The stability of ferrosilicon dense medium suspensions

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Synopsis

The stability of a ferrosilicon dense medium suspension is one of the most important parameters to keep under control since it determines the density gradient of the medium in the separation zone and thus directly influences separation sharpness. The stability of ferrosilicon suspensions were characterized using settling tests employing a differential pressure method. Particles smaller than 45 μm and especially the ore fines played an important role in the settling behaviour of the solids. High medium stability is favoured by ore fines, fine medium particles, and high medium densities.

Keywords: dense media, ferrosilicon, dense medium stability, ore fines

Introduction

General background

Dense medium separation is the process in which a heavy liquid of an intermediate density is used to separate minerals of different specific gravity. The heavy liquid is typically a suspension of dense powder such as ferrosilicon or magnetite in water. Ferrosilicon is used for high-density applications (medium density: 3200–4200 kg/m^3).

A ferrosilicon suspension must have a large fraction of solids in water to achieve high densities. For example to achieve a medium density of 4000 kg/m^3, 7 kg of ferrosilicon (density approximately 7000 kg/m^3) should be added to 1 litre of water to make up 2 litres of heavy medium.

The rheology of this thick and fast-settling suspension can be best described by its viscosity and stability. Viscosity is a measure of the medium resistance to fluid flow, while stability is a measure of the tendency of the medium to settle. These two properties are strongly influenced by parameters such as medium density, particle shape, particle size distribution, and the level of contamination with slimes. The viscous characteristics of the dense medium are generally non-Newtonian (which means that its viscosity is a function of the shear rate), and the term apparent viscosity (at a defined shear rate) is preferred. An ideal medium has a low viscosity to maximize separation and pump efficiency. A high viscosity is undesirable because it reduces the velocity of mineral particles being separated, increasing the chance for misplacement and reducing the separation efficiency. A low viscosity is typically obtained for a low medium density, coarse particles, smooth rounded particles, and clean uncontaminated medium[1].

The shape of ferrosilicon particles depends on the manufacturing process (milling or atomization). In this work, atomized ferrosilicon with a high degree of sphericity (Figure 1) was used.

Stability

Stability is a property of a suspension considered as a non-homogeneous two-phase system; it is related to the rheology of the solid phase in an environment constituted by the liquid phase. The relative movement of the solids in the liquid phase under mass and surface forces determines the degree of homogeneity of the suspension, an important medium property in dense medium separation. The medium stability determines the density gradient of the medium in the separation zone and thus directly influences separation sharpness. Therefore, it is one of the most important parameters to keep under control[2].

An ideal medium has a high stability, which results from high medium densities, fine medium particles, irregularly shaped particles and the presence of low-density contamination (ore slimes).

Influence of slimes

Slimes are the fines of the ore being treated

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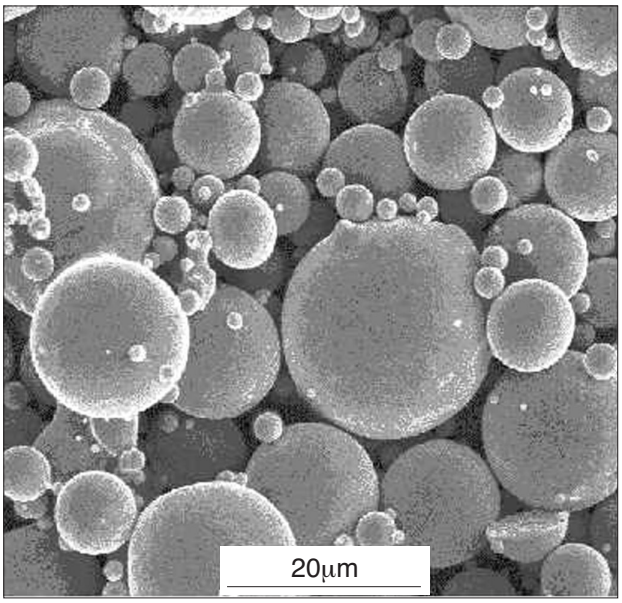

Figure 1—Scanning electron micrograph of atomized ferrosilicon

and are usually smaller than 10 μm. When the ore is added to the dense medium the slimes go into suspension, altering the properties of the dense medium. In order to limit this effect most plants make use of pre-washing screens to remove this material. However, during normal plant operation it is inevitable that some percentage of slimes will be present in the dense medium.

The presence of slimes is known to have a negative effect on viscosity and a positive effect on stability. One reason for this is that the slimes or contaminants have a lower density than the ferrosilicon; a contaminated medium will thus need to contain a higher solids concentration to achieve the same density. A higher solids concentration will cause greater resistance to medium flow[1].

In recent work on the rheology of ferrosilicon dense medium suspensions, regarding viscosity[1] and stability[2], no contaminant fines additions were used. Napier-Munn *et al.*[3] suggested that the effect of contamination is large, but no quantitative data is available. In the present work the stability of ferrosilicon suspensions containing fines was investigated.

Experimental

Materials used

The atomized ferrosilicon samples contained 14.5–14.6 per cent (by mass) silicon. Fresh samples were used for each test. Samples of four different size distributions were employed; these are depicted in Figure 2. As the Figure shows, the four samples were characterized by having different percentages smaller than 45 μm, namely 23, 29, 35 and 41 per cent.

The slimes (obtained from an iron ore mine) contained mainly hematite (78 per cent) silica (12 per cent) and alumina (9 per cent) (as found by X-ray fluorescence analysis), and had a size distribution of 70 per cent smaller than 10 μm, with 34 per cent smaller that 1 μm (see Figure 3).

Method

The simplest method for the measurement of stability is to agitate a sample of medium, and then to follow the settling rate of the mud-line (water-solid interface) under static conditions. However, in many cases where fines are present, no clear mud-line is visible. The settling of the larger medium particles would also be faster and this settling would not be visible due to the clouding of the medium by the fines. Komorniczyk *et al.*[4] developed a method based on pressure measurement within the medium: the change in the average density of the medium above the measuring point causes the pressure to change. A similar method was used here, with the difference that an electronic differential pressure transducer (Motorola MPX 12DP) was employed, rather than the manometer used by Komorniczyk *et al.*[4]. This transducer produces a voltage output (which is proportional to the pressure difference); the voltage output was recorded by computer.

A schematic of the experimental configuration used in this work is shown in Figure 4, which shows that the pressure at the measurement depth in the medium (which was 110 mm below the medium surface, above the mud-line

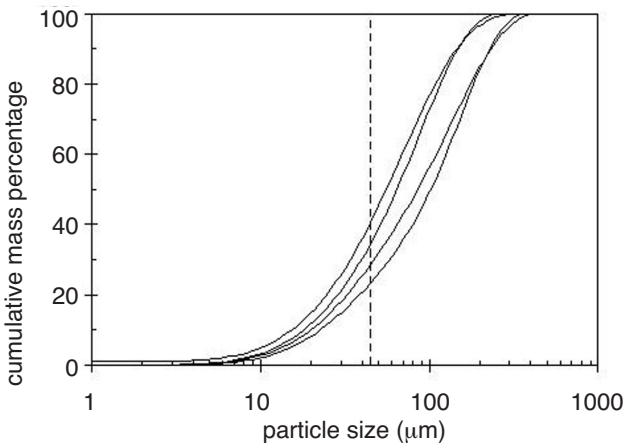

Figure 2—Size distributions of the four types of atomized ferrosilicon used to make up media (distributions measured with a Malvern size analyser). The vertical broken line is at 45 μm

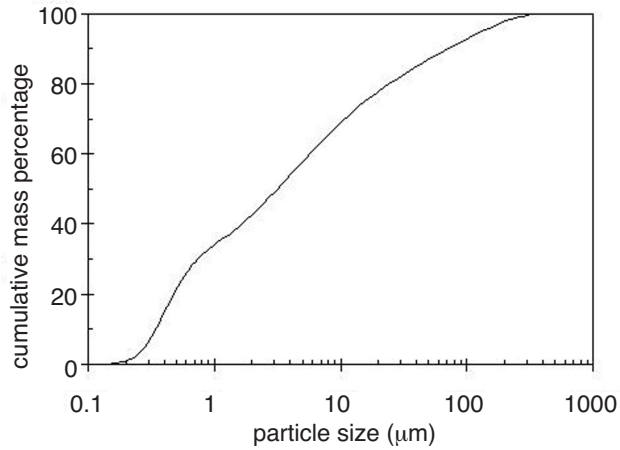

Figure 3—Size distribution of ore slimes (measured with a Malvern size analyser)

which formed if the medium had settled completely) was transmitted to the sensor through an air column. The pressure at the second inlet into the differential pressure transducer was controlled with a second air column which led to a container of water. Not shown in Figure 4 is a collection of valves, which were used to control the volume of air in the tubes before measurements started (largely with the aim of ensuring that the bottom of the air column in the suspension container was at the sampling depth of 110 mm). The glass container for the suspension had an inside diameter of 95 mm and was 400 mm deep, and was kept in a temperature-controlled water bath (maintained at 28°C). The stirrer had twin flat blades, of total length ca. 60 mm.

In the experiments, the medium was first suspended through stirring at 1500 rpm for five minutes (longer or stronger stirring was found not to affect the results, as discussed below). At the end of the stirring period differential pressure measurements started once the stirrer had been stopped. The differential pressure was recorded every 2 seconds.

The influences of the medium density (values of 3400, 3600, 3800 and 4000 kg/m^3), slimes content (0, 2% and 5% by mass), *p*H values (8, 10 and 12) and ferrosilicon particle size distributions (23, 29, 35, 41 per cent smaller than 45 μm, see Figure 2), were evaluated.

A typical set of results (for media of different densities) is shown in Figure 5, which also compares mud line measurements for this system (for the case where the medium contained no slimes). It is clear that the shapes of the curves for the pressure measurement and mud line displacement are quite different. This is as expected: the pressure measurement gives the average medium density in the volume above the sampling depth (as stated earlier, the sampling depth was 110 mm below the surface), whereas the mud line is a local measurement. However, it is clear from this comparison that medium density has a similar effect on these two measures of stability (with improved stability at higher medium densities).

The pressure measurements showed a sharp change in slope after an initial period of little change in relative pressure (see the arrowed points in Figure 5). The origin of this effect is not clear at this stage. The size of the effect was found to be affected by the stirring procedure: there was a major difference in the time of the slope change, for suspensions stirred for respectively 30 seconds and 3 minutes (the change occurring earlier with the shorter stirring period). However, no difference could be detected between 3 and 10 minutes stirring; for this reason, a minimum of 5 minutes of stirring was employed before all the settling measurements.

To characterize the stability of the medium, the inverse slope of the pressure curve beyond the sharp slope change was used; hence the units of stability used here are s/kPa. (More stable media take longer to settle, and have shallower slopes, and hence have larger values of this stability index.) Several repeat measurements were performed for each set of conditions, and the reproducibility was found to be good.

Results and discussion

The results are summarized in Figure 6, which shows the stability index as a function of medium density, for the four ferrosilicon size distributions considered. These figures confirm that the trend visible in Figure 5 is consistent for all the size distributions and slimes contents considered: higher-density media have higher stability (of course, these are also expected to have higher viscosities).

The size distribution of the ferrosilicon particles affects the medium stability in the expected direction—higher stability with finer particles (again, with expected higher viscosity). High slimes contents have a striking effect on medium stability, especially for finer medium particles and high medium densities. This favourable effect of slimes need to be offset against their expected deleterious effect on medium viscosity; this is to be addressed in future work. As higher viscosities adversely affect the dense medium separation it is clear that an optimum medium stability (favoured a combination of by fine medium particles, a high medium density and the presence of slimes) would exist for a particular separation operation.

A change in pH had very little effect on the stability of the suspension (Figure 7). It should, however, be noted that all experiments were done on freshly prepared samples which

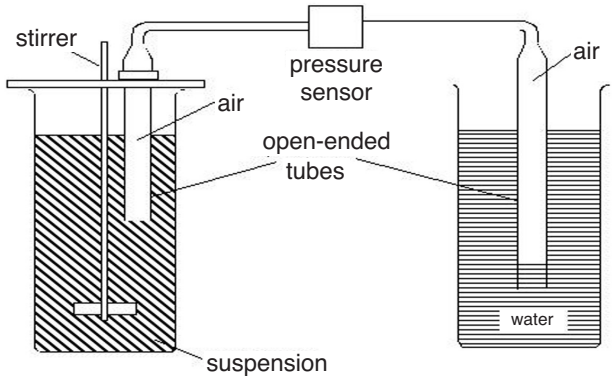

Figure 4—Schematic of experimental set-up

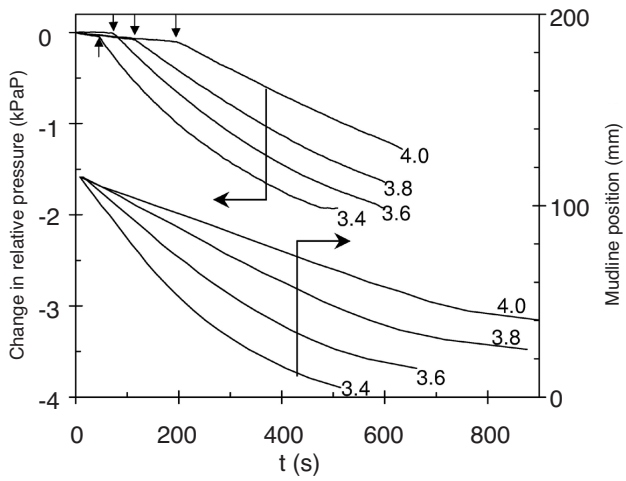

Figure 5—Correlation between mud-line movement and the change in relative pressure at a depth of 110 mm below the medium surface. Measured for ferrosilicon media of different relative densities, as listed on the curves (atomized ferrosilicon of size 35 per cent smaller than 45 μm; medium contained no slimes; *p*h = 10.2; temperature of 28°C). Arrows indicate the points where the pressure curves show sharp changes in slope

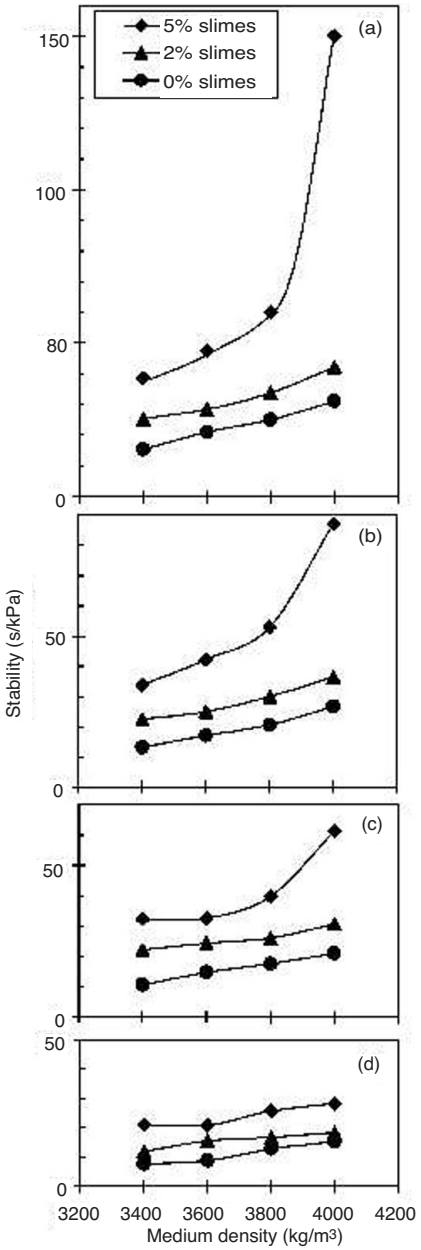

Figure 6—Effect of medium density, slimes, and size distribution of the ferrosilicon particles on medium stability. Size distributions, given in percentages smaller than 45 μm are; a) 41 per cent, b) 35 per cent, c) 29 per cent, and d) 23 per cent. Measured at a temperature of 28°C and *p*H = 10.2

allowed little time for corrosion to take place; corrosion of the ferrosilicon (which will change particle shape, and introduce solid corrosion products) is expected to be pH-dependent.

Conclusions

The following may be concluded from this work:

- The pressure differential method is a good indicator of the settling properties of ferrosilicon under static conditions
- The use of the pressure transducer simplified data recording and allowed for the accurate recording of multiple data points

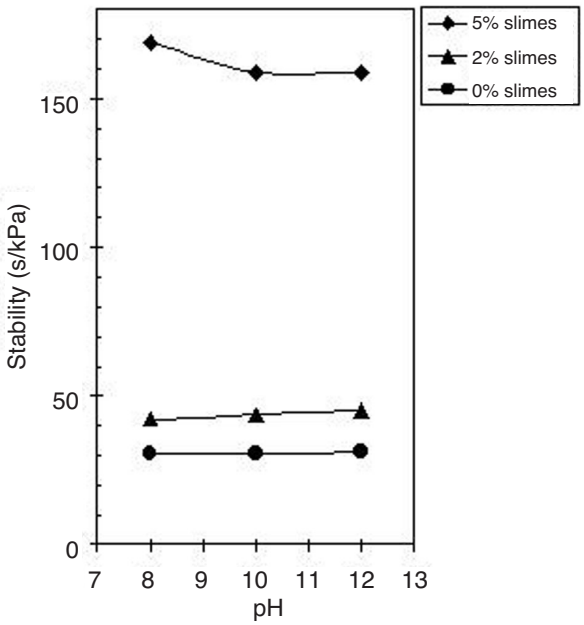

Figure 7—Influence of *p*H on medium stability, for media containing different fractions of slimes (atomized ferrosilicon particles, of size 41 per cent smaller than 45 μm, medium density 4000 kg/m³, and temperature of 28°C). Note that *p*H has little influence on the stability

- The settling behaviour of the ferrosilicon showed a slow initial rate followed by a faster but constant settling rate. This second rate was used to characterize the settling characteristics
- The pH of the medium did not influence the settling characteristics of the ferrosilicon during short tests. This may change if more time is allowed for the corrosion of the ferrosilicon
- The settling rate decreased with an increase in medium density and fineness of medium. Slimes (very fine ore) had a very strong effect of decreasing the settling rate, especially at high medium densities and with finer ferrosilicon particles.

It is recommended that future work include viscosity measurements to find media where an appropriate balance between stability and viscosity is obtained.

Acknowledgements

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