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FLOTATION OF IRON ORES

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This invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to us of any royalty thereon.

This invention relates to an improved process for the concentration of iron ores whereby froth flotation of the siliceous gangue constituents yields an iron enriched product; more particularly it relates to a froth flotation process for siliceous gangue constituents in iron ores, employing anionic reagents.

An object of the invention is the development of an improved flotation process for the concentration of natural oxides of iron from pulps containing them in the presence of siliceous gangue. A further object is to provide a flotation process for separating silica from iron oxides employing anionic reagents. A still further object is to provide a flotation process for concentrating iron ores or products containing both calcareous and siliceous materials. Still other objects include the development of a flotation process which will have greater selectivity in separating siliceous materials from iron ores and thereby effect greater economies. Other objects, purposes, and advantages of the invention will hereinafter more fully appear or will be understood from the detailed description of its practice.

We are aware that various methods have been proposed for the concentration of iron ores by flotation methods for the purpose of rejecting siliceous gangue constituents and recovering an iron enriched product. The most common method known to the art for concentrating iron ores has been to float the iron oxides from the siliceous gangue constituents employing an anionic collector, such as oleic acid or sodium oleate, in conjunction with auxiliary reagents, as soda ash or sodium silicate, to retard flotation of the silica. Those skilled in the art recognize that the method has limitations. The method yields good results on some iron ores, but is not applicable to others. Desliming of the ore pulps is generally necessary before good flotation of the granular oxides can be effected, and the pulps must be relatively free of soluble salts. The salts, such as lime or magnesia, derived from the ore or present in the water employed, activate the siliceous mineral to flotation with the soap collectors and results in poor selectivity. Soft water relatively free of lime and magnesia is generally required for satisfactory iron oxide flotation.

An alternative method for concentrating iron ores by flotation has been to reverse the separation and float the siliceous gangue minerals from the iron oxides by employing cationic collectors. The application of such reagents to iron ores has been described by Kirby and Gillson in United States Patents Nos. 2,217,684 and 2,221,485. This method is attractive in that iron ores in general contain less siliceous material than iron oxides, and flotation of the silica is in keeping with the preference of floating that constituent which occurs in least amount. Cationic reagents are not without their limitations, being, in general, more expensive than those of the anionic type. The cationic collectors, moreover, are not particularly selective, nor are they effective silica collectors in the presence of slime iron. Desliming of the iron ore pulps is usually necessary before acceptable flotation of silica can be achieved with cationic collectors. On many iron ores desliming results in a serious loss of iron. The iron oxides are relatively soft and friable as compared to siliceous gangue constituents, and grinding the silica to flotation size unavoidably slimes much of the iron oxides which would be lost if desliming were practiced.

The lack of a suitable flotation method for concentrating iron ores has long been apparent to those engaged in the art. The customary flotation methods, previously discussed, have many limitations and are not applicable to all iron ores. These methods give poorest results on those ore or products most in need of concentration, that is, fines resulting from treatment of iron ores by other methods of concentration. A satisfactory flotation method for recovery of the fine iron oxides and rejection of the silica would be of material aid for the concentration of those iron ores which slime readily on grinding or require fine grinding for liberation.

The need of a feasible flotation method for iron ores was particularly apparent in the concentration of the red iron ores of the Birmingham district, Alabama. These ores consist essentially of hematite associated with quartz and calcite, with minor amounts of other siliceous and calcareous materials including ferruginous clay. The red ores require relatively fine grinding for

the liberation of the hematite, and the hematite is soft and slimes readily. Wet concentration methods, such as hydraulic classification and tabling of the red iron ores, enables recovery of the coarse hematite in a product of acceptacle silica content. The fines resulting from such treatment are contaminated with too much silica and require processing by other methods such as flotation, to reject the silica and recover an acceptable iron product.

A satisfactory flotation method for the recovery of hematite and rejection of the silica in the red iron ores or concentrator fines was sought. Flotation of the iron oxides from the silica with anionic collectors, and flotation of the silica from the iron oxides with cationic collectors failed to give the desired results. Much of the silica floated with the hematite when using anionic collectors and gave low grade iron concentrates. The silica, predominantly quartz, was apparently activated to anionic flotation due to the presence of lime salts in the ore. Attempts to deactivate the silica and prevent its flotation with the hematite were not successful. Reversing the separation and floating the silica from the iron oxides with cationic collectors was not encouraging. The contaminated silica was reluctant to float with cationic collectors and much remained in the iron product. Neither of the methods customarily employed on iron ores was satisfactory, and other means of perfecting the separation was sought.

By extended research and experimentation, we discovered that we could make use of the acticated condition of the silica and effect its flotation from the hematite and calcite with anionic collectors while retarding flotation of the hematite with a metaphosphate in a strongly alkaline pulp. A moderate amount of meta-, hexameta-, or polyphosphate is effective in retarding flotation of iron oxides and calcareous materials when used in pulps made strongly alkaline with sodium or potassium hydroxides, or their equivalents.

A pulp with a pH exceeding 10, and preferably 11, is highly essential in our method of flotation. Rapid and complete flotation of the activated silica can be effected by any of the customary anionic collectors such as oleic acid, sodium oleate, or sulfate soap or talloel derived from paper mill black liquors. Slime is not detrimental to the separation of the silica, nor is soft water required. The method is particularly well adapted for the concentration of the red iron ores of the Birmingham district containing calcareous as well as siliceous gangue materials. A variety of ores and mill products from the district have responded readily to the method. The calcareous materials, largely calcite, may be floated with the silica or retarded with the hematite by choice of the amount of metaphosphate employed.

A prime requisite in our method of flotation of silica from iron ore is that the pulp be dispersed. The metaphosphates in the strongly alkaline pulps are effective slime dispersants as well as selective depressants for the iron oxides and calcareous materials. Supplementary reagents such as sodium silicate, dextrin, starch, various tannins, or ortho or pyrophosphates may be used as dispersants in conjunction with reduced amounts of metaphosphate. The pyrophosphates, when flotation of the calcareous materials is sought, are particularly advantageous in conjunction with metaphosphate. These reagents are not effective for retardation of hematite and must be used in conjunction with a meta- or polyphosphate.

The discussion heretofore relates to the flotation of silica from iron ores in which the silica was naturally activated to anionic flotation due to the presence of soluble salts. The highly siliceous and weathered iron ores of the Birmingham district are relatively free of soluble salts and the silica is non-activated. On such ores the silica requires prior activation before acceptable flotation can be achieved by our method. Extended research on a variety of siliceous iron ores from both the Alabama and Lake Superior districts has demonstrated that our method lends itself well to the use of silica activating agents. Conditioning the ore pulps with a moderate amount of a metal salt selected from the group which form soluble basic or complex salts in strongly caustic pulps in the presence of metaphosphate, activates the silica sufficient for its flotation by the fatty acid or soap collectors without adversely effecting subsequent retardation of the iron oxide. Such metal salts as calcium chloride, strontium nitrate, barium chloride, zinc sulfate, aluminum sulfate, or lead nitrate have been used on various iron ores for activation of the siliceous gangue and found satisfactory. Of these lead nitrate was most effective and was preferred. Calcium chloride and slaked lime were used on many ores and gave good results. From the standpoint of cost, slaked lime was particularly attractive. When using lime as the activator, best results were secured by adding the lime to the grinding operation in an amount sufficient to give a resulting grind water with a pH of about 11. The ground pulp was flocculated and settled readily. The grind water containing excess free lime was discarded and the solids repulped with fresh tap water and floated to reject the silica. Free lime is detrimental in the separation and must be avoided. Washing the pulp free of lime reduces the subsequent phosphate requirements in flotation. A moderate amount of free lime in the flotation pulp can be overcome by conditioning the pulp with soda ash to precipitate the lime as insoluble carbonate. The caustic alkalinity developed reduces the subsequent caustic requirements.

The invention will be further illustrated but is not intended to be limited by the following examples:

Example I

A sample of iron ore was obtained from a mine in the Graces Gap area, near Birmingham, Alabama. The ore was typical of the district and contained hematite associated with a gangue composed predominantly of quartz and calcite with minor amounts of accessory calcareous and siliceous materials including ferruginous clay. A head analysis gave 33.7 percent Fe, 11.8 percent CaO, and 28.1 percent insoluble. The ore was stage crushed to pass 20 mesh and used as the feed for subsequent flotation procedures.

A 250-gram portion of the ore was wet ground in a one-gallon pebble mill to pass 100 mesh using 4500 grams of flint pebbles as the grinding media and one liter of tap water. The ground charge was alkaline (pH—8.6) and qualitative tests on the grind water showed presence of lime salts. The ground charge, including slime, was transferred to a small mechanical agitation flotation cell of standard design using grind water as the

media. The resulting pulp for flotation contained 20 percent of solids.

Flotation of the silica from the hematite and calcite was effected by the following reagents expressed in conventional terms of pounds per ton of ore:

	Conditioner	Rougher	Cleaner	
			1	2
Sodium hydroxide	2.0		0.5	0.5
Sodium hexametaphosphate	0.8		0.04	0.08
Talloel	0.8			
pH of pulp	11.3	10.9	10.9	11.0

The pulp was conditioned with the sodium hydroxide and sodium hexametaphosphate for 2.5 minutes prior to the addition of the talloel which served as the silica collector. The talloel was emulsified into the pulp by conditioning an additional 1.5 minutes. Air was then allowed to enter the cell and resulted in an immediate formation of a compact, heavily mineralized froth of the siliceous material which was largely quartz. The froth was collected for a period of 5 minutes when flotation was completed. The rougher froth was twice cleaned by refloating in the same cell using tap water of moderate hardness and additional sodium hydroxide and sodium hexametaphosphate as indicated. The final silica reject, conventionally referred to as concentrates but designated here as "rejects" since they are the waste product, the combined middlings, and the iron concentrates, conventionally referred to as tailings in ore dressing terminology but designated here as "concentrates" since they represent the economic iron product, were dried, weighed, and analyzed.

The silica reject accounting for 19.8 percent of the weight of the charge, assayed 6.3 percent Fe, 4.7 percent CaO, and 82.1 percent insoluble, and represented a rejection of 57.9 percent of the total insoluble in the ore. Combining the flotation middlings and iron concentrates gave a composite iron product accounting for 80.2 percent of the weight of the charge, assayed 40.5 percent Fe, 13.6 percent CaO, and 14.8 percent insoluble, and represented a recovery of 96.3 percent of the total iron in the ore.

The above mentioned test was about "average" of a large number made on the ore. Grinding the ore to 65 mesh or 200 mesh in either a pebble mill or iron ball mill gave results entirely similar to those already recorded. In every case good flotation of the silica was achieved when the pH of the pulp was maintained between 10 and 12 by the addition of sodium hydroxide, caustic soda, lye, or similar alkalies. Ammonium hydroxide was also used in other tests but is less attractive from the cost standpoint and difficulty involved in handling.

Sodium hexametaphosphate was used as the hematite and calcite retardants in the test. The mono-sodium metaphosphate, or its polymeric forms may also be used. The alkali metal salts of the tetraphosphates are also effective for retardation of iron oxides in quartz flotation when used in strongly alkaline pulps. The ortho- and pyro-phosphates are ineffective iron oxide depressants, but have been used as supplementary dispersants in conjunction with the meta compounds.

Talloel, an impure mixture of rosin and fatty acids obtained from paper mill black liquor, was used as the collector for the activated quartz in the recorded test. Similar results were obtained when using oleic acid or sodium oleate. A combination of talloel and oleic acid is particularly effective.

Example II

A 250-gram charge of the Graces Gap area iron ore was ground to pass 100 mesh as in Example I. The ground charge was deslimed by sedimentation methods and the granular portion floated to reject silica. Sodium hydroxide and sodium hexametaphosphate were used to alkalize the pulp and retard flotation of the hematite and calcite. The amounts employed were 1.0 and 0.6 pound per ton of ore, respectively, in the roughing operation, and 1.0 and 0.12 pound per ton in the cleaning operation. Talloel and crude oleic acid were used as the collectors in the roughing operation in amounts equivalent to 0.8 and 0.4 pound per ton respectively. An additional 0.4 pound per ton of talloel and 0.2 pound per ton of lead nitrate were used to float a scavenger product which was subsequently combined with the rougher froth and double cleaned to yield the final reject. The test products were dried, weighed, and analyzed.

The slime fraction accounted for 23.5 percent of the weight and contained 28.2 percent of the total iron in the ore. Flotation of the granular portion yielded a silica reject product assaying 6.4 percent Fe, 8.2 percent CaO, and 75.9 percent insoluble, and represented a rejection of 64.1 percent of the total insoluble in the ore. The iron concentrates assayed 47.6 percent Fe, 10.8 percent CaO, and 9.8 percent insoluble, and accounted for 47.6 percent of the total iron in the ore. Combining the flotation middlings, iron concentrates, and slime gave a composite iron product representing a recovery of 95.5 percent of the total iron in a product assaying 42.9 percent Fe, 12.2 percent CaO, and 13.3 percent of insoluble.

Although desliming is not necessary in our method for successful flotation of silica from iron ores, it is helpful and should be practiced whenever possible.

Example III

A test was made on a sample of high-lime low-insoluble iron ore from the Spring Gap area of the Birmingham district, Alabama. The heads analyzed 34.1 percent Fe, 17.8 percent CaO, and 9.8 percent insoluble. The object of the test was to float the calcareous material, largely calcite, with the silica, largely quartz, while retarding the iron oxides. The sample was ground to 100 mesh for flotation using the procedure described in Example I and floated with the following reagent charge:

	Conditioner	Rougher	Cleaner	
			1	2
Caustic soda	1.0		0.4	0.4
Sodium metaphosphate	0.2		0.4	0.08
Tetra sodium pyrophosphate	0.2			
Crude sodium oleate	2.50			
Crude oleic acid	0.48			
Pine oil		0.08		
pH	10.9	10.4	10.6	10.8

Depression of the hematite was effected by sodium metaphosphate and tetra sodium pyrophosphate in a pulp made alkaline (pH—10.9)

with caustic soda. Sodium oleate and oleic acid were used as the collectors for the silica and calcite. The rougher froth was double cleaned for the final reject. Test products were dried, weighed, and assayed.

The reject product represented 50.0 percent of the weight and assayed 14.7 percent Fe, 30.5 percent CaO, and 10.7 percent insoluble. The lime and insoluble rejection were 86.1 and 53.9 percent respectively. The iron concentrates assayed 57.3 percent Fe, 2.0 percent CaO, and 9.7 percent insoluble, and accounted for an iron recovery of 47.1 percent. Combining the flotation middlings and iron concentrates gave a composite iron product representing a recovery of 78.4 percent of the total iron in a product assaying 53.4 percent Fe, 4.9 percent CaO and 9.1 percent of insoluble.

Example IV

A siliceous red iron ore was obtained from the Graces Gap area in the Birmingham district, Alabama. A head analysis gave 42.3 percent Fe, 0.5 percent CaO, and 31.3 percent insoluble. The sample differed from those previously considered in that the silica, largely as quartz, was non-activated.

A 250-gram representative portion of the ore was ground in a one-gallon iron ball mill to pass 100 mesh using 5000 grams of ½-inch steel balls and one-liter of tap water. Slaked lime equivalent to 6.0 pounds per ton of ore was added to the mill to activate the silica for subsequent anionic flotation. The ground pulp was flocculated and settled readily. Clear supernatant grind water (pH—11.0) was discarded and the solids repulped with fresh tap water and again allowed to settle. The wash water containing the remaining lime salts was discarded. The solids were repulped with tap water and floated as in Example I using the following reagents:

	Conditioner	Rougher	Cleaner	
			1	2
Sodium hydroxide	1.0		0.2	0.2
Sodium hexametaphosphate	0.6		0.03	
Talloel	1.0			
pH of pulp	11.2	10.6	10.6	10.6

The silica activated by slaked lime floated rapidly in a compact, heavily mineralized froth. The rough froth was double cleaned using tap water and additional reagents for a final reject. The floated material assayed 5.0 percent Fe, and 91.2 percent insoluble, and represented a rejection of 51.3 percent of the total insoluble in the ore. The iron concentrates assayed 53.4 percent Fe and 13.5 percent insoluble, and accounted for a recovery of 80.7 percent of the total iron in the ore. Combining the flotation middling and iron concentrate gave a composite iron product representing a recovery of 97.9 percent of the total iron in a product assaying 50.3 percent iron, 0.5 percent CaO, and 18.5 percent insoluble.

Similar tests in which lead nitrate, barium chloride, calcium chloride, or copper ammonium sulfate were used as the silica activator gave equally good results. From 0.5 to 4.0 pounds of the metal salt per ton of ore was required for complete activation of the silica. The preferred procedure when using the metal salts as activators is to condition the ore pulp with the desired amount of alkali and metaphosphate to retard the hematite and give a dispersed pulp with a pH of 10 to 12. The metal salt was added to the pulp and conditioned 2.5 to 5 minutes followed by the addition of the collector for flotation of the silica. Reversing the order of addition of activator and collector is permissible and may even give improved results on certain ores. A mixture of alkali, phosphate, metal salt, and collector prepared by admixing outside the cell has been used to float the silica from deslimed iron ore pulps with good results. The soluble metal soap complex served both as collector and activator for the silica.

Example V

A sample of Mesabi range iron ore washer tailings containing 31.5 percent Fe, and 52.0 percent insoluble was tested by flotation. The silica, largely present as quartz, was essentially finer than 100 mesh.

A 250-gram portion of the sample was blunged 15 minutes in a flotation cell with 500 cc. of tap water and slaked lime equivalent to 12 pounds per ton of ore. The pH of the slurry was 11.9. The slurry was withdrawn from the cell and washed twice with fresh tap water by decantation to reject the excess lime salts, taking care to avoid loss of slime in the operation. The lime-treated slurry was repulped with fresh tap water and floated to reject the silica using the generalized procedure described in Example I.

The reagent charge employed was as follows:

	Conditioner	Rougher	Cleaner	
			1	2
Sodium hydroxide	1.2		0.5	0.4
Sodium hexametaphosphate	1.0	0.2	0.1	0.1
Talloel	1.4	0.2		
Lead nitrate		0.2		
pH of pulp	11.0	10.3	10.6	10.8

Good flotation of the silica was achieved. The rejects assayed 10.3 percent Fe and 83.8 percent insoluble, and represented 90.8 percent of the insoluble in the ore. The iron concentrates assayed 61.0 percent Fe and 8.1 percent insoluble and represent a recovery of 50.2 percent of the total iron in the ore. Flotation of the silica increased the iron content 29.5 percent and decreased the insoluble content 43.9 percent. Combining the middlings with the iron concentrate gave a composite iron product representing a recovery of 81.6 percent of the total iron in a product assaying 58.81 percent Fe, and 10.95 percent of insoluble.

Example VI

A sample of slime filter cake from a gravity concentrator in the Birmingham district, Alabama, was tested by our method to reject silica and recover an iron enriched product. The sample assayed 41.6 percent Fe, 8.8 percent CaO, and 19.4 percent insoluble. The silica was present both as ferruginous clay and granular quartz essentially finer than 100 mesh, associated with granular and slime hematite and calcareous materials. Sedimentation tests revealed that 51 percent of the material was finer than 20 microns, about 800 mesh.

A 320-gram portion of the wet filter cake, equivalent to 250 grams of dry solids, was washed with fresh tap water to remove excess lime used in the concentrator to flocculate slime iron prior to filtration. The washed solids were transferred

to the flotation cell and floated using the procedure described in Example I.

Flotation of the quartz was achieved with the following reagents expressed in conventional terms of pounds per ton of solids.

	Conditioner	Rougher	Cleaner		
			1	2	3
Sodium carbonate	1.0				
Sodium hydroxide	0.5		0.2	0.2	0.2
Sodium hexametaphosphate	0.4		0.04	0.04	0.08
Sodium oleate	2.0				
Oleic acid	0.96				
pH of pulp	11.1	10.5	10.5	10.7	10.8

The pulp was conditioned 2.5 minutes with sodium carbonate to precipitate remaining lime salts prior to floating the activated quartz with sodium oleate and oleic acid from the strongly akaline dispersed pulp. The rougher froth was triple cleaned for the final silica reject product.

The silica reject, accounting for 10.3 percent of the weight of the dry sample, assayed 6.2 percent Fe, 6.2 percent CaO, and 76.4 percent insoluble, and represented a rejection of 40.6 percent of the total insoluble in the sample. The low rejection of insoluble may be attributed to the relatively large amount of ferruginous clay in the sample which does not float with the quartz.

The iron concentrates assayed 47.1 percent Fe, 8.3 percent CaO, and 12.7 percent insoluble, and accounted for 86.5 percent of the total iron present in the sample. Combining the flotation middlings and iron concentrates gave a composite iron product representing a recovery of 98.5 percent of the iron and assayed 45.7 percent Fe, 9.1 percent CaO, and 12.8 percent insoluble.

Laboratory batch flotation tests on the concentrator filter cake were supplemented by continuous flotation tests on a pilot plant scale at the plant. The product treated was a deslimed portion of fines bled continuously from the plant circuit. The tests were successful and demonstrated that our method could be used under continuous operating conditions to reject free silica from concentrator fines with only moderate loss of iron or lime. Less reagents were required in the continuous runs than in the batch flotation tests. Rapid and complete flotation of the activated silica was effected with talloel, oleic acid, or sodium oleate when used in conjunction with a moderate amount of a metaphosphate in a strongly alkaline circuit.

It will be clear from the description of our method and results obtained in practice as illustrated by the foregoing examples, that this invention is useful for preparing concentrates of acceptable iron content from ores containing too little iron to be normally of technical value. The method is applicable to ores and waste products containing calcareous as well as siliceous gangue materials and is sufficiently flexible to permit rejection or recovery of the calcareous materials with the iron oxides as desired.

The present process has several outstanding advantages as compared to previously known flotation methods of concentrating iron ores. First, it provides a feasible and economic method for rejecting quartz and silicate minerals from iron ore pulps without the necessity of desliming. Secondly, it permits the use of relatively inexpensive anionic collectors for silica flotation from iron ore pulps for the first time. Thirdly, it provides a method wherein precise reagent control is not necessary to perfect a separation. Fourthly, it provides a method for rapid and complete flotation of siliceous or calcerous materials from iron oxides in a froth which is easily controlled. Fifthly, it provides a method for flotation or rejection of calcareous materials in iron ores. Sixthly, it provides a method for concentration of a wide variety of iron ores and plant products. Conversely, the process may be used to recover quartz or siliceous products of high purity, when the principal contaminants are iron oxides or calcareous materials.

With the exception of calcareous iron ores such as those of the Birmingham district, an activator is necessary to insure flotation of the silica. We have found that the quartz in certain calcareous ores is naturally activated due to its long contact with lime salts present in the ore. We have also found that while the addition of an activating substance is not necessary with such ores, a small amount of an activating substance such as lead nitrate, barium chloride, calcium chloride or the like will often improve the results obtained. Weathered, highly siliceous ores from the Birmingham district, some ores from the Lake Superior region and other highly siliceous ores are found which seldom contain sufficient lime or other soluble salts to activate the silica and on such ores it is highly essential that an activator be employed in order to float the silica in accordance with the procedure which we have described above.

Those skilled in the art will understand that there may be several explanations for the results which we obtain, and while we do not wish to bind ourselves to any particular explanation, we postulate the ability of metal salts to activate quartz to anion flotation as being due to the adsorption of metal ions by the quartz, and, in turn, the reaction of such metal ions with a soap or like collector to form a relatively insoluble soap coating on the quartz surface which is water repellent and air avid. This explanation would assume that the purer the quartz surface the more readily the metal ions are adsorbed, and the results which we obtained seemed to show that this is the case. Impure or contaminated quartz surfaces are much less active in adsorbing metal ions apparently due to the fact that the surfaces are already satiated. Absolutely pure quartz surfaces are, of course, seldom, if ever, found. New surfaces can be produced by grinding but such new surfaces become contaminated as soon as formed by the release of soluble salts. Older methods attempted for the concentration of iron ores by flotation sought to inhibit the contamination of newly formed quartz surfaces but in the case of our process this is not essential as contaminated quartz surfaces will assist rather than inhibit the operation of our process.

The anionic flotation reagent is of a class consisting of fatty acids and soaps and those which we have found most effective are oleic acid, red oil (crude oleic acid), purified and crude sodium oleate, cocoanut oil soap, fish oil soap, sodium resinate, impure rosin acids (derived from talloel from paper mill black liquors), sulfate soap (saponified talloel), and various talloels. We prefer to use talloel as the collector in conjunction with a small amount of oleic acid to control the froth.

We wish to caution those skilled in the art that an excess of the anionic flotation reagent seems to inhibit the flotation of the activated silica, and it is apparently desirable that only just enough oleic acid, sodium oleate or the like be employed

to secure satisfactory flotation. We postulate this effect to be due to double coatings on the silica surfaces which are water wetted. It appears that the first coating has the polar group joined to the anchored metal ion in the quartz surface and the non-polar or lipophilic end of the collector molecule orientated outward. The second coating is then reversed, the two hydrocarbon or lipophilic ends being joined together and the non-polar end orientated to the water interface. This explanation seems logical and apparently fits the facts although we do not wish to be bound thereto. We wish to point out that an excess amount of soap may possibly exert a detergent action on ore formed soap coatings to thereby remove them but this explanation appears less likely than that of the reversed or double coatings.

While we have disclosed the preferred embodiments of our invention, it will be readily apparent to those skilled in the art that many variations and modifications may be made therein without departing from the spirit of the invention.

What we claim as new and desire to protect by United States Letters Patent is:

1. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron ore pulp in the presence of an alkali-soluble compound of an inorganic anion combined with a polyvalent metal selected from the group consisting of alkaline earth metals and heavy metals, establishing a strongly alkaline pH of at least 10 in said ore pulp and then subjecting said alkaline, activated ore pulp to agitation with aeration in the presence of an anion-active collecting agent selected from the group consisting of fatty acids, resin acids and soaps derived from such acids, and a phosphate compound selected from the group consisting of metaphosphates and polyphosphates, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

2. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron ore pulp in the presence of an alkali-soluble compound of an inorganic anion combined with an alkaline earth metal, establishing a strongly alkaline pH of at least 10 in said ore pulp and then subjecting said alkaline ore pulp to agitation with aeration in the presence of an anion-active collecting agent selected from the group consisting of fatty acids, resin acids and soaps derived from such acids, and a phosphate compound selected from the group of metaphosphates and polyphosphates, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

3. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron oxide ore pulp in the presence of an alkali-soluble compound of an inorganic anion combined with calcium, then removing excess soluble calcium compounds from the activated pulp and incorporating therein sufficient caustic alkali to establish a strongly alkaline pH of 10 to 12, thereafter subjecting the activated, alkaline ore pulp to agitation with aeration in the presence of an anion-active collecting agent selected from the group consisting of fatty acids, resin acids and soaps derived from such acids, and an alkali-soluble phosphate compound selected from the group consisting of metaphosphates and polyphosphates, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

4. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron oxide ore pulp in the presence of lime, then removing excess soluble calcium compounds from the activated pulp by washing with water and incorporating therein sufficient caustic alkali to establish a strongly alkaline pH of 10 to 12, thereafter subjecting the activated alkaline ore pulp to agitation with aeration in the presence of an anion-active collecting agent selected from the group consisting of fatty acids, resin acids and soaps derived from such acids, and an alkali-soluble phosphate compound selected from the group consisting of metaphosphates and polyphosphates, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

5. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron oxide ore pulp in the presence of lead nitrate, then incorporating therein sufficient caustic alkali to establish a strongly alkaline pH of 10 to 12, thereafter subjecting said activated alkaline ore pulp to agitation with aeration in the presence of an anion-active collecting agent selected from the group consisting of fatty acids, resin acids and soaps derived from such acids, and an alkali-soluble phosphate selected from the group consisting of metaphosphates and polyphosphates, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

6. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron ore pulp in the presence of an alkali-soluble compound of inorganic anion combined with a polyvalent metal selected from the group consisting of alkaline earth metals and heavy metals, establishing a strongly alkalin pH of at least 10 in said ore pulp, then subjecting said alkaline activated ore pulp to agitation with aeration in the presence of an alkali metaphosphate and an anion active collecting agent selected from the group consisting of fatty acids, rosin acids, and soaps derived from such acids, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

7. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron ore pulp in the presence of an alkali-soluble compound of an inorganic anion combined with an alkaline earth metal, establishing a strongly alkaline pH of at least 10 in said ore pulp and then subjecting said alkaline activated ore pulp to agitation with aeration in the presence of an alkali metaphosphate and an anion-active collecting agent selected from the group consisting of fatty acids, rosin acids and soaps derived from such acids, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

8. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron ore pulp in the presence of an alkali-soluble compound of an inorganic anion combined with a polyvalent metal, establishing a strongly alkaline pH of at least 10 in said ore pulp and then subjecting said activated alkaline ore pulp to agitation with aeration in the presence of an alkali metaphosphate and an anion-active collecting agent selected from the group consisting of fatty acids, rosin acids and soaps derived from such acids, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

9. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted

iron oxide ore pulp in the presence of an alkali-soluble compound of an inorganic anion combined with calcium, then removing excess soluble calcium compounds from the activated pulp and incorporating therein sufficient caustic alkali to establish a strongly alkaline pH of 10 to 12, thereafter subjecting the activated alkaline ore pulp to agitation with aeration in the presence of an alkali metaphosphate and an anion-active collecting agent selected from the group consisting of fatty acids, rosin acids, and soaps derived from such acids, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

10. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron oxide ore pulp in the presence of lime, then removing excess soluble calcium compounds from the activated pulp by washing with water and incorporating therein sufficient caustic alkali to establish a strongly alkaline pH of 10 to 12, thereafter subjecting the activated alkaline ore pulp to agitation with aeration in the presence of an alkali metaphosphate and an anion-active collecting agent selected from the group consisting of fatty acids, rosin acids, and soaps derived from such acids, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

11. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron oxide ore pulp in the presence of lead nitrate, incorporating therein sufficient caustic alkali to establish a strongly alkaline pH of 10 to 12, then subjecting the activated alkaline ore pulp to agitation with aeration in the presence of an alkali metaphosphate and an anion-active collecting agent selected from the group consisting of fatty acids, rosin acids and soaps derived from such acids, whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

12. A process for the beneficiation of iron ores which comprises blunging an aqueous comminuted iron oxide ore pulp in the presence of lime, then removing excess soluble calcium compounds from the activated pulp by washing with water and incorporating therein sufficient caustic soda to establish a strongly alkaline pH of 10 to 12, thereafter subjecting the activated alkaline ore pulp to agitation with aeration in the presence of talloel and sodium hexametaphosphate whereby siliceous gangue is floated and beneficiated iron ore is depressed and recovered.

13. A process for the beneficiation of iron ores which comprises comminuting, to 100 mesh in the presence of a soluble lime salt, such an ore containing also quartz and calcite, adjusting the solids content of the resulting pulp to 20 per cent, incorporating in the pulp per ton of ore about 2 pounds of sodium hydroxide, about 0.8 pound of sodium hexametaphosphate and about 0.8 pound of talloel; agitating the resulting mixture for about four minutes to condition the pulp, agitating and aerating the conditioned pulp for about five minutes, removing a froth product containing quartz, recovering an initial residue from the treated pulp containing iron ore of reduced quartz content, again agitating and aerating the quartz-containing froth product with additional quantities of the same reagents and water to further separate quartz in the froth and depress a middling residue of iron ore in the pulp, and combining said initial residue and middling residue to yield a beneficiated iron ore of reduced silica content.

14. A process for the beneficiation of an oxidized iron ore which comprises comminuting such an ore in the presence of water and lime, adjusting the alkalinity of the resulting pulp to a pH at least as high as pH 10, then agitating and aerating the thus-prepared pulp in the presence of a soluble phosphate compound selected from the group consisting of metaphosphates and polyphosphates, and an anion-active collecting agent selected from the group consisting of fatty acids, resin acids and soaps derived from such acids, whereby siliceous gangue is floated and removed, and beneficiated iron ore is depressed and recovered.

15. A process in accordance with claim 14 wherein talloel is employed as the anionic collecting agent.

16. A process in accordance with claim 14 wherein oleic acid is employed as the anionic collecting agent.

17. A process in accordance with claim 14 wherein a fatty acid soap is employed as the anionic collecting agent.

18. A process in accordance with claim 14 wherein a soluble pyrophosphate is also incorporated in the pulp, whereby calcareous gangue is floated and removed with the siliceous gangue.

19. A process in accordance with claim 14 wherein soda ash is incorporated in the prepared ore pulp to secure the desired alkalinity and precipitate excess lime salts.

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