[Article ID] 1003- 6326(2002)03- 0529- 05

Purification technology of flue gas from remelting process of aluminum alloy tailings①

LI Cai-ting(李彩亭), ZENG Guang-ming(曾光明), WEI Xian-xun(魏先勋),
YUAN Xing-zhong(袁兴中), WANG Li-ping(王丽平)
(Department of Environmental Science and Engineering, Hunan University,
Changsha 410082, China)

[Abstract] Through a practical example of treatment of the flue gas from the remelting process of aluminum alloy tailings, the design and calculation method of exhaust hood, as well as the principles and the equipments of dust removal, smoke abatement and harmful gas elimination were studied. Combination of centrifugal and wet dust removal can purify the dust high efficiently. The carbon black and harmful gases in the flue gas can be removed by adding a small quantity of activator to the absorption solution. The application results are that the dedusting efficiency is 97.43%, Cl_2 control efficiency is 88.03%, the exhaust fume blackness is lower than Ringelman number I, and the purification device resistance is 1 126 Pa.

[Key words] aluminum alloy tailings; flue gas; purification
[CLC number] X 51 **[Document code]** A

1 INTRODUCTION

In an aluminum alloy casting workshop of the automobile carburetor plant, there are ten electric furnaces, among which six operate simultaneously in average for aluminum alloy melting. The tailings including runners, feathers, remnants etc, will be generated during the process of casting and refinement afterwards. With the aim of economizing resources, the tailings need to be remelted for reuse. However, some oily dirties, cuticle removers, emulsifiers and dusts will cover the tailings, large numbers of black smoke and dust will discharge during the remelting process. Moreover, when refining, some Cl_2 and HCl will escape from the workshop[1~3]. Without treatment, the air pollution is tremendously serious in the workshop. The blackness level of the flue gas from the furnace opening reaches Ringelman number 5. The concentration of Cl_2 (standard state) in the air around the operating station is 3.8 mg/m^3 (the standard of Cl_2 is 1 mg/m^3)[4]. These pollutants are extremely harmful to the health of the workers. The plant lies in the dense community of the city, so residents are strongly against it.

2 PURIFICATION MEASURE

There is no example on the purification of flue gas from the remelting process of aluminum alloy tailings now. According to the properties of the flue gas, the project group carried out a small-scale test. Associated with the specific situation, a purification plan was made. First, collect the flue gas, and then input it into the self-made purification device to make it interact with the absorption solution, thus the objective of dust removal, black smoke abatement and harmful gas elimination can be realized. The concrete schematic diagram is shown in Fig. 1. The purified flue gas after dehydration is discharged into the air through the induced draft fan and chimney, and the absorption solution will be recycled. The following four critical problems must be solved in order to

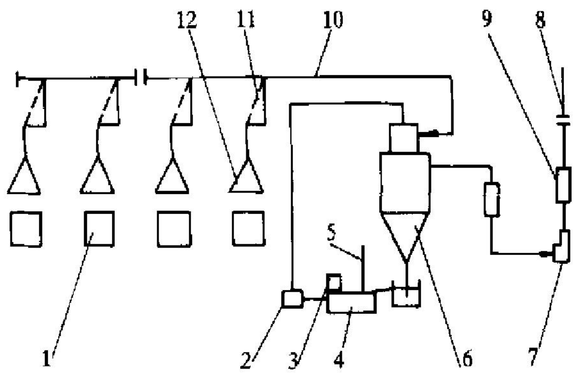

Fig. 1 Schematic diagram of purification process of flue gas
1 —Aluminum melting furnaces; 2 —Water pump; 3 —Activator concentrated pond; 4 —Precipitating and cycling pond; 5 —Automatic water compensation equipment; 6 —Purification device of flue gas; 7 —Induced draft fan; 8 —Chimney; 9 —Muffler; 10 —Main pipeline; 11 —Diagonal rope of exhaust hood; 12 —Exhaust hood

① **[Foundation item]** Projects (70171055; 50179011) supported by the National Natural Science Foundation of China; Project supported by the Chinese Teaching and Research Award Program for Outstanding Young Teachers in Higher Education Institutes in 2000
[Received date] 2001- 12- 26; **[Accepted date]** 2002- 01- 23

implement the above process: 1) collection of flue gas, 2) dust removal, 3) black smoke abatement and harmful gas elimination, and 4) anticorrosion and abrasion resistance of the device[5~8].

2.1 Collection of flue gases

2.1.1 Installation of exhaust hood

Under certain process conditions, whether the collection of flue gases is effective is of great importance for the air quality of workshop. In this work, an exhaust hood is set up at the top of electric furnace for flue gas collecting. Because the ten electric furnaces will not operate at the same time, a valve was installed on each exhaust hood in order to reduce energy consumption and ensure the purification effect. In consideration of the convenience of the crane loading and unloading materials and the facilitation of operations of alloy refining, slag removing and pouring and so on, the exhaust hood is designed to be rotary lifting and low hanged style. The shortest distance between the bottom of the hood and the entrance of the furnace is 150 mm, and the moving distance of the hood is 650 mm. In order to reduce the disturbance of cross flow and the loss of heat of the metal liquid, an inner hood is set in the exhaust hood. The exhaust hood, which is the telescope-feed style, uses the balancing ring to balance the mass of itself and the inner hood through pulleys. The rotary process of the exhaust hood is realized by ball bearings and the exhaust hood is hanged up with a diagonal rope that could reduce the twisting moment of the axial bearing and make the hood rotate skillfully and freely.

2.1.2 Calculation of ventilating gas volume

The scale of the exhaust hood opening is calculated by

$$D = d + 0.8H \tag{1}$$

where D is diameter of the hood opening, m; d is horizontal projection diameter of heat sources, m; H is vertical distance from the hood opening to the furnace opening, m.

Ventilating gas volume of single exhaust hood is calculated as

$$L = L_0 + v'F' \tag{2}$$

where L is ventilating gas volume of every exhaust hood, m^3/s; v' is indraft velocity of gas in expanded areas, m/s, given as 0.6 m/s; F' is the expanded area of hood opening, which is the subtraction of hood opening area and sectional area of heat current, m^2; L_0 is initial flow rate of heat flow above the heat source, m^3/s. L_0 can be calculated as

$$L_0 = 3.81(AFhA_p^2\Delta t^{4/3})^{1/3} \times 10^{-2} \tag{3}$$

where A is coefficient, given as 1.7; F is convection and heat elimination area, m^2; h is qualitative dimension of heat sources, namely the diameter of electric furnace crucible; A_p is horizontal projection area of heat sources, m^2; Δt is temperature difference, ℃.

The total ventilating gas volume is calculated according to 60% operational rate of furnaces (six electric furnaces operated simultaneously). In addition, the air leak factor is considered in some extent as

$$L_T = 6LC \tag{4}$$

where C is coefficient, given as 1.1.

The calculated ventilating gas quantity of every hood is 0.49 m^3/s and the total ventilating air quantity is 3.234 m^3/s, namely 11 642 m^3/h.

2.2 Dust removal

The flue gas containing dusts will enter the purification device from the tangential direction by passing through every exhaust hood, branch pipe and main pipe. The absorption solution is sprayed into the purification device from the top. In the purification device, the dusts with particle diameter over 10 μm are removed through the centrifugal force. According to the Stokes' law, the radial velocities of the dust particles moving to the tunnel wall under the combined actions of the centrifugal force and resistance can be written as

$$v_r = \rho v_t^2 d^2/(18\mu r) \tag{5}$$

where r is particle rotation radius, m; v_r is radial velocity of the particle when the rotation radius is r, m/s; ρ is particle density, kg/m^3; d is particle diameter, m; v_t is tangent velocity of the particle when the rotation radius is r, m/s; μ is kinetic viscosity of gas, Pa·s.

Eqn. (5) indicates that the radial velocities of particles with certain sizes vary directly as v_t^2 and inversely as r. The designed purification device, with a higher v_t value, has a r_{max} value only about half of the tube radius of conventional cyclone separators, and its gases haven't any radial centripetal flows. Thus, the radial moving velocities of the particles are comparatively larger. Therefore, the particles with diameter over 10 μm can be removed in the smaller device and in shorter time.

The dusts with particle diameter less than 10 μm have smaller v_r values, so they can not be removed efficiently only by the centrifugal forces. However, the wet dust remover, who removes the dust by collisions and condensation of the dust particles and liquid drops, can be used to reach a higher efficiency of dust removal. The collision probability of the dust particles and liquid drops is represented by the dimensionless collision number N as[5]

$$N = vd^2\rho C/(18\mu d_s) \tag{6}$$

where v is relative velocity of dust particle to droplet, m/s; d_s is diameter of droplet, m; C is Cunninghum slipping correction coefficient.

From Eqn. (6), it is clear that N is directly proportional to v and inversely proportional to d_s. Thus, increasing the relative velocity of dust particles and droplets and reducing the diameters of the droplets are the major ways to improve the dust removal efficiency. In the purification device, the components can enhance the relative velocity of gas and liquid, reduce the value of d_s which can atomize the absorption solution, and increase the value of N. As a result, a considerably high efficiency of dust removal can be acquired. Whereas, the droplet cannot be too small, or it will be flown along with the air currents, which will greatly reduce the relative velocity of gas and liquid. The optimum diameter range of liquid drop is 500~ 1 000 μm[5].

The test of dust removal efficiency is taken in a simulated test device. The experimental dust is standard pulverized coal powder with meso-position diameter d_{50}= 16. 02 μm. The inlet dust concentration is 5 g/ m^3(standard state) . The tests show that the ratio of liquid and gas is of slight effect on the resistance of dust remover. The relationship between the liquid/ gas ratio and the dust removal efficiency is shown in Table 1. It shows that the dust removal efficiency increases proportionally to the rise of the ratio of solution and gas under certain gas volumetric flow rate. When the ratio is 0. 2 L/ m^3 the dust removal efficiency will over 98. 5%, namely the gas and liquid are fully mixed in the dust remover and the effect of dust removal is excellent. The relationship between gas velocity in tower section and resistance of the equipment is shown in Fig. 2, which indicates that the resistance increases with the increase of gas velocity. When the gas velocity of tower section is less than 3. 1 m/ s, the resistance of equipment of less than 1 200 Pa can be obtained, which shows that the equipment is able to dispose higher flow of gas in a smaller device, and to minimize the space.

Table 1 Test results of dust removal efficiency (%)

Gas volumetric flow rate/ ($m^3 \cdot h^{-1}$)	Ratio gas to liquid/ ($L \cdot m^{-3}$)			
	0. 2	0. 4	0. 6	0. 8
400	98. 60	99. 10	99. 23	99. 30
600	98. 75	98. 80	98. 90	99. 25

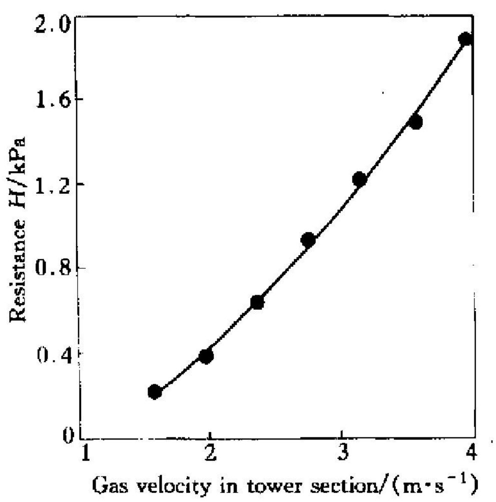

Fig. 2 Relationship between resistance and gas velocity in tower section

2. 3 Black smoke abatement and harmful gas removal

When the aluminum alloy tailing is remelted, the oil dirt and emulsifier on its surface will produce high carbon substances, including carbon black (benzene ring matter) and soot (cyclic hydrocarbon matter) through the processes of cracking, dehydrogenation, combination, and cyclization[1]. The discharges of the soot and carbon black (hereafter called carbon black) will generate black smoke. The carbon black is too light (relative density is about 0. 05) to be removed by the cyclone separators. There is an intermolecular force between the surface of carbon black and water molecular, which is not powerful enough to overcome the cohesive force among water molecules. Therefore, for the poor hydrophilic force between water and carbon black, the conventional wet dust removers could hardly gather the carbon black effectively[9~ 11].

Through theoretical researches[12], Walker method experiment and small-scale tests, it was found that the combination phases between the carbon black and the absorption solution can be improved by adding extremely small quantity of activators to the absorption solutions of wet dust removers. The ability of the absorption solution infiltrating the carbon black depends on the relative values of hydrophilic and hydrophobic energy of activator. If the hydrophobic energy is too strong, no enough affinity will exist between the activator and the water phase, and if the hydrophilic energy is too strong, the surface activity of the activator will decrease greatly which makes it hard to be combined with the carbon black. Only if the ratio range of hydrophilic and hydrophobic energies of the activator lies between 4. 5 ~ 6. 5, the bridge grafting effect between the carbon black and water can be sufficiently generated. According to experiment and optimized selection, the main component of the activator is a kind of macromolecule soap made of industrial products. The thick activator solution is put into the chemical medicine box above the recycling precipitation pond for periodically activator adding. The water pump put the absorption solution from the pond into the purification device. Under the effect of components in the device, the gas, liquid and solid phases are mixed thoroughly and contacted with each other. With the bridge drafting effect of activator, the absorption solution is able to effectively collect the carbon black. Thus the object of smoke abatement can be realized. The collected carbon black condenses and floats up the pond for periodically scraping out, and the absorption solution is recycled.

In a similar way, this kind of activator also has an excellent purification effect for oil mist.

During the process of aluminium alloy refinement and forming slag, some Cl_2 and HCl are discharged and then are eliminated in the purification device along with those harmful flue gases and dust. The reactions between Cl_2 and water in the purification device are shown as

$$Cl_2 + H_2O = HCl + HOCl \quad (7)$$

$$8HOCl = 6HCl + 2HClO_3 + O_2 \quad (8)$$

$$2HOCl = 2HCl + O_2 \quad (9)$$

The alkali components MeOH (Me represents certain metal element) in the activator will have a neutralized reaction with the acidic matters in the flue gas and the acidic products from reaction (7) ~ (9) by which some harmless water and salts are generated. In this way, the harmful flue gases can be removed as

$$MeOH + H^+ = H_2O + Me^+ \quad (10)$$

2.4 Anticorrosion and abrasion resistance of device

The original flue gas contains both dust and corrosive gases, so whether the materials are anticorrosive and abrasion resistant is of great importance for the device durability. By extensive investigation and analysis, it shows that the singular metal material is not enough for anticorrosion and abrasion resistance, such that the 5 mm thickness steel panel will be perforated due to the erosive and grinding process for about 20 d in practical application. At the same time, the strength of singular nonmetal material cannot be guaranteed. Therefore, according to the situation and the environment of the device and its components, different combination or complex of materials is used at different places in order to exert the individual advantages of different materials. The metal materials can guarantee the strength and the complex materials can guarantee the anticorrosive and abrasion resistant properties.

The inner tube of the equipment is made from pottery, while the inner wall of the device body is covered with inorganic nonmetal material whose Rockwell hardness reach HRC 68, and gives it a good anticorrosion property. The outer surface of the inlet water tube is covered with a special treated anticorrosion complex material. The complex material B is selected for realistic application after testing. The test method is that the samples are firstly hanged in 1 mol/L H_2SO_4 solution at 60 ℃, and then the mass changes of the samples were determined, at the same time the changes of the coating surface and corrosion of the base metal were observed. The experimental results are shown in Fig. 3 and Table 2. The coating A lost some mass, which was mainly caused by the acid corrosion and the coating material part dissolved, meanwhile the coating B and coating C got mass because of the media slightly permeating into the coating. Table 2 shown that the base metal of coating C had some stain pots, and shown a poor performance of anticorrosion. Coating B shown good results in both the surface and the base metal in the test, and was the best one in anticorrosive property.

Thus, the device has the features of low manufacturing cost, small size, less mass and excellent anticorrosive and abrasion resistant properties that can make the device have a service life for over 8 years.

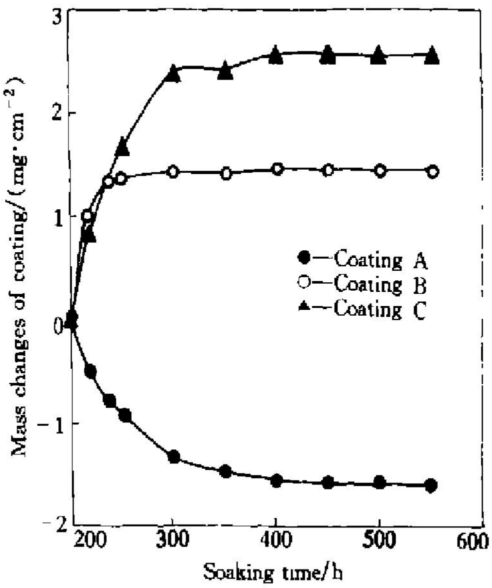

Fig. 3 Curves of coating mass changes vs soaking time

Table 2 Anticorrosion experimental results for different coatings (in 0.1 mol/L H_2SO_4, 60 ℃)

Item	Changes in coating mass /($g\cdot m^{-2}$)	Changes in coating surface	Corrosion of base metal
Coating A	−15.1	Surface luster lost	No corrosion
Coating B	14.0	Almost the same	No corrosion
Coating C	25.4	Color slight	A little rusting pots

3 PURIFICATION EFFECT

After put into use, the system works safe, regular, convenient for controlling and management and efficient for purification, which was highly praised by the workers and around residents. Through the test of environmental monitoring department, the concentration of Cl_2(HCl converted to Cl_2) in the workshop is lower than 1 mg/m^3. Other purified indexes are far superior to the requirement of Class I of the National Emission Standard of Pollutants. The effect of purification of flue gas is shown in Table 3. It shows that the dust purified efficiency is 97.43%, the Cl_2 purified efficiency is 88.03%, the exhaust fume black-

Table 3 Effect of purification of flue gas

Item	Inlet	Outlet
Operation gas volumetric flow rate / ($m^3 \cdot h^{-1}$)	11 136	10 961
Gas volumetric flow rate (Standard state) / ($m^3 \cdot h^{-1}$)	9 130	9 560
Dust concentration (Standard state) / ($mg \cdot m^{-3}$)	1 437	35.3
Mass flow rate of dust / ($kg \cdot h^{-1}$)	13.12	0.337
Cl_2 concentration (Standard state) / ($mg \cdot m^{-3}$)	2.568	0.293
Mass flow rate of Cl_2 / ($g \cdot h^{-1}$)	23.4	2.8

ness is less than Ringelman number I, the purification device resistance is 1 126 Pa.

4 CONCLUSIONS

1) The collection of the flue gas adopts the rotary lifting low hanged hood, which can greatly facilitate operation and reduce the air output.

2) The carbon black and harmful gases in the flue gas can be removed by adding a small quantity of active agent to the absorption solution. Combination of centrifugal and wet dust removing can purify the dust high efficiently.

3) The purification device has the advantages of the combination of dust removal, black smoke abatement and harmful gas elimination, compact structural and small spatial requirement. Through the combination and complex of different materials, the device and components have excellent anticorrosive and abrasion resistant properties.

[REFERENCES]

[1] Lopez F A, Pena M C, Lopez-Delgodo A. Hydrolysis and heat treatment of aluminum dust [J]. Journal of the Air & Waste Management Association, 2001, 51(6): 903-912.

[2] Trovant M, Argyropoulos S. Finding boundary conditions: a coupling strategy for the modeling of metal casting processes (Ⅰ) —Experimental study and correlation development [J]. Metallurgical and Materials Transactions, 2000, 31B(2): 75-86.

[3] Trovant M, Argyropoulos S. Finding boundary conditions: a coupling strategy for the modeling of metal casting processes (Ⅱ) —Numerical study and analysis [J]. Metallurgical and Materials Transactions, 2000, 31B (2): 87-96.

[4] TJ36-79. Design and Health Standard for Industry [S].

[5] de Nevers N. Air Pollution Control Engineering [M]. New York: McGraw-Hill, 2000.

[6] Hemmer G. Recent developments in hot-gas purification [A]. Ditteler A, Kasper G. High-Temperature Gas Cleaning [C]. Karlsruhe, Germany: Karlsruhe University, 1999. 525-544.

[7] Cao X Y, Bu C, Ge L P. A study of sulfur release and desulfurization in coal burning process [J]. Environmental Pollution & Control, 1989, 11(6): 2-6.

[8] Silence W L, Manning P E, Asphahani A I, et al. The selection and use of alloys for flue gas desulfurization systems [A]. EPRI CS-2897 [C]. 1983. 802-821.

[9] Overcamp T J, Mantha S V. A simple method for estimating cyclone efficiency [J]. Environmental Progress, 1998, 17(2): 77-79.

[10] Theodore L, de Paola V. Predicting cyclone efficiency [J]. Journal of the Air Pollution Control Association, 1980, 30(10): 1132-1133.

[11] FANG Jia-xing. Explore on purification experiment of flue gas from down draft kiln [J]. Industrial Kiln and Furnace, (in Chinese), 1994, 16(1): 39-41.

[12] Rosen M J. Surfactants and Interfacial Phenomena [M]. New York: Wiley, 1978.

(Edited by YUAN Sai-qian)