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Ask Joe! Column

High Temperature Pneumatic Conveying

Guest article by Marco Flores and Paul Solt of Pneumatic Conveying Consultants

Prologue

This article deals with some of the general aspects of high temperature pneumatic conveying.

Fifteen years ago, we were asked by a steel plant in Mexico to develop a system for conveying large abrasive particles pneumatically. The one condition was that we should try to keep particle breakage to a minimum. The client also told us that the product was highly reactive with air, temperature ranging from 35°C to 900°C, and when conveyed hot, the heat loss should be kept at a minimum. Because particle sizes and conveying capacities were continuously being changed, we were asked to develop a general scale-up procedure that would cover a whole range of possibilities, while keeping operative cost to a minimum.

Figure 1: An aerial view of the high temperature pneumatic conveying transfer line, 45 meters above ground level at an iron ore plant in Mexico

At that time, there was little information or literature available regarding high temperature pneumatic conveying. The equipment available for high-temperature, dusty gas applications was extremely expensive. While we had some experience using hot valves with dirty gases, the maximum temperature the valves available was 300°C with a few exceptions some that went as high as 700°C. The expected life of this equipment was less than 6 months with a massive repairs required afterward.

A word of caution, every material has its own personality and will react differently to temperature, pressure, friction and impact. Data cannot be directly extrapolated from experiments performed with other materials even if they have the same particle size distribution. This is critical to know when pneumatically conveying in low-velocity, dense phase mode.

High Temperature Pneumatic Conveying

Pneumatic conveying hot products has to deal with high temperature materials, high temperature equipment, wear and corrosion, crust build-up, start-up transients and pipeline stresses that are not normally found in cold applications. Contingency conditions must be consider including dealing with pipeline plugs without loosing containment integrity, early leak detection and controlled leak confinement, as well as built-in equipment for pipeline replacement.

Pilot Plant Research

Requirements: Sponge iron is a large and heavy particle, its particle density is above 3.5 s.g. and with a mean particle diameter of 1.2 cm, particle size range from is from dust-sized to 2.5 cm. Sponge iron's relative fragility and abrasiveness made the use of high velocity transport uneconomical and impractical.

Figure 2: Hot sponge iron discharge into the open atmosphere.
Fine product reacts with air and creates yellow flame.

Heat losses have to be kept to a minimum as the expected temperature of sponge iron at the melt shop should be kept above 400 ϵC and the percentage of fines generated should be kept below 10 % for the system to be profitable.

More over, the transport system would use the available process gases, hydrogen and CO, to avoid process contamination. Finally, the material conveyed was to be directly fed by the reactor without pressure lock, thus linking the reduction process to the pneumatic transport.

Pilot Plant Results

Particle Degradation

After the initial proof-of-concept runs was completed, an unacceptable level particle breakage gave birth to a new line of research dealing with particle degradation. In a year of continuous tests we found out that particle degradation was a function of the third power of the velocity of impact.

A set of transport parameters were developed that kept fines generation below 8%, making changes in the system to keep fines within acceptable limits. This in turn required that the line operate, for some distance, below saltation. Keeping the whole line below saltation proved feasible, but at least in one of our layouts, the resulting low-frequency pressure cycles made it difficult to control the overall process-transport system.

Pressure Drop For Horizontal Pipe

Sponge iron pellets show a somehow flatter phase transition zone than available data for similar size distribution, similar density materials. The saltation point is not as clearly defined. One explanation considered was that the pellets were rolling. The enormous amount of data collected, allowed for high confidence levels on correlation fitting, 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 in an 8” diameter pipe presented a lump in the saltation region that was not foreseen in 4’ diameter experiments.

Wear: Crust Formation, Scarring and Cracking

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 were 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 the pipe surface. Repetitive impacts deform this layer and in some cases laminations and destruction of the layer occur, re-exposing the pipe surface. Ultimate solution was the use of a high temperature, chromium carbide lining for the industrial installation as the increased capacity stressed the limits of the gas pre-heater and imposed lower temperature transport, which in turn originated the accelerated pipeline wear.

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. Attack-wear-buildup prediction algorithms are available and backed up with 5 years of industrial experience. A local University was called in to predict the cracking pattern in the overlay, and if this cracking will propagate into the base matrix material.

Fortunately no cracking has propagated into the base material and the life of the alloy pipeline will probably surpass the 16 year mark.

Industrial Scale Up

The next milestone, customer required matching the process pressure with the transport system, as no lock hopper system was allowed in between both systems. Extensive modification of the demonstration plant layout and control were necessary. Having accomplished the modifications, 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 feasible for full scale installation.

All scale up is based on a simulation program that was developed, for momentum transfer with a parallel heat transfer algorithm. Today we also use an empirical correlation within the same frame. Acceleration section pressure drop and length, bend and collector drop, come all from experimental data. The algorithm for final temperature predictions above includes Curie point energy.

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 requires an expert eye, following the piston movement by pressure drop profiling can be seen as an art.

Scale up Issues

Moving Product In and Out of the Conveying System

Conveying the product pneumatically is only part of the overall problem. The engagement and disengagement areas follow patterns ruled by heat transfer. The hot solid flow parameters have to be evaluated in real conditions, temperature and atmosphere, and, if possible, following the same process history as the one they will follow in the full-scale installation. Otherwise, you might find the material arching and in funnel flow, with a large stagnant mass in the feed, or discharge bins that could not foreseen. Under these conditions the system will not work even if you have designed the pneumatic conveying part properly.

Gas permeability and fluidization in the discharge bins could be critical in insuring a proper rate of discharge. If cold gas is allowed to move from a cold bin to substitute the displaced volume, its expansion, during heating, might inhibit flow, or cause flooding and quaking. The rule here will be to “know your material”, get acquainted with its personality, what it likes and doesn’t like to do.

Pick-up Heat Transfer

To pre-heat the conveying gas or not to pre-heat the conveying gas, that is the question.

You can go either way. If your product has high density or a high heat capacity, the overall temperature will hardly be impacted and the gas and the solids will reach equilibrium within the acceleration section. If the gas is cold, the expansion due to the temperature rise can shorten the acceleration section and might require an early pipeline expansion to control velocity and pressure drop.

If you are starting up below saltation point, or you are not careful about your feeder flow pattern, you might find yourself with cold gases riding on top of a hot product. The stresses in the pipeline then could surpass the plastic flow region of the pipe and end up with a pipeline, bent up like a bow when hot, and down when cold. To get away from this, preheat your gas, cool your pipeline acceleration section or use materials with low expansion coefficient and high conductivity. This will also make them more resistant to thermal shock as well.

Transport Heat Transfer

Heat losses to the environment can be minimized with the use of insulation and supports that provide a thermal break. Care has to be taken to prevent the insulation from getting wet and procedures established so that the installation and maintenance people replace the removable sections allowed at wear inspection points. Damaged or missing insulation will not only impact heat losses but pose an accident risk for fire

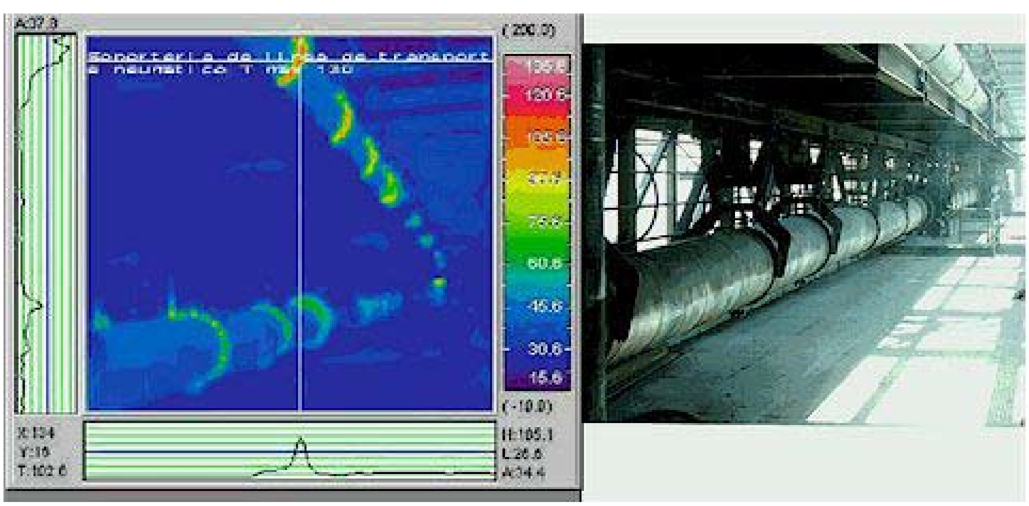


Figure 3: Thermograph of the double pneumatic conveying line on top of the melt shop. Bright spots correspond to location of pipeline supports.

Continuous or scheduled infrared scanning and alarm settings act as an early detection system of leaking flange fittings or a potential wear point failure.

Disengagement Heat Loss

Disengagement heat loss is associated to the heat carried out by the conveying gas, and losses to water jackets on bins and hoppers. This heat might be used to preheat the discharge bin purge gas, reducing the required purge gas mass. If the conveying gas stream has vapors that might condense or solidify as temperatures drop, forming zinc sulfides or water and carbonates, a crust might develop in the heat exchangers. In these cases it might be better to rapidly quench the gas stream or use self cleaning heat exchangers.

Crust Formation and Sticking

Many products form crusts when pneumatically conveyed. In cold pneumatic conveying this is largely due to humidity or absorbed fluids combining with fine powders. Cold weather can wreak havoc in unprepared solids handling installation, for example in tropical areas with infrequent cold winters.

When conveying hot materials it is necessary to know the dew points of all the components conveyed and keeping the conveying line above these values.

This is of crucial importance when conveying combustible or highly- reactive hot products with air or other potentially reactive gases. Yes, you can convey even hot sponge iron with air but, the air will react with the conveyed material and deplete its oxygen content with minimum loss of metalization. Sometimes with a small, but welcomed, increase in temperature, you might find yourself with frequent dust collector meltdowns when using cyclones or high temperature bag houses. However, if a crust is allowed to form, and the air is allowed into the hot pipeline without a sizable load of conveying material, you can find out that your pipeline is no more. The crust will react and melt, reaching temperatures even farther above the melting point of stainless steel.

Effect of Gas Mean Temperature on Final Pressure

Gas temperature also has 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.

The pressure in the receiving 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.

Line Startup Preheating

Given the nature of the transport gases, H and CO, some reaction products like water and CO_2 were 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 we call the "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 receiving 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 criteria for pipeline stepping is ruled primarily by bend impact energy, pressure drop being a secondary variable.

Effect of Gas Composition on Pressure Drop

Gas density as temperature has a significant effect on the overall pressure drop, being the reactor at a process fixed pressure, the significant variable would be the product delivery bin pressure.

Selecting High Temperature Components

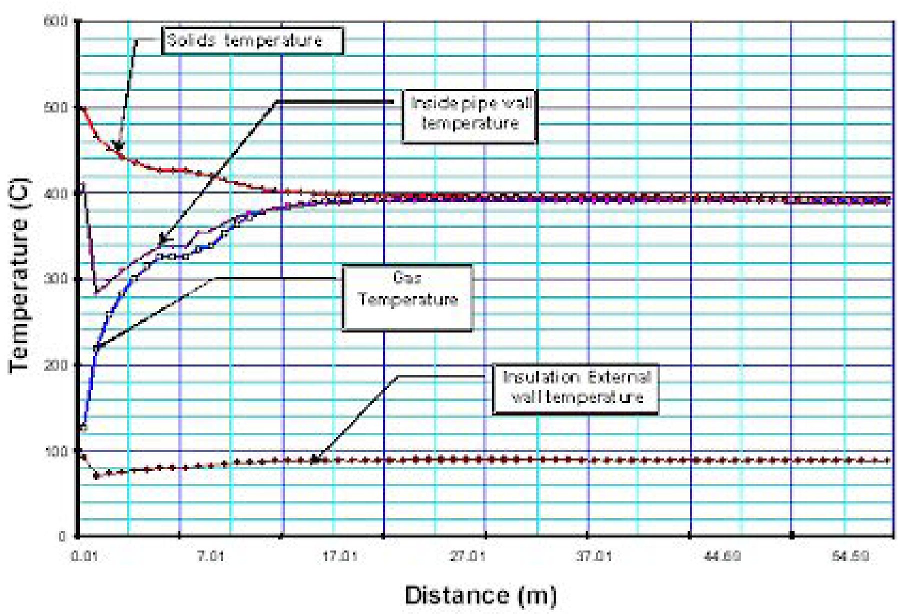
Seal Valves

Traditional wisdom and some patents support the concept of using double valves to handle hot products. One gate or clamshell valve to stop the solids and another, gate, plug, dome or sphere to seal the gas. We cannot argue against this practice although we have been successful in modifying commercially available single cut-off and seal valves to work. Today several manufacturers have profited from this experience and are offering high temperature seal valves. In the pneumatic transport circuit we were able to modify a lubricated, plug valve to perform the line switching work, and in the solids feed a modified dome valve out-performed the metal- to-metal riding disk valve, ball valve, super plug valve and clam- shell valve combination.

Flanges

When possible stay away from hot flanges. The high temperature bolts are very expensive, and the, some-times uneven, pipeline stresses can cause seal failure and dangerous containment loss. Use cold or cooled flanges whenever possible and use as few as possible. Be careful, in sulfur and CO2 bearing gases as the heat-affected area near a weld could turn brittle and cause catastrophic vessel or pipeline failure without warn-ing. The literature has numerous examples and we have experienced this first hand.

Figure 4: Temperatures as Measured from Inlet - Down the Pipeline



Conclusion

It took us the best part of six years, to develop the necessary equipment. Build and test operative prototypes, build a low-cost, disposable proof of concept, fully instrumented pilot plant, modify an existing technology dem-onstration plant and run an extensive test campaign to finally come out with a reliable scale-up procedure and a cost estimate of the full-scale system.

A large portion of this time was dedicated to studying the particle degradation in the conveying line and corrosion erosion wear at high temperatures.

The profit of using hot pneumatic conveying product handling was of such magnitude that the customer decided to invest in an industrial installation. The overall costs included a new processing plant and melt shop at an investment over $400 million dollars. The high temperature pneumatic conveying system accounting for about 1% of this investment.

The preliminary results were so encouraging that the customer decided to expand. He invested another $200 million dollars, building a fully dedicated melt shop for 100% hot product feed. This investment proved its worth, as the energy efficiency of this unit was so high, that it was still profitable to use even when the energy prices increased by 400% during the winter of 2000.

This plant, using redundant parallel conveying lines, has been operating now for more than 5 years without any major mishap or any loss of production attributable to pneumatic conveying. Conveying hot iron ore at 100 tons/hour for several years and the last year at a rate of 200 tons/hour, using a mix of CO and Hydrogen as conveying media.

From that time on, we have been approached by several companies interested in high temperature pneumatic conveying, whether it be for large briquettes, silica sands or very fine, light powders. Cement, foundry sand, metallic concentrates, radioactive materials, catalysts, coal and ashes. Fortunately very few require the use of toxic or explosive gases as a conveying media, and very few are interested in particle degradation or heat losses.

For More Information: We would like to thank our authors for a great article. For more information about high temperature pneumatic conveying you may contact them at:

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Welcome to Ask Joe!, a monthly column by our resident materials handling guru, Joe Marinelli of Solids Handling Technologies. Joe addresses the issues that bug you the most. And Joe knows!! Formerly with Jenike & Johanson, Solids Flow and Peabody TecTank, Joe is an expert on materials handling.

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Guest articles for the **Ask Joe!** Column are always welcome, for more information please contact Joe Marinelli directly at his email address: joe@solidshandlingtech.com.