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Analytical Research on Waste Heat Recovery and Utilization of China's Iron & Steel Industry

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Abstract

As energy crisis become increasingly prominent, the energy consumption has become the main problem which restricts the sustainable development of China's iron & steel industry. the recovery and utilization of different kinds of waste heat can effectively reduce energy consumption, the research of the scientific recovery and utilization of waste heat become very important. The current situation and status of recovery and utilization of waste heat in the China's iron & steel industry will be analysed from some aspects such as the quality and the source process of waste heat, Based on them the potential and develop directions will be pointed out, combining with the analysis of the basic principle using energy scientifically, the mode of the recovery and utilization of waste heat is given, it is hoped that it can promote the scientific and rapid development of recovery and utilization of waste heat of China's iron & steel industry.

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Keywords: waste heat; recovery and utilization; iron& steel

1. Introduction

The iron & steel industry is energy-intensive industry. its energy consumption is very large, which accounts for 11 ~ 15% of the total energy consumption and 15 to 20% of the total industrial energy consumption of China. Compared with the international advanced level, the energy consumption of per ton steel of China is about 20% higher than theirs[1]. As energy crisis become increasingly prominent, Chinese government pay more attention to save energy and eliminate backward production capacity,

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energy problem has become a main point which restricts the sustainable development of China's iron & steel industry.

A large number of waste heat is generated when it consumes in promoting the transformation of materials in the iron & steel industry, the recycling of different kinds of waste heat can effectively reduce energy consumption. For waste heat recovery and utilization of iron and steel industry, it has been studied as early as the 1980s in China, many researchs show that waste heat recovery and utilization of iron and steel industry has a huge potential, its further recovery and utilization is the main direction of energy saving in the iron & steel industry in future[2-7].

In the paper, the current situation and status of recovery and utilization of waste heat in the China's iron & steel industry will be analysed from some aspects such as the quality, the category, the source process of waste heat, Based on them the potential and develop directions will be pointed out, combining with the analysis of the basic principle using energy scientifically, the mode of the recovery and utilization of waste heat is given, it is hoped that it can promote the scientific and rapid development of recovery and utilization of waste heat of China's iron & steel industry.

2. Analysis of Waste Heat Recovery and Utilization of China's Iron & Steel Industry

The scope and definition of waste heat of iron & steel industry is a foundation which analyses the level of recovery and utilization of waste heat, different scope and definition may lead to different results. Therefore, the definition and the statistical range of waste heat are given before specific analysis. The waste heat referred in the paper is the heat carrier which can release energy with environmental temperature (25 °C) as a reference and other kinds of energy expect heat (pressure energy, chemical energy) produced by the iron & steel production process. The statistical range of waste heat includes the main processes such as coking, sintering/pelletizing, ironmaking, steelmaking and rolling etc. but energy conversion processes such as oxygen generator, electricity generation expect coking and the auxiliary raw material preparation processes such as iron alloy, carbon, refractory materials, metallurgical are not included.

2.1. Analysis of Recovery and Utilization of Different Quality Waste Heat

The Evaluation of waste heat resources not only depends on quantity, but also quality. The division of quality according to temperature level, has three categories such as high grade, medium grade and low grade. The high grade refers to the waste heat resources whose temperature is higher than 500 °C, including high temperature flue gas such as coke oven gas, converter gas, electric furnace gas and heating furnace flue gas etc. Among them the temperature of converter gas up to 1500 °C, the heating furnace flue gas also can reach 1000 °C; High temperature liquid such as high temperature iron slag, steel slag and

Table 1. The situation of recovery and utilization of different quality waste heat of China's iron & steel industry

The quality of waste heat	Quantity of total (GJ/t-s)	Quantity of recovery (GJ/t-s)	Rate of recovery (%)
Low grade	2.89	0.22	1.59
Medium grade	2.19	0.66	30.2
High grade	3.36	1.49	44.4

high temperature water etc.; High temperature solid waste heat such as high temperature sintering materials, high temperature coke, high temperature steel etc. The medium grade refers to the waste heat whose temperature at 150 to 500 °C, including blast furnace gas and sintering flue gas, exhaust gas

recovery of waste heat from the primary after flue gas etc. Low grade refers to the waste heat whose temperature below 150 °C, including waste steam and hot water, all kinds of low temperature flue gas and low temperature materials etc. As the statistics base on per ton steel, the situation of recovery and utilization of different quality waste heat of China's iron & steel industry is shown in table 1. The proportion of different grade of waste heat resources not recycling is shown in figure 1.

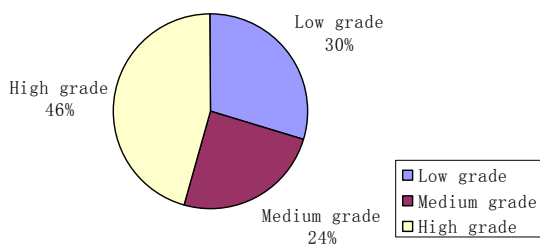


Fig. 1. The proportion of different grade of waste heat resources not recycling

As the table 1 shows, the recovery and utilization of high temperature waste heat is most, its rate is up to 44.4%, The secondly is the medium grade waste heat, the rate reaches 30.2%, however the rate of low grade waste heat is less than 2%. The rate of medium or high quality waste heat are not very high, the recovery and utilization of low grade is almost no begin. Figure 1 shows that the rate not recycling of high, medium and low grade waste heat resources is 30%, 24%, 46%, the low grade waste heat resources accounted for nearly half of all. In conclusion, the development of low quality of waste heat will be a key point in the future way of recovery and utilization of waste heat.

2.2. Analysis of Recovery and Utilization of Different Process Waste Heat

Table 2. The situation of the recovery and utilization of different process waste heat

Process	Quantity of total (GJ/t-s)	Quantity of recovery (GJ/t-s)	Rate of recovery (%)
coking	0.93	0.08	8.2
sintering/pelletizing	1.56	0.28	18.0
ironmaking	8.00	4.62	57.8
steelmaking	1.81	0.81	44.8
rolling	1.01	0.28	27.2

The typical metallurgy is a multiple process, which includes coking, sintering/pelletizing, ironmaking, steelmaking and rolling. The difficulty of recovery and utilization of waste heat and the recovery rate is different because of the diverse of the amount, the quality and the category. The table 2 shows that the situation of the recovery and utilization of different process waste heat, the figure 2 shows the proportion of different process of waste heat resources not recycling.

As the above table 2 and figure 2 show, the waste heat resource of ironmaking process is the largest, although the recovery and utilization rate is largest, the rate not recycling is also the largest, basically there is no recycling of the slag, the cooling water and the coal of blast furnace, so generating steam through using the dry granulation for blast furnace slag, developing new recovery and utilization

technology for low-grade cooling water and strengthening recovery of blast furnace gas will be the key point for recovery and utilization of ironmaking process waste heat. Through the recovery and utilization rate of coking process is lowest, the reason is that the sensible heat of coke oven gas isn't used, the popularity rate of dry quenching is very low, it is obvious that with the promotion of dry quenching technology and wet coal technology, the sensible heat of coke and coke oven gas will be used and the rate of coking process will be largely improved. The waste heat of sintering/pelletizing process belongs to the medium and low grade, the rate is low because they are difficult to utilize, with the promotion of the classification recycling and cascade utilization technology of the sintering waste heat, the recovery rate of sintering process will be improved. At present, each process has the typical advanced technology which has been applied in the domestic and foreign iron & steel enterprise. According to estimation, the recovery rate will be largely improved if the typical advanced technology be used in each process. So the energy consumption per ton steel will be greatly reduced when the typical advanced technology be used in China's iron & steel enterprise, it can promote the further development of China's iron & steel industry.

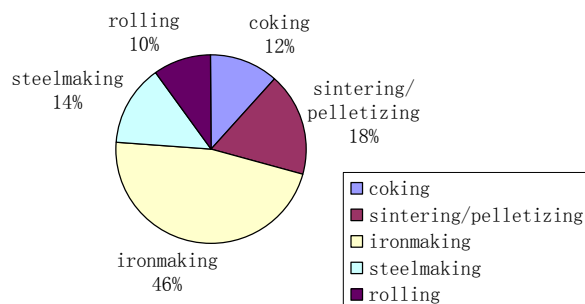


Fig. 2. The proportion of different process of waste heat resources not recycling

Now the recovery rate of waste heat resource (including vice produce gas) is usually next to 90% in foreign advanced iron & steel enterprises, such as Japanese Nippon steel reaches to 92%, but most of the iron & steel enterprises in China is just reach 30% ~ 50%[1]. The reason is: ① the manufacturing processes can't recover waste heat timely and adequately, meanwhile the recovery rate is low and the amount is insufficient; ② the utilization of all sorts of heat recovered is not in a more effective way, the hot air, steam, coal gas which have been recovered is diffused because of low temperature, heat source supply by instability or the balance of supply and demand of seasonal effects and so on. ③ the key technology of recovery and utilization of waste heat has been left behind, almost all major equipments depend on import, the recovery heat is either depreciation or instability and unable to meet the user's requirement, which make the large number of low-grade heat is no avail. ④ some enterprises are small scale, low productivity, backward equipment, at the same time because it is a large investment that import equipments which used for recovery waste heat, it always loss outweighs the gain, which affect enterprise's enthusiasm of recovering waste heat.

3. Study on High Efficient Mode of Waste Heat Recovery and Utilization in Iron & Steel Industry

The waste heat of the iron & steel industry is not only recovered and utilized but also required the scientific and reasonable way, the research methods which are studied the recovery and utilization proper way of waste heat have the thermal equilibrium analysis, exergy analysis and energy level analysis. The

first law of thermodynamics is used as the theoretical basis of the thermal equilibrium analysis, so the method just simply inspect the recovery of waste heat from the quantity relationships of the conservation of energy, not consider the quality of the heat and their changes, so the thermal efficiency index can't reflect the rationality of the utilization; The second law of thermodynamics theory is used as the theoretical basis of exergy analysis, so the method just consider utilization of convertible part of waste heat, but are blind to the other part which can't be used, on the contrary, the exergy efficiency index investigate the recovery and utilization of waste heat from the unequilibrium of energy; Energy level analysis method in essence is a component part of the second law of thermodynamics analysis, which still investigate whether the recovery of waste heat compliance with the utilization of heat energy which users needed on the quantity relationships of energy level's balance, just makes the difference of two energy level as the evaluation index, and considers only the situation about quality match between supplier and users, also ignore its' quantity change[8,9]. In short, the recovery and utilization of waste heat must be based on the first and second law of thermodynamics, not only to sees the number of heat loss, but also considers the quality reduction. Overemphasising on the any one is one-sided.

Figure 3 is the heat(exergy)flow diagram of the recovery and utilization system of waste heat. In the figure the waste heat of input system is Q_1 (energy level is Ω_1), output heat is Q_2 (energy level is Ω_2), output power is W (energy level is 1), the heat loss of system is Q_L (energy level is Ω_L). So the heat efficiency of system, output heat and the total energy level of system, system's exergy efficiency respectively by type (1), (2), (3) says:

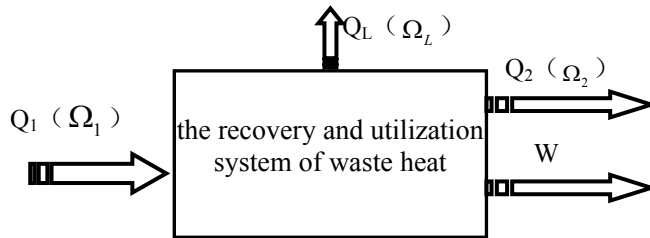


Fig. 3. the heat(exergy)flow diagram of the recovery and utilization system of waste heat

$$\eta_1 = \frac{Q_2 + W}{Q_1} \tag{1}$$

$$\frac{Q_2}{Q_2 + W} = \frac{Q_2 \Omega_2 + W}{Q_2 + W} = \alpha \Omega_2 + 1 - \alpha \tag{2}$$

$$\eta_2 = \eta_1 \frac{\Omega_2}{\Omega_1} = \eta_1 \left(1 - \frac{\Delta\Omega}{\Omega_1} \right) \tag{3}$$

In formula, α is the ratio of output heat accounted for the total output energy; $\Delta\Omega$ is the energy level difference between input heat and output heat. From formula (3) it can be seen that exergy efficiency depends on the thermal efficiency of the system and the difference between input heat level and output heat level, the former one is related to first law of thermodynamics, the latter is related to second law of thermodynamics. T_0 is environmental temperature, T_1 is the temperature of waste heat, T_2 is the temperature of output heat, $|\Delta\Omega|_r$ is energy level difference during pure thermal utilization, $|\Delta\Omega|_d$ is energy

level difference during pure power utilization, the energy level difference between input and output heat is a function of temperature: from formula (4):

$$|\Delta\Omega| = \left| \frac{T_0}{T_1} - \alpha \frac{T_0}{T_2} \right| \quad (4)$$

When $T_1 = 2 T_2$, $|\Delta\Omega|_r = |\Delta\Omega|_d$, the effect of thermal utilization is equal to power utilization, When $T_1 > 2 T_2$, $\Omega_1 > 1/2$, $|\Delta\Omega|_r > |\Delta\Omega|_d$, the effect of power utilization is better than thermal utilization, When $T_1 < 2 T_2$, $\Omega_1 < 1/2$, $|\Delta\Omega|_r < |\Delta\Omega|_d$, the effect of thermal utilization is superior to power utilization. Thus the general principle of recycling waste heat resources is: according to the waste heat resources quantity, quality (temperature) and customers' demand and the principle of matching energy level, recovered by the quality, temperature correspond and cascade utilization. ① If there are suitable heat users, using waste heat directly is most economic, For example, the sensible heat of product are supplied to the next process without transition, waste heat is used to preheat air and gas, preheat or dry material, product steam and hot water. The redundant quantity of heat can be used to refrigeration when users reduce in the summer. ② For high temperature waste heat recovery should be adopted by power recovery, such as power generation or cogeneration. ③ The low temperature waste heat should be utilized directly, for which can't be utilized directly, it can be used as the low-temperature heat source of heat pump system, used after improving the temperature level. ④ The medium grade waste heat resources can be used by heat recovery or power recovery according to the specific temperature. According to the above analysis, the mode of waste heat recovery and utilization in iron & steel industry can be concluded as shown in figure 4:

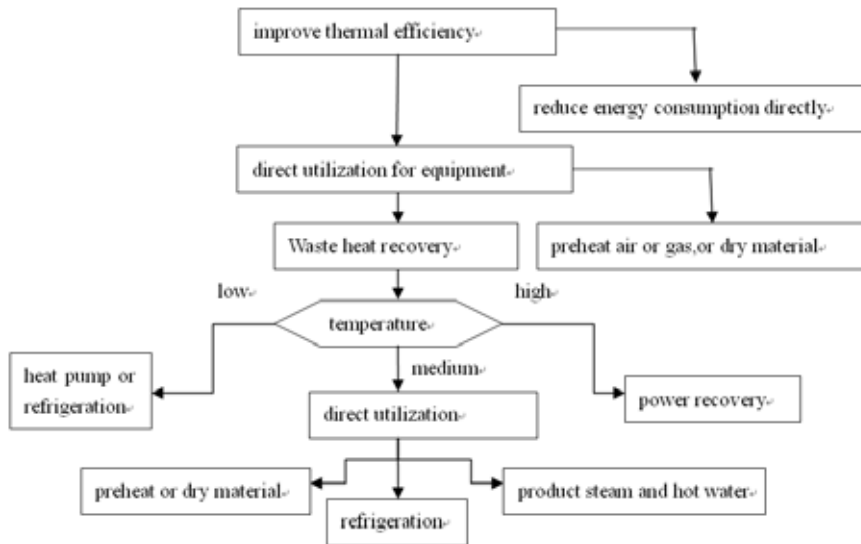


Fig. 4. The mode of waste heat recovery and utilization in iron & steel industry

4. Conclusions

All analyses show: ①the low-grade waste heat in China's iron & steel industry has not been used basically, it is the key point of the recovery and utilization of waste heat of iron & steel industry in future; ②The recovery rate of coking and sintering process is relatively low, should strengthen research and extension in coke dry quenching technology and grade recovery and cascade utilization of sintering waste heat resources; ③The recovery and utilization of waste heat in scientific way should depend on the first and second law of thermodynamics and accord to the quantity, the temperature and user's demand recovering by the quality, temperature correspond and cascade utilization. It is the fundamental of the recovery and utilization of waste heat of iron & steel industry.

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