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Key Technical Researches on a Waste-Heat Boiler Associated with Non-Ferrous Metal Smelting Furnace

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Smelting process requires the off-gases to be cooled, filtered, cleaned and exhausted in environmental compliance. Waste-heat boiler (WHB) is the heat recovery equipment directly connected with the smelting furnace outlet, which is working in a tough condition, leading to easy-fouling, easy-abrasion and easy-corrosion. The optimized design of WHB is key to ensure the smelting process safety and energy saving. Based on the composition test of the dust and a large amount of engineering experience, an optimized hood of WHB for the bottom-blow smelting furnace is presented. The air leakage is controlled in a reasonable range. The slagging problem and low-temperature corrosion near the furnace outlet are solved. The working rate of the smelting system is increased. It makes the metallurgical industry developing in a green and efficient way.

1. Introduction

Heavy non-ferrous metals (copper, nickel, lead, zinc, etc.) are the important basic raw materials of China's national economy, and now its production is top-ranking in the world. From January to November 2018, the output of ten non-ferrous metals was 33.84 Mt in China, increased 8.4 % year-on-year (FORWARD Business Information Co. 2019). Due to the high-speed growth of the production limiting by the leakage of domestic resources, a large number of foreign low-grade, polymetallic companion ore is imported. Ore in low grade causes the high-temperature flue gas with complex composition, high content of SO_2, heavy dust and humidity, and low dew point. The emission factor of SO_2 is 300 – 400 kg/t raw-cooper, and that of HF is 6 – 15 kg/t Aluminium, also the dust containing in flue gas is up to 300 g/Nm^3. The off-gas out of the furnace is corrosive and dusty with a large amount of waste heat, which poses a great challenge to the following equipment in the smelting system, the complex off-gas also causes worse air pollution problem. Zhou et al. (2018) studied the heavy metal data for particles sampled near an urban site affected by non-ferrous metal smelting in China, indicated that there are potential non-cancer effects and cancer risks in this area. Copper smelter even poses a health risk to residents who lived 7 km away (Yan et al, 2017). As its high-energy consumption and high pollution, the non-ferrous metal smelting industry is facing a new challenge of energy conservation and emission reduction (Zhang et al, 2019).

Some researchers (Sellitto and Murakami) studied the industrial symbiosis relationship involving a steelmaking plant, a cement plant and a zinc smelting plant. The by-products (slag, electric arc furnace dust, mill scale, and zinc sludge) could be in a full resource recycling in the technological clusters, which benefits for managing environmental and economic improvements. Besides trying the new production patterns, it is still very important to improve the current situation of the smelting process itself.

Generally, the smelting process requires the off-gases to be cooled, filtered, cleaned and exhausted as with any typical furnace system in environmental compliance (Moskalyk et al, 2003). WHB forms a connecting link between the furnace and the precipitation, to ensure the safe operation of the entire smelting system. The water in WHB absorbs heat in gas and turns into steam which can ensure self-use of the heat of the enterprise, also the surplus can be used for power generation (Li, 2016). Heat recovery reduces the energy consumption of the smelting process. WHB is indispensable equipment with good social, environmental and economic benefits.

WHB works in a tough condition, leading to easy-fouling, easy-abrasion and easy-corrosion. These have attracted many research efforts in designing this equipment since the 1950s (Beijing Nonferrous Engineering

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and Research Institute, 1982). Up to now, the configuration of the boiler was improved much to meet the above requests. It has an outside steam drum and a relatively large radiation cavity to collect dust; the posterior water wall surfaces are dense tube-banks to enhance the heat transfer when the off-gas is not so dusty and the temperature difference between the off-gas and the water is less. However, the off-gas components are different while smelting different ore, and each kind of smelting furnace is in different operation characters. So it is not easy to form a standardized design of WHB. Each WHB needs to specially design in engineering applications (Liu et al, 2015).

To ensure the safe operation of the boiler and prolong the boiler life, targeted inspection, skilled use of the boiler alarm system and the interlock protection device and strict management are several important factors. Wu et al. (2018) presented the important testing parameters and testing parts of the boiler based on the operation characteristics of WHB. Wu et al. (2019) summarized the problems of tube corrosion, ash deposition, tube explosion and explosion of the WHB based on the data in practical production. Controlling the boiler water pH value in 7 to 10, keeping reasonable velocity of the off-gas and proper operation of the ash removal device are effective measures to be used.

Smelting industry booms in China these years while reduces in the developed country due to its high-pollution. After the Noranda smelting, Outokumpu flash smelting, Teniente smelting, Mitsubishi smelting, Ausmelt/Isa smelting, Baiyin smelting, a newly developed intensified smelting technology, Oxygen bottom-blow smelting is developed in China. It has significant advantages and its intellectual property right belonging to China completely (Wang et al, 2017). The matching WHB for bottom-blow furnace is also developing equipment that needs to be well designed. It still has some problems reducing the productivity of the smelting process, especially low-grade, polymetallic companions ore is smelted, such as air leakage and slagging problems. In this paper, based on the composition test of the dust and a large amount of engineering experience, a new type hood of WHB for bottom-blow smelting furnace is presented. It matches well with the rotating furnace, and the air leakage is controlled in a reasonable range. The slagging problem and low-temperature corrosion near the furnace outlet are solved, raising the productivity of the smelting process.

2. Structure of the hood of WHB and Problems

Figure 1 is a sketch of a bottom-blow furnace and it is matching WHB. According to the requirements of the smelting process, slag mouth and copper matte mouth are located at both ends of the furnace. The cylindrical furnace body is supported on two sets of supporting wheels by two rolling rings. The furnace body can rotate 360° by moving the large-toothed ring fixed on the rolling ring through the driving device. During normal production, the furnace is fixed without any rotation. In case of product failure or replacement of an oxygen gun, the furnace body needs to be rotated to transfer the bottom oxygen gun out of the molten fluid surface. In that case, the off-gas goes through the bypass flue.

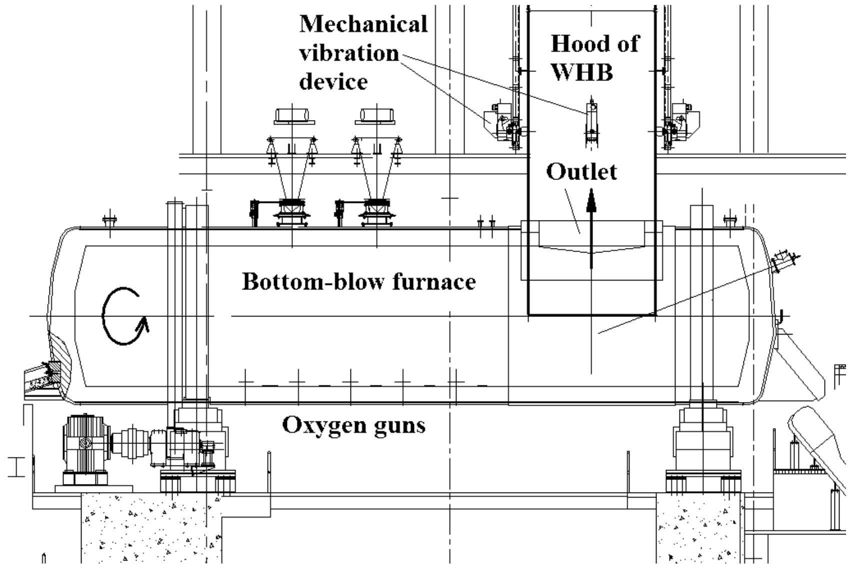

Figure 1: Sketch of the WHB hood matching the bottom-blow furnace

The hood of WHB covers the outlet of the furnace, and enclose the furnace body to prevent much air leakage. The profile of WHB is shown in Figure 2. In normal production conditions, the outlet of the furnace connects directly to the hood of WHB, hot off-gas flows into the uptake flue to exchange heat with water inside the WHB. In halt production condition, the furnace must rotate to the arc part of the hood which connects to the by-pass flue, the hot off-gas flows out through it and not flow into the WHB. The worker may repair the WHB.
In some smelting plant, during the pilot production time, misoperation or design defects may cause some problems at the hood part of WHB, and greatly reduce the operation rate of the process. Li (2017) summarizes as follows:

- The slagging of the hood is serious, which needs to rotate the furnace to clean up manually once per 3 d.
- Low-temperature corrosion occurs at the uptake flue near the outlet of the furnace, the tube is often broken.
- The time for repairing WHB is a total of 335 h during pilot production time, which greatly reduces the operation rate.

In this paper, the mechanism of slagging is deeply analyzed based on the data of the composition test, also combined the design defects of the hood. An optimized hood is presented.

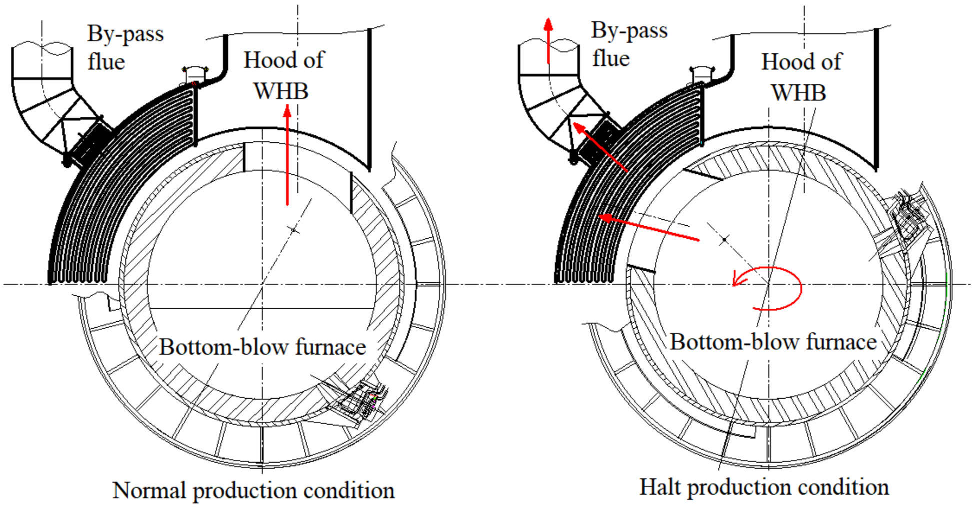

Figure 2: Cross-section of the furnace and the matching hood of WHB

Figure 3: Broken hood from the smelting plant

3. Optimized design of the hood

3.1 Mechanism of slagging

The slagging collected at the copper smelting plant is ground into power, as a sample to be X-fluorescence quantitative analyzed and XRD analyzed. The main elements are Fe, Pb, Sr, Zn, Si, and Cu, and Fe and Si account for the largest proportion, Pb and Sr are about 3 % – 5 %, and Zn and Cu are about 2 %. X-ray diffraction analysis shows that the Fe element mainly exists in the form of compounds. The compounds consist of Fe_2O_3 (27 %), $FeSO_4·H_2O$ (32 %), $CuSO_4·5H_2O$ (27 %), and $PbSO_4$ (14 %).
Generally, the melting points of pure metal oxides are higher, but when they are combined, a secondary physical and chemical process will occur, forming a new low-melting eutectic, which acts as binders and has a significant effect on ash characteristics. The melting temperature of the sample changes small from 1,025 °C (10 % smelted) to 1,062 °C (50 % smelted). That means at the outlet of the furnace where the temperature of the off-gas is about 1,200 °C, the slagging becomes cohesive and hard to clean up. When the temperature is lower by the leaking air to 1,025 °C, the slagging will become solidified on the surface and cause dust accumulation. The dense ash layer is too hard to be cleaned by the mechanical vibration device. That's why it needs to rotate the furnace to clean up manually once per 3 d.

3.2 Analysis of the design defects of the hood

The detailed design is shown in Figure 4. WHB can not be a full sealing equipment for some operation requirements, especially at the connection part with the furnace outlet. A gap should be considered between the hood and the furnace shell for the boiler expansion and the furnace rotation. Also maintaining a quantity of air leak here is necessary to lower the temperature of the off-gas, preventing the formation of monomer sulphur. Monomer sulphur may crystallize or combust at the ventilator at different temperature of the off-gas. However, the gap can not be too large because the cold air leakage will reduce the local temperature too much to cause low-temperature corrosion and slagging problems on the tube wall surface. So the gap is a key parameter of multi-factor. In the design of the former hood, the length of the uptake flue from the fixed point of WHB is about 20 m, which expansion is about 60 mm downward. Also, the expansion of the furnace of ~ 15 mm is considered. The gap is set as 100 mm, and covered with refractory textile changed regularly to the surface.

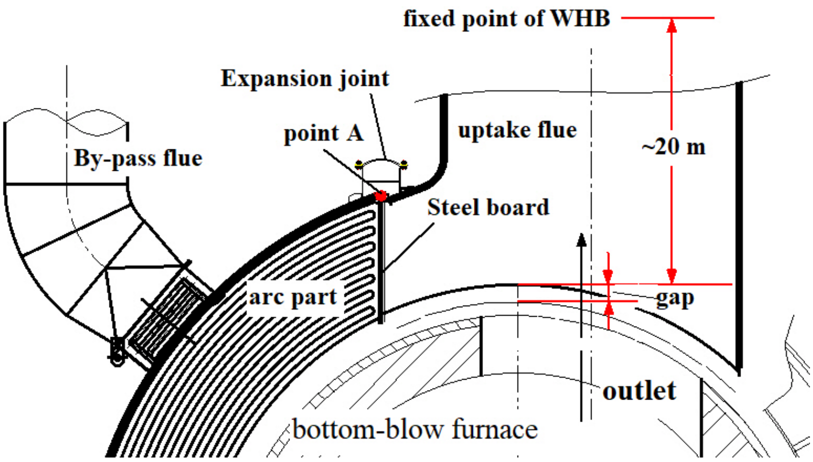

Figure 4: Structure of the hood

The hood has two parts, separated by the expansion joint. The arc part is connected with the by-pass flue which without hot off-gas flow into in normal production condition. The hot off-gas was blocked by the steel board which can rotate around Point A shown in Figure 4. It hangs on and not welded with the furnace shell. When the furnace rotates, it rotates around point A.
After practice, some design defects need to be optimized.

- Increase the ash cleaning device on the hood.
- Reduce the gap between the hood and the furnace.
- Rebuild the shape of the two parts of the hood. The size of the steel board blocking the hot off-gas is about 3,000 mm (width) × 1,000 mm (height) × 16 mm (thickness). Working in high-temperature make it easy to deform, deformation will limit the rotation of itself and the furnace.

3.3 Optimized structure of the hood

In a smelting process, the temperature of the off-gas is 1,200 °C. The slagging is smelted and cohesive, which is easy to adhere to the tube surfaces of the hood. The number of mechanical vibration devices is double increased as shown in Figure 5, and the strike force and frequency are also increased to clean the slagging.
In the normal production condition, the WHB operates in negative pressure. At the gaps where cold air leaking into, the local temperature is decreased, even below to 800 °C. At that temperature, the surface of the slagging becomes hard and need to clean up manually. The smaller the gap is, the better. Also maintaining a quantity of air leak here is necessary to prevent the formation of monomer sulphur. So two manhole doors are set in the walls of the upper-hood. It is convenient to clean up the slagging through them if necessary (Figure 5).
To reduce the gap, the structure of the whole uptake flue is changed. For stability, the fixed point of WHB is near or above the ceiling of the WHB, which fixed on the strong steel frame to support the WHB or hang the WHB. In the optimized design, to reduce the expansion, the hood separates from the uptake flue, where a new upper-hood connecting with an expansion joint setting between them. The expansion joint can bear the downward expansion from the uptake flue, while also the upward expansion from the new upper-hood. The height of the hood is only 2.3 m which fixed on the strong steel frame of the furnace. The total expansion at the gap is only ~20 mm, so make the gap of 50 mm is enough. The leak area reduces a half.
In the new hood, the difference of the expansion between the two parts is little. The expansion joint is canceled. The tube wall of the straight part stretches, while the steel board shortens. As shown in Figure 5, the steel board welds on the furnace shell. It rotates with the furnace at the same time.

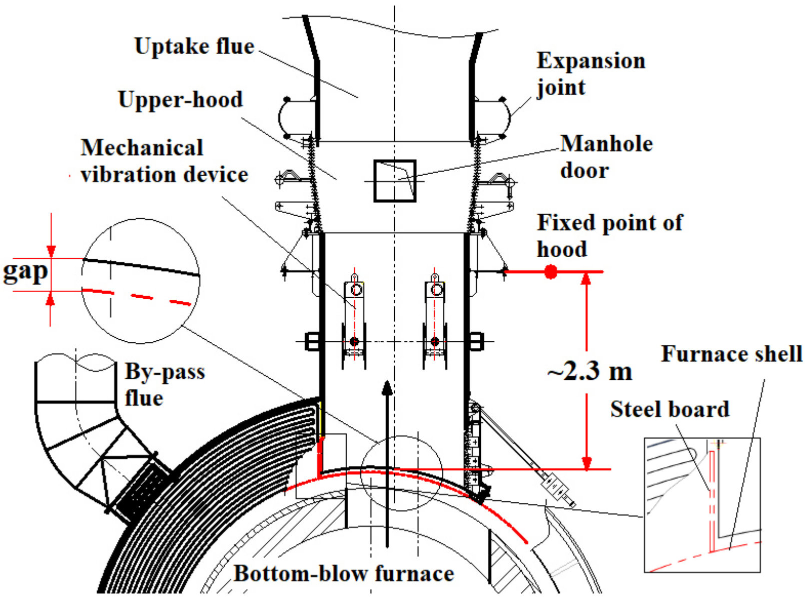

Figure 5: Optimized structure of the hood

With the optimized hood, the slagging problem is well solved. The mechanical vibration devices work well, and workers need not clean up manually. No slagging adhere to the tube wall, the heat transfer performance of the tube wall is well enough to overcome the overheat of the tube, the metal corrosion can also be avoided. The operation of the smelting system is greatly improved. The working rate increases from 89.3 % to 92.5 %, higher than the rated value of 91.7 %.

4. Conclusions

This paper provides an optimized design method of the hood of WHB for its safe operation and long life. The techniques are verified working well in the operating smelting system, but still need improvement further. The main conclusions are as follows:

- X-ray diffraction analysis shows that the slagging is a compound consisting of Fe_2O_3 (27 %), $FeSO_4 \cdot H_2O$ (32 %), $CuSO_4 \cdot 5H_2O$ (27 %), and $PbSO_4$ (14 %). Its smelting temperature changes small from 1,025 °C (10 % smelted) to 1,062 °C (50 % smelted). Local low-temperature makes the slagging too hard to be clean up by mechanical vibration device. In further study, to enhance the performance of the wall surface of the

WHB for preventing from slagging is valuable. An anticohesive agent should be developed based on the reaction analysis of the slagging.
- The gap between the hood and the furnace is controlled in a reasonable range (less than 50 mm) with the change of the structure of uptake flue. Low-temperature corrosion and slagging problems are accordingly controlled. The operation time is prolonged. But an efficient cleaning machinery is necessary to replace the manually cleaness near the furnace inlet.
- Welding the steel board on the furnace shell is an effective method to overcome the rotation problem causing by board deformation.

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