IFPS Pittsburgh meeting – 1996

Pneumatic Conveying of High Temperature Sponge Iron –

IFPS

International Freight Pipeline Society

PNEUMATIC TRANSPORT OF HOT SPONGE IRON.

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Introduction

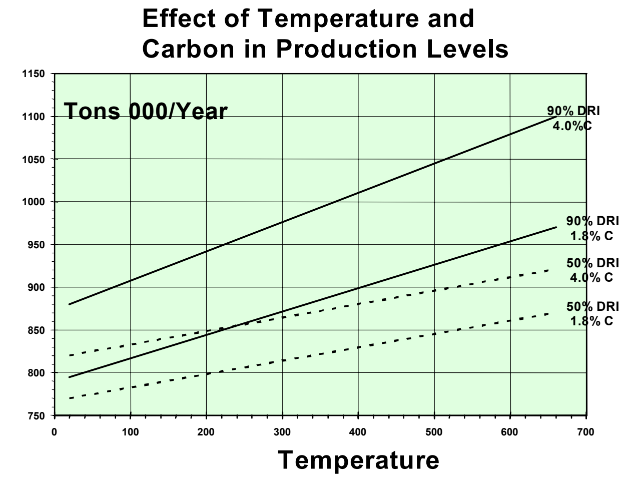


Fig. 1

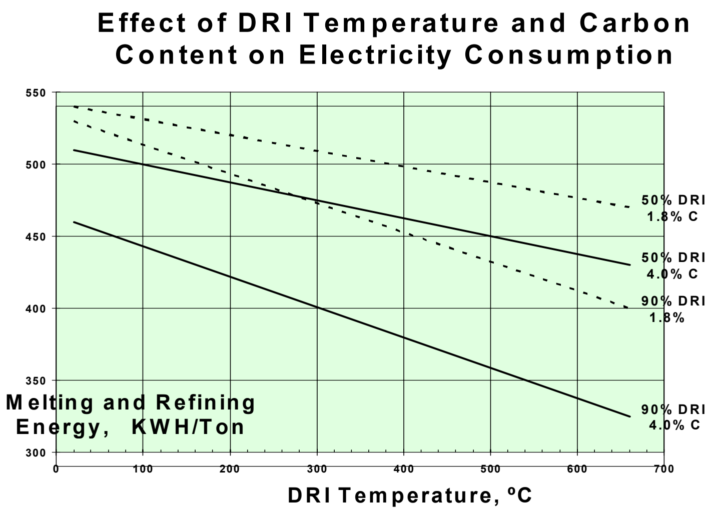


Fig. 2

HYLSA is an integrated steel shop that manufactures one Million t/y of flat product in its Monterrey plant and round products in its factory in Puebla. For 50 years now it has been involved in sponge iron (direct reduced iron, DRI) and has licensed its process to clients in Iran, Iraq, Indonesia, Brazil, India, Malaysia and Venezuela. As early as 1965, pneumatic transport was considered a potential improvement for HYL plants in Monterrey, but no commercial supplier of a full technological package was available at the time and the effort was limited to some trials with sponge iron fines. Scale up was not economically viable. Some years later sponge iron was successfully fed into an electric arch furnace, but the technology was abandoned due to problems in the containment of fines and furnace cooling. However, with the advent of new market conditions that reduced the margin of profit in steelmaking, discovering innovative ways to significantly reduce the cost of production was necessary. Realizing that the heat dissipated in cooling the sponge iron from 850º C to 60ºC, for handling and storage could be used in the melt shop (Fig 1. Effect of Temperature and Carbon on Production Levels Fig. 2. Effect of DRI Temperature and Carbon Content on Electricity Consumption), an experimental project was undertaken to understand the solid flow parameters and develop the basic technology to build a full scale hot discharge reactor and process.

HYL Sales Department soon became aware that the natural customers to such a technology would be the existing HYL licensees, whose reactors were separate from the melt shop. Therefore, means of transporting hot sponge iron from DRI plants to melt shops, or briquetting facilities, should be created. Early methods of transport that were considered include: rail transport, traveling elevated bins, bucket elevators, apron conveyors, capsule transport and all types of belt conveyors. However, none of the conveying systems fulfilled HYL expectations and the idea of pneumatically transporting hot sponge iron started to take form. We got in touch with Mr. Paul Solt, Professor G. Klinzing, Dr. W. Yang and Dr. Roy Marcus, to whom we are grateful for their help.

Research and Development Research Project Scope

The scope of the research project was to prove, beyond a reasonable doubt, that pneumatically transporting hot sponge iron is feasible and economically sound. Thus, the requirements of the system had to be clearly established, and the necessary tools and equipment had to be created.

Requirements

This project was named "THE NEW STEEL MAKING WAY." Since this was a different approach to steel making, technology had to be developed or purchased, if available. Maximum energy efficiency, and minimum labor needs were important requirements. The overall project included a new melt shop with direct current EAF, double thin slab continuous casting, single pass soaking furnace and mill, automatic continuous feed of sponge iron (now in operation) and pneumatic transport from the DRI plant to the melt shop, about 300 meters away, a 800 million dollar investment. In addition, the increased use of sponge iron was mandatory due to the increase in price of scrap, and the need for low nitrogen and residuals for the thin strip cast, as well as the requirement for low content of heavy metals on the melt shop's collected dust.

At that time, HYL could not find a responsible technology supplier for the pneumatic transport system, so an in-house development effort modifying the existing pilot plant for pneumatic transport research was started.

Pilot Plant Research

Requirements – Sponge iron is a large and heavy particle (particle density above 3.5, mean particle diameter 1.2 cm ranging from 1" to dust). Its relative fragility and abrasiveness made the use of high velocity transport, not only uneconomical, but also impractical. Heat losses have to be kept to a minimum as the expected temperature of sponge iron at the melt shop, if profit is to be made , should be kept above 400 ºC, with a percentage of fines generated below 10 %. Moreover, the transport system would use the available process gas Hydrogen-CO, to avoid process contamination, and be directly fed by the reactor without pressure lock, linking the reduction process to the pneumatic transport .

Experimental Results

Particle Degradation

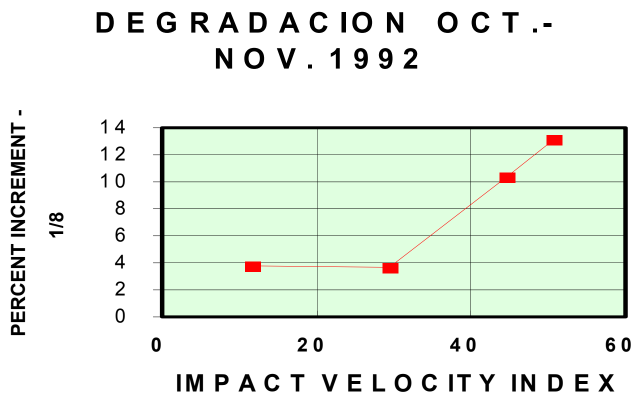


Fig. 3

After the initial proof of concept runs were successful, unacceptable particle breakage, gave birth to a new line of research dealing with particle degradation. A set of transport parameters (Fig. 3 Particle Degradation in Pneumatic Transport) were found that kept fines generation below 8%. A technique was developed to predict degradation, making changes in the system to keep fines within acceptable limits. This, in turn, required that the line operate, for some meters, below saltation. Keeping the whole line below saltation proved feasible, but, at least in one of our layouts, low frequency pressure cycles made it difficult to control the overall process-transport system.

In diameters above 6”, piston momentum originated forces that moved the pipeline, stressing the expansion joints. At the moment work is being done to control piston size, to minimize stresses on the pipeline.

The next milestone, matching the process with the transport system, required an extensive modification of the pilot plant layout and control. Having accomplished the former, a campaign was planned to determine the overall system response. The control loop was then configured. Pilot plant tests showed that the overall concept was workable and, to date, we have logged more than 6 months, in coupled process transport operation.

Pressure Drop for Horizontal Pipe

Sponge iron pellets show a somehow flatter phase transition zone than Mohlmmans - Marcus’ quartzite data. The saltation point is not as clearly defined. One explanation considered was pellet rolling. The enormous amount of data collected, allowed for high confidence levels on fitting correlations, although some engineering criteria must still be used when designing for customer plants where the supply of raw materials comes from external sources and might vary its particle mix. Pilot plant characterization of actual material will always be advisable, but is not always possible.

Data from iron ore 8" diameter pipe presented a lump in the saltation region that was

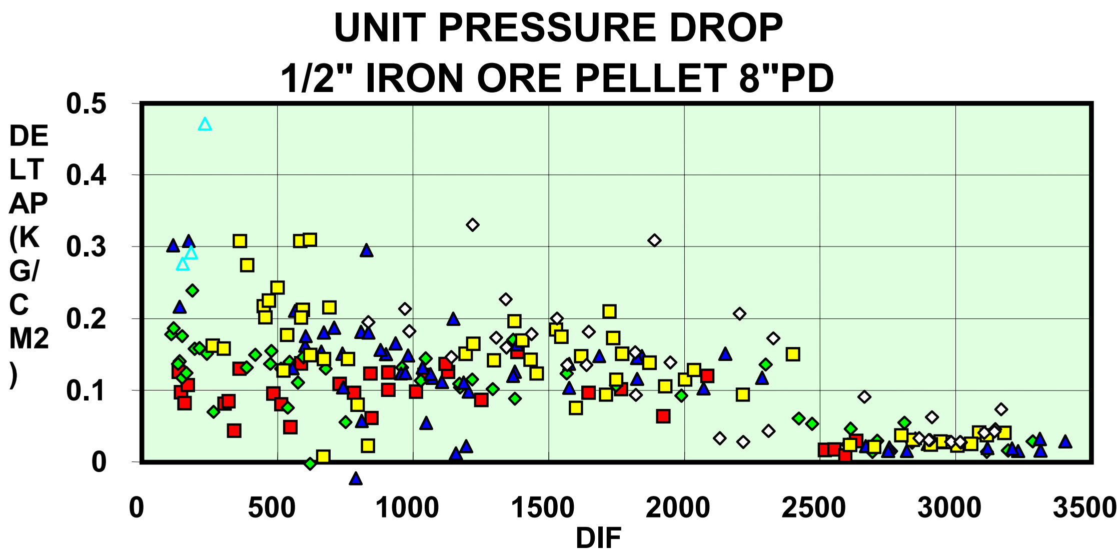


Fig. 4

not foreseen in 4" diameter experiments (Fig. 4 Iron Ore Transport Pressure Drop in Horizontal Lines).

At the time we were extrapolating data from iron ore that is not reactive with air, and the system design algorithm worked around keeping the system in the vicinity of the saltation point, to minimizing overall pressure drop. The lump meant that the available process pressure 4 to 5 bar was insufficient to propel the product without intolerable particle breakage for the average distance required. Fortunately the phenomena was not present when we switched to sponge iron.

Wear

Hot sponge iron is temperamental; it forms crusts in some places and wears the pipe in others. In straight horizontal line sections, we found that a laminated crust of sponge iron had formed. After removing this crust, angular particle impact scars could be seen in the pipe surface. It is believed that these scars were formed during the initial start-up when the pipe and the transported material are cold and the conditions were not suitable for crust building. As the sponge iron and pipe line heat up above 620°C., the impact energy heats the iron particles beyond the plastic flow region and they tend to deform and deposit a small layer of iron on top of the pipe. Repetitive impacts deform this layer and in some cases laminations and destruction of the layer occur, exposing the pipe surface.

Bend wear, analysis of worn out sections of short radius bends showed a deformed and hardened surface with internal pressures. In some sections these cracks propagated to the surface chipping off part of the material. The process is not fully understood, but the change to tee bends and the use of hard overlays resulted in a much longer period before containment failure.

The process gas, in turn, causes high temperature corrosion with some alloys. Today metallurgical treatments have been developed to protect the pipes from the gas attack, and are being evaluated for use in the pneumatic transport system. We expect to backup, attack/wear/buildup, prediction algorithms with industrial experience shortly.

Scale up

All scale up at the moment is based on a simulation program that has evolved with the project, starting with W.C. Yang's equation for momentum transfer with a parallel heat transfer algorithm. Today it uses empirical correlations within the same frame. Acceleration section pressure drop and length, bend and collector drop, come all from experimental data. Pressure drop predictions in a 250 meters cool loop are within 10%. The algorithm for final temperature predictions above 500ºC is under revision to include Curie point energy and expansion joint losses.

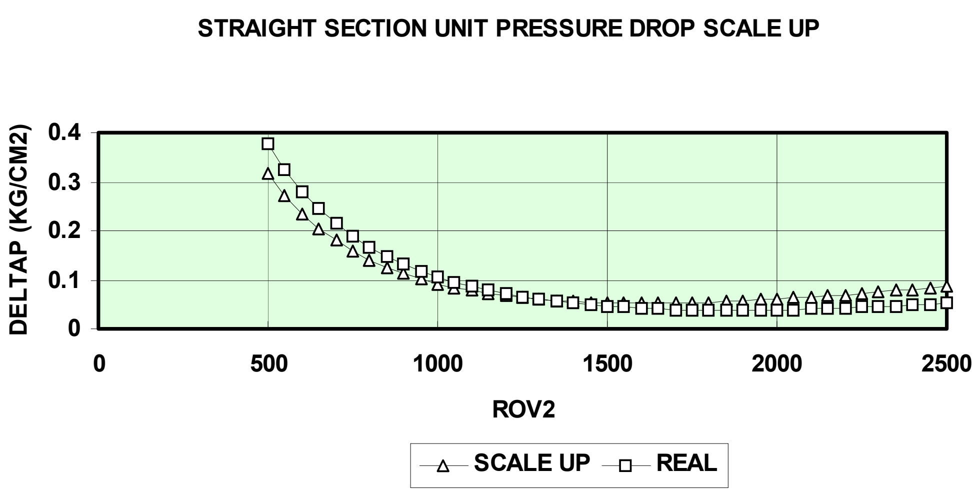
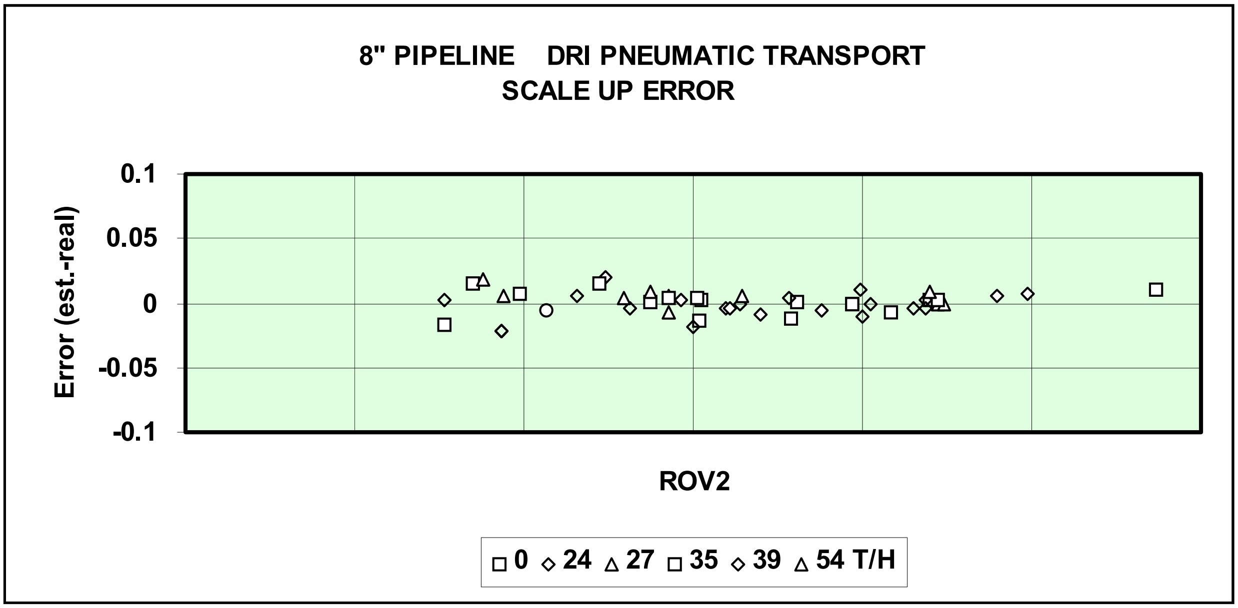


Fig. 5

Scale up error

Scale up error using the 4" pipeline data fitted well under saltation, being conservative above saltation.

Dense Phase field data are not easy to read as the piston movement creates pressure waves in the readings, figuring out the unit pressure drop in a given moment requires an expert eye , following the piston movement by pressure drop profiling can be seen as an art.



Predicting piston length and speed was not possible due to particle mix spread and local segregation , a safe margin instead would be a sound engineering practice, particle breakage in dense phase was insignificant, although in large diameter pipelines the noise and the pipe movement might indicate otherwise.

Effect of Gas Composition on Pressure Drop

Gas density as temperature has a significant effect on the overall pressure drop , being the HYL reactor at a process fixed pressure , the significant variable would be the product delivery bin pressure, using dynamic similarity scale up, (Marcus Mohlmman) the solution is rather straight forward . Experimental data backed up the concept.

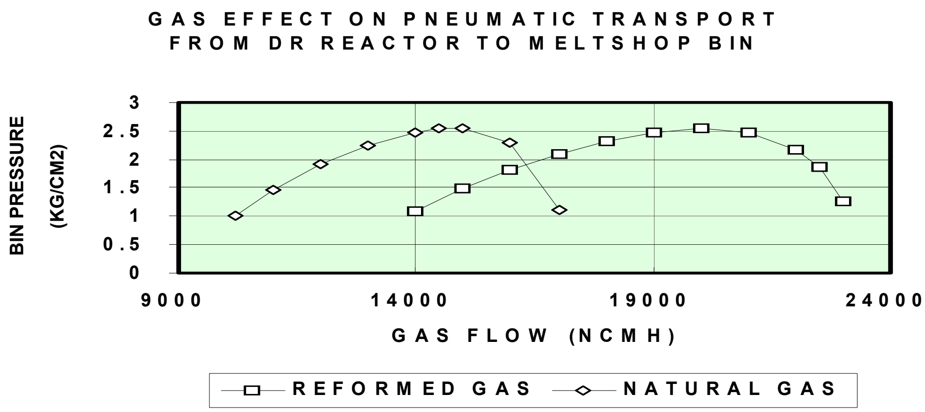


Fig. 6

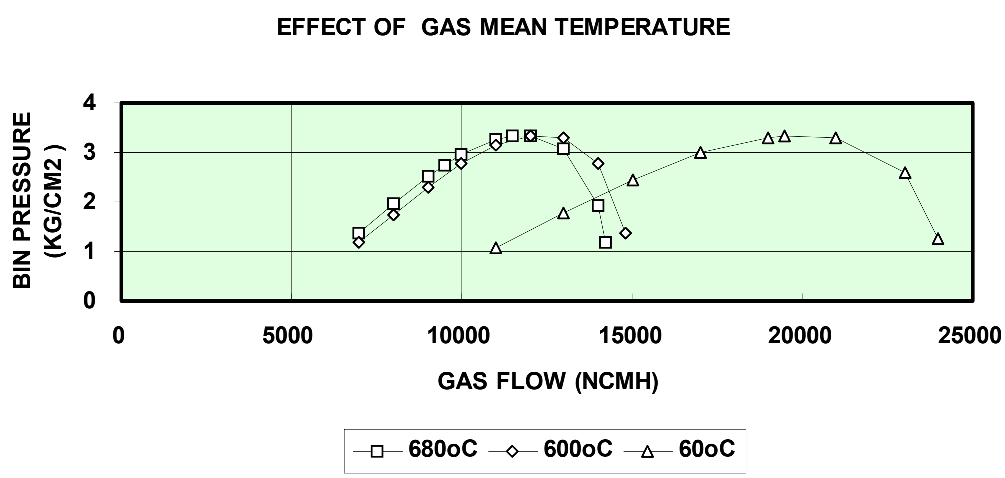


Fig. 7

Effect of gas mean temperature on final pressure

Gas temperature has also a significant effect on gas flow, the control system is required to reduce the gas flow as the pipe and pellets heat up, otherwise, the particles might accumulate impact energies above the acceptable limits, and once the limit is exceeded, the percentage of fines increase exponentially, reducing the profit margin as the metallic loss to the melt shop's dust collectors increases.

Also as can be seen in Fig 7

The pressure in the reception hopper will decrease, being the system a closed loop, the compressor suction pressure is the reception hopper's minus losses for gas cooling and cleanup. Given the nature of the transport gas H2 CO some reaction products like water and CO_2 are present; no line preheating is feasible without water condensation and dust accretion.

The pneumatic transport system is required to start up cold and keep operating continuously as it heats up keeping at all times the particle below, what can be called a critical breakage point. This concept poses strain to the piping and expansion joints when restarting the transport line with hot product, in any case, the need for switching reception bins also required the design of advanced expansion joints, and minimizing friction and inertial effects on the pipe while supporting the thermal transient stress.

Stepping lines effect on final pressure

With a fragile particle, the criterion for pipeline stepping is ruled primarily by bend impact energy, pressure drop being a secondary variable.

Nevertheless a compromise can almost always be reached. Care is taken when in stream flow, not to increase the pipe diameter to below saltation, unless particle inertia can keep the product from forming dunes or pistons.

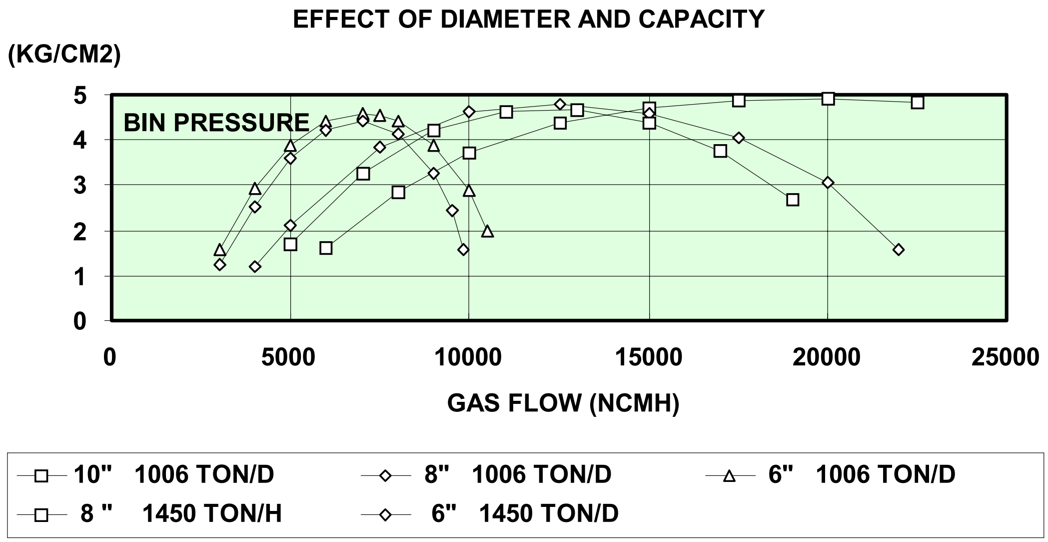


Fig. 8

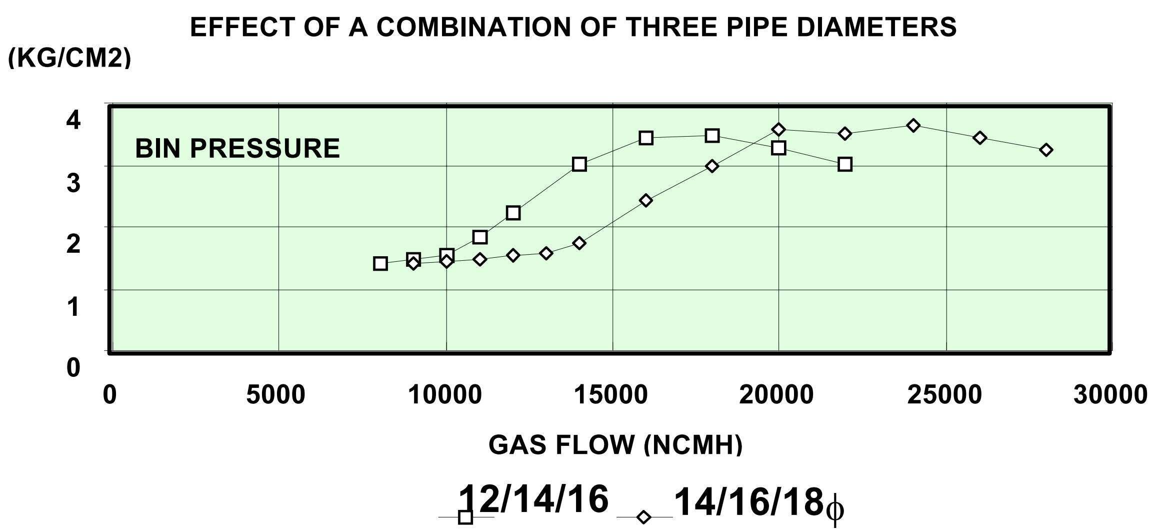


Fig. 9

The project is now entering perhaps its most difficult phase. The sealed delivery bins are installed as are all hot dossifier valves, but adapting the reactor to hot discharge, will require a plant shut down. Since the Mexican economy is undergoing what we wish to believe a transient slump, the internal market for steel products has collapsed, the interest rate has surged, and no risk capital is available for technological adventures, and all projects are on hold until the new melt shop has positive return. For the moment we believe the technological package is complete in what can be achieve at lab and pilot plant scale. Full scale operational data will have to wait.

UPDATE

4M plant was started successfully on Monterrey Mexico. From April 10 1998 To FEB 1999 has logged MORE THAN 1000,000 metric tons, full scale data reflect experimental data with scale up error within 5%. Temperature variations on the pipeline cross section within the acceleration section has been observed causing pipe bending and stressing the super plug valves, one of them was replaced by a VS2 valve operating successfully. Compressor noise still is excessive, cooling bin shakes frequently apparent cause is solids flow pattern shift.

Wear on bare stainless steel at low temperature reflects experimental data. 30 days expected life for a 200 thousands of an inch wear.

At high temperatures (>500°c), wear is negligible and the pipeline might reach working life well beyond the 3 year mark, carbide lined pipeline life can exceed 16 years .

Update November, 1998

Pneumatic transport successfully working, compressor noise reduced by new silencer design.

Valves ok. Cooler still shaking, two modifications have proved unsuccessful.

Transport to meltshop not yet ready

Update Feb 1999

Transport to meltshop operational since last days of December, no surprises yet.

Update January 2000.

Total accumulated production transported pneumatically 1,200,000 . temperature drop from reactor to furnace has been traced and recommendations issued, actual drop 210°c (see Alberto Soriano Report nov 1999) 160°c can easily be avoided. VS2 740 L1 frequent seal failures traced to improper cooling. And seal design.

Update 2003

Capacity was increased to 200 tons of solids per hr date of change unavailable

Change reverted to 120 tons of iron per day . Heater Limited.

Update November, 2007

Transport pipeline is changed to new pipeline , data on alloy performance or wear is unavailable , the pipeline was changed before the containment was breached , it is not clear what was the criteria used for the change information source Sergio Chavez Nava .

Update March, 2008.

9,600,000 tons transported.

Informal reports inform that the changes on the pipeline were local and preventive. Information source Ronald Lopez