide from talc, since up to 67% of iron oxide removal was achieved in the sole acid (HF) leaching step which was increased to 83% and 87% of iron oxide removal in the acid (HF) leaching assisted chlorination step [14]. The two-step process collectively helps to remove a higher amount of iron oxide from the talc sample.

3.3 Characterization of Treated Talc Samples

To evaluate the effect of leaching and chlorination on talc samples, before and after treatment, the samples were characterized by various instrumental analyses including EDX and XRD.

3.3.1 Elemental Composition

The treated talc samples were subjected to an energy dispersive X-ray analysis for the determination of elemental composition and iron content. As given in Table 1, the original talc sample shows the about 19% Mg, 21% Si, and 40% O along with other metals like Al, Ca, K, and Cr, which justify the presence of magnesium silicate and the minerals like carbonates and oxides of Ca, K, Al, and Cr in small amounts [18]. The original talc also contain about 6.07%

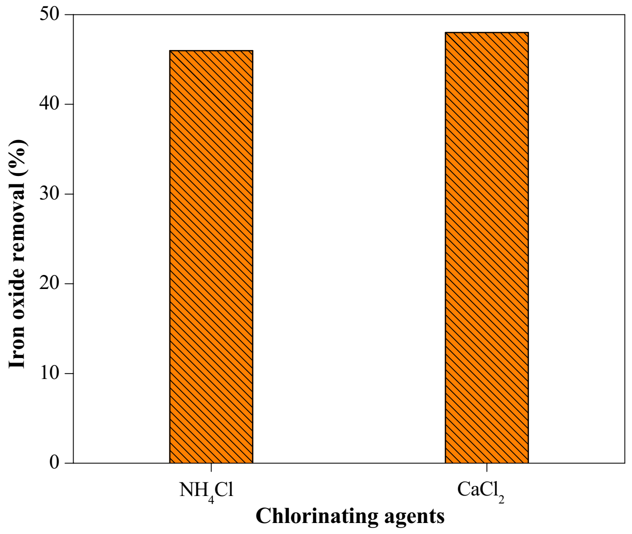


Fig. 5 Effect of dry chlorination on the removal of iron oxide from talc samples

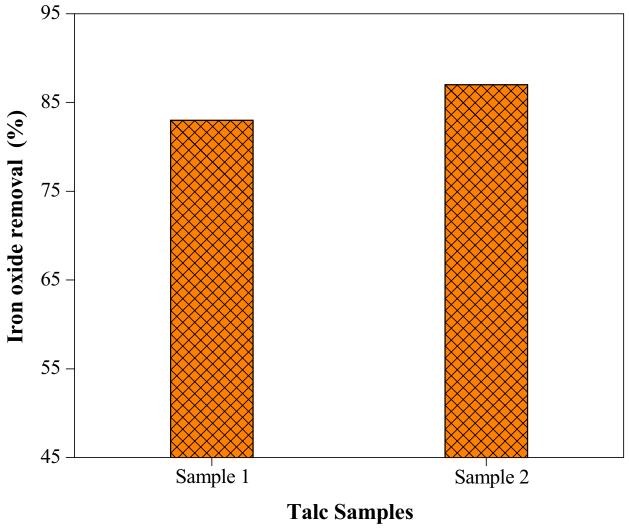


Fig. 6 Effect of HF leaching and wet chlorination on the removal of iron oxide from talc

Table 2 Average elemental composition of Iron content in original talc, HF leached talc, talc after wet ($KMnO_4+HCl$)/($NaOCl+HCl$) and dry chlorination ($NH_4Cl/CaCl_2$), and HF leached talc followed by wet chlorination ($KMnO_4+HCl$)

Talc sample	Average weight (%) of iron content	Average atomic (%)	Iron removal (%)
Original	6.07	2.16	—
HF leached	1.98	0.74	67
Wet chlorination ($KMnO_4+HCl$)	2.885	1.01	52
Dry chlorinated ($CaCl_2$)	3.14	1.12	48
HF leached an wet chlorinated (KMnO4 + HCl)	0.82	0.29	87

Table 3 Whiteness of the variously treated talc samples

S. No	Talc sample	Lump		Fine	
		Y	b	Y	B
1	Original talc sample	75.02	1.71	72.68	1.71
2	Leached with HF	87.06	2.51	84.49	2.51
3	HF leached followed by wet chlorination ($KMnO_4+HCl$)	86.44	2.91	83.69	2.91
4	HF leached followed by wet chlorination ($NaClO+HCl$)	86.29	2.96	83.47	2.96
5	Wet chlorination ($NaClO+HCl$)	76.76	2.62	73.99	2.62
6	Dry Chlorination with NH_4Cl	73.02	11.94	69.89	11.94
7	Dry Chlorination with $CaCl_2$	74.23	6.24	71.42	6.24

atomic wt% of iron as iron oxide. The iron content of the treated talc samples was determined by XRF analysis as displayed in Table 2. After HF leaching, the iron oxide content is reduced to 1.98 and shows 67% removal. Chlorination plays an important role in iron oxide removal which occurred mainly in the form of $FeCl_{3.}$ The effect of wet chlorination with $KMnO_4+HCl$ as a chlorinating agent removed up to 52% of iron oxide; however, dry chlorination with $CaCl_2$ removed up to 48% of iron oxide, thus proving wet chlorination employing $KMnO_4+HCl$ as a chlorinating agent to be more effective way of chlorination. The average iron content of talc sample after acid leaching followed by wet chlorination is reduced to 0.82 showing a removal of 87%. Hence, it can be concluded from the results that acid leaching with HF followed by wet chlorination with $KMnO_4+HCl$ shows maximum removal of iron oxide from the talc sample.

3.3.2 Whiteness of the Treated Talc Sample

Whiteness is a very important property of the talc which greatly impact its application in various industries such as cosmetics, paper, paint, ceramics, and plastics [22]. Talc cannot be used in majority of these application if it has an objectionable color and does not have the desirable whiteness. The faint reddish color of talc is due to presence of iron oxide as impurity, the removal of which is the focus of the current study.

The color or whiteness of the talc samples was measured by calorimeter. Results are indicated in Table 3 below. It can be observed from the data that on the whiteness scale, the value of original scale is about 75 and 72, which has been considerably increased to above 85 through simple leaching with HF, as well as leaching followed by dry and wet chlorination. However, the whiteness of the talc has not been improved by simple wet or dry chlorination, without HF leaching. These results also suggest that the current combined leaching and chlorination process are efficient enough the improve the whiteness of the sample for industrial application.

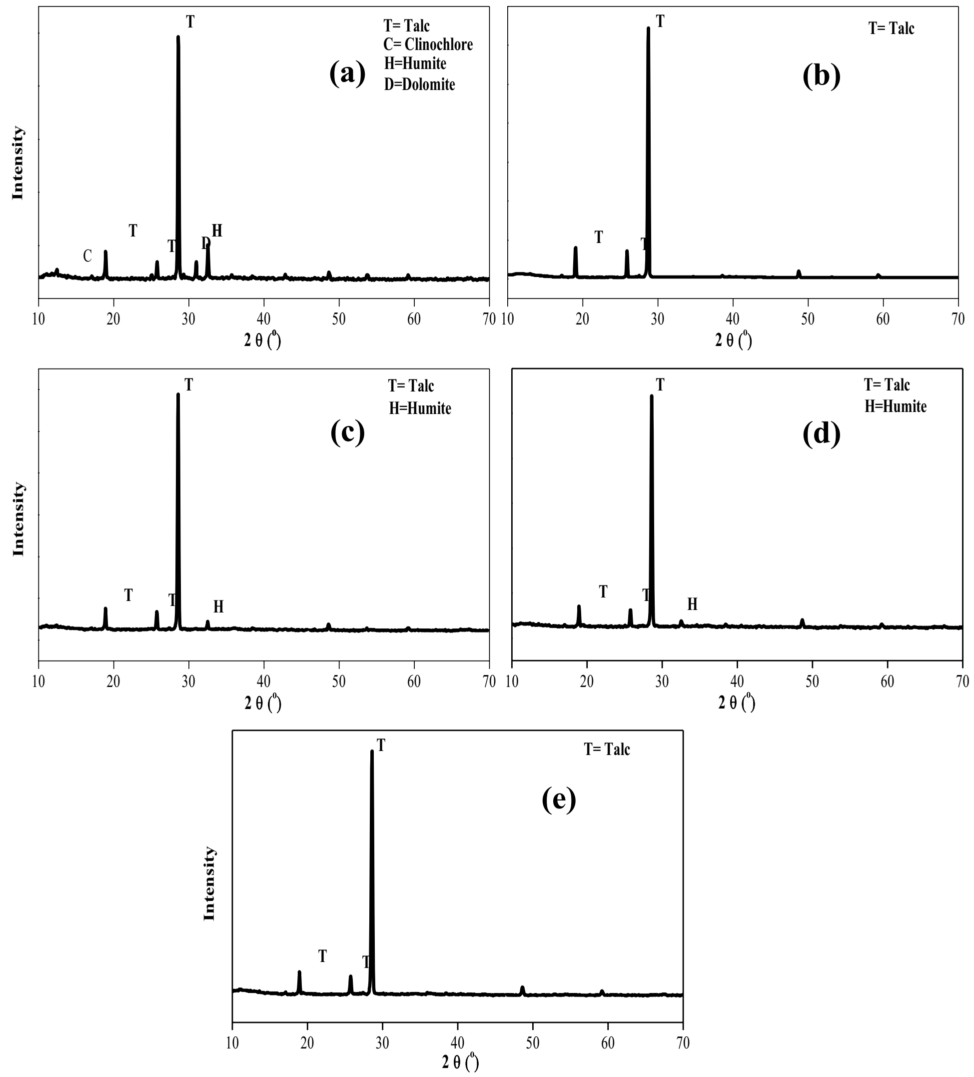
In case of talc samples, simply chlorinated by wet chlorination (without acid leaching), the yellowness is markedly increased, which may be attributed to the oxidized iron, retained in the talc sample. On the other hand, in case of the talc sample chlorinated by wet chlorination followed by acid leaching, most of the oxidized iron is removed during leaching step due to which yellowness is also decreased. Hence, in most of the treated samples, the increase in yellowness is very small, which is hardly observable visually and can therefore be used in most common applications.

3.3.3 XRD Analysis

The mineralogical composition of the original talc samples, HF leached talc, chlorinated talc, and acid leached chlorinated talc, was determined by X-ray diffraction analysis. Figure 7 demonstrates the presence of various mineral phases in the raw talc sample and the treated talc samples. The XRD diffractogram of the original talc sample shows the occurrence of talc ($Mg_3Si_4O_{11}.H_2O$) at 2Θ of 28.60, 18.93 and 25.78, the diffraction lines of which coincides with JCPDS card No. 20066, clinochlore [$(Mg,Fe,Al)_6$ $(Si,Al)_4$ O_{10}], humite [($5MgO.SiO_2.(H_2O, HF)$)], dolomite [$Ca\,Mg(CO_3)_2$] at 2Θ of 12.45,32.550 and 31.00, the diffraction lines of which coincides with JCPDS Card No. 70078, 70,168 and 360,426 respectively [18]. The XRD of the raw sample shows the presence of talc and other minerals which agrees with the reported literature.

The XRD diffractogram of HF leached sample shows the presence of talc at 2Θ of 28.60, 18.93, and 25.78; however, other mineral peaks disappeared. It is evident from the result that acid leaching had an effect on the talc sample by eradicating some of the minerals. The XRD diffractogram of wet and dry chlorinated talc is almost the same which

Fig. 7 XRD analysis of original (**a**), HF leached (**b**), wet chlorinated (**c**), dry chlorinated (**d**), and HF leached and wet chlorinated talc samples (**e**)



demonstrates the presence of talc at 2Θ of 28.60, 18.93, and 25.78 coinciding with JCPDS card No. 20066 respectively. Also, the presence of humite at 2Θ of 32.550 whose diffraction lines matches with JCPDS card No. 70168, is observed. The XRD pattern of HF leached sample followed by wet chlorination shows three major peaks of talc at 2Θ of 28.60, 18.93, and 25.78, the lines of which agree with the JCPDS card No. 20066.

4 Conclusion

The following conclusion may be drawn from the current study:

- Among acid leaching, HF leaching showed maximum removal of iron oxide from the talc sample. At optimized parameter, i.e., 120 min, 90–95 °C, 5% concentration of HF, and at a pH of 1, up to 67% of iron oxide removal was observed.
- Among wet and dry chlorination of talc, wet chlorination employing chlorinating agent ($KMnO_4 + HCl$) showed maximum removal of iron oxide up to 52%.
- The simultaneous acid leaching with wet chlorination removed up to 87% of iron oxide from the original talc sample.
- The results of EDX agree with the spectrophotometric analysis results of iron oxide removal from talc.
- The current method is an effective method for the maximum removal of iron oxide from the talc and can be scaled up for the upgradation of local talc for industrial utilization.

Author Contribution M. Nisar and Waqas Ahmad contributed in conceptualization, finalizing the draft, and analyzing the data. Mudassar Khan and Muhammad Salman contributed in experimental work, drafting, analysis, and compilation of data. Arshad Ali carried out sample collection and sample analysis.

Availability of Data All the data of this paper has been included in the paper.

Code Availability Not applicable to this study.

Declarations

Ethics Approval Not applicable to this study.

Consent to Participate/Publication All the authors have consent to participate or publish.

Conflict of Interest The authors declare no competing interests.

References

1. Boghdady G, Ahmed M, Ibrahim G, Hassan M (2005) Petrographical and geochemical characterisation of some Egyptian talc samples for possible industrial applications. J Eng Sci 33:1001–1011
2. Okunlola OA, Ogedengbe O, Ojutalayo A (2003) Composition features and industrial appralsal of the baba ode talc occurrence, South Western Nigeria. Glob J Geol Sci 1:63–72
3. Morris GE, Fornasiero D, Ralston J (2002) Polymer depressants at the talc–water interface: adsorption isotherm, microflotation and electrokinetic studies. Int J Miner Process 67:211–227
4. Ahmed MM, Ibrahim GA, Hassan AM (2006) Improvement of Egyptian talc quality for industrial uses by flotation process and leaching. JES J Eng Sci 34:1813–1830
5. Castro G (1996) Diagnostico De La Produccion De Talco Frente A La Demianda En. Inform Tecnol 7:175
6. Orosco R, Ruiz MdC, Barbosa L, González J (2011) Purification of talcs by chlorination and leaching. Int J Miner Process 101:116–120
7. Piga L, Marruzzo G (1992) Preconcentration of an Italian talc by magnetic separation and attrition. Int J Miner Process 35:291–297
8. Yehia A, Al-Wakeel M (2000) Talc separation from talc-carbonate ore to be suitable for different industrial applications. Miner Eng 13:111–116
9. Hojamberdiev M, Arifov P, Tadjiev K, Yunhua X (2010) Characterization and processing of talc-magnesite from the Zinelbulak deposit. Min Sci Technol (China) 20:415–420
10. Khraisheh M, Holland C, Creany C, Harris P, Parolis L (2005) Effect of molecular weight and concentration on the adsorption of CMC onto talc at different ionic strengths. Int J Miner Process 75:197–206
11. Ahmed HA (2015) Processing of Saudi talc ore for filler industries–Part 2: Magnetic separation and flotation. Mater Test 57:1006–1012
12. Al-Wakeel M, Geology and beneficiation of some Egyptian talc–carbonate rocks. 1996, Ph. D Thesis Ain Shams University
13. Yang H, Du C, Hu Y, Jin S, Yang W, Tang A, Avvakumov E (2006) Preparation of porous material from talc by mechanochemical treatment and subsequent leaching. Appl Clay Sci 31:290–297
14. Temuujin J, Okada K, Jadambaa T, Mackenzie K, Amarsanaa J (2002) Effect of grinding on the preparation of porous material from talc by selective leaching. J Mater Sci Lett 21:1607–1609
15. Sarquis P, Gonzalez M (1998) Limits of the use of industrial talc—the carbonate effect. Miner Eng 11:657–660
16. Baba AA, Ibrahim AS, Bale RB, Adekola FA, Alabi AG (2016) Assessment of a Nigerian talc ore for improved industrial application by sulphuric acid leaching. Mater Sci Eng 7:1
17. Baba AA, Ibrahim AS, Bale RB, Adekola FA, Alabi AG (2015) Purification of a Nigerian talc ore by acid leaching. Appl Clay Sci 114:476–483
18. Castillo LA, Barbosa SE, Maiza P, Capiati NJ (2011) Surface modifications of talcs. Effects of inorganic and organic acid treatments. J Mater Sci 46:2578–2586
19. Tamura H, Goto K, Yotsuyanagi T, Nagayama M (1974) Spectrophotometric determination of iron(II) with 1,10-phenanthroline in the presence of large amounts of iron(III). Talanta 21:314–318
20. Barani K, Aghazadeh V (2018) Removal of impurities from talc ore by leaching method. J Chem Technol Metall 53:296–300
21. Castillo LA, Barbosa SE, Maiza P, Capiati NJ (2014) Integrated process for purification of low grade talc ores. Part Sci Technol 32:1–7
22. Claverie M, Dumas A, Carême C, Poirier M, Micoud P, Martin F, Aymonier C (2018) Synthetic talc and talc-like structures: preparation, features and applications. Chem-A Eur J 24:519–542