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ANALYSIS ON PROCESS OPTIMIZING FOR HOPPER PRESSURE MODULATION OF BLAST FURNACE[1]

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Abstract
For the current hopper pressure process, blast furnace gas (BFG) diffuses into the air directly. In order to reduce gas emission and environment pollution, some new process for hopper pressure such as ballonet method, ejector method and gas substitution method are proposed. These three new technologies, with features of easy operation and high degree of automation, can achieve the purpose of gas recovery. However, ballonet method only can obtain economic benefits when the price ratio between BFG and compress gas greater than 4. Ejector method, can achieve full recovery of BFG and dust, has excellent economic and environmental benefits. Due to the need to increase the dust removal facilities and ejector, ejector method is more suitable for a new blast furnace. Gas substitution method can recovery most of BFG, but can't avoid dust emission. Compare to traditional method, it still get a huge economic and environmental benefits. In addition, it needs less fixed investment, shows flexible operation, not only applies to a new blast furnace, but also suitable for the existing blast furnace.
Key words: Hopper pressure process; Ballonet method; Ejector method; Gas substitution method.

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1 INTRODUCTION

Until now, traditional hopper pressure process , blast furnace gas (BFG) emissions into the air directly, is used all over the world. It means when produce 1 ton molten iron, 7～9Nm^3/tFe BFG and 280～400 g/tFe dust are diffused to air. According to 600 million ton molten iron yield per year in China, up to 4.2～5.4 billion cubic meters BFG and 168～240 thousand ton dust are diffused to air. It's not only a huge pollution to environment, but also causing a lot of waste of resource.

Therefore, a new hopper pressure process, which can avoid BFG diffusing to air directly and alleviate environment pollution , is badly needed.

In 1970s and 1980s, lots of new methods were attempted in Former Soviet Union, Japan and other countries[1]. Especially, a new hopper pressure facility designed by Ishikawajima-Harima Heavy Industries, Ltd., used in Kashima No.1 BF, was awarded Japanese outstanding energy-saving equipment project in 1980. In China, CISDI disclosed a patent on wet gas recovery system which using ejector, venturi tube and evaporator,[2] Anshan Hengtong blast furnace equipment engineering Co., Ltd. disclosed a patent which using bag filter purify BFG and then recovery to net gas pipeline network.[3]

Although these methods are different, the core idea is same, that is recovering the hopper BFG to net gas pipeline network. However, there are some defects in the above methods. Some may cause net gas pipeline network pollution, some confined to wet dust elimination, some can't effective recovery gas in time.

Contrapose the known technical features, ballonet method, ejector method and gas substitution method are proposed by this paper in order to recovering hopper BFG effectively and achieving the purpose of energy saving and environmental protection.

2 TECHNOLOGY ANALYSIS

2.1. Ballonet method

2.1.1 Technology description

Ballonet method uses a steel sealed tank to store hopper emissions BFG to achieve the purpose of BFG recovering and recycling. Fig 1 is the process diagram as follows. There is a ballonet in the tank, when hopper equalizing, open N2 shut valve and pressure balance valve, high pressure N2 goes to ballonet from N2 bin, then the ballonet expanded, pushing the BFG in the tank to the hopper until the hopper pressure equal to blast furnace pressure. When hopper gas release, opening pressure balance valve and discharge valve, N2 in the ballonet diffuses into atmosphere and the ballonet shrink, BFG in the hopper recovery to the sealed tank again until the hopper pressure equal to atmospheric pressure. If in accident, emergency valve is used to release hopper BFG.

In addition, not only N2 can be used in the ballonet, but other gas which doesn't cause security risk can also be used in the ballonet.

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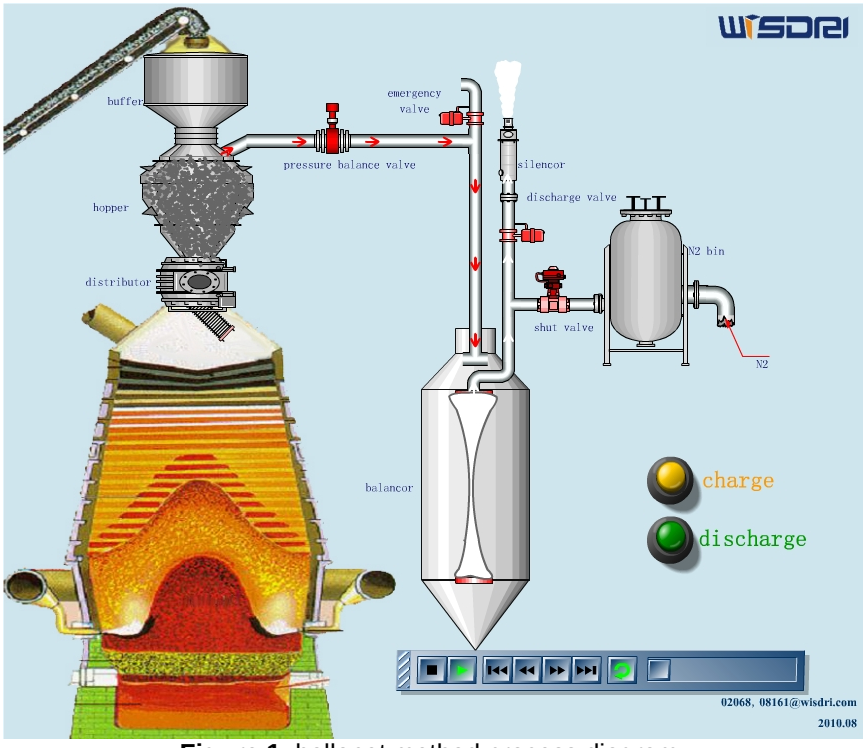

Figure 1. ballonet method process diagram.

The principle of ballonet method is assuming no temperature change in the hopper BFG, in order to confirm the amount of N_2 usage, some parameters should be defined first:

P_g：hopper pressure；P：atmospheric pressure；V_g：hopper volume；V_n：ballonet volume；V_h：recycling volume；V_d：N_2 consuming volume；

According to Boyle's law, we know：

$$P_g \cdot V_g = P \cdot (V_g + V_h) \quad (1)$$

$$P_g \cdot V_h = P \cdot V_d \quad (2)$$

By equation（2），

$$V_d = P_g / P \cdot V_h \quad (3)$$

Usually, the hopper pressure is about 0.35MPa, take into equation（3），it shows:

$$V_d = 3.5 V_h$$

It means every recycle process, N_2 consuming volume is 3.5 times than hopper BFG. But in fact, there are some space in the recycle pipe, upper and lower sealed tank, and these space pressure should also equal to the hopper pressure, so the ballonet volume $V_n > V_h$. Therefore, $V_d > 3.5V_h$. In actual design, N_2 consuming volume is no less 4 times than recycling volume.

2.1.2 Technology evaluation

This method brings excellent environmental benefit, but the operation cost in ballonet method is high because of it cost too much N_2. For some plant, this method is profitable, but others not. The actual economic benefits depend on the gas settlement

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price in the steel plant. Anyway, when the ratio between the BFG price and N_2 is larger than 4, this method can obtain economic benefit.

Because of the hopper BFG discharge into the sealed tank, it's volume usually very huge. To a hopper which effective volume is 30m³,it need a sealed tank with 4.2m in diameter and 8m in height. The tank is too big to stand on the roof platform of blast furnace, it need an extra area to be placed and more fixed investment. In addition, ballonet is easy to abrade but difficult to replace which increased labor intensity.

2.2. Ejector Method

2.2.1 Technology description

The core idea of ejector method is also recovering hopper BFG to the net gas pipeline network through some ways. In order to avoid the net gas in the pipeline network being polluted, bag filter is used before the hopper BFG go to pipeline network. In order to recovery the hopper BFG in time, ejector is employed to induce dedusting hopper BFG to the net gas pipeline network.

Fig. 2 is the specific recovering process. Ejector is placed after bag filter and connected in series. There are two entrance, working pipe and inducing pipe, in the ejector. Working pipe connected with working gas pipe, while inducing pipe connected with dedust hopper BFG through ejector shut-off valve. It's noteworthy that the bag filter in this program is in parallel with blast furnace gas bag filter system, and there is non -interference between each other.

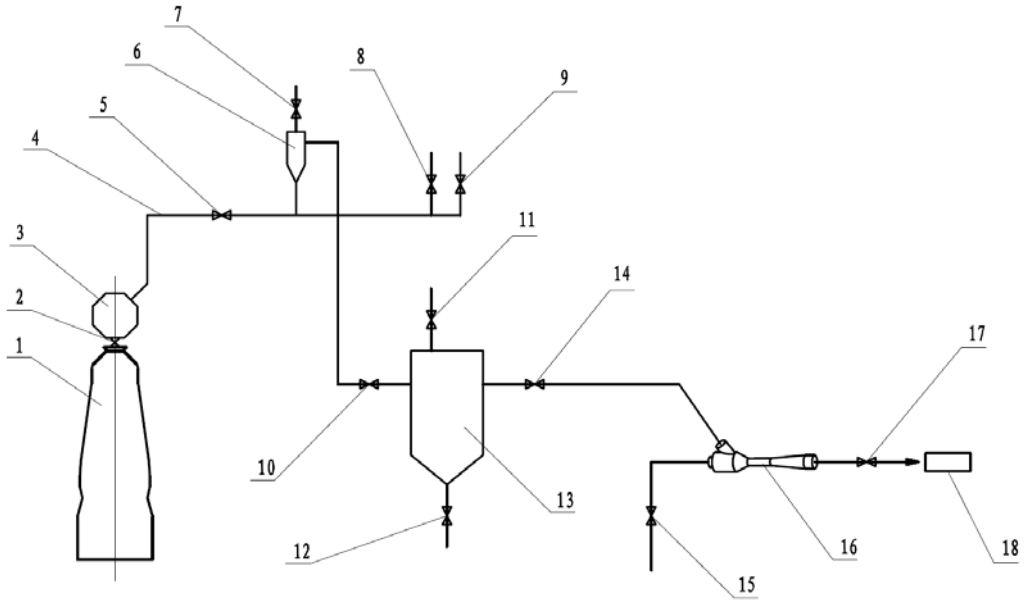

Figure 2. Ejector method process diagram: 1—blast furnace；2—feed-flow valve；3—hopper；4—pressure balance pipe；5—pressure balance valve；6—cyclone；7—discharge valve；8—main equalizing valve；9—secondary equalizing valve；10—bag filter shut-off valve；11—net gas discharge valve；12—dust unloading valve；13—bag filter；14—ejector shut-off valve；15—working gas shut-off valve；16—ejector；17—shut-off valve；18—net gas pipeline network

ISSN 2176-3135

The pressure balance process of ejector method is the same as traditional method, but emission process divided into two steps: natural recovery and mandatory recovery. When diffusing, hopper BFG goes to cyclone for preliminary dust eliminating, then goes to bag filter for main dust elimination. In the beginning, pressure in hopper is much higher than net gas pipeline network, the hopper BFG can recovery to pipeline network smoothly. When the hopper pressure reduce to 50～100kPa (relative pressure), pressure difference between hopper and pipeline network minished, the speed of BFG decreased. In order to recovery the hopper BFG in time, mandatory recovery measure is employed, opening working gas shut-off valve to start-up ejector, remaining gas is ejected quickly to the net gas pipeline network by high pressure working gas. When the hopper pressure decreased to atmospheric pressure, the recovery process is finish

2.2.2 Technology evaluation

Ejector method is easy to operate, can recovery hopper BFG completely, brings excellent environment. Because of mandatory recovery only use in the latter part which consuming little working gas, this method has low operating cost and bring good economic benefit. In this method, the working gas could be high pressure nitrogen, high pressure water vapor, or high pressure BF net gas.

Because of bag filter and ejector are used, compared to traditional method, the fixed investment will be increased. But considering the economic benefit of recovering hopper BFG, the fixed investment can be recoveried in six months.

The bag filter system and ejector should take up additional area, this method is not suitable for existing blast furnace. But with the advantage of economic and environment benefit, this method would be widely used in new blast furnace.

2.3 Gas substitution Method

The idea of gas substitution method is accessing clean gas to the hopper to replace the BFG. When hopper opening, the clean gas diffusing to the air instead of BFG to achieve the purpose of energy saving. The standard of clean gas here means a kind of gas that no pollution to air and no reaction with blast furnace gas. In this paper, use nitrogen as the clean gas.

2.3.1 Nitrogen sweeping method

As a starting point of gas substitution method, nitrogen sweeping method is raised first. When traditional hopper process is finished, before hopper BFG diffusing, the hopper is full of blast furnace gas. At this time, keep the feed-flow valve opening, pass into high pressure N_2 to the hopper. And then, the hopper BFG is reblowed into the blast furnace by N_2. When the N_2 concentration up to set concentration (such as more than 85%), close valve and stop passing into nitrogen, the gas in hopper diffuses to the atmosphere after cyclone dedusting.

In order to test the effect of this method, Ansys software is used. Suppose the effective volume is 100m³, the pressure is 0.22MPa, the diameter of nitrogen pipeline is DN500, the velocity of nitrogen is 70m/s and last for 20 second. For the purpose of simplifying the calculation process, suppose the composition of blast furnace gas

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(volume fraction) is N_2: 55%, CO:25%, CO_2:20%, the corresponding mass fraction is N_2: 49.4%, CO:22.4%, CO_2:28.2%. The result of analysis shows in Fig 3.

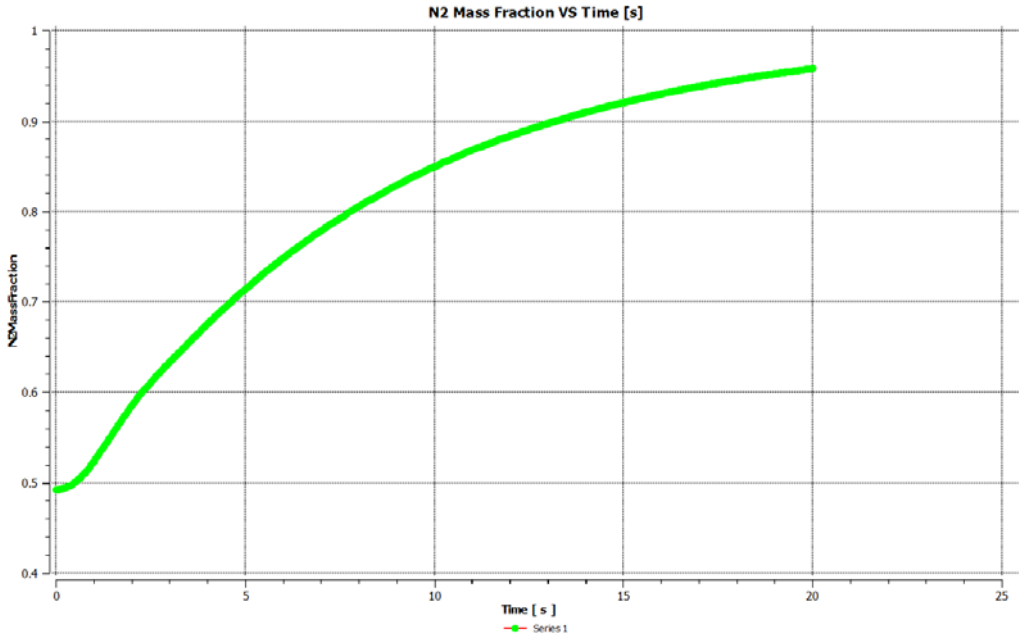

Figure 3. N_2 mass fraction in hopper vs time.

Table 1. N_2 access amount and volume fraction in hopper at different time

time（s）	0	5	10	15	20
N_2 access amount（m^3）	0	49.1	98.2	147.3	196.4
N_2 volume fraction（v%）	55	75.9	88.1	93.5	96.4

Table 1 is the result according to Fig 3. From table 1, we found that with N_2 accessing into the hopper, BFG is reblowed back to the blast furnace. At 10 seconds, most of gas was nitrogen in hopper.

With Ansys software, other factors such as sweeping ways, N_2 velocity to the sweeping effect were also analysed. But the results showed that all the other factors influence could be ignored but N_2 access amount.

From table 1, we can still find that with N_2 accessing amount increased, sweeping effect decreased quickly. Therefore, considering economic matter, it's better not to access more N_2 when the BFG in hopper reduced to a certain extent. Or it's not only consume more N_2 but also extend hopper pressure balance time and can't obtain the desired results. In table 1, when N_2 access time increased from 15 seconds to 20 seconds, N_2 concentration in hopper only increased from 93.5% to 96.4.

Thus, in the entirely sweeping process, N_2 accessing amount should consider energy saving and environmental protection, N_2 consumption, hopper pressure balance time restrict, etc. In addition, because of sweeping effect only closely related to N_2 accessing amount, we can increase N_2 velocity propriety to shorten sweeping time, thereby to decrease hopper pressure balance time.

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2.3.2 Nitrogen complement method

Contrapose the defect of nitrogen sweeping method, recovery effect decrease rapidly along with the sweeping time extending and prolong hopper pressure balance time, new method called nitrogen complement method is proposed. In this method, hopper equalizing uses nitrogen. After the hopper equalizing, open feed-flow valve. At the same time, N_2 passes into the hopper slowly to compensate the extra space that charging dropping leaved, avoid blast furnace gas going to the hopper. When charging dropping finished, the hopper is full of nitrogen. Then close feed-flow valve, stop accessing nitrogen. When hopper diffusing, N_2 diffuses to atmosphere instead of blast furnace gas to achieve the purpose of recovery BFG and reduce environmental pollution.

The key point of nitrogen complement method is the amount of complement nitrogen should always be coordinated with the speed of charging dropping. Due to the type and quantity of charge is different, the speed of charge is different. Therefore, two control schemes can be used as follows:

Option 1：To simplify operation, use the one charging dropping fastest as the benchmark, calculate the space charging dropping leaves in unit time, to determine the nitrogen access amount in unit time. Other cases, the nitrogen access amount in unit time according to former determined. This option treats all cases as one case, has an advantage of operating simple and convenient, but it results in nitrogen consumption increased, not conducive to lower operating costs.

Option 2：To reduce nitrogen consumption, according to different charging , calculate different charging speed, and then confirm the nitrogen access amount in unit time in different circumstance. Compare to option 1, this option is complicated to operate. Fortunately, automatic control is used in the entire process, it would not cause operation inconvenient significantly. But this option can receive more economic benefit by reducing nitrogen consumption and operation cost.

Compared to nitrogen sweeping method, nitrogen complement method not only avoid the defect of recovering effect decrease rapidly along with the sweeping time extending and prolong hopper pressure balance time, but also can cancer main hopper pressure balance pipe to save some fixed investment. Therefore, nitrogen complement has more advantages.

2.3.3 Technology evaluation

Gas substation method, presents as nitrogen sweeping method and nitrogen complement method, not only can be used in new blast furnace, but also can be used in existing blast furnace. For the new blast furnace, nitrogen complement method can even cancer main hopper pressure balance pipe to reduce the construction difficulty. For the existing blast furnace, use this method only need to add a gas analyzer. And according to production needs, it can switch smoothly among traditional method, nitrogen sweeping method and nitrogen complement method, which reflects the flexibility of the gas substitution method.

However, due to the inherent defect, gas substitution method can’t recovery the hopper gas completely. When nitrogen emission, it would discharge some dust to atmosphere inevitably, but compared to traditional method, the environment effect is still get a great improvement.

ISSN 2176-3135

In addition, this method saves investment, has low operation cost, can bring great economic benefit. Furthermore , it flexible to operate, is the most convenient hopper pressure modulation technology to implement in blast furnace

3 CONCLUSIONS

In this paper, new hopper pressure modulation such as ballonet method, ejector method and gas substitution method (present as nitrogen sweeping method and nitrogen complement method) were proposed. Each method can achieve the purpose of hopper blast furnace gas recovery, but each one has unique characters. Detail characters see Table 2 as follows.

Table 2 Comparative analysis on new hopper pressure modulation method

technology		advantage	disadvantage
Ballonet method		1） recovery hopper blast furnace gas completely; 2） recovery dust completely; 3） excellent environment benefit.	1） the sealed tank is huge which need extra area and not suitable for existing blast furnace; 2） ballonet is easy to abrade but not easy to replace 3） consume plenty of nitrogen, only when the ratio between the BFG price and N2 price is larger than 4, this method can get economic benefit
Ejector method		1） recovery hopper blast furnace gas completely; 2） recovery dust completely; 3） low operating cost and good economic benefit.	1） bag filter and ejector need extra area which not suitable for existing blast furnace; 2） compare to traditional method, it prolong the entire process time; 3） the BFG recovery process may influent net gas pipeline network.
Gas substitution method	Nitrogen sweeping method	1） recovery most hopper blast furnace gas; 2） less fixed investment; 3） easy and flexible operation, suitable for existing and new blast furnace; 4） good economic benefit	1） couldn't avoid dust diffusing 2） N2 sweeping effect decreased quickly along with N2 accessing amount increased ; 3） compare to traditional method, it prolong the entire process time.
	Nitrogen complement method	1） recovery most hopper blast furnace gas; 2） less fixed investment 3） easy and flexible operation, suitable for existing and new blast furnace 4） great economic benefit	1） couldn't avoid dust diffusing.

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From Table 2, we found that because of ballonet method needs extra area and high cost on operation, ejector method and gas substitution method are much better. Although ejector method could gain good economic and environment benefit, bag filter and ejector need extra area and not suitable for existing blast furnace.

In spite of gas substitution method can't avoid dust diffusing result in it's less environmental than ejector, it's still much more environmental than traditional method. Furthermore, it needs less fixed investment, has good economic benefit, easy and flexible operation not only suitable for new blast furnace, but also for existing blast furnace. Especially nitrogen complement method, it's not only has not the phenomena of sweeping effect decreased quickly along with N_2 accessing amount increased, but also not prolong the entire process time, is an ideal new hopper pressure modulation technology that easy to implement.

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