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The Study and Applications of Modern Potline Fume Treatment Plant (FTP)

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Abstract

Primary aluminum reduction is energy and emissions intensive. It is very important for the environment and for business to treat potline fume efficiently. This article discusses how to improve potline fume efficiency from several respects based on CHALIECO GAMI's experimental studies which were applied successfully in many modern potline's Fume Treatment Plants (FTP), and also demonstrates the significance of improving alumina injection feeding and flow field inside the bag filter. A new and efficient method for the filter pulse control system is introduced, which is used in Vedanta's recent Jharsuguda project in India.

Based on these studies and applications, as well as new development of pulsing control system, CHALIECO GAMI is now able to control the HF emission concentration and the dust emission concentration respectively below 0.8mg/Nm^3 and 5mg/Nm^3 at the stack outlet of the FTP.

Introduction

In order to improve the purifying efficiency of the fume treatment system, fume and alumina must be mixed equally. Alumina particles move in the fume by the following forces: resistance, gravity, buoyancy, acceleration force of particle, diffuse force of fluid' electrostatic force, etc. Alumina, as a powder material, is mixed with gas mainly by the characteristics of particle material, movement characteristics of airflow and the act that airflow to particle material to make particle material "actively " contact and mix with fume. Alumina particles mixed with fume has the following characteristics:

- Alumina particles without the presence of a gaseous fluid have no flowability;
- When flow velocity is relatively high, small alumina particles （0～150μm） are suspended in the flow;
- When particle diameter is small, particles can be considered as fluid medium;
- When particle diameter is big, momentum characteristics of particles must be considered.

When fresh alumina enters to fume flow field, alumina particles of small granularity will move with fume immediately; the effect of inertia force and influenced by fume, movement direction of alumina particles of big granularity changes slowly, and they will continuously keep or do their best to keep original movement direction for a period of time. During the research, the feeding and mixing characteristics of alumina were investigated.

The distance between alumina particles injected into the flow field is considerably larger than the particle diameter of alumina particles, moreover hydrogen fluoride molecules distribute in the space among these particles, if the scrubbing efficiency of fume treatment system wants to reach above than 99%, it is impossible to achieve it only by the adsorption of alumina and fume in the reactor section. Improvement of dust distribution on bag filter and improvement of the gas-solid two-phase flow. two-phased flow field inside the bag filter section of the filter should be applied to achieve the scrubbing efficiency of above 99%.

Research for alumina feeding

Equipments for test that mixed alumina with fume done by GAMI

When developing the alumina feeding scheme for the equipment, in order to achieve the target of alumina "actively" mix with fume, we decided to spray [2] alumina into the fume as the feeding method. We decided to apply the method of flue radial spray to improve the mixing effect for alumina and fume. Part of flue feeding is designed as a venturi duct [3] (see fig 1)which is good for making use of the turbulent flow effect of fume to promote the mix between alumina and fume.

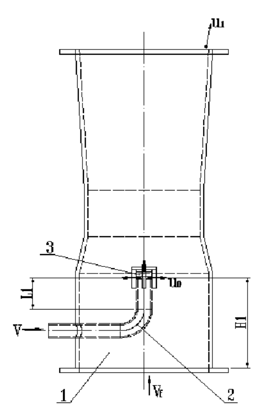

Fig 1 Feeding scheme of fume pipe center

1—venturi pipe，2—spray pipe，3—muzzle end plate

Movement calculation and test result of the design scheme for mixing equipment for alumina and fume

To make alumina mixing with fume fully via the feeding reactor, alumina particles can reach near the reactor wall at the exit position of feeding reactor. This acts as assumed condition (feeding equipment size for test design) to process operation: distance from nozzle to wall is 110mm, distance from nozzle to reactor exit is 500mm, fume flow velocity inside the flue duct is 18m/s (see fig 2), flow duct is assumed as direct duct, alumina granularity is accounted as 85μm [4]:

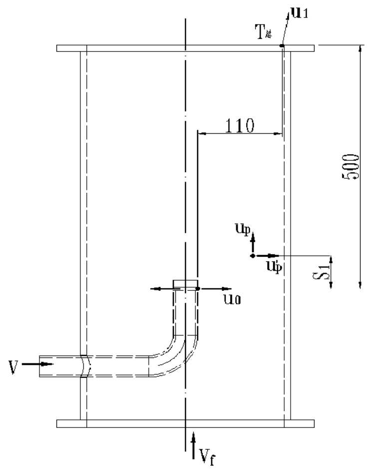

Fig 2 particle motion calculation

a. Calculation for the motion at axis direction

The forces computation of particle materials in fluid motion :

Alumina particle gravity:

$$m_p g = \frac{1}{6}\pi d_p^3 \rho_p g = 1.736\times10^{-6} \text{ (N)}$$

Fume buoyancy force by alumina particles:

$$\frac{1}{6}\pi d_p^3 \rho_f g = 5.32\times10^{-10} \text{ (N)}$$

Alumina particle flow resistance:

$$c_d \frac{\pi d_p^2}{4}\frac{1}{2}\rho_g u_p^2$$

There is no temperature difference in this test, so temperature gradient force is not considered; Pressure intensity gradient force and slippage-shearing lift force are relatively small, they are not considered in the simplified calculation either. Contrast for buoyancy to gravity: $1.736\text{x}10^{-6} >> 5.32\text{x}10^{-10}$. Compared with gravity, buoyancy force by alumina particles can be ignored.

Alumina particle acceleration calculation adopts the experiential formula for calculating relaxation time:

$$T_d = \frac{\rho_p d_p^2}{18\mu_c}$$

substitute with parameter, calculation result is:

$$t = 2.33\times10^{-2}\text{ s}$$

Calculated distance(vertical, see fig 2) for the particles on uniformly accelerated motion in relaxation time:

$$s_1 = \frac{1}{2}at^2 = \frac{1}{2}(\frac{u_0}{t})t^2 = \frac{1}{2}u_0 t = \frac{1}{2}\times18\times2.33\times10^{-2} = 0.21m$$

After the relaxation time in fume tube, uniform motion axial velocity of alumina particles is the same as fume. The motion time that alumina particles get to the predetermined position (u_1) is:

$$t_{total} = \frac{0.5-0.21}{18} + 0.0233 = 0.0393s$$

We can get a conclusion from the above simplified calculation: radial direction motion time of particles is 0.0393s, spray velocity at critical radial direction of alumina particles can be calculated with this data.

b. Calculation for the motion at radial direction

Range estimation for Reynolds number for spray at radial direction of alumina (based on project experience, duct velocity is assumed as 18m/s):

$$R_e = \frac{d_p u_0}{\mu} = \frac{85\times10^{-6}\times18}{1.5\times10^{-5}} = 102$$

Radial motion lies in the low Reynolds number area, when $1<Re_d<2000$ (correspond to transition state), empirical formula for particles motion resistance coefficient C_d' is: $C_d' = 18/Re_d^{3/5}$. Particle motion at radial direction only considers that, when resistance coefficient at radial direction is similar to the resistance coefficient of initial velocity, differential equation of particles motion is: $m_p \frac{du_p'}{dt} = -C_d' \frac{1}{4}\pi d_p^2 \times \frac{1}{2}\rho_g u_p'^2$,

substitute with resistance coefficient expression, diffenential equation can be calculates as : $u_p' = (7.69+c)^{-2.5}$. And then:

$$\int_0^{t_m} u_p' dt = \int_0^{t_m} (7.69t + c)^{-2.5} dt = 0.11$$

Substitute with boundary conditions can get c=0.292, speed at the start: $u_0 = 18.5 m/s$.

With the known boundary conditions, the radial velocity the particles are subject to, is:

$$u_p' = (7.69 + c)^{-2.5} = (7.69\times0.0393 + 0.292)^{-2.5} = 3.67m/s$$

Above calculation shows that alumina particles from the nozzle of spray pipe to the predetermined full mix position (fringe of the reactor outlet), radial velocity at the nozzle outlet is 18.5m/s, when get to predetermined position, radial velocity decreases to 3.67m/s. All of these provided reference frame for the design of experimental devices and the set of initial coefficient.

According to the above calculations, we designed small scale test system and carried out small scale tests. During the testing, we made several improvements to the small scale test experimental devices, after which air and alumina of experimental devices mixed well. Based on the small scale test results we carried out the semi-industrialized test. During the semi-industrialized testing process we found that: when system is on feeding and mixing, for the alumina feeding quantity is far bigger that it of small scale test, alumina will be fed to reactor by air transport, and feeding energy consumption is high. If this is put into industrialized production,, it is not good for the energy saving of system, so we designed a kind of feeding style and equipment which transport material by applying gravity action — gravity counter flow spray feeding reactor. This equipment uses high pressure blast to radial spray the alumina via the section feeding into the venturi pipe of reactor to mix , and this method has a very good feeding and mixing effect. Monitoring results for feeding and mixing of semi-industrialized test can be seen in detail in table 1 (concentration monitoring table for dust at the outlet of reactor).

table 1 ***concentration monitoring table for dust at the outlet of reactor***

Sampling point	1		2		3		4	
Filter cylinder number	013	003	005	010	004	009	002	008
Volume at standard condition Nm^3	94.8	99.5	105.8	98.9	97.8	93.6	92.6	88.7
Flow rate m^3/h	55639	58305	62249	57961	57408	54612	54028	52229
Dynamic pressure Pa	293.8	326.8	367.6	318.8	315.3	285.5	279.6	263.3
Flow velocity m/s	18.6	19.5	20.9	19.4	19.2	18.3	18.1	17.5
Fume temperature□	32	32	32	32	32	32	32	32
Section area m^2	0.949	0.949	0.949	0.949	0.949	0.949	0.949	0.949
Sampling time min	5	5	5	5	5	5	5	5
Dust weight g	2.1422	1.8277	1.8949	1.6033	1.2330	1.3314	2.1227	1.7049
Fume and dust concentration mg/m^3	22592	18356	17898	16202	12595	14210	22903	19220

Research for the flow field inside the bag filter [5]

Distribution condition of inside flow field of the formerly bag filter

During the process of aluminium smelting fume treatment test, air inlet for bag filter of small scale test system is set at the upper of the ash bucket, after the air flow containing dust entering into the bag filter hopper, it will form a cross flow with high speed inside the equipment, velocity of air flow among bags of bag filter is far higher than the theoretical uplift air flow velocity of bag filter. Motion condition of air flow inside the flow is not the same to the ideal condition of uniform uplift.

Air inlet for the bag filter of pilot scale experiment system is set at the side face of the middle cabinet of the bag filter. Air intake passage is set inside the middle cabinet of the bag filter, two phase flows, gas and solid, will enter into hopper of bag filter via air intake passage. (see fig 3) After the gas and solid flows entered into the hopper of bag filter, they will be scoured to the opposite side of the air intake side, for the hopper is a cone-style structure, air flow will concentrate to the central part of the opposite side of the air intake side to form a strong uplift air flow with high speed which has a very strong scour effect to several local parts inside the bag filter. After the air flow uplifted from the opposite side of air intake passage, a very big return flow is formed in the whole cabinet. Air flow among bags inside middle cabinet has become a down flowing air flow, and the non-uniform distribution condition of flow field is obvious.

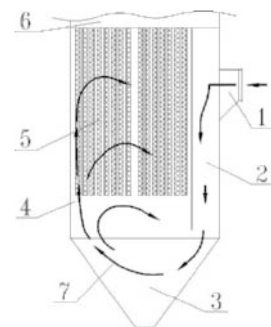

Fig 3 sketch map for the flow field inside the bag filter

1—air inlet，2—air intake passage，3—ash bucket，4—mid cabinet，5—filter bag，6—upper cabinet，7—trace and direction for gas-solid two-phase flow

Test result of the flow field for the formerly bag filter

To get a exact flow field distribution condition for the formerly bag filter, we took a air velocity test for the same horizontal plane in middle cabinet of the lower part of the bag filter, and the sampling points are distributed as follow (see fig 4):

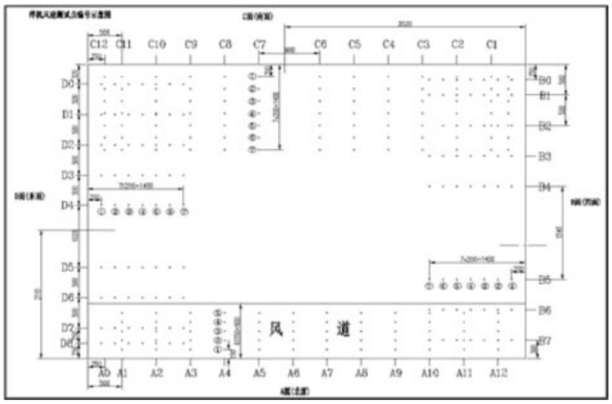

Fig 4 Distribution figure of sampling points inside bag filter

From the figure above, we can see that the air velocity distribution in the air intake passage is uniform, wind velocity distribution measured at the opposite side of air intake passage (side C) are as follow（see fig 5）:

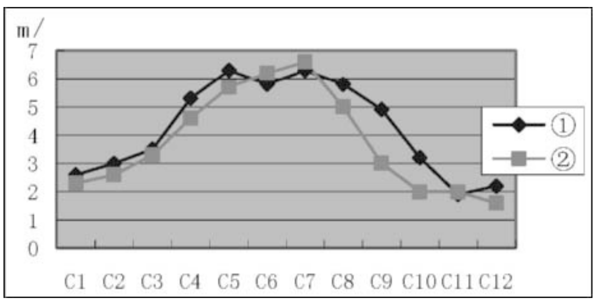

Fig 5 Figure of wind velocity distribution for the opposite side of air intake passage

□ wind velocity of the first row of sampling points，□wind velocity of the second row of sampling points

Dust distribution on the filter bags the formerly bag filter

On the picture showing dust distribution on the filter bags of the bag filter for experiments (see fig 6), the left side is windward face of filter bags. When gas velocity is extremely high, so dust can not build up at the windward face of filter bags. Some dust deposits on the surface of the filter bags and is blown away soon, and some goes through the filter bags due to impact by local air flow, flows upward to the upper segment(clean gas chamber) of the bag filter and is discharged into the atmosphere. The right side of the picture shows the leeward face where gas velocity is comparatively low, and gas flow produces tiny vortexes at the leeward face after flowing around the filter bags. When gas flows though the filter bags the dust is retained on the surface of filter bags and builds up constantly here, giving rise to inhomogeneous dust distribution on the filter bags as shown on the figure. Some of the dust on the right side of the filter bags falls off because of less adhesion on the surface than its weight when the fan stops.

Fig 6 Dust Distribution on Filter Bags of Original Precipitator

Improvement of Internal Flow Field in the Bag filter and Dust Distribution after Improvement

After careful observation for running condition of bag filter, we analyzed test result of inside flow field and took computer simulation experimentation to determine to install air flow distribution plate inside the hopper of bag filter. Test result for flow field inside the improved bag filter can be seen in the figure below (see fig 7), position of sampling points did not change. Test result shows that the degree of non-uniform air flow distribution inside bag filter has decreased greatly, and there is no too high flow velocity in locals inside equipment, air flow distribution at the same level has been improved greatly.

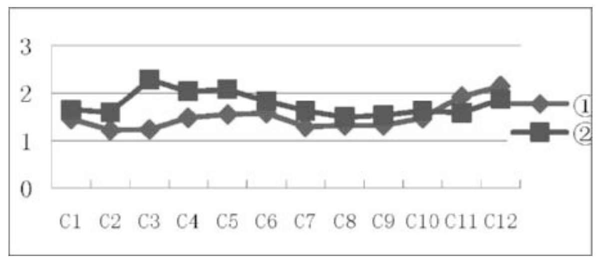

Fig 7 Figure of wind velocity distribution for the opposite side of air intake passage for the improved bag filter

□wind velocity of the first row of sampling points，□wind velocity of the second row of sampling points

Dust distribution on filter bags has become relatively uniform (see fig 8) after the flow field was improved.

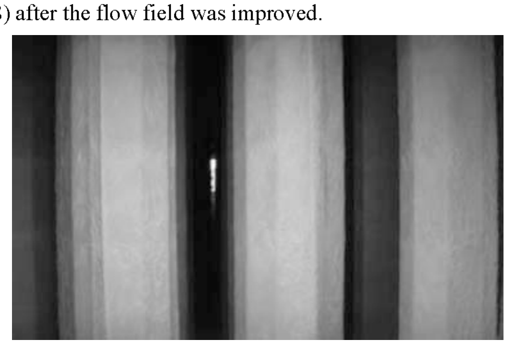

Fig 8 Dust Distribution on Filter Bags of Modified Precipitator

Measured by the test, when running resistance of test system is 1700Pa～1900Pa, the dust concentrations of duct at the bag filter exit were 0.8mg/Nm^3,1.7mg/Nm^3, 2.5mg/Nm^3, 4.4mg/Nm^3, and 1.7mg/Nm^3 , respectively. The gas temperature is 36 °C. The target of dust emission concentrations are all under 5mg/Nm^3 .

Research for pulse control system

Pulse control system of formerly bag filter

Pulse control manner of formerly bag filter usually adopts differential pressure control, time control and discontinuous dust removal. When differential pressure pulse control treats single compartment, differential pressure of bag filter will decrease greatly which will make large amount of fume that should be distributed to other compartments being sent to the pulsed compartment automatically to lead a non-uniform fume distribution among compartments. Initially, GAMI set the differential pressure control as the bag filter pulse manner for potline fume treatment system of phase I project of Jharsuguda , Vedanta with the pulse differential pressure is set as 1600Pa, number of compartments in a single row is 8. When filter bag differential pressure of certain compartment reaches the pre-set pulse differential pressure and conducts pulsing, comparing the single compartment differential pressure before and after pulsing, filter bag differential pressure of the compartment waiting to be pulsed decreased from about 1600Pa to around 1350Pa and without to be applied pulse, fume volume treated by this cabinet decreased more than 8.1%，the decreased part of fume will be sent to the compartment which being applied pulse. For there is only one of eight compartments being applied dust removal during certain period of time, there are seven compartments with a decreased treated fume volume while only one compartment that is being pulsed has an increased fume volume. Supposed that decreased fume volume of 7 compartments are the same, then the increased fume volume of the compartment being pulsed is about 56.7%. Certain quantity of fresh alumina proportionally treats certain quantity of fume, for system fume itself has certain level of resistance self equilibrating effect, the change for the 56.7% fume volume mentioned above will generate from every compartment of the same group irregularly and by turns, this will decrease gas scrubbing efficiency.

The discontinuous dust removal effect will lead to the alumina originally being fed uniformly to system has being all sent back to enriched alumina silo by air lift at the dust removal time, and this will lead the unstable conveyance volume and short time over loading of the air lift.

As for traditional time pulsing manner，except for the problems taking place in the differential pressure dust removal, will also lead to uncontrollable differential pressure of bag filter, and the system stability will get worse.

Control manner for sequence pulse time

In order to solve the problems occurring during the running process of gas treatment system, phase I of Vedanta's Jharsuguda project of India adopted the pulse manner which change sequence of pulse valve and apply time control to keep the air flow among chambers in the system balanced and stable. Target of control the dust discharge concentration can be achieved by changing pulse interval to control filter bag differential pressure of system. The newly modified control manner is (sequence in turn for pulse valves):

No.1 chamber No.1 valve→ No.2 chamber No.1 valve……No.8 chamber No.1 valve→No.1 chamber No.7 valve→No.2 chamber No.7 valve……No.8 chamber No.7 valve→No.1 chamber No.13 valve→No.2 chamber No.13 valve……No.8 chamber No.13 valve→No.1 chamber No.19 valve→ No.2 chamber No.19 valve……No.8 chamber No.19 valve→

No.1 chamber No.2 valve……No.8 chamber No.2 valve→No.1 chamber No.8 valve……No.8 chamber No.8 valve→No.1 chamber No.14 valve……No.8 chamber No.14 valve→No.1 chamber No.20 valve……No.8 chamber No.20 valve→

Dust removal sequence is on the analogy of this.

No.1 chamber No.6 valve……No.8 chamber No.6 valve→No.1 chamber No.12 valve……No.8 chamber No.12 valve→No.1 chamber No.18 valve……No.8 chamber No.18 valve→No.1 chamber No.24 valve……No.8 chamber No.24 valve→No.1 chamber No.1 valve→

If a proper design is made for the gas distribution plate of the bag filter, updraft velocity on the same horizontal plane in the bag filter is almost even, and gas velocity comparatively low. If pulsing is done in a mode with a number of solenoid valves on the same individual compartment opened at the same time, only little dust retains on the filter bags having just been cleaned. This reduces the flow resistance and a lot of dust retains on the filter bags on the other side of the bag filter to be cleaned soon, which increases the flow resistance. Therefore, it results in inhomogeneous gas distribution inside the bag filter.

Actual application effect of the control manner for sequence pulse time

Pressure among compartments will be basically balanced after the pulse program of purifying system has been modified. Pressure distribution condition of the bag filter chambers of the phase I of Vedanta's Jharsuguda project of India can be seen in the table below (see table 2). There will be differential pressure between two rows (A,B) of bag filter compartments because the change of pulse system there will be differential pressure among chambers in the same row of compartments because the sequence difference of pulse time, different feeding quantity among compartments and non work of particular pulse valve.

Table for filter bag resistance of bag filter chambers for potline FTP-1 (A,B row) (Table 2)

chamber No.	1	2	3	4	5	6	7	8
A row	1716	1703	1807	1771	1770	1808	1870	1749
B row	1668	1749	1810	1746	1601	1666	1711	1633

There are still non-uniform distribution of air stream and dust of FTP-1,2 because supplier did not manufacture the bag filter air flow distribution plate for FTP-1,2 according to the requirements. From figure of filter bags differential pressure change (see fig 9), we can see that 8 chambers in a single row of bag filter all have a periodic differential pressure fluctuation which shows that cake thickness on filter bags changes accordingly. Change for pulse control program avoids a big difference for differential pressure distribution among chambers. Although differential pressure inside each chamber changes in different period and this kind of change happens simultaneously, which avoids non-uniform air flow distribution among compartments because of pulse for the bag filter in the same row. This provides factors for improving system purifying efficiency.

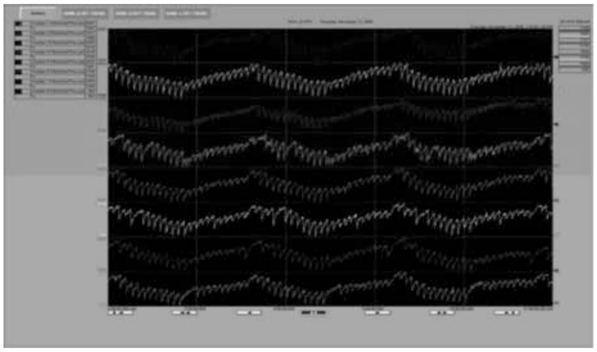

Fig 9 differential pressure change of bag house in FTP-1 D row

Conclusion

By researching the feeding reactor for potline FTP, we can reduce the energy consumption for equipments and system and improve the mixing effect for alumina and fume which makes alumina mix with fume quickly when after feeding. This improves the mix and adsorption efficiency.

Distribution for air and dust at the same level inside bag filter and dust distribution on filter bags can be more uniform by improving flow field inside bag filter which ensures sufficient contact for alumina and fume and improves filtration and purifying effect.

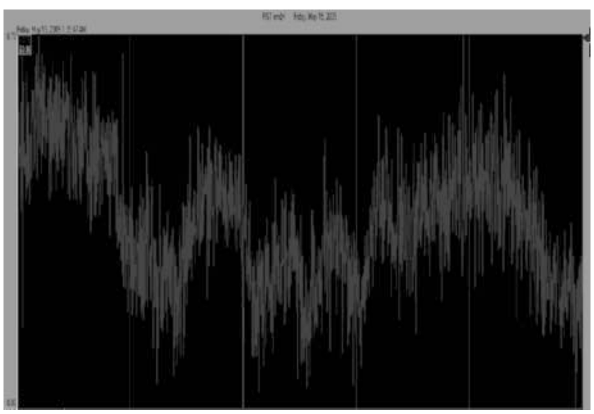

Fig 10 Online HF emission concentration monitoring of scrubbing system for phase I of Vedanta's Jharsuguda project of India

Problems like non-uniform air flow distribution among chambers during running of system can be solved by improving the control system which gets a more reasonable and stable distribution of alumina and fume. This can improve scrubbing efficiency of purifying system, at the same time, keep system running more stable. Online HF emission concentration monitoring of scrubbing system for phase I of Vedanta's Jharsuguda project of India show results consistently lower than $0.8mg/Nm^3$. (see fig 10)

GAMI has presently got certain achievement for the research of scrubbing system. Stack exit emission index of system has met the requirements of the international contract in India. CHALIECO GAMI is conducting a further research and improvement program for FTP equipment, feeding mixing ability of feeding reactor; flow field for gas–solid two-phase flow inside bag filter is getting developed and optimized, and uplift air flow velocity control inside bag filter and dust distribution are becoming more reasonable; setting of compressed air pulse pressure, pulse width and pulse interval of bag filter are becoming more reasonable, dust removing and scrubbing efficiency of bag filter will get a further improvement. Lastly, to determine the best combination of bag length, bag diameter, bag spacing according to particle size of alumina dust is the direction of the further research.

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