Heating Iron Ore Slurry to Improve Filtering Efficiency Prior to Pelletizing

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Abstract

Engineers have known for some time that the efficiency of filtering iron ore concentrate slurry can be significantly improved by pre-heating the slurry ahead of the filters. However, heating such large quantities of dense slurry by conventional means has proven to be inefficient and high-maintenance. Recently though, submerged combustion was considered by Altos Hornos de Mexico SA (AHMSA), an integrated steel producer in the state of Coahuila, Mexico, as a means of pre-heating their iron ore concentrate. The company toured many iron ore facilities in Brasil and Labrador, reviewing their heating processes, and concluded that submerged combustion could provide a competitive advantage through operational efficiency and lower capital cost than steam boilers.

Inproheat was retained by the company to design and manufacture a SubCom slurry heating system to heat 403 m^3/h of iron ore concentrate slurry from 25°C to 60°C. The 60GJ/h SubCom system consists of five natural gas combustion chambers mounted in an iron ore concentrate storage tank. The system features a heat recovery unit whereby the exhaust gases are used to preheat the incoming slurry stream, giving the system an overall thermal efficiency of 95%. As a result, the steel company expects to realise significant improvements in filtering efficiency which will enable them to increase the capacity of their pelletising plant without installing additional filters.

Biographies

Robert E Wood is responsible for business development of SubCom systems at Inproheat Industries Ltd. He has been focused on developing Inproheat's submerged combustion technology in the mining industry. Robert joined Inproheat in 2009 after completing an MBA at the Sauder School of Business at the University of British Columbia in Vancouver, British Columbia. Robert also holds a Bachelor of Applied Science degree in Civil Engineering from the University of British Columbia. Robert previously worked as an engineering consultant designing and managing a variety of municipal works projects for cities, municipalities and First Nation communities around the province.

Wes Young is Chief Engineer and Project Manager for Inproheat SubCom systems. He has worked in the design, development and operations of resource projects for 35 years, predominantly in the mining and oil and gas industries. He received his Bachelor of Applied Science degree at the University of Toronto in 1975 and holds a certificate in management from the Canadian Institute of Management. He spent several years in the operation of uranium processing plants in Saskatchewan and Alberta, and many years with Fluor Daniel Wright Ltd in the design and construction of hydrometallurgical plants for the recovery of nickel, copper, gold, vanadium, molybdenum, zinc and other metals. He is a registered professional engineer in the Provinces of British Columbia and Alberta.

Introduction

This paper describes the design process and expected outcomes of a slurry heating system, using submerged combustion technology, at an integrated steel plant in Mexico. The purpose of heating the iron ore concentrate slurry prior to pelletising was to increase the filtration rate and cake moisture, enabling the pelletising plant to increase production without increasing the number of filters. The benefits of heating the slurry prior to filtering has been shown through independent studies, but has not been considered until now because of the high cost of heating the slurry using conventional heating technologies, such as a boiler / heat exchanger system, or direct steam injection. The two above-mentioned conventional heating technologies are high capital cost systems due to the ancillary systems needed to support them, relatively low thermal efficiencies achieved and maintenance required.

Boilers operate at thermal efficiencies of around 75% to 85% in optimal conditions and require regular maintenance to ensure safety, due to the high-pressure operation. The thermal efficiencies of boiler systems tend to decrease with time as the heat exchangers foul. Furthermore, boiler systems require condensate return systems to maintain a reasonable efficiency; adding more components requiring maintenance. Steam and condensate piping must be insulated for heat conservation and personnel protection, adding to the cost.

Direct steam injection systems are less complicated and more efficient than a boiler and heat exchanger system since the steam is used to directly heat the liquid. However, direct steam dilutes the heated slurry, which is counterproductive prior to filtering and offsets the benefits of heating the liquid.

Submerged combustion is a proven technology in several heavy industrial applications, and perhaps most notably in the liquid natural gas (LNG) industry where it has been used for over 50 years to heat seawater for the vaporisation of LNG. Relatively unknown in the mining industry, submerged combustion has the advantage of being able to heat any type of non-combustible liquid to near boiling point at thermal efficiencies approaching 100%, and without significant maintenance requirements. Submerged combustion is a process in which the products of combustion are exhausted through the liquid-to-be-heated. The energy transfer occurs directly between the liquid and the hot gases, resulting in high efficiencies with no fouling issues.

Submerged Combustion Technology

The slurry heating system highlighted in this paper is trademarked SubCom and was developed by Inproheat Industries in the early 1970’s in response to the global energy crisis. A SubCom liquid heating system consists of a fuel burner mounted at the top of a combustion chamber, which extends down from the top of a tank containing the liquid-to-be-heated, as shown in **Figure 1** below. The burner is connected to a blower that provides air for combustion as well as heat transfer. The blower evacuates the liquid from the combustion chamber allowing the flame to burn in a dry atmosphere without impingement, for complete combustion. The heat transfer takes place between the exhaust gases and the liquid-to-be-heated. An inherent property of the technology is that the temperature of the exhaust gases are the same, or close to the same, temperature as the heated liquid, which means high heat transfer efficiencies.

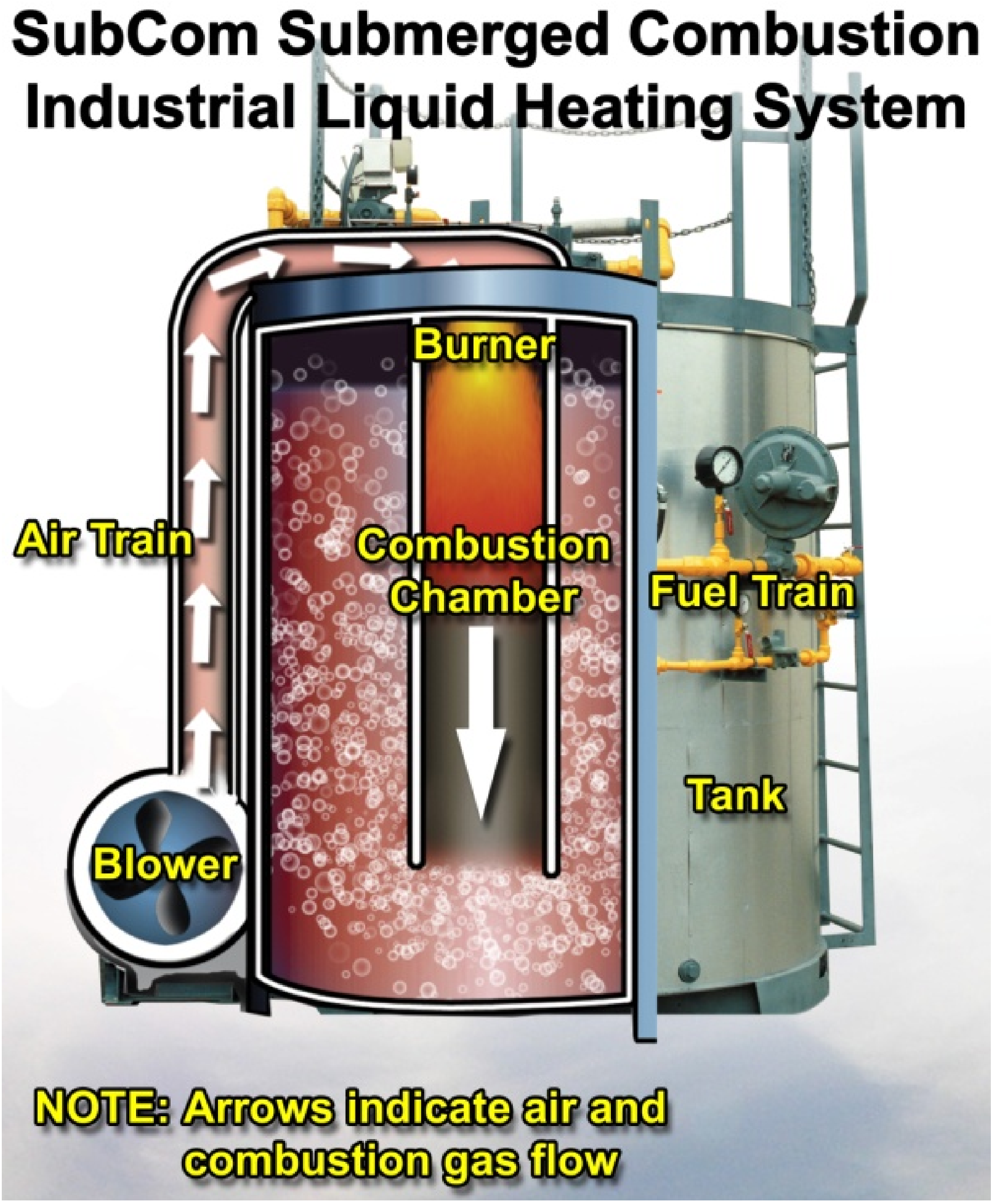

Figure 1 – SubCom Cutaway

The Plant

The project is located at an integrated steel production facility. The facility receives concentrate from a its mine via a 400 km pipeline. A diagram of the partial process is shown below in **Figure 2**. Part of the processing requires the dewatering of iron ore concentrate slurry (approx. SG = 2) in order to make iron pellets. Dewatering of the slurry is done by vacuum disc filters.

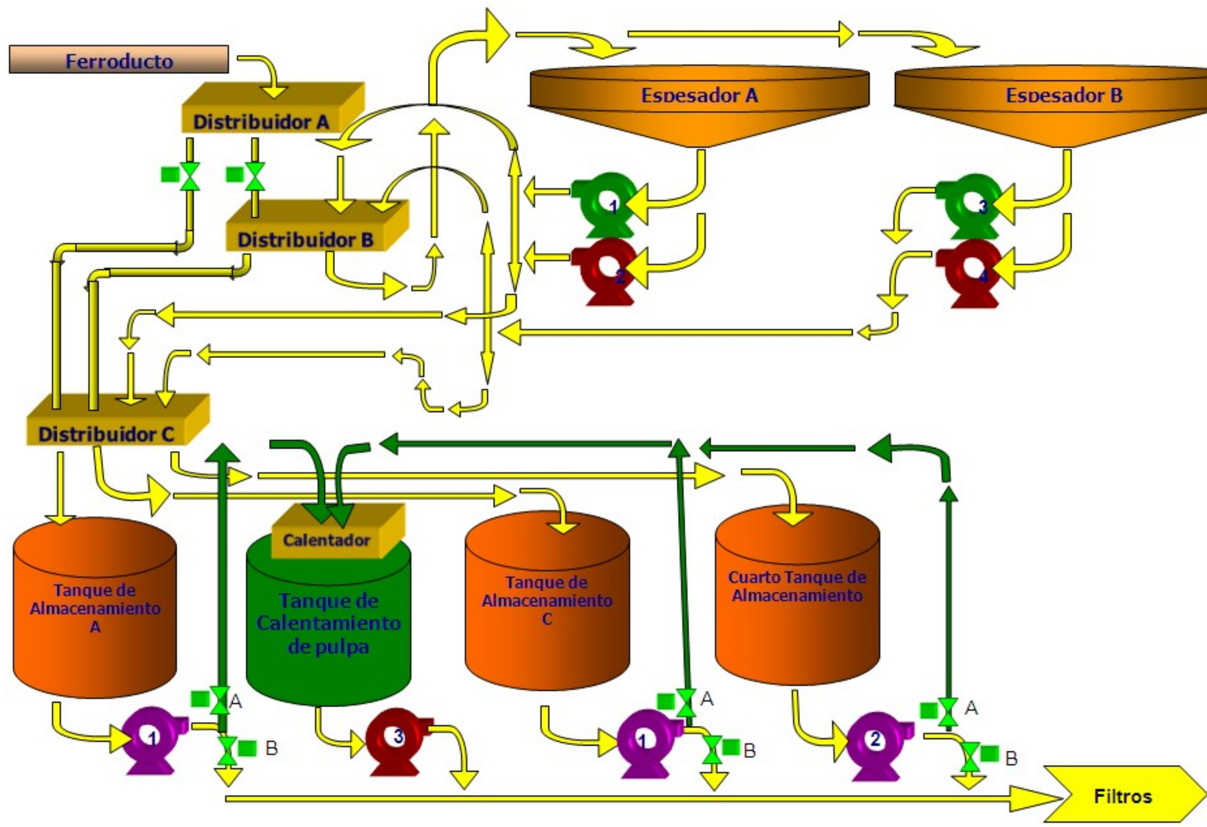

Figure 2 – Iron Ore Processing Flow Diagram

The Beginning

AHMSA approached Inproheat wondering if submerged combustion could provide an economic and operational advantage versus upgrades to the pelletising operation. Over several months of investigation, including a pilot project, the customer determined that a SubCom system would provide the increased operating capacity at a lower cost than upgrading the vacuum disc filter system. The expected result was an efficiency gain of at least 30% at the vacuum disc filters (AHMSA).

Heating the slurry reduces the surface tension of the water, which improves the capacity of the vacuum filters. AHMSA indicated preliminary results showed an increase in filtering capacity of 33% and a reduction in water content of 0.5%. They stated heating the iron ore slurry also increased the temperature of the green pellet entering the furnace from 30°C to 50°C, reducing the moisture content by a further one percent. The reduced moisture content results in fuel savings at the furnace of 1.6m^3 of natural gas per tonne of pellet product (3.1m^3 of coke gas per tonne of pellet product). At an annual production rate of 3.55M tonnes per year this equates to a fuel savings of $900,000 at a price of $0.16/m^3 ($4.25/GJ) for natural gas.

Design Considerations

The following sections describe the major design decisions that were made during the course of the project.

Installation Type – Retrofit or Standalone?

The iron ore concentrate slurry is stored in a 15m diameter, 15m high steel tank equipped with a 4.25m diameter single pitched blade turbine impeller agitator, as shown in **Figure 3**. The slurry is pumped from the tank to the vacuum disc filters. The slurry heating system needed to be installed either in one of the existing slurry storage tanks, or in a separate system in-between the storage tanks and filters. This was the first main design consideration of the project. Retrofitting the existing tank would require sealing the top of the tank to be able to direct the exhaust gases to the external Heat Recovery Unit (HRU), while constructing a standalone system would require a new tank to house the five burners required and scarce real estate on which to place the tank.

Chamber Cooling

The top portion of the combustion chambers, above the static liquid level, are normally cooled by the wave action and turbulence caused by sparging the combustion gases through the liquid. In this case, the specific gas release area (area of the tank to volume of gas released) was considerably higher than traditional design for SubCom, the specific gravity (SG) of the liquid was greater than two and the viscosity was 5cP. It was the highest SG and most viscous liquid Inproheat had heated. Inproheat was concerned that the high SG and viscosity, and lower than usual specific gas release area might reduce the wave action enough to limit the cooling effect on the combustion chambers.

A slurry jet cooling system was devised by Inproheat and tested at at the University of British Columbia's (UBC's) NBK Institute of Mining Engineering. The slurry jet cooling system comprised four nozzles that sprayed a slipstream of slurry, pumped from the storage tank, onto the top portion of a full scale mock-up the upper section of a combustion chamber. The flow rates, nozzle design, and nozzle arrangement were developed from the test work.

Chamber Design

The SubCom combustion chambers normally have an enclosed bottom to minimise or eliminate liquid level fluctuations inside the chambers due to hydraulic wave action created by the gas sparging. The combustion chambers fill with liquid when the combustion air blower is shutdown. The blower then evacuates the chambers by pressuring them during start-up.

There is concern that settled slurry inside the chamber may be difficult to displace. Therefore, Inproheat designed the chambers with a larger than normal drainage orifice to reduce the amount of solids retained inside the chambers and for the slurry to be forced out of the when positive pressure is applied by the blower. In addition, Inproheat also designed and incorporated a new bottomless chamber as a trial to assess the performance characteristics between the two chamber designs.

System Components Description

The Inproheat SubCom system supplied to the customer was designed to heat 403 m^3/h of iron ore concentrate slurry from 25°C to 60°C. The SubCom system consisted of five independent burner systems, each with a heating capacity of 12 GJ/h. The burners were designed to be natural gas fuelled.

The SubCom combustion chambers were suspended in the top of a slurry storage tank, shown below in **Figure 3**. The blowers and fuel train frames with Burner Panel were located on the tank top beside the combustion chambers.

A Heat Recovery Unit (HRU) preheats the incoming iron ore concentrate slurry by contacting SubCom exhaust gas with the feed slurry.

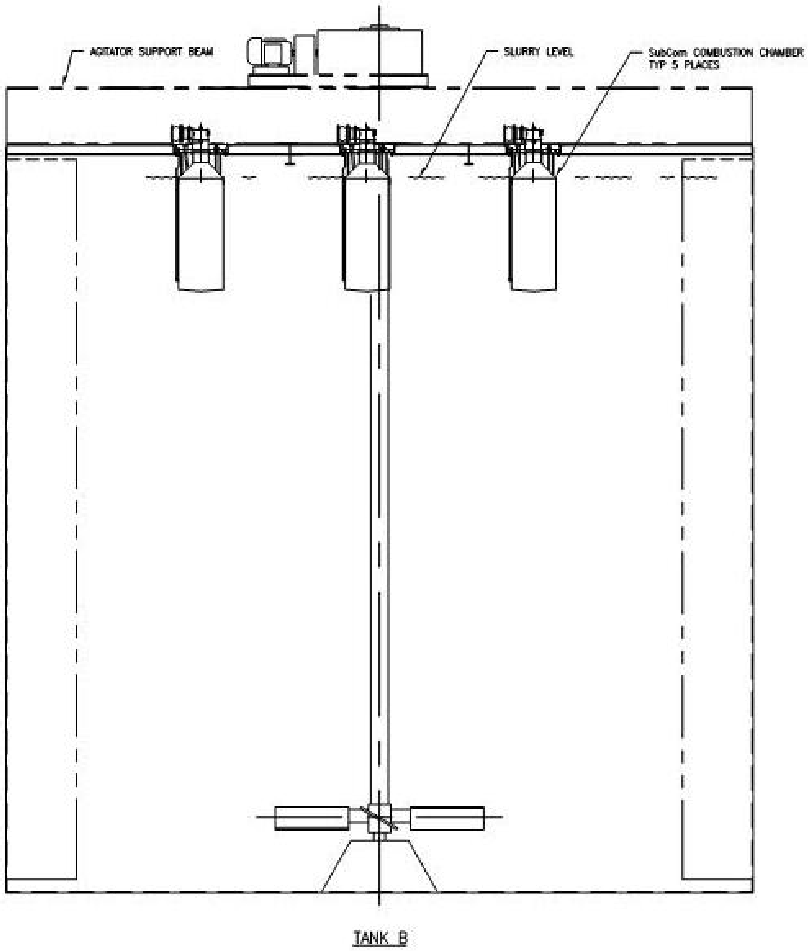

Figure 3 – Slurry Storage Tank Heater Elevation Layout

General Process Description

Slurry, at 25°C, is pumped to the HRU where it contacts exhaust gas from the slurry storage tank. The gas is hot (about 60°C) and saturated with water vapour. When the slurry and gas mix, sensible heat and latent heat from the condensing of water vapour are transferred to the slurry. The cooled gas is exhausted out the HRU stack. The heated slurry flows by gravity from the HRU and drops into the slurry storage tank.

The five SubCom burners heat the slurry in the slurry storage tank to 60°C. The temperature of the slurry in the tank is monitored by a thermocouple in the tank. The slurry level in the tank is controlled by a level control loop that modulates the pumping rate of slurry out of the tank. A software low level switch, backed up by a hardwired mechanical float-type level switch, ensure that the burners will not operate if there is not enough slurry in the tank to cover the combustion chambers. If the level is too low, the fuel supply to the burners is disabled by closing of the main gas shutoff valves.

If the design heating capacity is required, all five burners will be running. If conditions change that lowers the heating input requirement, some burners can be put into the low-fire mode, standby mode or completely shutdown. Some conditions that would reduce heat input requirements are: reduced feed flow rate; higher than design (25°C) feed temperature; and lower than design (60°C) output temperature. In low-fire mode, the burner output is about 30% of the maximum heat output. In the standby mode, the fuel to the burner is shutoff but the blower continues to run. This prevents the combustion chamber from filling with slurry and maintains system readiness for immediate re-firing of the burner.

A stream of slurry taken from the incoming feed line is distributed to each burner chamber. A series of four nozzles sprays slurry onto the upper region of the combustion chamber to keep it cool.

Heat Recovery Unit

The exhaust gases from the submerged combustion process, at 60°C, contain a significant quantity of recoverable heat. The Heat Recovery Unit (HRU) transfers some of that heat into the slurry that feeds into the slurry storage tank.

The HRU is a 2.4m diameter vertical vessel with a cone bottom. Cold (25°C) slurry feeds by a 200mm diameter line into the apex of the cone bottom. The slurry flows upward inside the HRU tank. SubCom exhaust gas from the slurry storage tank is forced through a rectangular duct that feeds into the side of the HRU vessel. A 1.8m diameter gas chamber, similar to the combustion chambers, conducts the SubCom exhaust gases into the HRU vessel and sparges the gas into the slurry through a series of holes in the side of the chamber. Heat transfer and condensation of water vapour occurs on contact between the slurry and the gas. The heated slurry then overflows over an internal weir, and drops through a discharge launder that transitions into a 250mm diameter pipe into the slurry storage tank. The discharge pipe outlet is submerged in the slurry so that it acts as a seal leg at all times.

Cooling Slurry System

With conventional SubCom systems, the chambers are mounted in small tanks. In the confined space, the high amount of turbulence created by the release of the combustion gas from the liquid causes splashing of liquid onto the chamber cone. This fluid helps to cool the cone. In the large 15m diameter slurry storage tank there may be insufficient liquid turbulence on the surface of the slurry around the combustion chambers to provide the necessary amount of cooling. Therefore, a system to spray slurry onto the upper cone of the chambers has been provided. The cooling system consists of four spray nozzles that direct a stream of slurry onto the discharge throat of the burner. The slurry then flows down the throat and onto the chamber cone.

Conclusion

The project is currently in the final stages of construction, with start-up expected this summer. Everyone is excited and confident about the commissioning. However, several questions about how the system will function in a dense slurry are unknown. Questions such as:

- How will the slurry react to being forced out of the combustion chambers on start-up? Will the combustion chambers be required to be bottomless to evacuate the chambers during start-up? The blowers have been oversized to ensure success, but nevertheless it is an unknown.
- Will the cooling slurry system be required or will the bubbling action of the system provide enough wave action to cool the upper sections of the combustion chambers?

The customer expects a greater than 30% efficiency gain at the vacuum disc filters and fuel cost savings of nearly $1M at the pelletising furnace by heating the iron ore slurry.

References

HÄKKINEN, ANTTI and EKBERG, BJARNE, 2009, Dewatering of iron ore slurry by a ceramic vacuum disc filter, p. 6, ICheaP-9; The Ninth International Conference on Chemical & Process Engineering.

Anecdotal information from AHMSA.