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I-ThERM

D6.1 Report on operating environment of FHPS
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Executive Summary

In the iron and steel industry, once of the major waste heat sources are the solid products, like Slabs, Coils, Rail, Wire rod...etc, around 10-35 MW thermal energy is stored in these products that are not being in use due to the absence of commercially viable solutions to date.

In the frame of I-Therm project,WP6 will investigate and deliver a 200kW flat heat pipe system (FHPS) to facilitate waste heat recovery from hot sources in the steel process facility of ArcelorMittal España. The new system will be developed to have a modular design where sizing up or down the heat recovery capacity requires only adding or removing FHPS modules.

The first step to carry out this work is to do a characterization of the different process in the Iron and Steel making in order to can select the best facility to do the FHPS test. The operational environment for the FHPS has been investigated with regards to the space availability, grid specifics, ambient air quality, etc. Taking into account the waste heat that could be recovered by radiation, two facilities seem to have the highest potential: Continuous Casting and Wire Rod Mill.

- In the case of Continuous Casting the temperature of the slabs is around 700ºC; moreover, the material is not cooled with external sources (like air fans), so up to 3MW of waste heat could be recovered by radiation.
- At Wire Rod Mill depending on the material class and quality, there are different cooling programs and as a consequence the cooling of the wire has different profiles. Most common programs are done by forced convection. Other materials cool down at room temperature, so all the fans are stopped. The average temperature could be around 500ºC. The potential waste heat that can be recovered by radiation in both lines would be 2.2 MW.

Although in both facilities, external utilities (electricity and water) that will be required for the FHPS installation are available, Wire Rod Mill meets better than Continuous Casting with space availability and safety requirements.

Within Wire Rod Mill, it can be possible to test the FHPS in the different zones along the line and with different material class and taking into account the additional cooling that will be done by the FHP.

The next step will be to do a thermal characterization campaign (in continuous operation) of the hot solids in order to identify the temperature variation between the start and the end of the production line and under different process conditions. The collected data will be utilised by Brunel University London to optimise the design of the FHP.

1 Introduction

During steel manufacturing process, there are many potential sites to utilise waste heat recovery in order to reduce energy consumption and enhance the efficiency of the process in general. One of these sites is the rolling products process that usually come out to the cooling table and yards. It is estimated that around 10-35 MW thermal energy is stored in these products that are not being in use due to the absence of commercially viable solutions to date.

The main objectives of the WP6 under the i-Therm project are

- Developing a heat pipe system to facilitate waste heat recovery from hot solids (> 500ºC)
- Investigate the modular design approach to facilitate sizing up/down based on the heat loads/cooling requirements
- The system will be designed by *Brunel University London*, manufactured by *Econotherm* and will be installed and tested by *ArcelorMittal at their facilities* in collaboration with *Brunel University London*.
- The testing plan, instrumentation and data analysis will be managed by *Brunel University London* and *ArcelorMittal*.

The objective of this report is identify and characterize the operational environment of the potential facilities where can be tested the Flat Heat Pipe System (FHPS), with regards to space availability, utilities resources and safety requirements

2 Solid Waste Heat Sources in the Iron and Steel industry

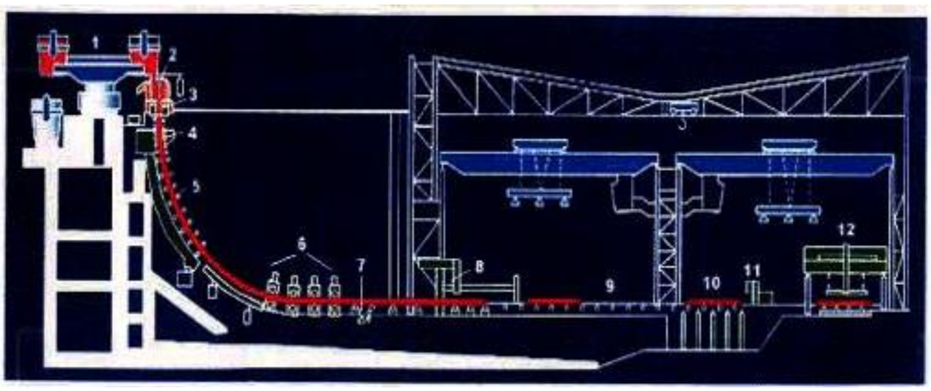
In the following section, the different processes where hot solid products are produced will be described. These processes can be potential facilities to test the Flat Heat pipe system that will be developed under the i-Therm project WP6.

From each facility information was requested in order to can evaluate if it could be candidate to act as a demo site for the developed system. The requested information is:

- Temperature and flow working duty
- Space availability
- Utilities resources (electricity , water main and properties)

2.1 Slabs

In the frame of Steel Shop, Continuous Casting (CC) is the process whereby molten steel from the converter, is solidified into a "semi-finished" billet, bloom, or slab for subsequent rolling in the finishing mills. The difference among these three products are the dimensions.



1:Ladle Turret, 2:Tundish/Tundish Car, 3:Mold, 4:First Zone (Secondary Cooling), 5:Strand Guide (plus Secondary Cooling), 6:Straightener Withdrawal Units, 7:Dummy Bar Disconnect Roll, 8:Torch Cut-Off Unit, 9:Dummy Bar Storage Area, 10:Cross Transfer Table, 11:Product Identification System, 12:Product Discharge System. Source :AIIS

When these products out from the continuous casting machine, they go through roll strip where they are cut, identified and picked up to storage zone.

In the case of ArcelorMittal Asturias plant, there are two continuous casting:

- Avilés Continuous Casting that produces slabs that will be used to produce coils at the host strip mill.
- Gijón Continuous Casting where blooms and billets are produced. With these two products rails and wire are made respectively.

The average temperature of these products is 700 ºC. The ideal place to try to recover the waste heat can be between the exit of the continuous casting machine and flame-cutting zone. The space availability around this zone is enough to install a prototype, see Figure 1 and 2. In the different zones, electricity and water connections are available.

Figure 1:Facility :Avilés Steel Shop; Product:Slabs; Average Tª: 700ºC

The potential heat that can be recovered from the slab has been estimated for radiation mechanisms. For a of 1.7 m width at 700ºC, according to the radiation law, heat emission is:

$$Heat\ (\mathrm{kW}) = \sigma(\frac{\mathrm{W}}{\mathrm{m}^2 \cdot K^4}) \cdot S\ (m^2) \cdot \varepsilon \cdot ((T_s(K))^4 - (\mathrm{T(K)})^4)/1000$$

Where σ is the constant of Stefan-Boltzmann, S is the surface (1.7 m^2), ε is the emission coefficient for the slab at 700ºC, *Ts* is the temperature of the slab 700ºC (973 K) and *T* is the room temperature (about 293 K), and for this data radiation heat released by a slab is 728 kW. Avilés steel shop has a length of about 15 m and as there are four slab lines, the radiation heat potential is about 3MW.

Figure 2: Continuous Casting Zone

2.2 Coils

The hot strip mill is a rolling mill of several stands of rolls that converts slabs into hot-rolled coils. The hot-strip mill squeezes slabs, which can range in thickness from two to ten inches, depending on the type of continuous caster, between horizontal rolls with a progressively smaller space between them (while vertical rolls govern the width) to produce a coil of flat-rolled steel about a quarter-inch in thickness and a quarter mile in length.

Figure 3: Facility: Hot Strip Mill; Product: Coils; Average Tª: 580ºC

The temperature of the coils at the end of the coiler is around 580ºC, then the coils are transferred in a conveyor to coil yard where they are cooling at ambient temperature.

The part of the process that can be more accessible is the conveyor, but in this part the temperature is lower than 580ºC.

Next pictures (Figure 5) show the coils at the conveyor (a) and the radiation temperature measured in one of the conveyor walls (b), the temperature is around 200ºC.

Other issue is that the residence time of the coils in the conveyor is short and this can affect the amount of waste heat to be recovered. The potential waste heat to be recovered could be increased if it would be possible to cover all the conveyor (100-200 m).

Figure 4: a) Coil in the Conveyor b) Punctual temperature measurement

The potential heat that can be recovered from coils has been estimated by radiation. Coils dimensions vary within the following parameters:

- *Internal diameter*: between 0.61 and 0.76 meters
- *Outer diameter*: between 0.8 and 2.2 meters
- *Height*: between 0.7 m and 1.223 meters

For the case of the largest coil at 580ºC, with internal diameter 0.76 meters, external diameter 2.2 meters and height 1.223 meters, the heat emission is:

$$Heat\ (\mathrm{kW}) = \sigma\left(\frac{\mathrm{W}}{\mathrm{m}^2 \cdot K^4}\right) \cdot S\ (m^2) \cdot \varepsilon \cdot \left(\left(T_s(K)\right)^4 - \left(\mathrm{T(K)}\right)^4\right)/1000$$

Where σ is the constant of Stefan-Boltzmann, S is the surface (30.3 m²), ε is the emission coefficient for the coil at 580ºC, Ts is the temperature of the coil 580ºC (853 K) and T is the room temperature (about 293 K), and for this data, the radiation heat potential is about 762 kW per coil, assuming that in the bottom part of the coil does not take place profitable radiative heat.

2.3 Wire rod

The objective of a wire rod mill (WRM) is to reheat and roll steel billets into wire rods.

The Wire rod rolling mill at ArcelorMittal Asturias plant produces wire rods with diameters from 5.5 to 24 mm. The mill layout consists of a walking beam furnace, descaler, 3 stands, Isolated roller table, roughing mill, 2 intermediate mills, wire-rod finishing mill, the reducing/sizing mill, laying heat, and coolers fans.

After the walking beam furnace, the billet goes to the descaler where the scale is removed on the billet before it feeds the Break Down Mill. The roller table takes the single strand billets coming from the Break Down Mill and directs these billets either to the left or right strand of the existing mill.

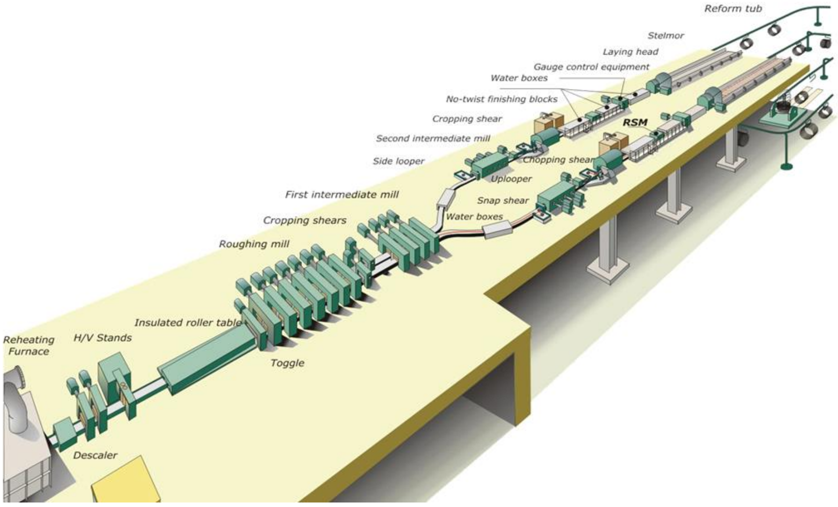


Figure 5: Wire Rod Mill Lay out

Then in the roughing mill, the stands feed the First Intermediate Mill. Gears arrangements have been revamped in the year 2000 in order to meet the speed increase. The second intermediate mill has a horizontal regulation loop entry of first stand. The arrangement is horizontal-vertical in order to roll with no twist and vertical loops between the automatic regulation stands.

The Reducing/Sizing Mill (RSM) has a reducing unit (Two 230 mm stands), and a sizing unit (Two 150 mm stands). The stands are coupled to an external drive driven by a motor.

The next step is the Laying Head. It is a rotating unit which changes the stock linear movement into a circular one and transforms the rod into rings. At the end of the line there are a total of 29 fans, the blowers are located below the conveyor length in order to supply a controlled air flow for the material cooling.

The reform is located at the end of the cooling conveyor and has adjustable rollers, double iris, ring distributor and nose cone. This cone helps the rings to uniformly fall onto the coil plate and the mandrel. The tub shear is located below the iris and it is only used to produce half coils. After a complete coil has been formed in the tub, the mandrel rotates and puts that coil in horizontal position for the transfer car to collect it. This car transports the coil to the hook in waiting position.

Figure 6: Facility: Wire Rod Mill; Product: Wire Rod; Average Tª:900ºC

Depending on the material class and quality, there are different programs and as a consequence the cooling of the wire has different profiles. Most common programs are done by forced convection. Therefore, it is used 29 fans that usually cool the wire from 920 ºC to 250 ºC. Other materials cool down at room temperature, so all the fans are stopped. The average temperature could be around 500ºC.

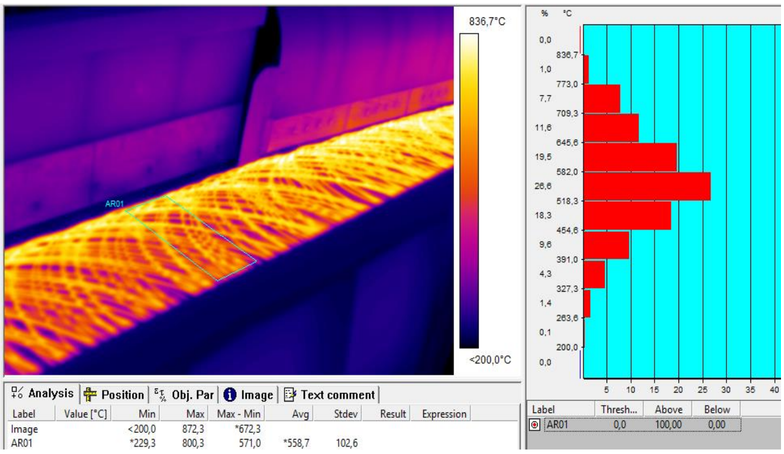


Figure 7: Thermal Characterization. Spot measurement

Due to this fact, it could be possible to test the Flat Heat Pipe prototype in different zones along the line, in order to be able to evaluate how much energy can be recovered in the zone away from the fans and depending on the cooling programs of the material.

In this facility, electricity and water connections are available.

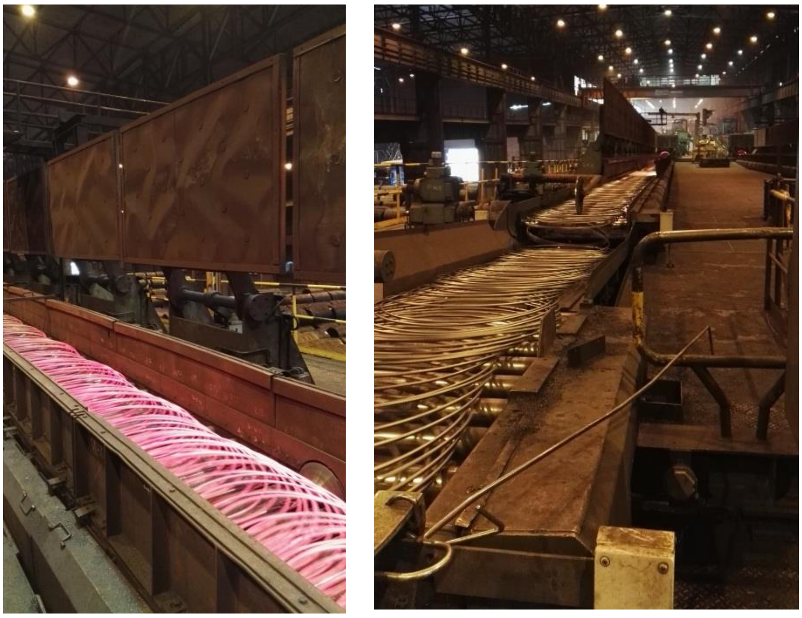


Figure 8:Wire Rod Mill . Zone 1 and Zone 2

The potential heat that can be recovered from the spires has also been estimated by radiation laws. The average heat emission for each wire rod is calculated taking a maximum temperature of 920ºC near the laying head and a minimum of 400ºC at the final step of the line. The maximum weight of a wire rod is 2 tons and its footprint in the conveyor 36 meters.

In this case the radiative heat transfer between the wire and the surrounding is:

$$Heat\ (\mathrm{kW}) = \phi \cdot \sigma\left(\frac{\mathrm{W}}{\mathrm{m}^2 \cdot K^4}\right) \cdot S\ (m^2) \cdot \varepsilon \cdot \left(\left(T_s(K)\right)^4 - \left(\mathrm{T(K)}\right)^4\right)/1000$$

Where ϕ is the shape factor, the relationship between the volume of the wire and the total footprint volume in the conveyor (0.3), σ is the constant of Stefan-Boltzmann, *S* is the surface of the transfer (36 m^2), ε is the emission coefficient, *Ts* is the temperature of the steel between 920ºC and 400ºC and *T* is the room temperature (about 293 K), and for this data radiation heat released by a wire rod in the cooling bed is 567 kW.

Gijón wire rod mill has a length of about 70 m and as there are two lines, so the potential radiation heat is about 2.2MW

2.4 Rail

Railway steel profiles are manufactured in the facilities of ArcelorMittal Asturias in Gijón. The process for all the different types of rails is essentially the same: a steel bloom is heated up to a target temperature and is then placed on a roller conveyor. The deformation needed to transform the bloom, which has rectangular cross-section, into a rail is imposed using several intermediate shapes. The rail mill has three different stands, the rolls in the first two have five different shapes and the las one only has one unique shape. The rails are usually manufactured using nine or eleven shapes (two of the shapes in the intermediate (second) mill are not used sometimes). Once the bloom has been transformed in a rail which is between 60 and 90 meters long it is cut into pieces of the desired length. Additional processes may be required, for example head hardening. The rails undergo surface inspection after cooling and shape inspection both at high temperature and after going through the cooling bed.

Figure 9: Facility: Rail Mill; Product: Rail; Average Tª:around 500ºC

In this facility it is not possible to implement a waste heat recovery solution due to the fact that the material controlled cooling is done with fans along the line at a pre-specified cooling speed that is set to control the quality of the product.

3 Conclusion: Site Selection

The operational environment for the FHPS has been investigated with regards to the space availability, grid specifics, ambient air quality, etc.

Taking into account the waste heat that could be recovered by radiation, two facilities seem to have the highest potential: Continuous Casting and Wire Rod Mill.

- In the case of Continuous Casting the temperature of the slabs is around 700ºC; moreover, the material is not cooled with external sources (like air fans), so up to 3MW of waste heat could be recovered by radiation.
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