Mikoviny Sámuel Doctoral School of Earth Sciences

Head of Doctoral School:
Dr. h.c. mult. Dr. Ferenc Kovács
Professor, member of the Hungarian Academy of Science

Investigation of Hydraulic Transport of High Concentration Slurries, Paste Technology

Theses of (PH.D.)
Doctoral Dissertation

Research Institution: University of Miskolc
Faculty of Earth Science and Engineering
Department of Raw Material Processing and Environmental Process Engineering

by I**mre Gombkötő M.Sc.** Process Engineer

Supervisors of Research:

Dr. József Bőhm C.Sc.
Associate professor

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Miskolc, 2008

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Brief Summary of the Research Problem

During raw material production, huge amount of residual material has been arisen. Storage of this, so called tailings is enormous technical and financial objective of mineral processing operators. Reducing the amount of tailings remains from wet mineral processing technology is high priority social interest. Although, presently there is no significant amount of ore mining in Hungary. For this reason, there is no significant tailings production as well. Despite this fact, tailing management is still very important area due to red mud, fly ash are stored as dilute slurry. Using thickened tailing and paste technology in tailing management instead of low concentration technology is in accordance with social effort to protect environment and natural resources.

First time, I have dealt with paste technology as a researcher in an EU 5th Framework research program, carried out in University of Miskolc, Department of Raw Material Processing and Environmental Process Engineering between 2003 and 2006. It was „Sustainable Improvement of Safety of Tailings Facilities" – TAILSAFE program. I have to dealt with feasibility study and modelling of thickened tailing and paste tailing management within the frame of the project. In parallel, I was also involved in numerous different research programs where I was dealt with rheology and hydraulic transport properties of slurries. Slurries made of fly ash and ore tailings are generally showing Newtonian or time independent non-Newtonian flow behaviour. Parameters of hydraulic transport, such as pressure loss are generally determined by Pilot – Scale measurements in engineering practice. The case is not that similar however using thickened tailing or paste technology. One of my objectives is to examine the models for hydraulic transport taken from literature, if they are applicable for pressure loss calculation, as main parameter of hydraulic transport design for dense slurries.

It is known that slurry with a given flow property could be paste at high concentration, but sometimes, slurry with very similar flow property is not becoming paste at very high concentration. The reason is probably the difference between the material properties of the solid in the suspension. In addition, definition of paste is still not clear; therefore definition of paste is also become of my objective.

The main objectives of this research work are doing experiments to determine a method for calculation of hydraulic transport parameters of ultra high concentration slurries. I believe that the results I have got are applicable for design and optimum calculations for paste pipe transport operations. Further objective is to overview existing and innovative tailing management practice to determine the areas in Hungary where innovative paste technology can be applied. I would like to finish a part of my research work to open a new one, because some of the questions have been answered, but some new questions have arisen.

Description of the research work

The research work was multi – staged. In first stage I have done literature study regarding to the objectives of the research work. Therefore large amount of literature was processed in the area of tailing management, hydraulic transport of slurries, thickened tailing and paste technology. Literature study was extended to trusted internet sources, mainly to web pages organised on professional basis.

Doing experiments was the second stage. It was started with the precise selection of test materials. It was taking into account that for describing and compare of examined processes are require model and realistic materials as well. It was also taking into account that the chosen materials is better to get from domestic sources. Fly ash (India, Mátraalja, Pécs, Dorog), sand, quartz flour, flotation tailing from Gyöngyösoroszi, bentonite (Mátraszele, Mád), cement and gypsum were involved into the investigations.

Determination of liquid limit, pressure loss in horizontal pipe flow, rheology and slump cone test had been carried out. For the present investigations a tube viscometer was used which is actually a big capillary viscometer with a large tube diameter. The principle of the measurement is that the mixed slurry is circulated through a pipeline by a screw pump, at low flow rates to enable laminar flow. Pseudo shear curves can be obtained by measuring the pressure loss and flow rates under known geometric and physical properties. Flow parameters and rheology of the fine suspension can be determined using such pseudo diagrams. Every investigation was started at c_v = 0.1 volumetric transport concentration, going up to the maximum concentration which could still be transported by the pump. At least 6 different flow rates were measured, controlled by a frequency controller from 60 Hz to 15 Hz. Higher flow rates were applied after every lower flow rate between two measurements to avoid settling of particles and obstruction of the system. Pseudo shear diagrams could be obtained during the experiments. Flow properties of the slurries have also been determined at every measured volumetric concentration.

Another way to measure yield stress of a paste material is the ASTM slump cone test after Phasias and Boger, which uses a truncated cone 305 mm (12 inches) in height. The cone is filled with paste and then removed allowing the contents to assume a pile shape with a natural slope. The distance of the top of the pile from 305 mm is the slump. A slump measurement reflects the yield stress of a paste. Dense paste would have low slump of 50-200 mm (2-8 inches). Materials at the transition between a slurry and paste would have high slump, up to a maximum of 305 mm.

Description of the hydraulic test loop

The equipment was designed to allow me to use different types of pumps. As it can be seen in the fig. 1 schematic, the system has a mixing tank. The volume of the mixing

tank is 400 litres. There is a mixer built inside the tank. This mixer is driven by a hydraulic engine. Continuous mixture helps us to reach the right homogenisation state. Its importance is higher at low concentrations than at higher concentrations. Homogeneity of paste is permanent without mixture.

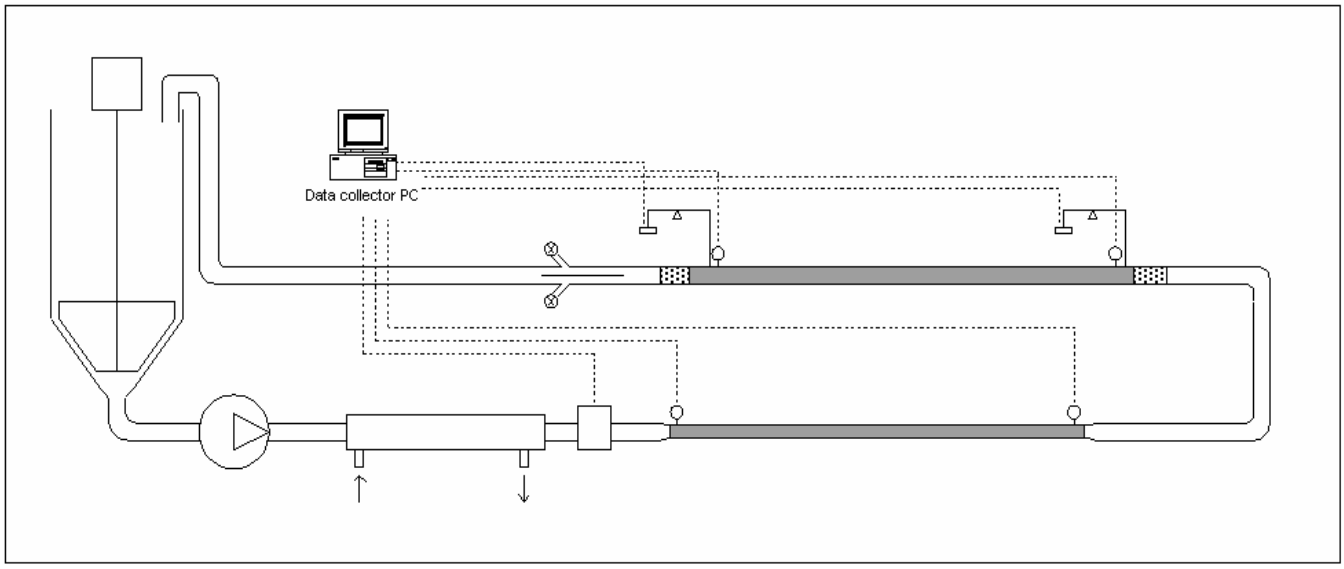

Figure 1: Schematic of the test system.

Three types of pumps were used for our investigation. There is a centrifugal pump built in at Figure 2. I have started the tests with this type and determine that maximum volumetric concentration, as high as can be reach with centrifugal pumps. Centrifugal pump was a WARMAN type slurry pump. The pump case and the impeller are coated with rubber in that type of pumps.

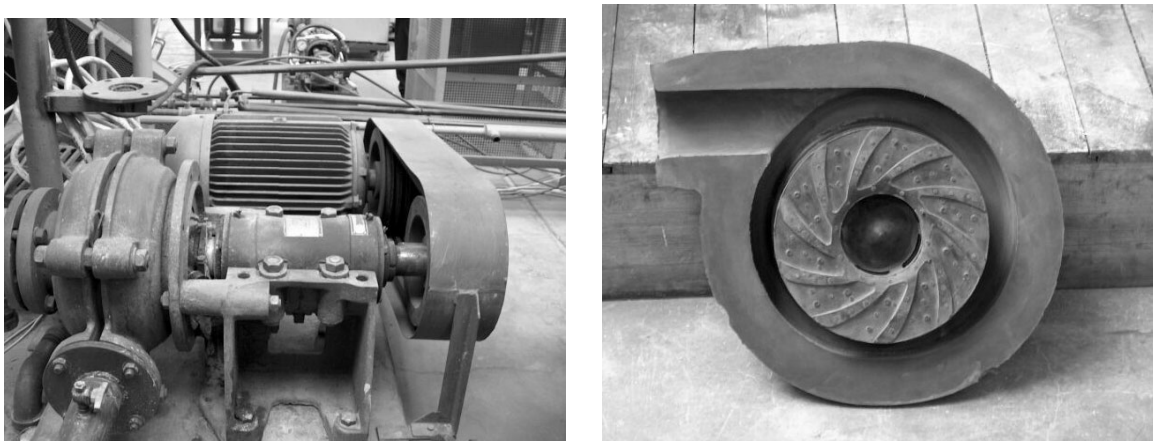

Figure 2: WARMAN type centrifugal pump.

The second pump was a screw pump, which was enabled me to transport much higher volumetric concentration slurries than by centrifugal pumps because of its strict characteristic. The screw pump was a British made, MONO type pump (Fig 3) with 15 m^3/hour flow rate and with the ability of 15 bar pressure head.

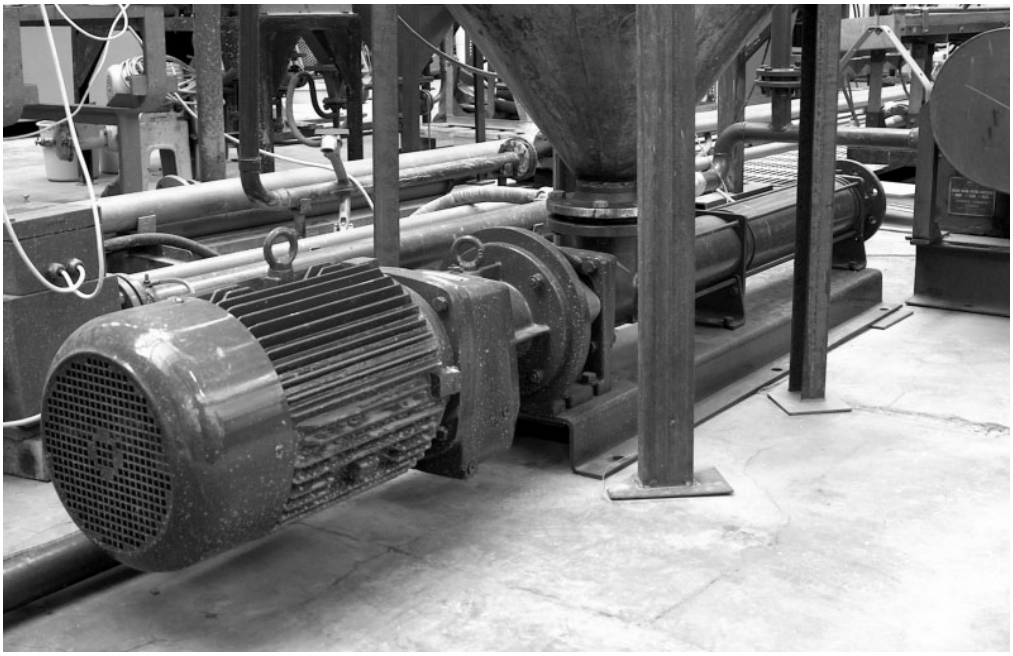

Figure 3: Mono type screw pump.

An ABEL type piston and membrane pump also was available for my experiments (Fig. 4). The piston and membrane pump was a German made, ABEL type, special slurry pump with 11 m^3/hour flow rate and with the ability of 15 bar pressure head. During slurry transport by this type of pump, the abrasive material did not contact directly with the piston or its sealing. The transported material and the piston are separated by a membrane. The piston is contacting only an oil and water emulsion agent. The second sensitive part of slurry transport piston pump is a valve. Ball valves were used at this type of pump. The diameter of valve balls were approximately 100 mm and the balls coated with elastic, wear resistant material.

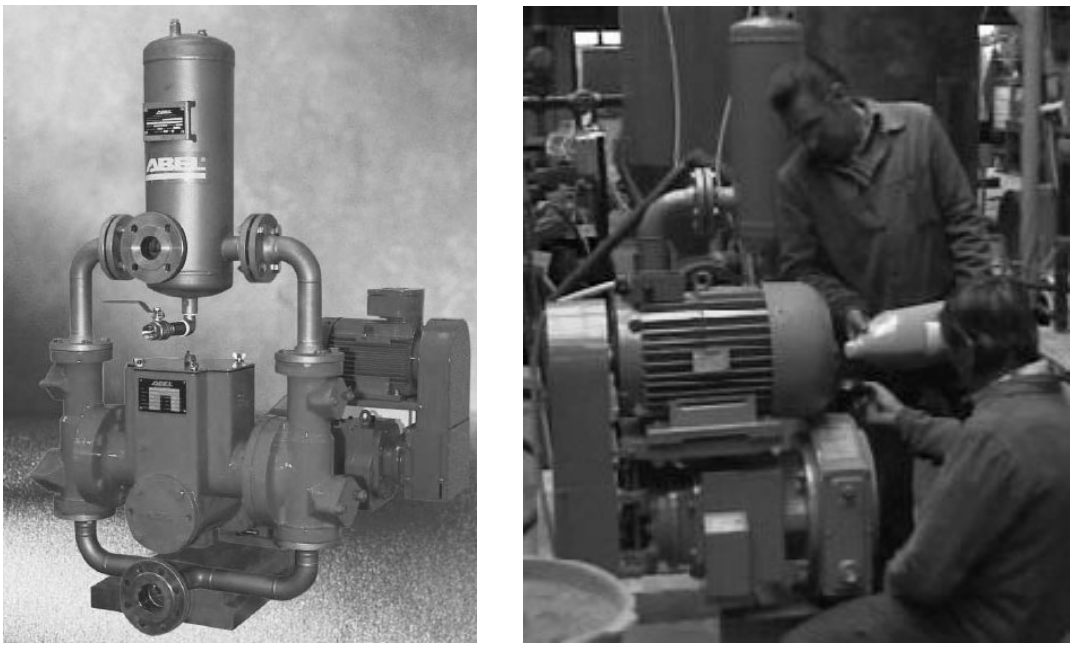

Figure 4: Abel type piston and membrane pump.

Right after the pump outflow a cooling section was built in for the purpose of keep the temperature of the slurry in permanent value. After cooler, an induction flow meter was built in.

The system consists of 2 measurement sections. First measuring section 6 meters long 6/4” (40 mm) diameter pipe, where pressure drop of transported slurry is measured, so the pressure loss is determined in a given pipe section. For measure pressure differences, a Hottinger-Baldwin type differential pressure meter was used. The pipeline is turning back and than the second measuring section was a 6 meters long 2” (50 mm) diameter pipe, Here I have measured directly the pressure values at the beginning and the end of the section, the difference between the two measured values is the pressure loss. In the other hand the weight of the pipe section is also measured by a scale system. If the weight of the empty pipe section, its volume, density of water and the density of transported material are known, volumetric concentration can be calculated. After measuring sections, a special sampling point was enabled me to taking samples from the bottom and the top section of the tube to determine the concentration difference between the bottom and the top of the tube. Then slurry flow back to the mixture tank. All measuring device is sending its signal to a PC where they had been processed. .Data acquisition software was written by József Faitli

Summary of the Scientific Results, Drafting the Theses and Applying the Results

Thesis 1

Flow properties of suspensions, behave as Newtonian at low and Bingham-plastic at high concentration can be described with the following correlations as a function of concentration

Coefficient of Rigidity

$$\eta[Pas] = \mu_o\left(1 + K_1 c_v + K_2 c_v^{K_3}\right)$$

Yield-stress

$$\tau_0\left[Pa\right] = K_4 e^{K_5 c_V}$$

The upper concentration limit for the applicability of the equation is the liquid limit of the solid. With lower water content, the bulk material cannot be described with fluid mechanics..

Thesis 2

Paste is possible to produce from only those high or ultra high concentration slurries which have yield-stress. Paste like behaviour can be detected by carrying out slump cone test. Therefore slurry is paste if the residual cone height after slump cone test is higher than the 50% of the height of the original cone

Thesis 3

The results of the slump cone tests are depend on the particle density of the solid phase of the suspension, because the share force is based on the weight of the suspension. It follows that, results got from investigating different materials cannot be compare directly, modified test is necessary. The modified test must ensure similarity of the geometry of the cone and the forces cause collapsing of the cone. Therefore, modified test should be carried out with a cone in which the weight of the measured slurry is 11,1 kg at 50% of volumetric concentration. Therefore slurry is paste if the residual cone height after modified slump cone test is higher than the 50% of the height of the modified cone

Thesis 4

It can be seen by my results that the particle size distribution, especially the amount of particles less than 20 micron has no exclusive influence to the material become paste or not. Containing clay minerals, especially Montmorillonit is necessary for a suspension to become paste. The phenomenon might be explained the specific surface, different crystal structure or surface properties of the Montmorillonit.

Thesis 5

It is evident by my investigation, that pressure loss of hydraulic transport of high or ultra high concentration suspensions, if they are pastes according to thesis 2 and 3, through pipeline can be calculated with fine suspension model. This means that paste is a monophase liquid which can be described its density and flow properties.

Results of my research can be used in design operations of hydraulic transport tasks. Further possible field of use is the introduction of Thickened Tailing Technology (TTD) in Hungary. Thickened tailing management techniques are not present Hungary at this time. In my opinion, there are three main are of raw material processing in Hungary where TTD should be applied. Those are:

- Red mud is a residual material of bauxite processing, known as Bayer – process. Well known dry stacking technology could be applied for this material as it comes clear from the literature. Nowadays, red mud is stored a dilute slurry in Hungary.

- The second area for using thickened tailings technology could be fly ash operations at coal fired power plants. Fly ash is transported and stored as dilute slurry in most cases in Hungary. Increasing the solid concentration of fly ash operations could cause less place requirements or extended operation time in the same facility, lower risk of dam failure. Additional materials can be used as well, such as cement, gypsum or bentonite to increase stability of fly ash tailings.

- Paste backfill of abandoned underground mines are generally accepted technique worldwide. There are many underground mine site, waiting its final closure in Hungary, where paste backfill technique might be used.

Owned publications in the topic

J Faitli;J Bőhm; ***I Gombkötő****; Á Debreczeni*; Paste type pipe transport for the safety of tailings facilities. XXIII International Mineral Processing Congress 2006 September. Procidings Volume 3. pp:2287

Dr. József Bőhm; dr. József Faitli; dr. Ákos Debreczeni; ***Imre Gombkötő*** Safety and health, tailings management questions, ISCSM 2006 09 24-27, Aachen Konferencia kiadvány: 331-339 oldal

Imre Gombkötő*; Dr. József Faitli*; Whether Paste Is A State Of The Material?; Universitaria SIMPRO 2006 Petrosani, Romania, 2006. 10. 13-14. Konferencia Szekciókiadvány: 43-49 oldal

Imre Gombkötő, Environmental Friendly Tailing Management, MicroCAD 2007 Konferencia szekció kiadvány, 33-39 oldal

J Bőhm, Á Debreczeni, J Faitli, ***I Gombkötő*** *and T Meggyes*, High-concentration hydraulic transport of tailings, Land Contamination and Reclamation Vol.15 Num. 2 (2007) oldal: 195 – 217

J. Faitli, ***I. Gombkötő***: Flow Properties of Fine Suspension at High Concentrations microCAD 2005 International Scientific Conference, 2005. 03. 10.-11.SBN:963-661-647-7

Gombkötő Imre, Környezetbarát meddőzagykezelés, Bányászati és Kohászati Lapok 140. évfolyam 3. szám 20-25. oldal, 2007

Accepted, but not yet published

I. Gombkötő *and J. Faitli*, Application of Paste Technology for Tailings Handling The XXIV International Mineral Processing Congress, 2008 Beijing