Shenqin Zhang *et al.* NEM:FOMI(2024)06
DOI: 10.62022/FOMI.issn3005-5466.2024.02.004

ISSN: 3005-5466
EISSN: 3005-5474

ARTICLE Open Access

Analysis and Prospect of Waste Heat Utilization from Blast Furnace Slag Flushing

Shenqin Zhang[1,2], Junyi Qing[2*]

(1. Baowu Group Guangdong Shaoguan Iron and Steel Co., Ltd.; 2. Shougang Changzhi Iron and Steel Co., Ltd.)

Abstract: Estimating the residual heat of blast furnace slag flushing in China, classifying and introducing the current proposed methods of slag flushing waste heat utilization, and listing existing cases. In order to better save energy and water in the slag flushing process of blast furnaces, an ideal comprehensive cascade utilization system scheme for annual recovery of waste heat is proposed. Based on the measured waste heat data of a steel plant, design calculations are carried out to further analyze the economic feasibility of the new scheme and provide reference for its promotion and application.

Keywords: blast furnace slag flushing; waste heat utilization; comprehensive cascade utilization; energy saving and water-saving

Introduction

Blast furnace slag flushing is the final process in ironmaking and smelting. The large amount of high-temperature slag generated after blast furnace ironmaking is cooled by slag flushing water, which can generate a large amount of hot water and steam [1,2]. To ensure the recycling effect of slag flushing water, it is necessary to cool the slag flushing water and recycle it again, resulting in serious waste of slag flushing energy and fresh water.

In 2017, China's steel production was approximately 830 million tons. Calculated based on 350 kg slag/t iron and 60 kg standard coal sensible heat/t slag, the sensible heat of blast furnace slag flushing in the steel industry reached 17.4 million tons of standard coal. If all of it is recycled, it is equivalent to reducing carbon dioxide emissions by 45.3 million tons, sulfur dioxide emissions by 418000 tons, and nitrogen oxide emissions by 122000 tons [3].

In recent years, the Chinese government has attached increasing importance to energy conservation and emission reduction, and green development has become an industry consensus. The full utilization of waste heat from slag has also become one of the important measures for energy conservation and emission reduction in the steel industry, which has also driven investment in technology research and engineering promotion in this area [4–6].

* Corresponding authors.
E-mail addresses: 2654784125@qq.com

1 Review of waste heat utilization methods for slag flushing

The current utilization of waste heat from slag flushing is mainly focused on the field of waste heat utilization from slag flushing water, with research and utilization methods mainly focused on heating, swimming pools, power generation, and other fields. The slag flushing water has many impurities and solid particles, high turbidity, high salt content, and is prone to scaling during cooling. Therefore, the water use of blast furnace slag flushing requires high requirements for pretreatment and heat exchangers, and has also been given special attention in practical engineering projects [7,8]. Usually, indirect heat exchange after filtration is used for waste heat utilization [9]. There are also literature mentioning the use of heat pipe heat exchange, vacuum phase change heat exchange, nano coatings, non-metallic heat exchange materials and other technologies for waste heat utilization.

© The Author(s) 2024
Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any mediumor format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changesweremade. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

1.1 Waste heat heating

Nowadays, the utilization of waste heat from blast furnace slag flushing water is generally concentrated in the winter heating field of northern steel plants, which is more convenient and cost-effective compared to other utilization methods.

The slag flushing water waste heat heating renovation project implemented by Angang has supplied 140000 square meters of heating area. It is expected to increase the supply of slag flushing water waste heat in the future with a small amount of steam, to meet the heating needs of Angang's 1.56 million square meters of factory and residential areas, and reduce the consumption of high-quality steam for heating. The Tianjin Iron and Steel Plant in Shexian County, Hebei Province, utilizes the waste heat from slag flushing water to provide heating for the 300000 square meter living area around the plant, replacing the original steam heating system [10]. According to statistics, during the four month heating season, about 12000 tons of standard coal were used, reducing carbon dioxide emissions by about 31000 tons and resulting in direct economic benefits of over 10 million yuan [11]. After the implementation of the blast furnace slag water waste heat recovery and utilization project at the ironmaking plant of the Laiwu branch of Shandong Iron and Steel Co., Ltd., an annual savings of 127600 GJ of domestic steam heat and 5105900 yuan of steam cost have been achieved [12]. Gao Honghong from Northeast Special Steel Plant analyzed that a certain steel plant can save 54000 tons of steam, 5130 tons of standard coal, and over 10 million yuan in heating costs during a heating period by recovering waste heat from slag flushing water for heating and providing domestic hot water engineering. The total investment in the waste heat recovery and utilization system is about 3.8 million yuan, and the investment can be recovered in the same year [13]. The Jigang slag flushing water waste heat heating system provides heating of 500000 square meters, with a total winter heating load of 25000 kW. The actual operating power consumption is 1200 kW, and the electricity cost for 1 kWh of heat recovery heating is about 0.03 yuan. Compared with coal-fired and gas boiler heating, the annual heating cost savings are 5.4 million yuan and 18.6 million yuan. The waste heat from the slag flushing water of Taiyuan Iron and Steel blast furnace is reused for municipal heating projects. The amount of waste heat recovery during the heating season is 9132500 GJ, equivalent to approximately 311700 tons of standard coal. Every year, it can reduce sulfur dioxide emissions by about 865 tons and dust emissions by about 1730 tons. After the implementation of this project, adding steam peak shaving during the heating period can reach a heating area of 4 million square meters.

1.2 Bathtub heating and hot water production

Hanggang produces hot water for surrounding enterprises through waste heat recovery from slag washing water, with a renovation project investment of about 2 million yuan. According to statistics, the cumulative production of commercial hot water from January to May was 72884 tons, with an average temperature rise of 50 ℃. The cumulative heat recovery was 15233 GJ, equivalent to 520 tons of standard coal, and a thermal energy usage fee of 220000 yuan was charged [16].

Tangshan Stainless Steel Co., Ltd. has transformed the heat source for heating domestic water in the factory area from steam to waste heat from slag flushing water through renovation. The saved steam can be used for power generation, creating an annual benefit of up to 4.717 million yuan. The total investment of the project is about 3.8 million yuan, and the cost can be recovered in 10 months [17].

1.3 Desalination of seawater

The soft water station of Tangshan Iron and Steel Stainless Steel Company adopts the process of ultrafiltration+reverse osmosis for water production. Ultrafiltration requires an inlet water temperature of 20 ℃ , but the average winter temperature in Tangshan area is around 2 ℃. By using slag flushing water for heat exchange, the inlet water temperature of ultrafiltration is increased from 2 ℃ to above 25 ℃, which increases the water production capacity by nearly three times and can save 10000 tons of standard coal per year [18]. Shougang Jingtang Iron and Steel United Co., Ltd. constructed the largest seawater desalination project in China at that time, with a construction scale of 50000 t/d. The plan was to use waste heat recovery from blast furnace slag flushing water instead of steam heat sources, with an expected annual benefit of 8.632 million yuan. The cost of the slag flushing waste heat heat heat exchange system will be recovered in 2 years.

The literature analyzes the application of seawater desalination based on the waste heat of blast furnace slag flushing water as the heat source. If the low-temperature waste heat recovery of blast furnace slag flushing water in coastal steel enterprises is used as the heat source for seawater desalination, the theoretically recoverable waste heat can be equivalent to 720000 tons/a of standard coal, while producing high-quality fresh water of 7.5 million tons/a, and the comprehensive cost of seawater desalination can be reduced by more than 20%.

1.4 Research on other utilization methods

Zhou Yong et al. conducted a comparative analysis of two power generation methods, flash evaporation power generation and ORC power generation, using waste water and waste heat [19]. At a blast furnace slag flushing water volume of 2600 t/h and a temperature of 90 ℃, the power generation of flash

evaporation and ORC power generation are 4000 kW and 3200 kW, respectively. Chen Jun et al. introduced ORC power generation and temperature difference power generation [3], and believed that due to the current technological conditions, the utilization efficiency and economy of using these two technologies in slag flushing water waste heat utilization projects are still relatively low.

Lv Yongpeng used the concept of equivalent electricity to calculate the equivalent electricity consumption of waste heat from blast furnace slag washing water for absorption refrigeration under typical conditions, and compared it with the energy consumption of conventional voltage contraction refrigeration systems. The critical conditions for energy-saving operation of blast furnace slag washing water waste heat absorption refrigeration systems under specific operating conditions were obtained, providing reference for waste heat refrigeration from slag washing water [20].

2 Outlook on the utilization system of waste heat from slag flushing

The current research and application of waste heat utilization in slag flushing mainly focus on slag flushing water, while there has not been any relevant research and demonstration on the utilization of slag flushing steam. In actual operation, most of the energy generated by the waste heat from slag flushing is carried away by steam, and the steam discharge also takes away a large amount of water, which is the main water consumption part of slag flushing. Han Hongsen et al. analyzed the sensible heat of blast furnace slag at Jigang, and found that the sensible heat of blast furnace slag was 31920 kW, the heat carried away by flushing water was 8620 kW, and the heat carried away by flushing steam was 23300 kW [14].

For the heating method of waste heat recovery from blast furnace slag flushing water, the total waste heat recovery and utilization rate is very low due to the influence of the heating season. To improve utilization efficiency, it is necessary to promote the use of more widely used waste heat utilization technologies. Based on Professor Wu Zhonghua's principle of "temperature matching and cascade utilization", an ideal blast furnace slag flushing utilization system is proposed, which uses temperature from high to low for power generation, cooling/heating, drying, and bathing. To better design the new system, design and measure the slag flushing parameters of the steel plant, and perform temperature and flow rate parameter variation curves over time.

Compared to the temperature of the return ditch, the temperature inside the tower is higher during blast furnace slag flushing. Nowadays, the main application of waste heat utilization is the waste heat from the return ditch. If steam waste heat is recovered, the quality and quantity of waste heat will be greatly improved. Meanwhile, the recovery and utilization of steam waste heat condensation can generate a large amount of condensate water, reducing the water consumption for slag flushing.

To better utilize the waste heat from slag flushing for energy conservation and emission reduction, an ideal comprehensive cascade utilization system for annual waste heat recovery is proposed. Based on a steam temperature of 100 ℃ for slag flushing waste heat, indirect heat exchange generates saturated steam at 90 ℃, while self condensation decreases to 90-95 ℃. After being cooled by a single effect absorption refrigeration unit, the self temperature is reduced to 80 ℃ (or heated according to demand), and then dried together with the heat source of the return ditch. Finally, heat exchange is carried out to provide bathing heat.

Comparing the parameters of the Fengshun single stage flash low temperature power generation system (as shown in Table 1), the design calculates the 90 ℃ saturated steam power generation, and the calculated heat absorption value is 90% of the heat carried away by the slag flushing steam of Jigang. The calculated parameter values are shown in Table 2. After mixing the condensate water with the slag flushing water, the next stage of waste heat recovery and utilization is carried out. Different utilization methods and calculation parameters are shown in Table 3, where the drying amount calculation is based on the moisture content of the dried item drying from 90% to 80%.

Table 1 Parameters of fengshun single stage flash low temperature power generation system

Parameter	Design value	1984.01.12 Perating value
Hot water temperature /℃	91	91
Hot water flow rate /(t/h)	230	228.3
Circulating water temperature /℃	28	14.4
Circulating water volume /(t/h)	418.6	515
Flashing pressure /MPa	0.034	0.029
Inlet pressure /MPa	0.032	0.026
Steam flow rate/(kg/h)	7362	8805
Steam consumption rate /(kg/kWh)	25.1	27.5
Exhaust pressure /MPa	0.0078	0.0063
Hot water power generation /(kWh/t)	1.27	1.4
Power generation /kW	293	320
Auxiliary power /kW	125	90

Table 2 Parameters of steam waste heat recovery power generation system

Parameter	Design value
Saturation temperature /℃	90
Steam enthalpy value /(kJ/ke)	2660
Cooling circulating water volume /(t/h)	1640
Flashing pressure /MPa	0.07
Intake pressure /MPa	0.066
Exhaust pressure /MPa	0.007
Exhaust steam temperature /℃	39
Steam flow rate /(kg/h)	30280
Exhaust steam dryness	0.8995
Power generation /kW	1922
Steam consumption rate /(kg/kWh)	15.75

3 Ideal utilization methods and economic analysis

In the newly designed comprehensive cascade utilization system, the investment payback period for heating and bathing systems is generally within one year, while for waste heat power generation systems, the power generation efficiency is improved to about 10% due to the use of steam recovery power generation, and the investment payback period is increased to 2-3 years. The investment payback period for absorption refrigeration mainly needs to consider the refrigeration time and refrigeration demand. If it operates at full load for 3000 hours in the south, the investment payback period is about 2 years, The investment payback period of waste heat drying system is related to the duration of drying utilization and the type of heat source compared. If compared with steam heat source, its investment payback period is generally shorter.

From the above analysis, it can be seen that the combined waste heat recovery and utilization system of new slag steam and slag water can achieve annual waste heat recovery and utilization. The system has a short investment recovery period, good economic and energy-saving environmental protection effects.

4 Conclusion

The discharge of waste heat from blast furnace slag flushing is large and consumes a lot of water. With the increasing requirements of the government for energy conservation and environmental protection, the recovery of waste heat from slag flushing has received attention. Classify and explain the existing methods of waste heat recovery and utilization of blast furnace slag water, introduce relevant cases and actual operating conditions, and summarize some theoretical utilization technologies. Based on the energy distribution of waste heat emissions, an ideal cascade utilization system for annual waste heat recovery is proposed. By combining waste heat recovery with slag steam and slag water, the cascade utilization of power generation, refrigeration, heating, drying, and bathing is carried out. The design parameters of each waste heat utilization link are calculated based on the measured parameters of a steel plant.

Received: March 10, 2024 Accepted: March 25, 2024 Published: June 20, 2024

Table 3 Parameters of ideal next stage waste heat utilization method

Purpose	Parameter	Condensed water	Slag flushing water
Single effect Absorption refrigeration	Hot water flow rate /(m^3/h)	30	1500
	Customized cooling capacity /kW	240	12000
	Hot water inlet/outlet temperature /℃	95/85	95/85
	Chilled water flow rate /(m^3/h)	42	2100
	Chilled water inlet/outlet temperature /℃	95/85	95/85
	Cooling water flow rate /(m^3/h)	105	5200
	Cooling water inlet/outlet temperature /℃	27/32	27/32
Heating desiccation	Hot water inlet/outlet temperature/℃	85/65	85/65
	Heating area/10000 m^2	1.15~2	58~100
	Hot water inlet/outlet temperature /℃	85/65	85/65
	Drying capacity /(t/h)	1	50
Bathing	Hot water inlet/outlet temperature /℃	65/50	65/50
	Bathing water inlet/outlet temperature /℃	20/50	20/50
	Heating water volume /(m^3/h)	60	3000

Reference

1. Wenjun Duan, Qingbo Yu, Zhimei Wang, et al. Life cycle and economic assessment of multi-stage blast fur - nace lag waste heat recovery system [J]. *Energy*, 2018, 142 (**1**): 486-495.
2. Hao Yong. Analysis and comparison of the waste heat utilization project of slag flushing water in Ansteel blast furnace [D]. Master's Thesis from Northeastern University, 2009.
3. Chen Jun, Wu Guofeng, Lei Zhendong, et al. Analysis of the current situation and technological development of waste heat utilization of blast furnace slag flushing water [J]. *China Steel Industry*, 2011 7:26-28.
4. Zelong Zhang, Lingen Chen, Bo Yang, et al.. Thermodynamic analysis is and optimization of an air Brayton cycle for recovering waste heat of blast furnace slab [J]. *Applied Thermal Engineering*, 2015, 90 (**11**): 742-748.
5. Siyi Luo, Yu Feng. The production of fuel oil and combustible gas by catalytic pyrolysis of waste tire using waste heat of blast - furnace slag [J]. *Energy Conversion and Management*, 2017, 136 (**3**): 27-35.
6. Liu Man. Theoretical analysis and application research of vacuum phase change heat transfer technology in waste heat recovery of slag washing water [D]. Hebei Engineering University, Master's Thesis, 2016.
7. Zhang Yanping, Li Wulong, Zhang Guowei. Development and application of a corrosion-resistant and scale resistant blast furnace slag flushing water heat exchanger [J]. *Metallurgical Energy*, 2017, 26 (**8**): 79-80.
8. Zhu Binshuai, Chen Feifei. Analysis of the current situation of waste heat utilization of blast furnace slag flushing water [J]. *Energy saving technology*, 2015, 33 (**5**): 425-427.
9. Liu Hongbin, Yang Dongyun, Yang Weidong. The practice of using waste heat from blast furnace slag flushing water for heating in Xuangang [J]. *Energy and Environment*, 2010, 3:45-46+55.
10. Li Huanzhi. Current Status and Energy Conservation and Emission Reduction Prospects of Waste Heat Utilization of Blast Furnace Slag Water at Angang Iron and Steel Co., Ltd. [J]. *Resource Conservation and Environmental Protection*, 2016, 6:9+15.
11. Liu Shuqing. An example of heating engineering with waste heat from blast furnace slag flushing water [J]. *Energy Conservation and Environmental Protection*, 2014, 5:69-70.
12. Yang Zhonghua. Recovery and utilization of waste heat from blast furnace slag flushing water [J]. *Shanxi Metallurgy*, 2017, 3 (**40**): 59-60.
13. Gao Honghong, Jie Hong, Guan Fengjun. Application of waste heat recovery from blast furnace slag flushing water [J]. *Industrial furnace*, 2014, 36 (**5**): 59-60+67.
14. Han Hongsen, Yao Bin, Li Xingfang, et al. Utilization of waste heat from slag flushing water in Jigang blast furnace [J]. *China Metallurgy*, 2013, 23 (**3**): 50-52+57.
15. Wang Liping. Discussion on the reuse of waste heat from slag flushing water in Taiyuan Iron and Steel blast furnace for municipal heating [J]. *Shanxi Architecture*, 2017, 43 (**7**): 118-119.
16. Huang Dongning, Ding Liang, Ren Lan. The practical application of waste heat utilization of blast furnace slag flushing water in Hanggang [J]. *Metallurgical Power*, 2013, 11:43-44.
17. Zhang Jianguo, Wu Qiaomei, Qian Lili, et al. The application of waste heat from blast furnace slag flushing water in bathing water for enterprise employees [J]. *Energy saving technology*, 2013, 178 (**31**): 191-193.
18. Dong Jiahua, Wang Wei, Gao Chengkang. Research on the application of waste heat recovery from blast furnace slag flushing water in seawater desalination process [J]. *China Metallurgy*, 2012, 22 (**10**): 51-54.
19. Zhou Yong, Wu Liangyu, Yan Bin, et al. The current situation and development of waste heat recovery technology for blast furnace slag flushing water [J]. *China Steel Industry*, 2014, 1:21-23.
20. Lv Yongpeng. Energy consumption and energy-saving critical conditions of a waste heat absorption refrigeration system for blast furnace slag flushing water [J]. *Shandong Industrial Technology*, 2016:81.
21. Wang Dongbao. Equipment system renovation of waste heat heat exchange station for blast furnace slag flushing water [J]. Metallurgical Equipment, 2023, (S2): 165-172.
22. Miao Huiyuan, Guo Liping. Design and application of waste heat recovery equipment for blast furnace slag water flushing [J]. Today's Manufacturing and Upgrading, 2023, (02): 72-74.
23. Zhao Liping, Wang Tiemin. Improvement and optimization of waste heat recovery and utilization of blast furnace slag flushing water [J]. Metallurgical Power, 2021, (06): 80-82.
24. Li Yiming. Research on concentrated brine vertical tube liquid film evaporation concentration technology using industrial waste heat as the heat source [D]. Tianjin University, 2021.
25. Ni Peiwei. Research on the Heat and Mass Transfer Mechanism of the Key Process of Wet Recovery of Blast Furnace Slag Waste Heat [D]. Beijing University of Science and Technology, 2022.
26. Yu Yang, Li Yan, Zhang Chao, Li Jiao. Energy saving renovation practice of waste heat recovery from blast furnace slag flushing water [J]. Industrial Safety and Environmental Protection, 2021, 47 (S1): 80-82.
27. Meng Fanshuang, Wang Dongshan, Li Jianjun, Zeng Yu, Li Xiaochun, Tong Minying. Analysis and application practice of corrosion and scaling caused by waste heat heating from blast furnace slag flushing water [J]. Ansteel Technology, 2021, (02): 43-46.
28. He Fei. The application of waste heat utilization technology for blast furnace slag flushing water in steel enterprises [J]. Metallurgical Management, 2021, (07): 167-168.
29. Chen Ronghua. Discussion on the utilization of waste heat from blast furnace slag flushing water [J]. Industrial heating, 2021, 50 (03): 47-49.
30. Liang Wente. Research on the technology of waste heat recovery and utilization of blast furnace slag flushing water [J]. Metallurgical Management, 2021, (01): 144-145.
31. Zhang Fuchun, Ji Xiaoliang, Li Dequan. Analysis of the application of waste heat from blast furnace slag flushing water in coking refrigeration [J]. Mechanical and Electrical Information, 2020, (34): 70-72.
32. Miao Huiyuan, Guo Liping. Design and application of waste heat recovery equipment for blast furnace slag water flushing [J]. Today's

Manufacturing and Upgrading, 2023, (02): 72-74.
33. Chen Yang. Feasibility study on industrial wastewater waste heat recovery and heating scheme for a steel plant in Yichun City [D]. Harbin Institute of Technology, 2021.
34. Zhang Chengguang. Experimental study on heat pipe heat exchangers for waste heat recovery in the steel industry [D]. Xi'an University of Architecture and Technology, 2020.
35. Gong Xin. Application example of waste heat recovery from blast furnace slag flushing water [J]. Energy and Energy Conservation, 2019, (10): 63-64.
36. Zhang Zhijiang. The treatment and utilization of industrial discharged water and waste heat recovery in Xuangang blast furnace slag [J]. Ironmaking, 2019, 38 (04): 53-55.
37. Su Xiangcheng, Huang Bo. Recovery and utilization of waste heat from slag flushing water in Linggang blast furnace [J]. Metallurgical Power, 2019, (02): 46-49.
38. Gao Wentao. Analysis of utilization technology for waste heat recovery from blast furnace slag flushing water [J]. Modern Industrial Economy and Information Technology, 2018, 8 (09): 63-64.
39. Zhu Peizhang. Application of Environmental INBA Slag Flushing Technology for Waste Heat Recovery of Slag Flushing Water [A]. Collected Papers from the 7th National Building Environment and Energy Application Technology Exchange Conference [C]. Building Environment and Energy Application Branch of China Survey and Design Association, HVAC Magazine, 2017: 4.
40. Yang Zhonghua. Recovery and utilization of waste heat from blast furnace slag flushing water [J]. Shanxi Metallurgy, 2017, 40 (03): 59-60.
41. Huang Linhui, Yang Jingling, Zhang Yanping, Yang Qing. Technical analysis of non-metallic heat exchangers for waste heat recovery from blast furnace slag flushing water [J]. Metallurgical Energy, 2017, 36 (03): 10-13.
42. Du Wenya. Overview of utilization technology for waste heat recovery from blast furnace slag flushing water [J]. China New Technology and New Products, 2016, (11): 63-64.
43. Liu Man. Theoretical analysis and application research of vacuum phase change heat transfer technology in waste heat recovery of slag washing water [D]. Hebei University of Engineering, 2016.
44. Liu Man, Chen Linqi. Waste heat recovery technology for blast furnace slag flushing water [J]. Technology Innovation and Application, 2016, (11): 143.