bulk solids handling Volume 1 Number 3, September 1981

# Evaluation of Basic Slurry Properties as Design Criteria for the Marconaflo System

**W.N. Sims, R.R. Beebe, A.K. Andersen and A.K. Bhasin, USA**

**Die Auswertung der grundlegenden Slurry-Eigenschaften für die Anwendung des Marconaflo-Verfahrens**
**Evaluation des propriétés de base des boues en tant que critères de conception du système Marconaflo**
**Evaluación de las propiedades básicas de líquidos pastosos en los criterios de diseño para el sistema Marconaflo**
マーコナフローシステムの設計規準としての基本的スラリ特性評価
基本泥浆特性的鉴定作为Marconaflo系统的设计准则
تقيم الخصائص الأساسية المميزة للملاط كمنهج تصميمي للنظام ماركونافلو. بقلم دبليو. ان. سيمز.


## Summary

In developing a means of slurry handling iron ore pellet feed to and from ocean vessels, Marconaflo found it necessary to establish a slurry laboratory to develop the technology and hardware. This paper is a review of the principles involved in such developments and the importance of testing the principles for the commercialization of slurry systems. The data, as presented, is applicable to a wide range of materials, many of which have been subject to comprehensive testing and evaluation in the laboratory and subsequently handled on a commercial basis as the result. Most references to the Marconaflo system have been deleted from the text of the paper unless there is absolute need for such identification.


## 1. Introduction

The Marconaflo system is a body of technology comprising specialized equipment and related procedures for handling, storing, loading, transporting and discharging bulk mineral commodities as slurries. Since the system is designed to accomplish specific objectives when dealing with a particular mineral slurry, it is necessary to characterize certain slurry properties to provide design criteria. Bench-scale, pilot-scale and full-scale experiments were employed in developing the system, and routine procedures are now available for pre-design testing.

## 2. The Slurry Transportation Concept

Since the early 1960s, Marcona has been studying basic slurry handling technology as applied to transportation systems for bulk mineral commodities, especially iron ore concentrate slurries [1]. Early in these studies, it was recognized that well-established principles of slurry pumping as practiced in beneficiation plants could be adapted readily to integrated slurry transportation systems, and that the emerging commercial long-distance slurry pipelines could complement the total system, bringing products to loading ports from distant mines, and taking products from discharge ports to processing plants. In order to realize the potential advantages of the total slurry system, it was necessary not only to adapt existing technology, but also to develop new techniques appropriate to unique structural limitations of ocean-going carriers, and usable under the stringent economic limitations of the international bulk commodity trades. To accomplish these tasks, it was required that the first mineral commodity of interest to Marcona, high-grade magnetite pellet feed, be characterized as acccurately as possible in terms of its intrinsic properties and the interactions of these properties with the physical elements of the slurry system.

### 2.1 Types of Slurry Systems

The slurry concept properly integrates production, transportation and reception segments of a mineral delivery system into a logical and workable whole, automated to the optimum degree and minimizing intermediate non-slurry handling steps. Whether the *vessels* under consideration are storage ponds or bunkers, the holds of a ship, rail cars, or whatever, it is evident that a given slurry system might be:

— Slurry load and slurry discharge,
— slurry load and dry discharge,
— dry load and slurry discharge.

System requirements are different in each case, hence design criteria are different, and the critical slurry properties requiring evaluation may also be different.

### 2.2 Criteria for Slurry Systems

A slurry of fine mineral particles in water can be contained in a vessel in one of only two modes, namely as a true suspension, or as a settled mass with interstitial and supernatant water. Maintenance of a true suspension requires some means of constant agitation, which in practice places such systems outside the economic area of interest for large-volume, low value mineral commodities. The settled mass remains as the only mode to be considered, hence slurry system criteria must take account of:

— Sedimentation rate of the solids,
— ultimate density under static conditions,
— chemical and physical influences on ultimate density,
— decantation rate for removal of supernatant water,
— exudation and drainage rates for removal of interstitial water,

W.N. Sims, R.R. Beebe, A.K. Andersen and A.K. Bhasin, Marconaflo Div., McNally Group, 5296 South 320 West, P.O. Box 7660, Salt Lake City, Utah 84107, USA

Presented at the Conference on the Hydraulic Transport of Solids, December 2, 1980, London, organised by the Institution of Mechanical Engineers, Birdcage Walk, London, England

Correspondence to be addressed to: R. Bromley-Martin, Babcock Hydraulic Handling Ltd., 10/18 Spurgeon Street, London SE1 4YP, England

— chemical and physical effects on the containing vessel (corrosion, structural stresses, instability),
— physical strength of the settled mass (resistance to physical breakage, decompaction and reslurrying, tendency of the mass to bridge or to stand at steep angles).

Beyond these factors, of course, are the normal hydraulic charateristics which must be considered in design of input and output pumping systems.

Logic leads to the conclusion, substantiated by over five years of experimental and commercial experience, that the slurry load-slurry discharge system is the most challenging to design. Fig. 1 illustrates the basic elements of this system [2]. The broad criteria which such a system must meet can be discussed in terms of the unit operations of loading, containment and transport, and discharging. Magnetite concentrate used as pelletizing feed provides a convenient and relevant example to illustrate these operations.

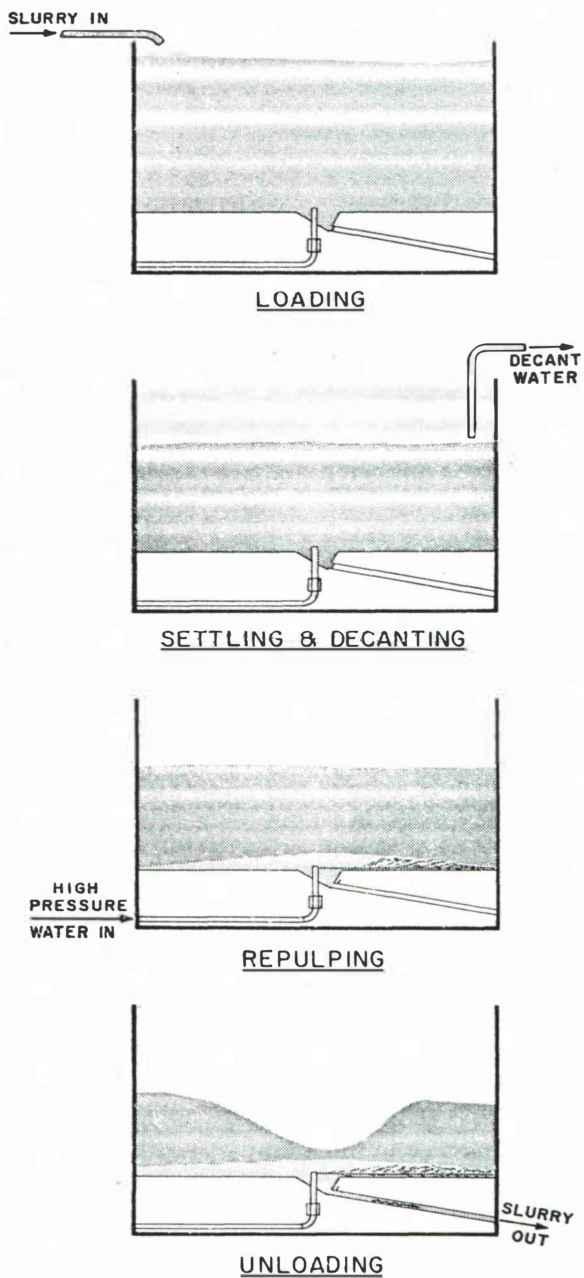


Fig. 1: Basic elements of the Marconaflo system

### 2.3 Loading

A slurry of fine magnetite is quite fluid up to 80 % solids or more by weight, and can be loaded into a vessel by pumping even at this density. As a practical limitation, however, the slurry must be reclaimed from some intermediate vessel — a thickener, an agitator, or a bunker, for example — hence the loading density will rarely be higher than 70 to 75 % solids. For loading at great distances, as into a vessel moored several miles at sea, lower optimum pulp densities may be selected as determined by pump capabilities, power costs, vessel demurrage costs, and capital considerations. For a vessel at sea, loading sequence must also be considered, since the vessel has specific structural characteristics and deballasting capabilities.

Once slurry is in the vessel, afloat or ashore, it is desirable that the mass be dewatered to a maximum degree consistent with the time available, and in a manner which will avoid losses of solids and disposal of water contaminated with slimes. Magnetite concentrate will settle quite rapidly to a density of 83 to 85 % solids, leaving an essentially clear supernatant fluid which can be decanted and discarded or recycled to the loading point. Multiple fill-settle-decant cycles may be used, and chemical additives can be used to accelerate sedimentation, but the flocculated structure which results may actually hamper rapid achievement of maximum density.

Hydrostatic head can also be expected to influence ultimate density, but under static conditions, the ultimate density of the settled mass will approach a constant figure for a particular solid specific gravity, particle size distribution, and physico-chemical environment. Any motion of the vessel, transmitted to the mass, will encourage exudation of additional water and a concomitant increase in density. In shore-based vessels, this effect can be achieved with mechanical or electrical vibrators, but these vessels are well-damped and in practice the energy input required would not be justified by the increased storage capacity achieved. In ocean-going vessels, however, the effects of vibratory and rocking movements inherent in the propulsion system and ship's motions have important and far-reaching consequences to the design and performance of the slurry system.

### 2.4 Containment and Transport

In general configuration, vessels for containment and transport are basically similar, incorporating some or all of the following features:

— The containment vessel (tank, bunker, ship's hold, rail car, etc.),
— dewatering appliances (decanting arms or trunks, drainage panels),
— means for discharging (access for conventional unloading equipment, reslurrying and related equipment).

The vessel must be large enough to contain the desired quantity, and strong enough to sustain the required loads. Shore-based vessels would ordinarily be designed to withstand the loads exerted by the slurry at its maximum density, assumed to be acting as if the mass were completely fluid. For ocean-going vessels, the situation is much more complicated in that three fundamental problems must be considered:

— Compartmentation to provide sufficient cubic capacity well-disposed in relation to the overall design,

— strength, including longitudinal strength as a whole and local strength at the slurry compartments. Static and dynamic strength must be considered, and
— stability and provision for free-surface effects.

Dewatering appliances can be as simple as hose eductors, or as elaborate as automated floating arms capable of simultaneously decanting water while the vessel is being loaded. Where the solids drain freely, drainage panels can also be used to conduct interstitial water to pumps for discharge. Whatever means are used, the dewatering function should be rapid, positive and proof against loss of solids.

Vessels which are to be discharged by Marconaflo techniques may be provided with access from below for installation and maintenance of the slurry systems, including the high-pressure water supply and motive power supply for the jets used in slurrying. The access space also serves for installation of sumps, pumps and pipelines for removal of the reslurried material. The floor of the containment space proper must have openings for the jets and their sumps, and the number, size and disposition of these openings will be largely determined by the characteristics of the settled material to be reslurried. Fig. 2 is a schematic representation of such an installation aboard ship and ashore.

### 2.5 Discharging

Slurry discharge of a dense, compacted mass of magnetic concentrate is made possible by the use of specially-designed jets which are rotated just above the bottom of the containment vessel. A stream of high-pressure water sweeps out undercutting, decompacting and reslurrying the settled mass. As the jet stream continues to undercut the mass, the compacted material begins to break, cave in and fall into the path of the high-pressure water. Decompaction by the water stream is thereby aided and accelerated, and pulp density of the reslurried material entering the sump increases. As water delivered to the working face flows back to the sumps, it reslurries and carries back more fine solids, so that the sumps receive both particulate material and broken lumps of compacted solids. The sumps are protected with gratings or screens against entry of lumps too large for the downstream pipelines and pumps; the sumps can also be fitted with small auxiliary jets. The settled mass, progressively excavated from below, is thus decompacted and reslurried, and finally pumped away from the vessel.

## 3. System Design Requirements

For economic reasons, each component element of a slurry system should operate at the highest pulp density which can be achieved in the correct relation to the steps in the process which precede and follow it. Overall, an efficient system design must accomplish this at minimum capital and operating costs with maximum reliability. Available technology can frequently be used to design certain system elements, based on routine data for slurry material characterization. For other elements in the system, special tests are required to evaluate material and slurry properties critical to the design. In order to identify the areas where special tests may be required, it is desirable to set out the design requirements and attempt to relate them to basic slurry properties which may or may not be already understood.

### 3.1 Pumping and Pipeline Flow

Ideally, a slurry for pumping through a pipeline should exhibit high pulp density, low viscosity and low critical velocity. Solid properties which control these slurry properties are specific gravity, maximum particle size, particle size distribution, particle interactions due to electrochemical or magnetic phenomena and hardness (resistance to degradation). Data on these variables can be assembled rather readily, and many operating companies and engineering firms now have computer programs to correlate basic data and synthesize pumping requirements and line configurations.

Although high pulp density is a logical pumping design goal, high volumetric loadings may not be acceptable, since the system will ordinarily require restart capability following unprogrammed shut-downs. Line configuration for long overland lines must avoid slopes which exceed the angle of repose of settled solids in the pipe, otherwise solids will slough into low spots during outages, plugging the line.

Certain line configurations go beyond our capabilities to calculate the system's responses, and even strain the simulation abilities of computers. Examples of this include the steeply rising portion of a submarine line where it joins a mooring buoy, and the floating slurry hose which connects the mooring buoy to the slurry ship. Large-scale simulations of these situations were used to confirm calculations and computer projections.

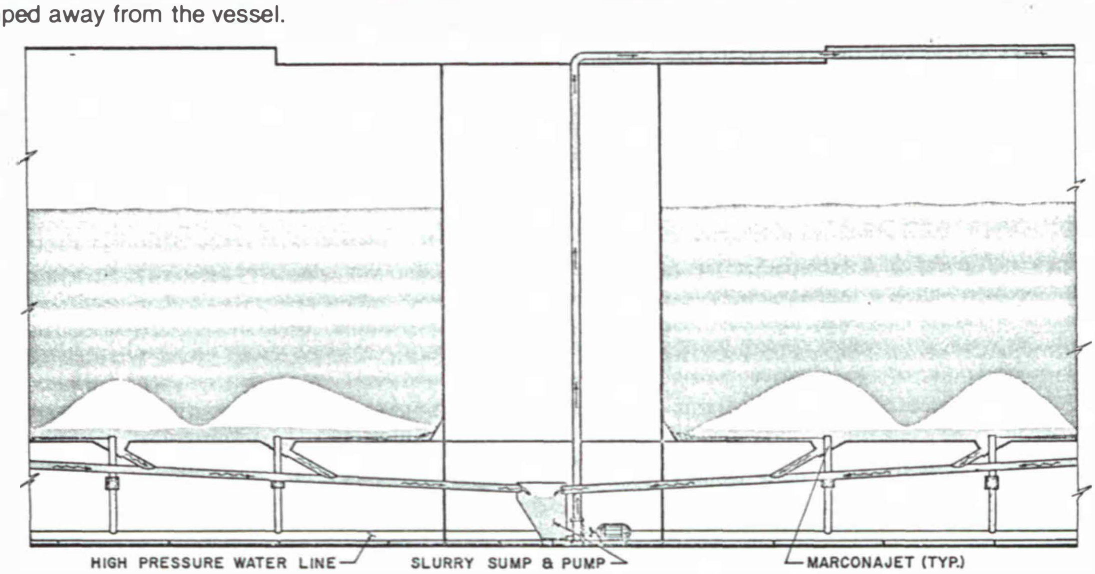


Fig. 2: Marconaflo system aboard ship

### 3.2 Settling and Dewatering

In dilute suspensions, fine magnetite particles settle freely and at high rates. Even with solid concentrations over 20% by volume, a magnetite pellet feed slurry will settle quite rapidly, leaving an essentially clear supernatant liquor. While rapid settling can pose a problem in pump and pipeline design, this property is highly desirable overall, as it minimizes the time necessary to fill vessels to maximum capacity. Flocculation by means of chemical additives or magnetization can be used to accelerate sedimentation of fine particles and clarify the supernatant, but the flocs themselves entrap water and diminish static compaction.

As a magnetic slurry, at perhaps 70% solids by weight, is loaded into a vessel, the solids will immediately begin to settle. Since the slurry is well-mixed and already in the hindered-settling range, there will be relatively little opportunity for the particles to become segregated by size. As the mass begins to compact and the settling slows, hydrostatic pressure will continue to exert some influence, but if the vessel is stationary, equilibrium will shortly be reached. The mass below the supernatant layer will then be at 83 to 85% solids, and will remain so indefinitely unless vibratory or translational motions transmit energy into the mass, permitting the particles to migrate into a more compact relationship. This process causes water to be exuded from the mass, and ultimate densities of 93% solids or more can be reached.

In the containment and transportation phase, an efficient system depends upon high pulp density, but this can only be realized if the excess water can be removed from the system rapidly and efficiently. Magnetite pellet feed is not only fine, but also has a broad size distribution, hence plenty of fine particles are available for the compaction and exudation processes. These same fines, however, would work against any attempt to remove water through drainage panels, so for systems involving fine solids, decanting methods alone are used. In dealing with coarser solids, especially where extreme fines may be absent, decantations will do only part of the job, and exudation will not play a significant role. In such systems, gravity drainage systems are installed if high densities are required.

Whatever water removal system is used, it must be designed to minimize loss of solids. While these considerations are probably less critical with magnetite slurries than with almost any other material, they must be recognized and dealt with as part of any overall system design.

### 3.3 Dynamics of the Settled Mass

Fixed installations to contain settled slurry may be tanks, ponds or bunkers, but in any of these, the principal structural design requirement is that the structure is capable of supporting the slurry load. Since movement of the container is not contemplated, and since energy input to aid exudation of water is not generally used, conditions of dynamic loading will not exceed those that would exist if the slurry, at its maximum density, could behave in a truly fluid manner.

In a portable container such as the hold of a ship, dynamic loads can be caused by fluid slurry, supernatant liqour, and quasi-fluid compacted slurry, either as individual load elements or in very complex interactions with one another. Strain-gauge experiments on a large-scale simulator and on full-scale vessel structures have been used to verify engineering calculations in relation to these problems. Experience has shown that design to accommodate dynamic loading can be readily accomplished without excessive cost or loss of vessel capacity.

### 3.4 Decompacting and Reslurrying

The jets which deliver high-pressure water to decompact and reslurry the compacted mass are the heart of the Marconaflo system, and their design is fundamental to successul operation. The design requirements for the jets themselves fall into two broad areas:

- Capability — size, operating pressure, nozzle design, inlet piping design, drive mechanism, rotational speed, etc., and
- reliability — mechanical strength, startup procedure, maintenance access, speed and flow controls, corrosion resistance, etc.

To operate satisfactorily as part of an efficient system, the jets must be correctly integrated into the overall design. This involves choices regarding number and size of jets, pressure and flow required, drive mechanism (high-pressure water, hydraulics, electro-mechanical), water and working fluid access, slurry piping and pump locations, frequency of use, degree of reliability required, capability in hazardous or extreme working conditions, and so on.

The nozzles are of a patented design to insure that turbulence is removed from the water and that a highly integrated jet stream is created to maximize the effective range of the stream and to best utilize the energy of the stream.

### 3.5 Discharging

Whilst it is tempting to consider the job done once the difficult decompacting and reslurrying functions are accomplished, the designer must consider the total commodity delivery system, and it is only successful when the commodity is delivered to the point of use. The discharging portion of the system must be designed to handle the correct tonnage and volume of slurry, and to accept or protect against surges. The discharge piping and pumps should also be designed with inherent restart capability, especially where access problems might make clearance of plugged lines difficult and time-consuming.

The reslurrying jets may be located in specially-designed sumps to which the slurry can flow, and through which it can exit from the vessel proper. These sumps must offer minimum restriction to flow, yet if they are made larger than necessary, they may act to pond the heavy slurry and encourage plugging. The sumps must also be protected against inadvertent entry of foreign material. Since typical installations involve multiple jet-and-sump units, the output of the various sumps must be gathered to provide steady feeds to the large discharging pumps. To minimize headroom requirements beneath the vessel, it is desirable that the design for these gravity-flow gathering lines to be run at minimum slopes. This requirement dictates careful testing of the open-channel flow characteristics of the reslurried material.

For a particular installation, the number, size and type of discharging pumps will depend upon the capacity demanded of the system, and on the configuration of the vessel. A storage bunker, for example, can be designed in such a way that jet-sump units, disposed about the long axis, can deliver to a large axial gathering pipe or launder leading to a single large discharge sump. In a sea-going vessel, on the other hand, line slopes in the direction of the long axis are limited, hence two or more discharge pump stations may be required.

The slurry system ordinarily includes sufficient pumping capacity to deliver material to the receiving facility (a steel-mill's storage pond, for example), or to the next processing step in the case of in-plant vessels. This capability can be extended where necessary by booster pump stations. The main propulsion engines of slurry ships provide sufficient motive power not only to drive their discharging pumps, but also to provide high-pressure water, hydraulic pressure (if required) and auxiliaries. These ships also carry equipment for fast, positive hook-up to slurry loading and discharging pipelines.

## 4. Testing and System Simulation

At its iron ore concentrating and pelletizing complex in San Nicolas, Peru, Marcona gained extensive operating experience in pumping magnetite slurries. When slurry transportation studies began, programs were instituted at San Nicolas to determine:

1. Normal sedimentation rates and ultimate densities by bench-scale methods.
2. Resistance to slurrying by a scale-model agitator propeller and a laboratory penetrometer.
3. Effect of hydrostatic head in a 35 x 35 ft tank.
4. Effect of chemical additives such as flocculants by bench-scale methods and tank tests.
5. Effect of vibratory motion by bench-scale methods.

Although these tests were necessarily empirical, they served to provide early identification of problem areas where more exact work was required, and they generated the data needed for design of the first test hold aboard a full-scale vessel.

As the slurry development program progressed, a number of tanks were built at San Nicolas, and the first prototype MARCONAJET was tested there. A jet test range was also built, in an effort to evaluate different equipment designs. By mid-1969 it was evident that this program would soon require a facility exclusively devoted to slurry technology; not only for hardware development, but also to investigate the amenability of other bulk commodities to slurry transportation techniques. The test procedure described hereafter are those in use at the Marconaflo Research Center, located in San Francisco.

### 4.1 Bench-Scale Tests

Three routine bench-scale procedures are invariably used to screen and evaluate materials for potential slurry application. A fourth procedure is now being developed and will be added to the routine testing program. All bench-scale procedures are subject to review and may be changed as additional experience indicates that changes are desirable.

### 4.2 Sedimentation

To establish settling rate, static compaction and clarity of the supernatant liquor, a variation of the time-honored thickening test is run in a two-liter graduated cylinder. Tests are made at 20 and 50 % solids, without chemical additives, and additional tests at other densities may be made as required. Data taken include:

— Settling rate,
— mode change points (free settling, hindered settling, compression),
— static compaction,
— condition of supernatant (clarity, solids, pH).

In a concentrated slurry, particles are sufficiently close together to cause the velocity gradients surrounding each particle to be affected by the presence of neighboring units, and the settling particles displace liquid and generate an appreciable upward velocity. Settling under these conditions is termed *hindered settling*. A general equation of settling velocity under hindered settling conditions [3] is:

$$V = \left(\frac{4 g d p^{1+n}(1-\phi)^{2-n}\psi_p(\varrho_b-\varrho_m)}{3 b_1 \varrho^{1-n}\eta^n}\right)^{\frac{1}{2-n}} \quad (1)$$

Where $V$ = Settling velocity (ft/sec)
$d_p$ = Particle diameter in ft.
$\varrho_p$ = Particle density (lb/ft³)
$\varrho_m$ = Medium density (lb/ft³)
$\phi$ = Volume fraction in slurry
$\psi_p$ = Empirical correction factor
$\eta$ = Viscosity of slurry liquid (lb/ft sec)
$b_1$ = 24, $n$ = 1 for Stokes law range
$b_1$ = 18.5, $n$ = 0.65 for Intermediate range
$b_1$ = 0.44 $n$ = 0 for Newton's range

Fig. 3 is a plot of the correction factor against solid volume fractions.

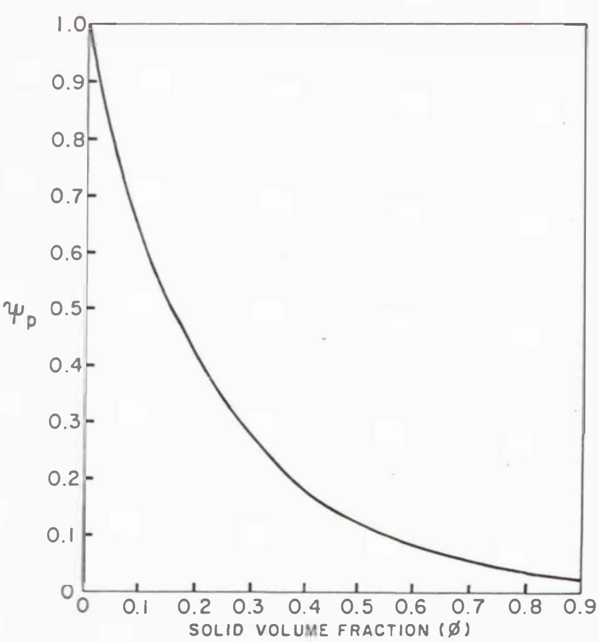


Fig. 3: Correction factor $\psi_p$ vs. solid volume fraction

A general relation between $\phi$ and $\psi_p$ over the entire range of Reynolds numbers has not been determined. Assuming that Stokes law range terminates at Reynolds number of 2.0, the criterion for hindered settling in Stokes law range is:

$$K = \left( d_p \frac{g \varrho_m (\varrho_b - \varrho_m) \psi_p^2}{\eta^2} \right)^{\frac{1}{3}} \qquad (2)$$

If $K$ is less than 3.3, the settling is in the Stokes law range. Table 1 gives the values of $K$ along with measured and calculated settling velocities for slurries of various commodities. These slurries tend to fall in the Stokes law range ($K$ less than 3.3)., however, calculated settling velocities from Stokes law ($b_1 = 24$, $n = 1$ in Equation (1)) are greater than the measured velocities by an order of magnitude. This demonstrates the need for performing settling tests on each commodity for design purposes.

Fig. 4 is a typical graphic representation of data obtained in the laboratory on settling rates and initial compaction. The descending curve represents the nominal interface between settling solids and supernatant liquid with respect to time. There are normally three clearly-defined zones — free settling, compression and compaction. In an ideal curve the free settling zone would have a sharp slope, the compression zone would be of short duration or essentially absent, and the pulp in the compaction zone would be at a high percentage of solids. The ascending curve is the calculated pulp density in the compacted pulp related to time.

### 4.3 Compaction

Routine procedures employing a flash shaker and a small vibrator are used to determine ultimate compaction. A settling pulp is subjected to vibration and motion for successive time periods. Pulp compaction and supernatant clarity are observed at the completion of each period until maximum compaction is reached.

### 4.4 Drainage

To measure the potential for elimination of interstitial water from a settled slurry, samples are placed over screens or filter media sized to prevent passage of significant quantities of solids. Where drainage is appropriate to a particular application, both static tests and tests with the container in motion are conducted. For tests involving motion, the laboratory drainage set-up can be shaken or vibrated by the same apparatus used for compaction tests.

Slurries of small particles at solid concentrations greater than 30 % tend to exhibit Bingham plastic properties and for the purpose of this paper, that characteristic is assumed to exist, therefore the following relationship:

$$\tau = \tau_o + \eta_{pi} \dot{\nu} \qquad (3)$$

Where
$\tau$ = applied shear stress (dynes/cm²)
$\tau_o$ = yield stress (dynes/cm²
$\dot{\nu}$ = rate of shear (sec⁻¹)
$\eta_{pi}$ = plastic viscosity (poise)

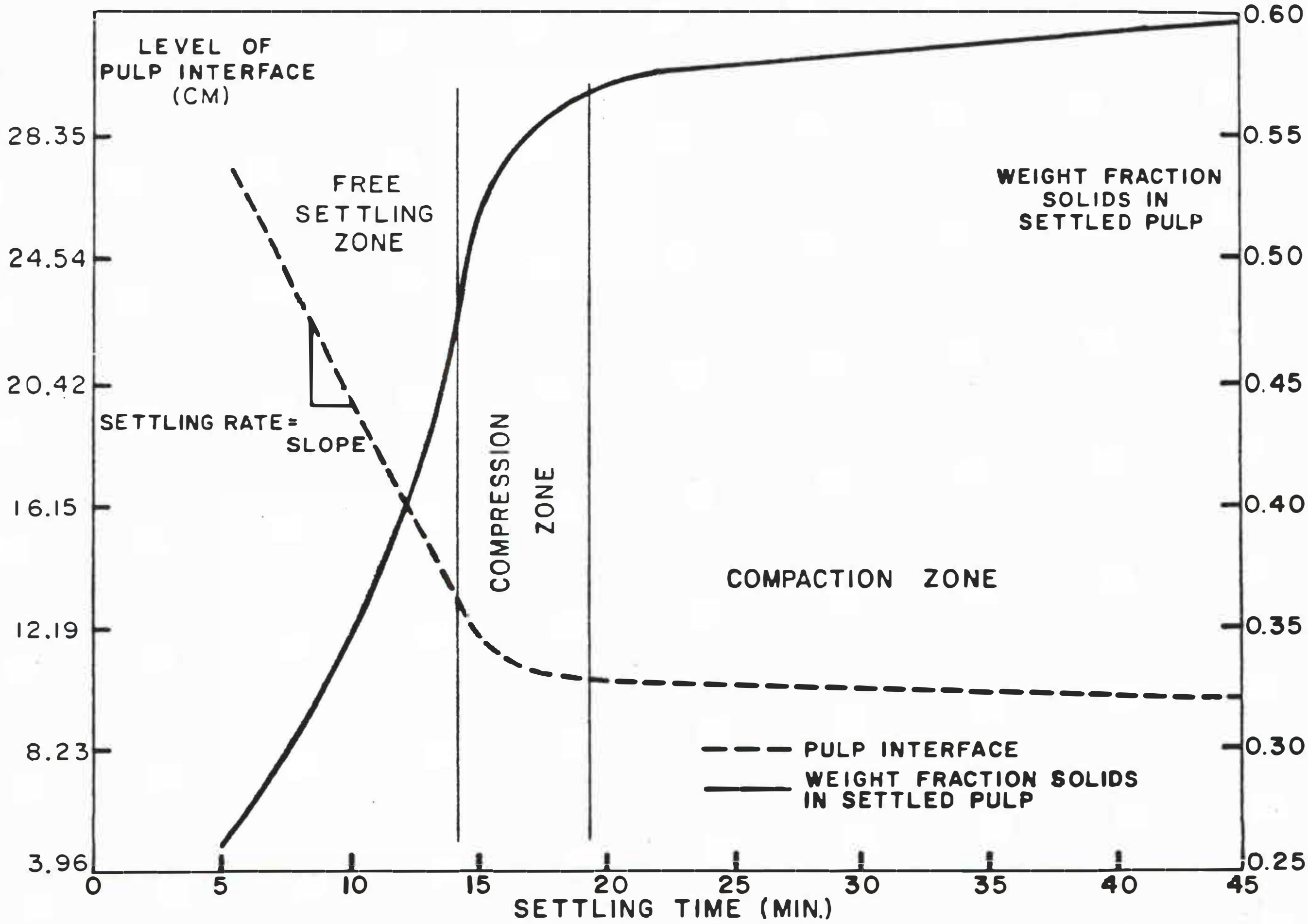


Fig. 4: Settling rate plot for 20 % bauxite slurry

Equation (3) is illustrated in Fig. 5, a plot of shear stress against rate of shear for Marcona magnetite slurry.

Yield stress, plastic viscosity and apparent viscosity are functions of the solid concentration in a slurry. At the Marconaflo Research Center, a Contraves RM-15 viscometer is being used to measure these quantities. Slurries to be studied must be treated with stabilizing agents to reduce the sedimentation rate, however this technique can be employed in such a way that other inherent physical properties are not materially changed.

Figs. 6 and 7 are plots of apparent viscosity and yield stress as functions of solid concentration in a magnetite slurry. Similar measurements are made on other bulk commodities being studied for possible slurry applications. The data yield estimates of viscous resistance and necessary pumping pressure, thereby leading to prediction of optimum solid concentration.

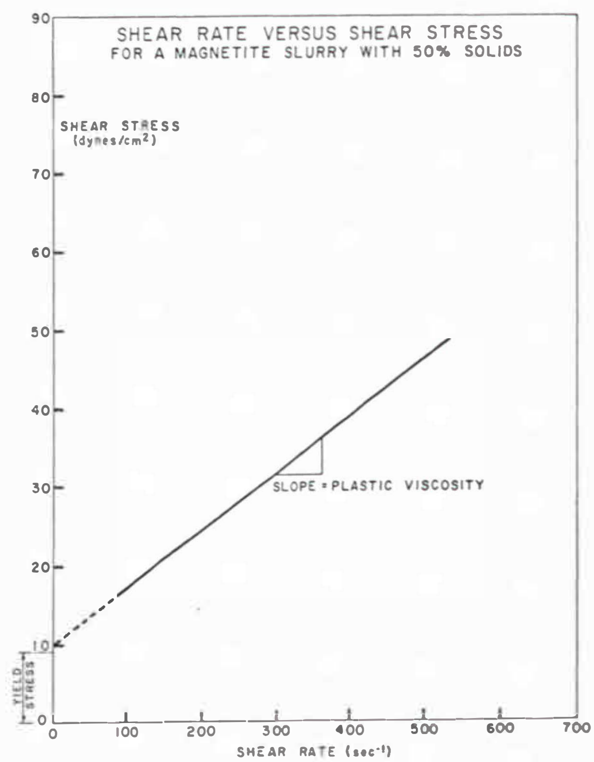


Fig. 5: Shear rate vs. shear stress for a magnetite slurry

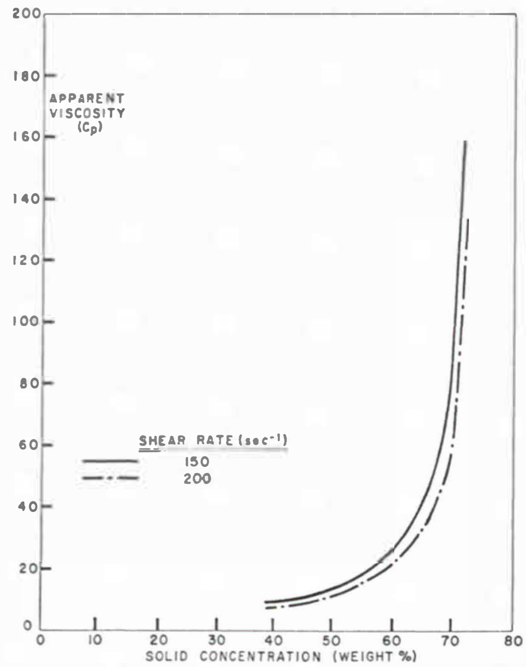


Fig. 6: Apparent viscosity vs. solid concentration for a magnetite slurry

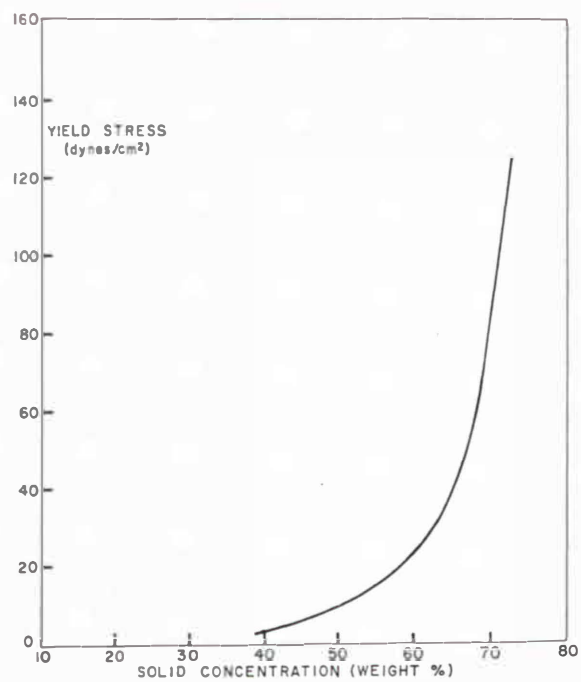


Fig. 7: Yield stress vs. solid concentration for a magnetite slurry

Tab. 1: Settling Velocities of Various Commodities

| Commodity | Average Particle Diameter (Inch) | Particle Specific Gravity | Solid Wt. % In Slurry | *K* | Settling Velocity (ft/h) Calculated | Settling Velocity (ft/h) Measured | Ratio of Calculated Velocity Measured Velocity |
|---|---|---|---|---|---|---|---|
| Calcined Aluminia | 0.0035 | 3.860 | 20 | 0.115 | 97.63 | 8.7 | 11.22 |
| | | | 50 | 0.088 | 34.21 | 2.1 | 16.30 |
| Copper Concentrate | 0.0025 | 4.010 | 20 | 0.083 | 52.56 | 1.67 | 31.47 |
| | | | 50 | 0.069 | 21.02 | 0.66 | 31.84 |
| Gypsum | 0.0017 | 2.34 | 24 | 0.042 | 6.46 | 0.55 | 11.74 |
| | | | 60 | 0.025 | 1.32 | 0.033 | 40.74 |
| Iron Ore | 0.0017 | 4.85 | 35 | 0.062 | 33.48 | 11.00 | 3.04 |
| | | | 65 | 0.051 | 14.94 | 0.84 | 17.78 |
| Iron Ore (hematite) | 0.0017 | 5.22 | 20 | 0.069 | 37.33 | 9.00 | 4.17 |
| | | | 50 | 0.054 | 17.50 | 3.00 | 5.83 |

### 4.5 Marconaflo Simulator

During the development of the slurry transportation for magnetite concentrates, experiments in static tanks had been followed up by tests aboard SS ALLEN D. CHRISTENSEN, a 31,500 DWT ore carrier originally built for Marcona in 1956. These tests, which were carried out in an ore hold which had been converted into a test compartment, proved invaluable in evaluating simultaneous effects of high hydrostatic pressure, vessel motions and machinery vibrations. Slurry compaction and dynamic load conditions were achieved to degrees which had been impossible in the laboratory and static tank tests up to that time. It was recognized, however, that on-board testing during trans-Pacific voyages was both time-consuming and expensive.

To permit rapid and meaningful evaluation of slurry transportation in a land-based facility, Marcona engineers designed a pilot scale evaluation plant for the San Francisco Research Center. The principal unit in this plant is a 720 $ft^3$ simulator tank which was designed to contain over 50 tons of magnetite. This massive vessel is activated by two hydraulic motors acting through a crank arm. The rolling motion generated can be varied in amplitude up to 15°, and the roll period can be set as desired. The tank is also equipped with four vibrators, each capable of 1600 pounds force at 9000 cycles/min, to simulate machinery and structural vibrations.

A commodity to be tested is slurried in a small receiving tank and pumped to a 32 ft diameter thickener, wherein the pulp density can be adjusted. The slurry is then pumped into the simulator; multiple fill-settle-decant cycles are conducted until the desired loading is reached. The simulator is then started at predetermined settings of roll amplitude, roll period, and vibration. Depending on its purpose, a test may run for a predetermined time or until a desired compaction is reached. Compaction is measured by ullage readings and checked by taking samples from the mass. As excess water accumulates on the surface, it is progressively decanted.

At the end of the *voyage*, the simulator is discharged by a scaled-down MARCONAJET centrally located in the bottom of the tank. The jet is rotated hydraulically at a controlled speed, and is arranged to facilitate testing of various jet configurations, piping systems, and sump designs. The material reslurried by the jet passes from the sump into an adjustable open-channel launder, then into a pump sump from where it is returned to the thickener for reuse. When a series of tests has been completed, the material is pumped into drums, dewatered and stored.

Data taken during a simulator test include filling rate, pulp density, settling rate, decantation rate, supernatant clarity and pH, static terminal density, progression of compaction as a function of motion, dynamic pressures, and structural stresses. On discharge, in addition to routine measurement of discharge rate and pulp density, the simulator generates data on effects of jet rotational speed, position, water pressure and flow, sump design and launder slope.

### 4.6 MARCONAJET Test Range

While the original jets were developed and tested in slurry tanks and during shipboard programs, more direct and comprehensive methods were required to perfect and optimize nozzle designs. The Research Center was therefore equipped with a special test range. The range is essentially a trough of steel plate, the open top equipped with a removable cover to protect the water jet stream against wind currents. The trough contains a target sled which can be locked into place at any distance from 5 to 70 ft from the jet being tested. On the sled, a 10-inch diameter steel target coupled to a compression cylinder measures the jet's impact pressure. Test engineers make visual observations and take photographs to evaluate the jet's conformation.

The test stand itself is capable of pressures in excess of 450 psig, and flows of up to 600 gal/min. The stand can be served interchangeably by 4-, 6- and 8-inch piping systems, and will accept a wide variety of experimental or prototype nozzles, jet bodies and inlet piping configurations. Fully assembled MARCONAJET units can also be tested prior to commercial installation.

## References

[1] Thomas, T.B. and Beebe, R.R., "Ocean Transportation of Iron Ore Slurries", Proc. of Thirtieth Annual Mining Symp. and Forty-Second Annual Meeting of Minnesota Section AIME, 1969, pp. 29—38

[2] Fraser, M.J. and Connolly, L.P., "Marconaflo and Its Use in New Mineral Developments", 73rd Annual Gen. Mtg. of Canadian Institute of Mining and Metallurgy, 1971

[3] McCabe, W.L. and Smith, J.C., "Unit Operations of Chemical Engineering", McGraw Hill, 1967, pp. 170

[4] Koch, Jr., J.W., Graham, J.H. and Ghusn, A.E., "Cargo Handling Systems on Slurry Tankers", Paper No. 50 in Stacking Blending Reclaiming of Bulk Materials, pp. 663, Trans Tech Publications, Clausthal, Germany, 1977