HYDROMETALLURGICAL APPLICATIONS OF RHEOLOGY TESTING

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ABSTRACT

Experimental rheology data are needed to produce design criteria for mass and energy transfer processes. Large throughput plants operate under continuous flow mode. The capital cost is determined by the accuracy of the rheology data used for design. The operating cost is dictated by the energy required to sustain the flowing conditions of various process slurries. Typically, rheology investigations are carried out during the final stages of metallurgical testwork, which is too late to set the design criteria for the pilot plant. This leads to increased testwork cost, and sometimes lowers confidence in the quality of the data produced. In addition, the engineering and feasibility studies are often delayed because of the lack of pertinent rheology data. One of the objectives of this paper is to emphasize the importance of timely planning and execution of the rheology study, which is shown to be a critical component of the overall testwork program. Various applications are discussed, including elaboration of process and equipment design criteria. In this paper, the emphasis is placed on gold and nickel laterite hydrometallurgy applications.

INTRODUCTION

Rheology, the science of flow and deformation of matter is a well-established discipline with applications in several fields of engineering. Although the fundamentals of rheology as a science are well established, its use within the mineral industries in general and hydrometallurgy in particular is not as widespread compared to fields such as polymer processing, food industry, biotechnology, etc. Extensive fundamental and applied rheology research focusing on mineral processing was carried out throughout the last few decades [1 to 7]. Examples of applications included long distance pumping, liquid - solid separation, comminition and others. Inherently, a solid knowledge base was created, which in turn was instrumental in supporting a relative upturn in the demand for rheology testwork. Laterite projects in particular led to a relative increased need for rheology data in recent years. On the other hand, most new laterite projects are on "hold" at the time of writing this paper. The experience gained from several laterite projects carried at SGS pointed unequivocally the fact that the rheological properties of the feed ore slurries were a decisive factor in the success or failure of the projects and impacted enormously in the economics of the full-scale plants. Even in case of unsuccessful laterite projects, the negative financial (and perhaps psychological) impact could have been reduced if rheology data would have been produced in earlier stages of those projects.

The main objective of this paper is to outline the capabilities of applied rheological testwork throughout the various phases of hydrometallurgical processes.

THE IMPORTANCE OF RHEOLOGY IN HYDROMETALLURGY

IMPACT OF FLOW BEHAVIOUR

Flow behavior of process slurries impacts energy and mass transfer-based unit operations. Processes that involve physical separation of liquids from solids (settling, thickening and filtration) and of solids from solids (screening and cycloning) are also slurry-rheology dependent. Examples of unit processes that are rheology-driven are included in Table 1.

Table I Rheology Dependent Unit Processes

Grinding	Pumping	Adsorption	Solid Liquid separation
Screening	Leaching	Drying	Paste production
Cycloning	Gas transfer	Precipitation	
Mixing	Heat exchange	Crystallization	

Rheological data requirements from the mineral and metallurgical industries consist of overall flowability assessment studies and generation of design criteria for the above unit processes.

OVERVIEW OF RHEOLOGY CONCEPTS

The following concepts are relevant to rheological applications in hydrometallurgy:

- Particulate Fluids (i.e. slurries)
- Non-Newtonian Flow
- Rheological Modeling
- Yield Stress
- Time Dependency

Detailed description of these concepts is provided elsewhere [1, 2, 3, 8 and 9]. In summary, a particulate fluid can be simplistically defined as a system composed of a discontinuous solid phase dispersed in a continuous liquid phase. Particulate fluids of specific interest in hydrometallurgical processes are commonly known as "slurries" or "pulps". A non-flocculated or partly deflocculated, low particle concentration slurry (i.e. particulate fluid of low pulp density) tends to follow so-called Newtonian behavior, characterized by a unique value of the viscosity that is independent of the rate of shearing to which that fluid is being subjected. The viscosity of these slurries can be calculated, hence their flowing behavior is predictable. In hydrometallurgical processes, high volume fraction (i.e. high pulp density) particulate fluids are common occurrences. These slurries display a flowability behavior that is dependent of the rate of shearing to which they are subjected during processing. This behavior is called Non Newtonian, meaning that the relationship between viscosity and solids density cannot be calculated and therefore, "flowability "must be determined by experimental measurements. Most of these materials will not flow unless a force that exceeds a certain value called "yield stress" is applied (through shearing). This is known as Bingham Plastic behavior and is widely encountered in the study of mineral and metallurgical slurries. The behaviour of Non Newtonian particulate fluids tends to vary with time to a certain degree (i.e. until they reach their ultimate flowability), since shearing history generally influences rheological properties of slurries. Rheological modeling of particulate fluids is based on experimental flowcurves generated by test data. Several models have been used over the years. The equations for the most prevalent laminar flow models are given elsewhere [1, 2, 3, 8 and 9]. The purpose of this paper is to discuss the applications of rheology to hydrometallurgical slurries, based exclusively on the Bingham Plastic Model:

$$\tau = \tau_y + \eta_P \Upsilon$$

where τ and Υ are the shear stress and shear rate respectively, τ_y is the yield stress, η_P is the Plastic (Bingham) viscosity. While this approach may appear simplistic, it has the advantages of being broadly applicable in practice, it is intuitive, and most importantly, it is representative of most processes encountered in hydrometallurgy. Examples of applications involving Non Newtonian flow other than Bingham Plastic are provided in previous work [8 and 9].

Rheology is a simple yet powerful tool that should be used in all phases of metallurgical testing. That is because any change in flowability will immediately cause a change in metallurgical (process) behavior. This change will require in turn the need of a change in the operating parameters. Hence, it must be known when and why the change in flowability occurs. The main operating parameters that affect slurry rheology are:

- Related to particle properties: concentration, shape, size and size distribution
- Physico-chemical factors: inter-particle attractive and repulsive interactions between particles, as dictated by the zeta potential of the system
- Chemical factors relating to the liquid-particles interactions
- Physical (hydrodynamic) factors relating to liquid-particle interactions ("shearing")
- Temperature

DETERMINING FLOWABILITY

The flowability of most mineral and metallurgical slurries can be determined by quite simple rheological measurements. Depending on requirements, various types of instruments can be used for rheology testwork. In principle, these instruments measure the torque exerted by the viscous drag of a fluid in a container ("cup") on a sensor (spindle, vane,

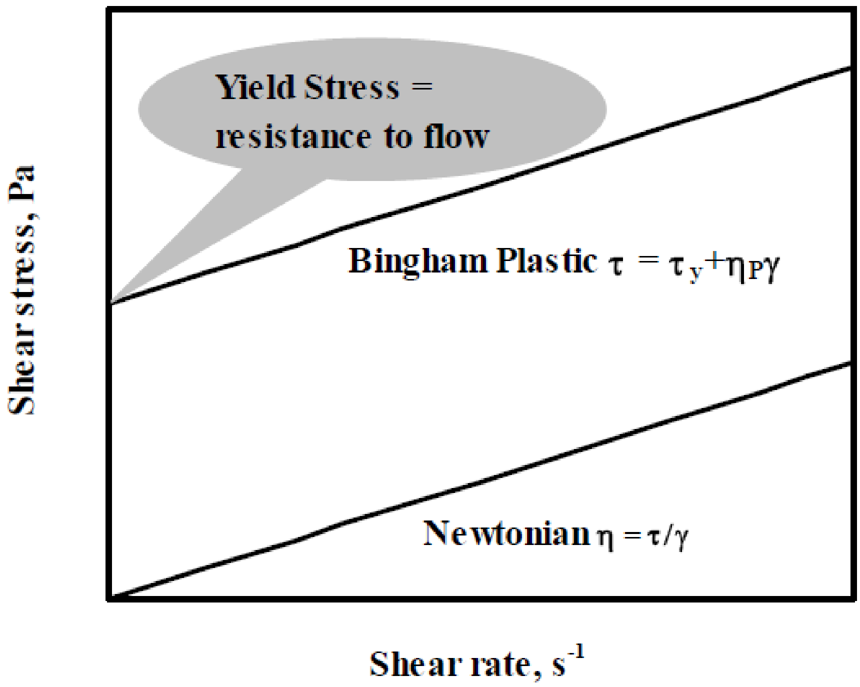

Figure 1 Bingham Plastic vs. Newtonian Flow Behavior

bob, etc.) when subjected to various rotation speeds. When the resulting data are represented as a plot of shear stress versus shear rate, flowcurves are obtained. The flowcurves illustrate the response of slurry samples to "process-like" experimentally-simulated flowing conditions. Different types of instruments, such as concentric cylinder rotational viscometers, vane viscometers and other techniques and their pros and cons related to testwork for generation of rheological data are discussed elsewhere [7 to 13]. The rheological properties of unstable (fast settling) slurries cannot be determined by using conventional viscometry. Instead, the torque response is evaluated using mixers of various geometries [8]. A succinct application example is provided in this paper.

APPLIED RHEOLOGY TESTWORK

The concept of applied rheological testing is common to most process industries, including mining and metallurgy. Important factors that determine the quality of rheological testwork results include [8]:

- Understanding of rheology fundamentals;
- Generation of unambiguous test-data;
- Interpretation of the results and elaboration of design criteria.

The applications of rheology can be divided into several categories. "Application Groups" that are relevant to hydrometallurgical processing include:

- Elaboration of process design criteria
- Equipment sizing
- Process control
- Due diligence
- Product characterization
- Miscellaneous applications

Slurry transport studies (i.e. ores, concentrates, process intermediates and tailings) tend to dominate the scene of applied rheology testwork. However, this situation could change in favor of more complex testwork programs and/or new applications. Elaboration of process criteria appears to be a promising application group - for that reason it will be discussed in more detail and exemplified for the case of gold hydrometallurgy.

Our experience suggest that most of the practical flowability situations occurring in mineral and metallurgical processing, including hydrometallurgy can be investigated by a study of yield stress versus solids density. Figure 2 illustrates yield stress versus solids density relationships for three typical process slurry groups, selected for the purpose of exemplification:

- Pastes and laterites - the least flowable
- Common process slurries (leach pulps, thickener feeds and underflows, etc.)
- Fairly typical gold process slurries - the most flowable

It should be pointed out that the dependencies shown in Figure 2 are not an attempt to propose a classification. The yield stress values of slurries belonging to a certain group may in fact fall significantly outside the range of values exemplified. Typical in that sense is the behavior of jarosites, which can behave as pastes at solids densities as low as 60% (Table 2, [9]). For the case of gold and laterite ores, feed variability (i.e. the mineralogy of the ore and gangue minerals) is the main factor that affects flowability. One of the major aims of process rheology is to identify and address these situations. In order to achieve that, the Critical Solids Density ("CSD") needs to be determined. Conceptually, "CSD" is the solids density that corresponds to the inflexion point of the yield stress vs. solids density function (Figure 2) and represents the rheologically optimum solids density for the particular slurry in the overall flowsheet. Determination of the critical solids density is generally included in most rheological studies done at SGS, as this parameter is the basis for generating design criteria for process and equipment design, as well as many other applications.

RHEOLOGICAL APPLICATIONS IN GOLD HYDROMETALLURGY

The example presented below discusses aspects that are specific to the processing of gold ores that generally contain variable amounts of fine materials such as clays. The capital and operating costs associated with the various gold mill unit operations involving these feed stocks are strongly influenced by the flowability of the slurries involved. Process and equipment design requires knowledge of the rheological properties. That is because flowability influences critical parameters in gold extraction such as leaching kinetics and carbon adsorption kinetics.

Flowability of gold ore slurries can be measured using concentric cylinder viscometry (CCRV). Assigning a rheological model that describes most

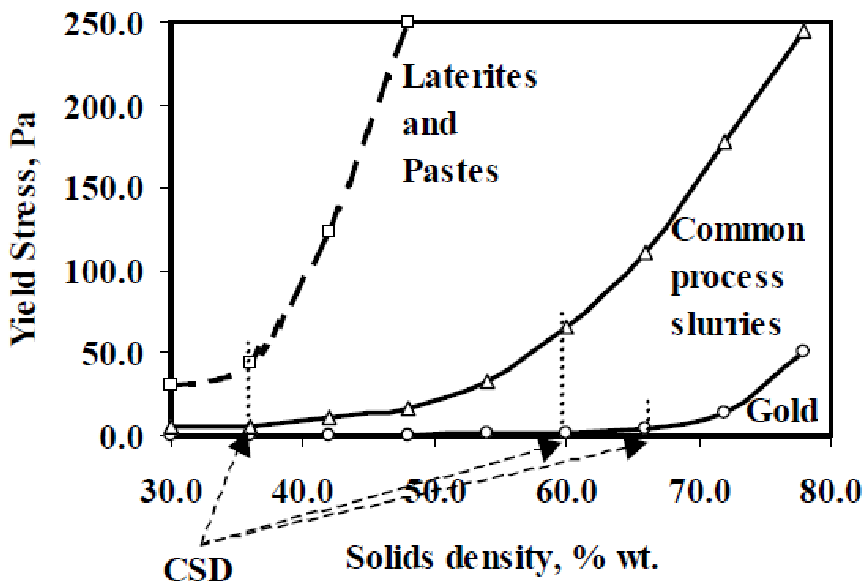

Figure 2 Examples of Process Slurries Flowability Domains

closely the flow behavior of the samples tested quantifies the results of the measurements. The application of the results is based on generally accepted engineering calculations.

The flowcurves illustrated Figure 3 exemplify the comparative rheological behavior of two gold ore samples with quite different flow behavior. Accordingly, one of the samples, when mixed with water produced a slurry that displayed free flowing properties at solids densities as high as 43%. The other sample on the other hand did not flow freely even at solids densities as low as 35%, hence displaying a Bingham plastic behavior.

The initial "optimum" solids density for the first sample, selected from basic laboratory metallurgical testwork was 42%, while for the second sample it was 37%. Only at the very end of those projects was rheology testing carried out, as it was needed to generate equipment design data for screens, thickeners and pumps. The results for the first sample indicated that it was "flowable" at significantly higher pulp densities than the previously selected optimum value. In fact, it was substantiated that this sample could be brought into a well-flowing state at up to 48% solids, by the simple shearing effect of normal processing. The second sample, on the other hand, produced slurries that resisted flow to the extent that processing was impossible above 33% solids. Accordingly, even though the laboratory metallurgical testwork data were correct, they did not yield the optimum solids densities for continuous flow in the pilot plant. This could have resulted in poor pilot plant operation and non-optimized full scale plant design. Relevant illustrations are provided in Figure 4, which show the practical processing domains for the two samples, in fact clearly delimitated by the critical solids densities (i.e. CSD values of 33 and 48%, respectively). The above considerations illustrate the necessity of producing timely rheology data. To summarize, gold recoveries and/or mill throughput can be severely impaired by even a slight decrease of process slurry flowability due to operation above the critical solids density. Therefore, significant process benefits can be gained by its determination.

Table 2 Examples of Yield Stress Values

Sample ID	Solids	Temperature	Yield Stress
	% by weight	°C	Pa
Laterite ore	30.3	26	26
	36.1	26	56
	40	26	119
	40.6	153	17
	40.9	210	3.5
Jarosite paste	55	24	40
	60	24	100
	65	24	150
Gold CIP	55	32	4.5
	73	32	12.8
Flotation tailings blend	55	22	9
	60.4	22	16
	65.3	22	26
Thickend gold tailings (Paste)	76	20	77
	77.5	20	110

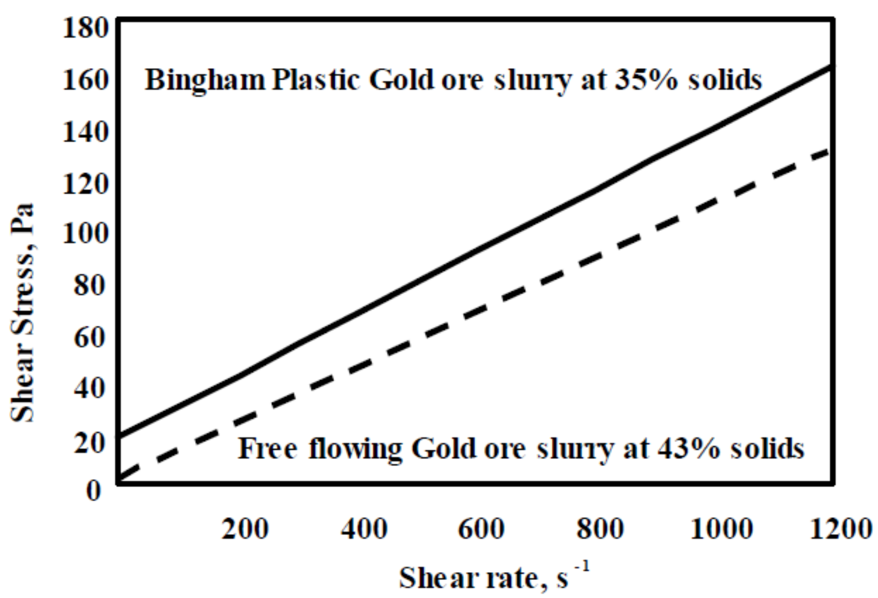

Figure 3 Comparative Flowcurves: Bingham Plastic vs. Free Flowing Gold Ore Slurries

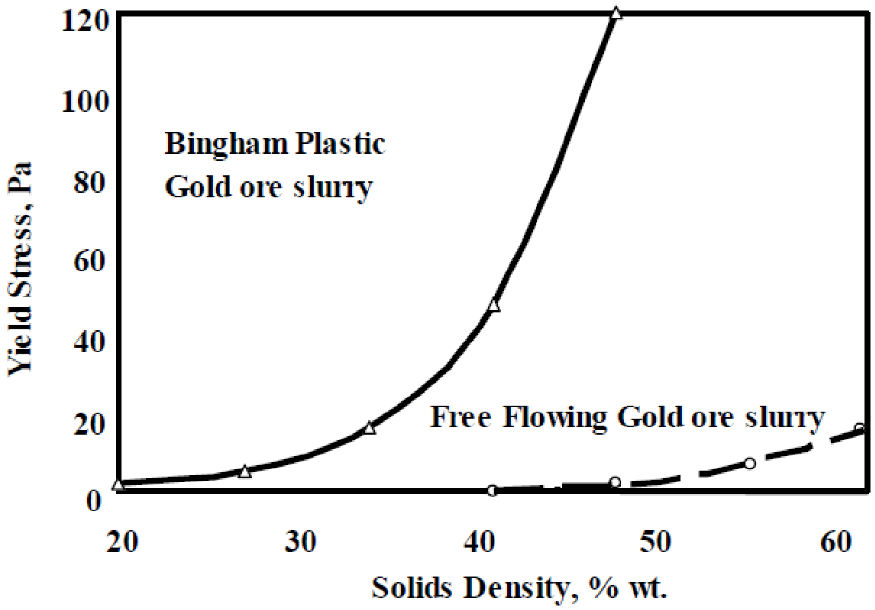

Figure 4 Processability: Bingham Plastic vs. Free Flowing Gold Ore Slurries

ADDRESSING RHEOLOGY PROBLEMS IN GOLD ORE SLURRIES

Under normal gold mill operating conditions, the causes of poor flowability can be traced to any of the following factors or combination thereof:

- Clay fraction in the "as is" ore too high
- Over-grinding
- Un-optimized chemical conditions.

Colloidal clays are responsible for the rheological behaviour of several process slurries, including gold ores. Given their very small particle size (microns and below), the colloidal particles display a very large surface area per unit weight. These materials also generally exhibit net negative charge because of cation substitutions in the crystalline structures of the clay. Cations from solutions are attracted to these negatively charged particles, allowing ionic exchange with a solution to take place. For example, calcium ion exchange (onto the particle surface) will prevail when competing with sodium, and it can cause particle bridging and subsequent flocculation ("swelling"). The net result is an increase of the yield stress, which in turn decreases flowability. This can impact the leaching process chemistry, as an increase in viscosity of the slurry results in a decrease in the rate of oxygen mass transfer, which in turn reduces the rate of gold leaching. The rate of adsorption of gold onto carbon is also strongly dependent on yield stress. The most common means of controlling the affected operations include optimizing the process water chemistry in terms of operating pH range and source of alkalinity. The pH optimization is beneficial because it stabilizes the slurry through its direct influence on zeta potential - so the slurry will not settle out, yet it will still be (reasonably) flowable. The source of alkalinity influences is also important in that lime may not be suitable when treating rheologically difficult ores, especially when poor rheology is due to increased clay content. So, alternatives such as sodium hydroxide or sodium silicate are often looked at, as these reagents display dispersing capability that can partially offset the flocculating effect of the calcium hydroxide. While expensive compared to lime, these reagents have the added benefit of reducing the formation of scale in the mill equipment.

Flowability is often sensitive to the properties of the individual ore-body samples. Therefore, whenever possible, ore blending could be one of the low-cost options available towards optimizing process slurry rheology.

The considerations outlined above address the flowability problem in the most conventional way, i.e. involving relatively minor and inexpensive measures. Radically improved results can be obtained however by using rheology modifiers, commonly known as "dispersants". Organic and polymeric materials such as sodium lignon sulphonate, sodium polyacrilate and polymetacrilate, polyethylene oxide, etc. are examples of reagents that are widely used for that purpose. Reagent screening should make provision for testing of various polymeric additives, as they display fairly large molecular weigh domains (i.e. ranging from about 2,000 to 20,000). Under constant process conditions (grind, chemistry, etc), the optimum dosage level of different additives varies in function of charge density and molecular weight. Overdosing can led to an increase in yield stress, due to charge-reversal.

Clearly, optimization is required in order to produce data suitable for comparative economic calculations, in order to provide a cost/ benefit analysis. That optimization can be carried out exclusively through rheology testwork.

RHEOLOGY TESTWORK PROGRAM CONSIDERATIONS

Rheology testwork for gold projects can serve two main purposes:

- To improve the profitability of an existing operation, and
- As part of metallurgical testwork programs on new deposits or ore bodies.

As far as the existing operations are concerned, the testwork should generate data in relation to the actual operating requirements. Since optimized rheological conditions minimize energy consumption, the testwork results influence directly the bottom line of the operation. This is always desirable, but particularly within the context of depleting gold reserves and constantly increased energy costs encountered in the process of extraction.

Common to the optimization of existing operations as well as work on new projects is the fact that rheology testing provides maximum benefit if carried out during the early stages of the metallurgical testing program. This is contrary to the traditional approach in such this activity is often left to the feasibility study and piloting. Suggested additions to conventional test programs normally applied for gold ores are listed below:

- Rheological optimization of grind size and solids density in parallel with the exploratory bottle roll testing. Determination of a preliminary critical solids density range is the main objective of this testwork stage.
- Confirmation through agitated tank testing based on the results of optimization tests. It should be pointed out that improvement in recoveries under agitated leach conditions compared to bottle roll results could be indicative of a flowability related problem.
- Altered rheology testing (i.e. to increase flowability) can be carried out at this stage if required.
- Solid/liquid separation testing and subsequent rheology testing for tailings pumping. Since solid/liquid separation and tailings disposal data are critical, a preliminary decision on the project viability (including the necessity of further testwork) can be made, based on the results produced up to this stage.
- If CIP or CIL processing is selected, modeling of these processes can be conducted, based on kinetics and equilibrium loading of gold cyanide on carbon under different rheological conditions, to generate optimum plant design parameters, by using tools such as the Nicol - Fleming Model [14]. The data produced up to this stage should be sufficient for pre- feasibility purposes.
- Pilot plant operation should include confirmatory rheology testing, to ensure data consistency with regards to ore variability as well as to changing slurry properties due to process solution recycling. The data produced during this stage should be suitable for feasibility study.

THE ADVANTAGES OF THE PROPOSED TESTWORK APPROACH INCLUDE:

- Conducting rheology testing in parallel with the more traditional test items allows for the simultaneous optimization of the grind size and solids density from both physical handling and extractive metallurgical perspectives.
- Early rheology testing eliminates the possibility of negative surprises, in that the rheology test results will reveal whether or not the ore sample(s) tested can be processed using well-established, commercial unit operations and equipment.
- Furthermore, the necessity, opportunity and possibility of correcting the flow behavior will be established from the incipient stages of the project. For example, base line rheology test results may indicate whether a deposit (sampled and tested) is "hopeless" or a "great prospect" from the point of view of commercial processing.
- An added benefit of using an entirely physical approach such as rheology measurements is the fact that it reduces the analytical bias, which can be considerable, especially at low gold content and high nugget effects.
- The use of applied rheology can significantly reduce the cost of testwork by avoiding testing under incorrect conditions.

RHEOLOGICAL PROCESS CRITERIA CONSIDERATIONS

The rheologically valid process criteria encompass flowability characteristics of slurries that include practically all mill streams from grinding to tailings. Previous Lakefield work [9] provides examples of rheological parameters values/ranges that are common for the case of gold processing slurries. Updated knowledge gained in the meanwhile confirmed that in the case of a standard CIP or CIL flowsheet, it is possible to pre-determine with reasonable accuracy the carbon adsorption kinetics based on the yield stress of the pulp. Accordingly, slow kinetics should be expected at yield stress values exceeding 10 Pa, intermediate rates at yield stress values ranging from about 5 to 10 Pa and fast kinetics below 5 Pa (preferably ranging from 1 to 3 Pa). The solids densities associated with these values range however from 30% to over 60% by weight. It is only rheology testwork that can produce pertinent data that can be used to determine the critical solids density. That value should not exceed the metallurgically determined optimum. Conversely, yield stress values that are extremely low may render the respective process slurries free flowing. While this property is generally desirable, it may have a downside, in the sense that settling ("sanding-out") may occur, leading to increased mixing energy costs and higher carbon attrition. The intrinsic value of rheology testwork is that the selection of critical solids density ranges that are relevant for commercial applications can be determined, and the accuracy of scale-up is unmatched by any other standalone metallurgical testwork technique (at same complexity/cost levels). The use (and value) of rheology data can be further extrapolated, in the sense that they can be used to analyze the process options. For example, the possibility of using a resin instead of carbon may appear more feasible if a gain in rheological properties is obtainable.

In summary, there is significant potential for using rheology data to assist in the selection of process design criteria. The author believes that applied process rheology could be an important tool for future developments in the extractive metallurgy of gold.

EQUIPMENT SIZING

Applications include slurry transport (pumps and pipes), thickener rakes, heat exchangers, mixers and others.

SLURRY TRANSPORT

Defining optimum pumping conditions for slurry transport is a typical rheological testwork task that provides direct design criteria. Typical examples include pumping of concentrates, beneficiated products and tailings for disposal. The confidence in the quality of bench scale tests results (produced by concentric cylinder and vane viscometry) is high. Unless highly difficult slurry samples are tested, in conjunction with large capital expenditure projects, the need for additional data, produced by large scale testing (i.e. pump-loop) is generally negated. Extensive exemplification of these aspects is provided in previous works [8 and 9]. Typical friction pressure loss profiles for a gold mill tailings stream are illustrated in Figure 5. The profiles identify two critical parameters: the solids density of about 76% (CSD that is) and a fluid velocity of about 2 m/s, which in fact define the optimum pumping conditions.

DETERMINATION OF RHEOLOGICAL PROPERTIES DURING MIXING

While the rheological behavior of stable slurries can be investigated through concentric cylinder or vane viscometry, the situation is more complicated with fast settling slurries. However, data are still needed for these slurries, mainly for mixing applications. The relevant SGS test protocol is based on torque measurements carried out using precision mixers. These instruments measure the torque required to maintain a given fluid in suspension, at a certain rotational speed of the impeller. In the particular case of settling slurries, adequate agitation is generally defined as such when both mixing and homogenization take place concomitantly, so the particles are maintained in suspension. Various mixing configurations are tested by using impellers of different geometries. The power-torque data are produced according to a Standard Operating Procedure (SOP) and are plotted into a Newtonian calibration chart, allowing for the comparison to fluids of known viscosity ("standards"). The correlations allow for further investigations of rheological behavior of the sample tested under conditions characterized by a certain range of Reynolds number values and subsequent power number correlations. An example of power-torque mixing curve is illustrated in Figure 6.

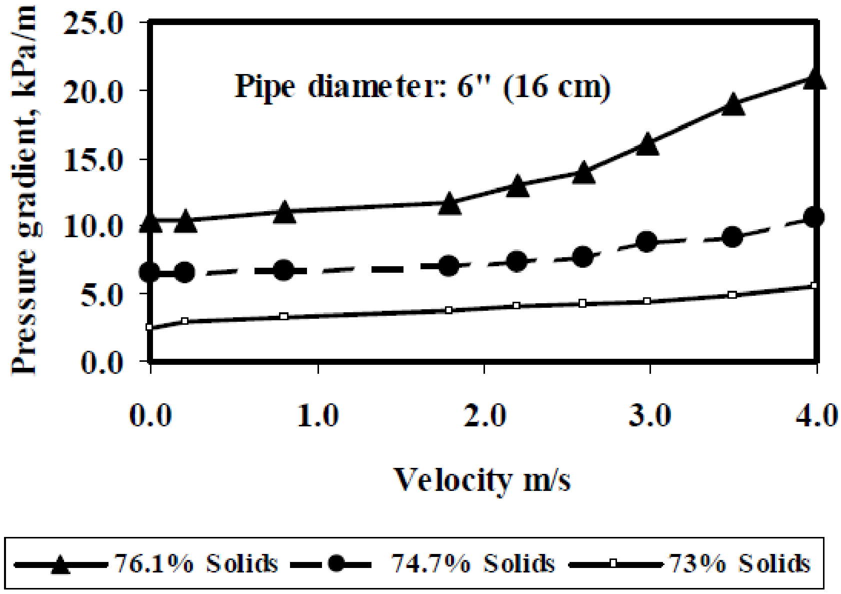

Figure 5 Friction Pressure Loss Profiles

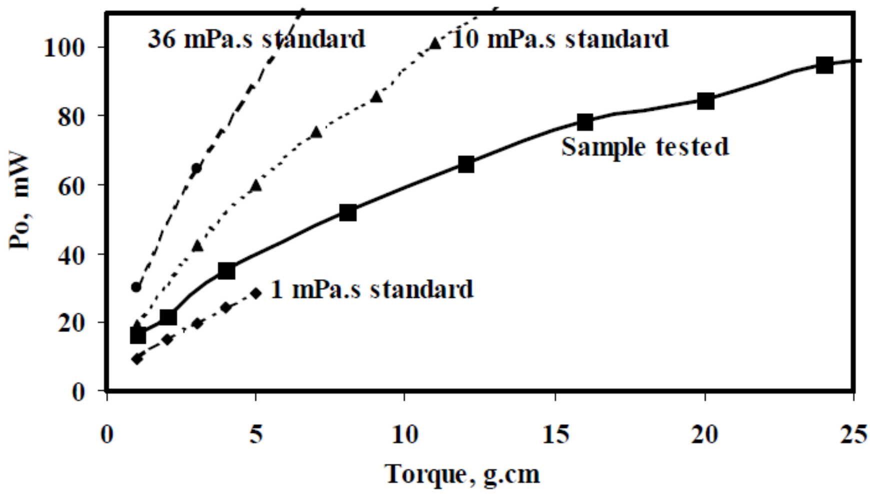

Figure 6 Example of Power-Torque Relationship and Comparison vs. Calibrated Fluids, mPa.s

DUE DILIGENCE

Due diligence applications can be related directly to the process and equipment design considerations discussed earlier. Relevant in this context is the fact that early rheological testing in case of gold projects can be indicative of their commercial success potential. Rheological studies on other projects than gold can also have due diligence value. For example, testwork data produced through commercial testwork carried out on laterite slurries originating from several deposits around the world allowed for the comparative determination of their main rheological properties [8]. Accordingly, lateritic ore slurry samples were identified as a type "M" and a type "I". Type "M" lateritic ore slurries display relatively poor flowability, and in general may not flow readily at solids densities as low as 29% wt., i.e. characterised by yield stress values of 30 Pa or more. Type "I" lateritic ore slurries typically display excellent flowability at solids densities as high as 42% wt., i.e. characterised by yield stress values of 30 Pa or less. Certain lateritic ores form slurries that display rheological properties intermediate between types "M" and "I". Comparative flow curves at ambient and elevated temperatures are illustrated in Figure 7. High temperature behavior in terms of yield stress reduction is illustrated in Figure 8. The flowability of these slurries can be improved by ore-blending, optimising the salinity of the process water, controlled dilution during preheating, and the use of rheological additives [15]. These properties relate directly to laterites processability and ultimately decide project viability.

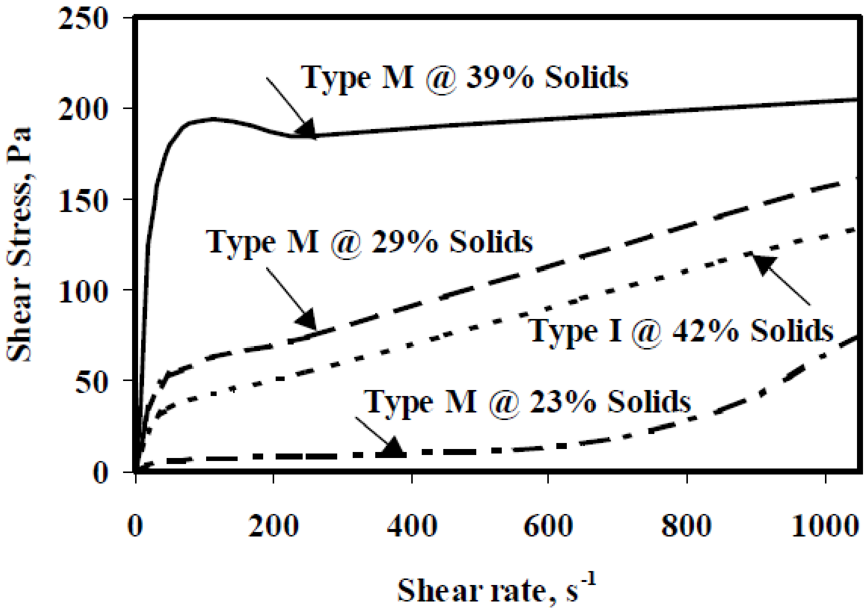

Figure 7 Comparative Flowcurves - Laterite Slurries Types "M" and "I"

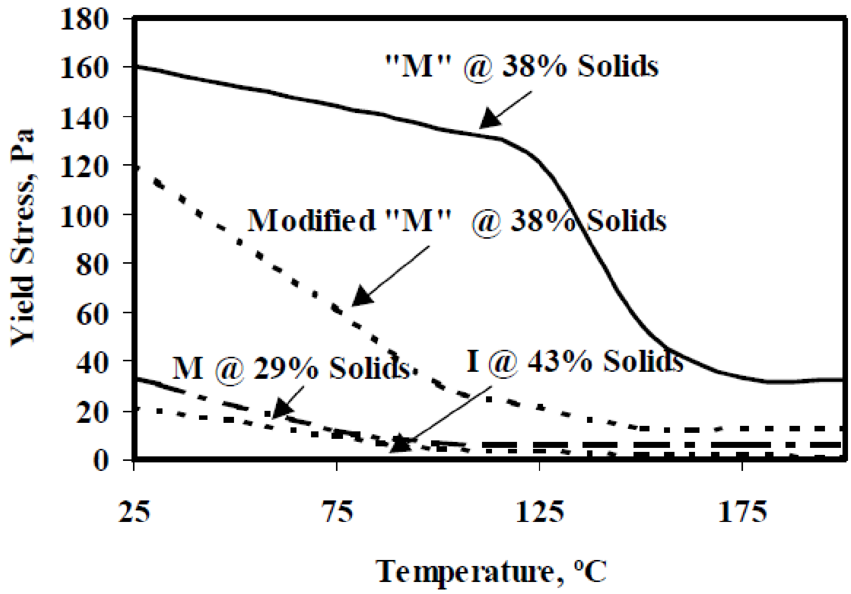

Figure 8 Effect of Temperature on Laterites Flowability

POTENTIAL APPLICATIONS

Heat exchange: high temperature rheology data are needed for the design of the heat exchangers, autoclaves, heated holding tanks, etc.

Process rheology and deposit mapping: allow for the blending of the ore, hence creating the pre-requisites for low cost flowability optimization throughout the plant.

Product Characterization: hydrometallurgical processes commonly treat intermediate products such as precipitates, sludges, high clay content fractions, etc. Recent Lakefield work [8] substantiated that these materials display transient properties whereby their solids content as well as the specific gravity of the respective solids change during the processing. This affects the representativity of process samples, and hence the accuracy of the data gathered. Lack of awareness of this phenomenon can lead to erroneous mass balances, generation of incorrect process design data and chaotic process conditions in operation.

Process control: while applications are in relative early stage of development, they present significant upside potential. This is because process control translates directly into the bottom line of the mill balance sheet, through optimization of energy utilization in unit operations. The rheological concepts outlined above are suitable for the elaboration of control strategies for hydrometallurgical operations.

FUTURE TRENDS

- Altering the rheology of the process slurries as to enhance their flowability. Possible areas of application include laterite processing, gold extraction, paste production, etc.
- The renewed interest in hydrometallurgical processing of sulfidic nickel bearing ores will create the need for rheological data, as gas transfer in slurry systems is rheology-dependent. The rheology of these systems is greatly influenced by the size and particle size distribution, such as in the case of low-temperature oxidative processes. In addition to the size-fraction effect, the presence of molten sulfur in these systems could render them rheologically complex.
- The need for increasingly pure process intermediates and final products could lead in some cases to requirements for the production of precipitate and crystalline products displaying sub-micron particle sizing. Therefore, the rheology of these nano-particle-based slurries could be an important field of study and testing in the future.

CONCLUSIONS

- Applied rheology testwork is needed because flowing properties influence the economics of continuous hydrometallurgical operations involving process slurries
- Rheology studies allow for the elaboration of additional process design criteria for gold, laterite and other extraction processes.
- Including rheology into the metallurgical testwork program from its incipient phase provides the added benefit of due diligence value.

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