Energy Consumption Calculation and Analysis of Gas Suspension Calciner

Yinbao Li, Jing Li, Rui Yin, Mengzhen Zhang, Guowang Li, Rui Guo and Wenfeng Li

Henan Building Materials Research and Design Institute Co. Ltd., Henan Academy of Sciences, Zhengzhou 450002, P. R. China

Abstract: Gas suspension calciner is a kind of ideal fluidization process equipment for energy economy. In order to improve the effective of gas suspension calciner, a series of effecting factors such as producer gas component, air-fuel ratio, products moisture and heat dissipation on calciner energy consumption were discussed in this paper, which is based on the research of thermal balance calculation of gas suspension calciner. The study of thermal balance calculation has significant meaning on the energy-saving and the whole refinery energy consumption.

1. Introduction
Gas suspension calciner, rotary kiln and other equipments are most commonly used during the roasting production process of the alumina, especially the gas suspension calciner has a wide range of applications with the technology advancement and the efficient use of energy in the industry [1, 2]. The gas suspension calciner currently uses the production gas as the fuel, which can recycle heat by the Multi-stage heat method and have the high energy conversion efficiency. However, How to save energy is an important research direction because of the high energy prices. In the paper, the whole roaster as a thermodynamic system is researched to provide the new way for saving further energy [3].

2. The gas suspension calciner theory
2.1. The gas suspension calciner progress
The gas suspension calciner is made up of the several parts, such as a venturi dryer, two stage cyclone preheaters, a cyclone separation of gas suspension calciner, a band four cyclone coolers, second fluidized bed cooler, the electric dust collector, and dust return system. It is as shown in Fig. 1. The process makes use of the negative pressure operation and dilute phase fluidization [2, 3].

Aluminum hydroxide containing about 10% product moisture content are put in the venturi dryer by the screw feeder, which are carried to the PO1 by the PO2 gas, then enter into the main furnace PO4 after the PO2 preheating. The whole G. S. C system reactor consists of the PO3 and PO4. The fuel gas from the PO4 cone section will burn after mixing the high temperature combustion air. The materials are suspended in the furnace and stay for several seconds on the condition of the 1100 ~1150 ℃ high temperature, then are transported into the PO3. The burnt product gets into a band four cyclone cooler after separating from the PO3 heat flow. Through counter current heating exchanging,
the product will pass through the second fluidized bed cooler KO1 / KO2 and cool to about 80 °C, and are transported into alumina storage bin after that[4, 5].

![Gas suspension calciner flow diagram](image)

AO2- Venturi dryer; PO1—Primary cyclone separator; PO2—Secondary cyclone separator; PO3-PO4—Main reactio furnace; CO1—Primary cyclone cooler; CO2—Secondary cyclone cooler; CO3—Tertiary cyclone cooler; CO4—Fourth cyclone cooler; KO1/KO2——Second fluidized bed cooler

Fig. 1 Gas suspension calciner flow diagram

2.2. The thermal balance of the Gas Suspension Calciner

The energy of the fuel combustion provides the needs of the generating Al₂O₃ chemical energy and the gasification of the crystallization water and attached water. At last, the production Al₂O₃ and the flue gas carry off some energy, and part of energy is heat dissipation. In this paper, the thermal balance is calculated by the producer gas on the domestic alumina plant at present. The initial conditions and the producer gas components are shown in the Table 1 and Table 2.

| Table 1 The external conditions |
|-------------------------------|
| Relative air humidity | 0.6% |
| Air-fuel ratio | 1.15 |
| Conversion rate of γ- Al₂O₃ to α- Al₂O₃ | 10% |
| Gas inlet temperature | 30°C |
| Flue gas outlet temperature | 160°C |
| Alumina Hydroxide inlet temperature | 50°C |
| Alumina Hydroxide moisture | 4.5% |
| System energy loss ratio | 5% |
| Alumina outlet temperature | 245°C |

| Table 2 Producer gas component content |
|---------------------------------------|
| CO₂ | CO | H₂ | N₂ | H₂S | CH₄ | C₂H₆ | H₂O | O₂ |
| Producer gas | 6.2 | 27.3 | 12.4 | 53.4 | 0 | 0.7 | 0 | 0 |
The whole thermal balance is shown in Table 3.

| Heat income               | Heat spending              |
|---------------------------|----------------------------|
| **Producer gas combustion heat** | **Al(OH)₃ reaction heat**  |
| 2993.06                   | 2055.10                   |
| % 95.15                   | % 65.33                   |
| **Producer gas sensible heat** | **Moisture reaction heat** |
| 23.39                     | 176.45                    |
| % 0.74                    | % 5.61                    |
| **Al(OH)₃ sensible heat** | **Flue gas sensible heat** |
| 106.40                    | 482.22                    |
| % 3.38                    | % 15.33                   |
| **Air sensible heat**     | **Al₂O₃ sensible heat**   |
| 22.69                     | 274.41                    |
| % 0.72                    | % 8.72                    |
| **System heat loss**      | **Total**                 |
| 157.28                    | 3145.53                   |
| % 5.00                    | % 100.00                  |

It can be drawn from the above table that the sensible heat of flue gas and heat dissipation has its certain part. Therefore, the total energy consumption can decline by the method of reducing the sensible heat of the flue gas and the heat dissipation.

3. The major effecting factors of Gas Suspension Calciner

Gas suspension calciner is an open thermodynamic system, which has the rather complex thermal processes. The major factors, which mainly influence the energy consumption, are analyzed with the thermal balance calculation of gas suspension calciner in detail.

3.1. Producer Gas component

The calorific value of the producer gas has the important impact on the energy consumption, and the fuel gas composition reflects that how much calorific value is. The properties of the producer gas are shown in Table 4 and Fig. 2.

| Higher calorific value | 5841.74 KJ |
| Lower calorific value  | 5034.78 KJ |

![Fig. 2 Combustion temperature of Producer gas on different air-fuel ratio](image-url)

It can be seen in the Table 4 and Fig. 2 that the theoretical combustion temperature of the producer gas will decrease with the increase of the air-fuel ratio, which will affect the properties of product alumina. Therefore, the air-fuel ratio should not be too high in fact. According to the surrounding
condition of alumina plant, the high calorific value of producer gas should be used to reduce the diameter of the delivery pipe and the cost.

3.2. Air-fuel ratio
Keep the PO4 furnace reaction temperature, the product moisture and the heat dissipation stable. As the air-fuel ratio changes, the furnace production status are as shown in Fig. 3.

![Fig. 3 Gas consumption and temperature on different air-fuel ratio](image)

It can be seen in the Fig. 3 that the gas consumption of the main furnace PO4 will improve for the purpose to make the main furnace PO4 temperature stable because of the increasing the air-fuel ratio. The whole system thermal balance of gas suspension calciner will change by adding larger amount of the combustion air, which will decrease the main furnace PO4 temperature. Therefore, there is need for combustion energy of producer gas to improve the furnace temperature. Whereas the venture dryer AO2 decrease with the increase of the air-fuel ratio. The flue gas amount will become large as well as the air-fuel ratio, and the sensible heat of the flue gas will improve greatly under the stable furnace temperature. Most of the product moisture, attaching the aluminium hydroxide, can be removed, when the flue gas pass through the venture dryer AO2. In this case, the producer gas consumption of the venture dryer AO2 will decrease obviously. Based on the increase of the air-fuel ratio, the reducing amount of the venture dryer AO2 is much than the increasing amount of the main furnace PO4, so the
whole gas consumption and the energy consumption will decrease. Most of the alumina sensible heat is taken away by the increasing amount of combustion air, so the alumina outlet temperature is low.

In the actual production operation, there is almost no producer gas consumption on the venture dryer AO2, and the PO4 gas consumption is all. Therefore, the air-fuel ratio should be in the suitable range, which can not only ensure the full combustion of producer gas, but also generate less flue gas amount.

### 3.3. Product moisture

Keep the PO4 furnace reaction temperature, the air-fuel ratio and the heat dissipation stable. As the product moisture changes, the furnace production status are as shown in **Fig. 4**.

It can be seen in the **Fig. 4** that there is a rising trend of the producer gas consumption on the main furnace PO4 and venture dryer AO2 as the product moisture increase, so the overall gas consumption and the whole energy consumption have larger growth. On the contrary, the aluminium outlet temperature decreases continuously. The more producer gas there is, the more combustion air requirement there should be. A great quantity of combustion air will take away more energy form the outlet alumina sensible heat, so that the outlet alumina temperature decreases. The AO2 gas consumption will increase when the feed aluminum hydroxide has the higher product moisture.
The content of the product moisture has the great influence on the energy consumption, and the main reason is that the sensible heat of water is much less than the latent heat of water. As a consequence, the gas consumption and the flue gas amount are lower by reducing the product moisture.

3.4. Heat dissipation
Keep the PO4 furnace reaction temperature, the air-fuel ratio and product moisture stable. As the heat dissipation changes, the furnace production status are as shown in Fig. 5.

![Fig. 5 Gas consumption and temperature on different heat dissipation](image)

It can be seen in the Fig. 5 that the producer gas consumption of the total gas amount, the main furnace PO4 and venture dryer AO2 will raise with the increase of the heat dissipation. In the overall balance, the heat dissipation occupies a certain percentage, which will be compensated through the combustion heat of producer gas. Therefore, when the heat dissipation increases, the fuel amount improves, so that the energy consumption increases. The CO4 outlet temperature decreases because of the increased demand of air.

In the actual production, the whole heat preservation of the gas suspension calciner should be carried out, and regular checks and maintenance, so that keep the gas suspension calciner in a good thermal insulation state to reduce the heat dissipation. At the same time, adopting the new heat preservation liner material can significantly reduce the heat dissipation.

3.5. Orthogonal experiments analysis of Gas suspension calciner factors
From the above single factor experiments, we can obtain the significant value dates from the air-fuel ratio; the product moisture; and the heat dissipation, which are as the further study in order to acquire
the optimal portfolio. The orthogonal experiments results and analysis were showed in Table 5–8.

Table 5 Orthogonal experiment (3 factors and 4 levels)

| Level | air-fuel ratio | product moisture/% | heat dissipation/% |
|-------|----------------|--------------------|-------------------|
| 1     | 1.05           | 2.5                | 3                 |
| 2     | 1.1            | 3.5                | 4                 |
| 3     | 1.15           | 4.5                | 5                 |
| 4     | 1.20           | 5.5                | 6                 |

Table 6 The results of orthogonal experiment

| No. | air-fuel ratio | product moisture/% | heat dissipation/% | Energy consumption/KJ |
|-----|----------------|--------------------|--------------------|-----------------------|
| 1   | 1.05           | 3.5                | 5                  | 3013.63               |
| 2   | 1.1            | 5.5                | 3                  | 3032.74               |
| 3   | 1.15           | 5.5                | 5                  | 3076.73               |
| 4   | 1.20           | 3.5                | 3                  | 2925.59               |
| 5   | 1.05           | 4.5                | 3                  | 3002.27               |
| 6   | 1.1            | 2.5                | 5                  | 2959.44               |
| 7   | 1.15           | 2.5                | 3                  | 2895.43               |
| 8   | 1.20           | 4.5                | 5                  | 3022.23               |
| 9   | 1.05           | 2.5                | 6                  | 2998.75               |
| 10  | 1.1            | 4.5                | 4                  | 3016.75               |
| 11  | 1.15           | 4.5                | 6                  | 3060.84               |
| 12  | 1.20           | 2.5                | 4                  | 2910.51               |
| 13  | 1.05           | 5.5                | 4                  | 3072.29               |
| 14  | 1.1            | 3.5                | 6                  | 3028.77               |
| 15  | 1.15           | 3.5                | 4                  | 2962.85               |
| 16  | 1.20           | 5.5                | 6                  | 3095.03               |

Table 7 Range analysis of orthogonal experiment

| No. | A- air-fuel ratio | B- product moisture | C- heat dissipation |
|-----|-------------------|---------------------|---------------------|
| K1  | 12086.94          | 11764.13            | 11856.03            |
| K2  | 12037.7           | 11930.84            | 11962.4             |
| K3  | 11995.85          | 12102.09            | 12072.03            |
| K4  | 11953.36          | 12276.79            | 12183.39            |
| k1  | 3021.735          | 2941.033            | 2964.008            |
| k2  | 2982.71           | 2982.71             | 2990.6              |
| k3  | 3099.425          | 3025.523            | 3018.008            |
| k4  | 2988.34           | 3069.198            | 3045.848            |
| Range-R | 33.395          | 128.165             | 81.84               |
| Major factors | B>C>A          |                     |                     |
| Optimization levels | A4            | B1                  | C1                  |
| Optimal Portfolio  | A4B1C1        |                     |                     |
Table 8  Variance analysis of orthogonal experiment

| Energy          | Sum of squares | degree of freedom | Estimator of variance | F value | F0.01 | F0.05 | Effect       |
|-----------------|----------------|------------------|-----------------------|---------|-------|-------|--------------|
| A- air-fuel ratio | 48661438       | 3                | 16220479.5           | 26.86   | 9.78  | 4.76  | highly significant |
| B- product moisture | 49757136       | 3                | 16585711.9           | 27.47   | 9.78  | 4.76  | highly significant |
| C- heat dissipation | 41891548       | 3                | 13963849.2           | 23.13   | 9.78  | 4.76  | highly significant |

As seen from Table 5, the product moisture is the main influencing factor. Next is the heat dissipation. The third is the air-fuel ratio. Compared with the single factor experiments, the orthogonal experiments have the more comprehensive analysis and scientific. The optimum conditions of the gas suspension calciner are 1.2 of the air-fuel ratio, 2.5% of the product moisture and 3% of the heat dissipation. In addition, the three factors, such as the product moisture, the heat dissipation and the air-fuel ratio, have the significant impact on energy consumption. The calculated thermal balance is as shown in Table 9 under the optimization combination condition.

Table 9 The whole thermal balance of Producer gas under the optimization combination

| Heat income                        | kJ/kg | %   | Heat spending               | kJ/kg | %   |
|------------------------------------|-------|-----|----------------------------|-------|-----|
| Producer gas combustion heat       | 2884.49 | 95.22 | Al(OH)₃ reaction heat      | 2055.10 | 67.84 |
| Producer gas sensible heat         | 22.54  | 0.74 | Moisture reaction heat     | 96.06  | 3.17 |
| Al(OH)₃ sensible heat              | 99.52  | 3.29 | Flue gas sensible heat     | 466.89 | 15.41 |
| Air sensible heat                  | 22.82  | 0.75 | Al₂O₃ sensible heat        | 320.44 | 10.58 |
| Total                              | 3029.37 | 100.00 | System heat loss           | 90.88  | 3.00 |

The energy consumption is the lowest from the Table 9, which is 2.884 GJ/kg. As a result, the influence parameters should be under the optimization combination as much as possible to reduce the energy consumption.

4. Conclusions

Through the analysis of this paper, it can draw the conclusion from the following several aspects to reduce the energy consumption.

- The air-fuel ratio should be in the stable range, and the advantage value is about from 1.0 to 1.1, which can not only ensure the full combustion of producer gas, but also generate less flue gas amount.
- Reduce the product moisture of the alumina hydroxide and use the dehydrating agent to strengthen the dehydration. Through the measure, it can greatly drop the energy consumption and save the production costs.
- It is very necessary to regular checks and maintenance on the whole heat preservation of the gas suspension calciner, and adopting the new heat preservation liner material can significantly reduce the heat dissipation.

In order to reduce the energy consumption of gas suspension calciner, the reaction and the heat transfer process need to be further discussed and researched, and the device structure and
configuration should be optimized. At the same time, it is very useful to control the main furnace combustion temperature and product quality, so as to stabilize production and reduce energy consumption.

In the future research on the energy consumption of gas suspension calciner, the new thermal insulation refractory materials should be developed to minimize the heat dissipation loss of gas suspension calciner. Researching the innovative structure of gas suspension calciner can improve the heat exchange efficiency of materials and conveying gas, which can reduce the temperature of the waste gas and discharge materials. It is important that developing the new dehydration reagents to further reduce the Product moisture. Thereby, it can reduce the overall energy consumption of gas suspension calciner.

Acknowledgements
This study was financially supported by the Basic Scientific Research Project of Henan Academy of Sciences (Grant Number 200609090).

References
[1] Lu, M. Wu, H.W. Energy consumption calculation and analysis on roaster furnace. (2013). Light Industry Science & Technology. Vol. 1: 73-74 (in Chinese).
[2] Feng, W.J. Fan, L.J. Wu, S.Z. and B.Y. Hou. Application of gas suspension calciner in shanxi branch of Chalco and discussion on energy economy approach. (2004). Energy Saving of Non-Ferrous Metallurgy. Vol. 21: 44-46 (in Chinese).
[3] Wang, J.L. Technical innovation of energy saving for gaseous suspension calciner. (2012). Nonferrous Metals Design. Vol. 3: 31-33 (in Chinese).
[4] Zhang, J., Feng, G.Z. Application of gas suspension calciner (GSC) and its improvement. (2002). Conservation and Utilization of Mineral Resources. Vol. 6: 42-46 (in Chinese).
[5] Roldan, D. Energy and material balance for alumina fluid bed calciners. (1987). Light Metal. Vol. 8: 51-55.