Fuel Combustion in the Fluidized Bed of an Inert Material Equipped with an Unmovable Catalytic Small-Volume Package

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Abstract

The capability of combustion of solid fuels (such as the brown coal of the Kansk-Achinsk coal deposit) in the fluidized bed of an inert material in the presence of unmovable catalytic packages is investigated. This arrangement of the catalytic process is shown to allow the achievement of the same parameters of the fuel burn off and the content of toxic substances in the flue gas as in the case of fuel combustion in the fluidized bed of catalyst grains. The new arrangement of catalytic processes can be recommended for the accomplishing of some other exothermic catalytic reactions which require the maintenance of isothermal conditions.

INTRODUCTION

Today, the use of fluidized bed of catalyst to conduct some exothermic catalytic reactions is a common approach of chemical industry [1, 2]. An important advantage of such arrangement of catalytic processes is the possibility to maintain their isothermity, and as result, there is possibility to eliminate heat directly from the bed at the maintenance of the predetermined temperature.

One of directions of the use of fluidized bed of catalyst is the low-temperature combustion of fuels [3, 4]. Indeed, the presence of a catalyst allows to decrease the temperature of the organic fuels combustion from 1000–1200 °C (the temperature of a torch combustion) to 300–700 °C, with high rates of the fuel combustion being saved and the complete fuel combustion being provided without excess of air. In comparison with known conventional ways, fuel combustion in the fluidized bed of catalyst allows: to reduce the requirements to thermochemical stability of constructional materials of the combustion apparatus and to diminish their erosive wear; to reduce losses of heat through the walls of the apparatus; to reduce the explosion risk of the combustion devices; to achieve high (up to $5\ 10^8$ kJ/(m^3 h)) values of the calorific intensity of the furnace volume and, therefore, to reduce considerably the overall sizes, weight and power-to-weight ratio of the combustion devices; to eliminate the secondary reactions which are accompanied by producing the toxic products. On the base of the fuel combustion in the fluidized bed of catalyst, a set of apparatuses for heating and evaporation of liquids, drying and heat treatment of solid materials, neutralization of industrial gaseous, liquid and solid emissions as well as for number of other processes [5–9] were created.

At the same time the fluidized bed of catalyst has two essential disadvantages.

(1) The attrition of the catalyst achieves 0.3–0.5 % mass per day, that requires a permanent additional loading of the catalyst in the reactor during its operation. Under condition of the catalyst high selling value (up to $15 000 per ton), there are certain financial difficulties during the operation of existing plants as well as at the creation of new installations.

(2) The fluidized bed is usually characterized by the presence of gas bubbles, within

those the running of the fuel burning process via the conventional flame mechanism is possible, that leads to the formation of toxic compounds (CO, NO_x, SO_2, *etc.*). To exclude the phenomenon of the bubbles formation, it is needed to regulate the fluidized bed with a small volume package which is able to break the gas bubbles. But the package presence results in an increase of the catalyst attrition.

Previously we have shown [10], that the both disadvantages can be avoided with the use of the fluidized bed of an inert material (for example, sand) regulated with an unmovable small volume catalytic package. The rings from the pressed nickel-chrome wire or blocks from the metal-ceramic plate were used as the packages in these experiments. Catalytic active components (palladium, copper chromite, and other) were deposited on the packages.

However, the technology of the manufacturing the indicated above packages is indeed rather laborious. In addition, the increase of the surface of the catalytic packages requires precoating the packages with a porous carrier.

In the present work, the possibility of an application of the unmovable catalytic packages on the base of the shaped porous alumina with the developed specific surface to carry out the solid fuel combustion in the fluidized bed of inert material is considered.

METHODS

The study of the solid fuel combustion in the fluidized bed of an inert material with catalytic packages was conducted with the laboratory installation, the scheme of which is shown in Fig. 1. A stainless steel reactor *1* had 40 mm in diameter, 1000 mm in height and 1260 cm^3 in volume. The bottom of the reactor was provided with a gas-distribution grid *2* made as a stainless steel plate with thickness 1.5 mm and holes of 0.5 mm. The upper part of the reactor was provided with a water heat exchanger *3* for cooling the powder-gas mixture.

The procedure of the experiments was the following. A catalytic package *4* with overall height 850 mm was placed in the reactor *1*, and then an inert material (a river sand) with the particles size of 0.63–1.25 mm in quantity 0–400 cm^3 is loaded. The bed of this inert material in the fixed state is heated up to the operating temperature with an external electric heater *5*. The temperature control in the reactor is carried out with thermocouples. Then, the necessary air supply to an ejector *6* and to the bottom of the reactor under the gas-distribution grid *2* is fixed with the use of valves *7* equipped with rotameters *8*. The total air supply to the reactor makes up 3.5 m^3/h. After supplying the air in the reactor and fluidizing the sand bed, the mover of a transporter-feeder *9* is turned on to doze a solid fuel. The fuel supply to the reactor is regulated by the size of a gap between bunker *10* and the transport tape and makes up 105 g/h. The powder-gas mixture formed in the reactor goes to a cyclone *11*, where the ash particles are separated from the gas. Then, the ash particles are transported to a bunker *12*.

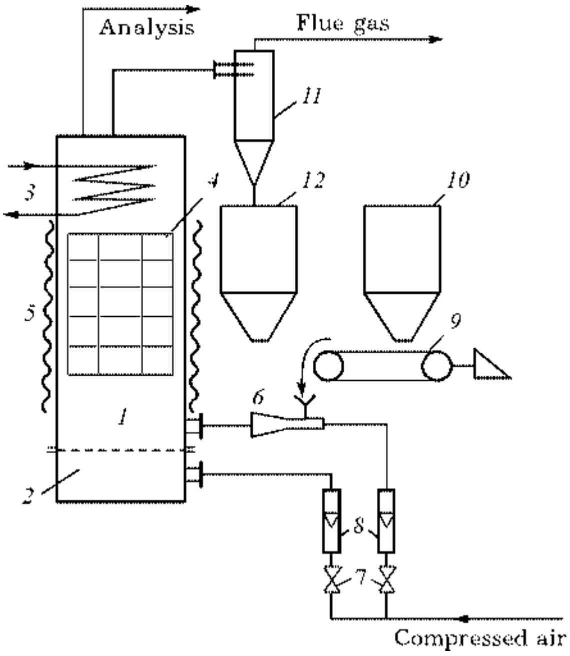

Fig. 1. A scheme of the laboratory set up for testing the unmovable catalytic packages at the solid fuel combustion in the fluidized bed of an inert material: *1* – reactor; *2* – gas-distribution grid; *3* – water heat-exchanger, *4* – unmovable catalyc package; *5* – electric heater; *6* – ejector; *7* – rotameters; *8* – valves; *9* – transporter-feeder; *10* – bunker for solid fuel; *11* – cyclon; *12* – bunker for ash.

Chromatograph LCM-80 (USSR) and a Quintox (Kane International Ltd.) equipment were used for the flue gas analysis.

A brown coal of the Kansk-Achinsk deposit with wetness of 13.0 %, ash content of 29.0 % and the particles size less than 0.2 mm was used as the solid fuel.

The burn-off, β, of the coal was determined with the data on the ash content in the solid products as:

$$\beta(\%) = 10\ 000\ (A_t - A_0)/(A_t\ (100 - A_0))$$

where A_0 is the initial ash content in the coal, %; A_t is the ash content in the solid products after the coal combustion, %.

Porous ceramic rings of 18–20 mm in height, 10–11 mm in internal diameter, 18–20 mm in external diameter were used as elements for the preparation of the packages. The rings were prepared by the extrusion of a mixture of plasticized aluminum hydrate and powder-like alumina with the following drying and calcination at 600 °C. The specific surface area of the rings was 150 m^2/g. The rings were impregnated by the 30 % copper bichromate solution. The solution amount for the impregnation was corresponded to the pore volume of the rings. Then the rings were dried at 120 °C during four hours and calcinated at 700 °C during 2 h. Two types of packages (*A* and *B*) both 850 mm in the overall height with a different disposition of the rings were produced (Fig. 2). In package *B*, the distance between the layers composed of three rings was equal to the height of one ring. In package *A*, one additional catalytic ring was placed between such layers of the rings. The volume part of package *B* in the reactor made up 22.0 %, while the volume part of package *A* in the reactor made up 28.0 %.

A commercial catalyst IC-12-73, produced by AO "Katalizator" (Novosibirsk) and consisting of aluminum, copper, magnesium and chromium oxides, with the particles 2 mm in diameter was used for providing some comparative experiments with the fluidized bed of catalyst. In this case, the fluidized bed of the catalyst was regulated with a small volume package made of a stainless steel with sells 15×15×15 mm in size.

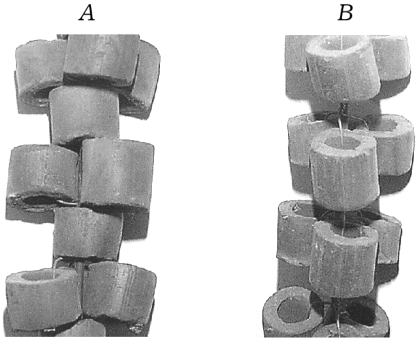

Fig. 2. The tested arrangement of the unmovable catalytic packages on the base of the Raschig rings.

RESULTS AND DISCUSSION

It is well known [11], that in the cylindric reactors of a small diameter, particles fluidization occurs in a plug mode. In this connection, the effect of the discussed catalytic packages on the character of the fluidization of sand with the particles size of 0.63–1.25 mm was studied preliminary with a "cold" model of the reactor. This model reactor has shape of a glass tube of 40 mm in diameter, the range of the air flow velocity varied from 0.88 to 3.3 m/s. The bottom of the glass tube was provided with the same gas-distribution grid as the experimental reactor for the coal combustion. The packages were placed above the gas-distribution grid of the glass tube, and the distance between the bottom of the packages and the gas-distribution grid made up 100 mm. It turned out, that in the presence of catalytic packages *A* or *B*, the character of the sand fluidization along the packages becomes uniform. That provides an intensive circulation of the sand particles between the bottom and upper part of the bed. The plug mode of the sand fluidization is observed only under the packages at the bottom of the bed, which is used for the mixing of the sand and solid fuel particles. The plug mode of the sand fluidization disappears at placing, in the bottom of the reactor, of a small volume metal regulating package with sells 15×15×15 mm in size. Such arrangement of the catalytic and regulating packages was used in the stainless still reactor too for conducting the coal combustion in the fluidized bed of the sand.

The combustion of the brown coal in the fluidized bed of the sand in the presence of the catalytic packages and comparative experiments with the fluidized bed of catalyst IC-12-73 were conducted at the air supply

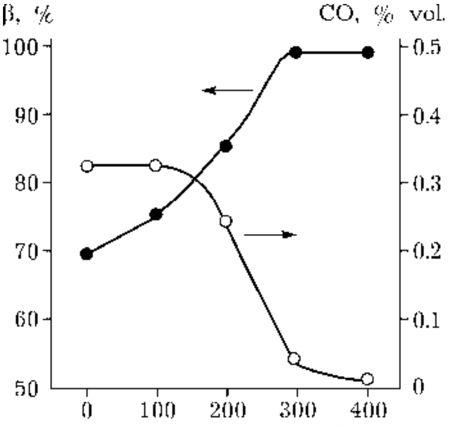

Fig. 3. Dependence of the brown coal burn-off (β), and CO concentration in the gas at the brown coal combustion in the flluidized bed of the river sand in the presence of unmovable catalytic package *B* at 750 °C on the load of the sand.

3.5 m^3/h and the bed temperature 700–800 °C. In these conditions, the operating velocity of the gas flow makes up 2.8–3.0 m/s. At the same time, the coal particles with the size less then 0.2 mm pass through the fluidized sand bed as well as the catalyst bed in the regime of the pneumatic transport.

Fig. 3 shows the influence of the sand quantity loaded in the reactor on both the burn-off of the brown coal and the CO concentration in the flue gas at the coal combustion temperature 750 °C in the presence of package *B*. It is obvious, that in the absence of the sand, the burn-off of the brown coal achieves only 70.4 %, and the CO concentration makes up 0.32 % vol. Gradual increasing of the sand load leads to an essential increase in the burn-off of the brown coal particles and decrease in the CO concentration in the flue gas. The maximal burn-off of the brown coal at the predetermined temperature was reached at the sand load 300 cm^3; accordingly, the CO concentration falls to 0.03 % vol. At the further increasing of the sand load from 300 up to 400 cm^3, the burn-off of coal practically does not change, however, the CO concentration in the flue gas falls from 0.03 to 0.01 % vol. The amount of the loaded sand influences also the temperature regime of the coal combustion. For example, at the combustion of the brown coal with package *B* in the absence of the sand, the temperature of the bottom of the reactor (under the package) makes up 550–600 °C, while in the upper part of the reactor the temperature makes up 750 °C. The temperature gradient between the bottom and upper part of the reactor keeps the same value, when 100 cm^3 of the sand is loaded in the reactor. The equilibration of temperatures in the bottom and upper part of the reactor occurs only at increasing the sand load from 100 to 400 cm^3; in this situation the unmovable catalytic package *B* completely locates inside the fluidized bed of the sand.

Thus, the combustion of dusted brown coal in the mixture with air in the presence of catalytic package *B* without a load of sand does not provide the required coal burn-off, and the flue gas contains a significant amount of CO. At the same time, the gradient of temperatures along the reactor achieves 200 °C. A high burn-off of the brown coal under isothermal conditions is achieved when the catalytic package locates completely inside the fluidized bed of sand.

The data on the influence of temperature on the burn-off of the brown coal and the CO concentration in the flue gas at the coal combustion in the presence of unmovable catalytic package *B* with the sand load 400 cm^3 are listed in Table 1. It is evident, that with rising the temperature from 700 to 800 °C, the burn-off of the coal increases from 89.8 % to 97.6 %. While the CO concentration in the flue gas decreases from 0.06 % vol. to less than 0.01 % vol. It should be stressed, that at the temperature interval from 750 to 800 °C the change of the brown coal burn-off is negligible the same as the change of the CO concentration in the flue gas.

The use of unmovable catalytic package *A* allows to achieve a higher, in comparison with

TABLE 1

Influence of temperature in the reactor on the burn-off of the brown coal in the fluidized bed of the sand with catalytic package *B* (the load of the sand particles is 400 cm^3)

Temperature, °C	CO concentration, % vol.	Coal burn-off, β, %
700	0.06	89.8
750	0.01	93.7
800	< 0.01	96.6

TABLE 2

Comparison of the brown coal burn-off at its combustion in the fluidized bed of the sand in the presence of different unmovable catalytic packages and in the regulated fluidized bed of catalyst IC-12-73, the temperature in all cases is 750 °C

Catalyst	CO concentration, % vol.	Coal burn-off, β, %
Package *B* and 400 cm^3 of the sand	0.01	93.7
Package *A* and 400 cm^3 of the sand	< 0.01	98.0
400 cm^3 of IC-12-73	< 0.01	97.6

TABLE 3

Concentration of harmful substances in the flue gas at the brown coal combustion in the fluidized bed of the sand with catalytic package *A* and in the fluidized bed of catalyst IC-12-73 at 750 °C (the data are obtained with the Quintox device)

Catalyst	Concentration in the flue gas, ppm			
	NO	NO_2	SO_2	CO
IC-12-73	76	1	16	41
Package *A*	92	1	23	70

the package *B*, burn-off of the brown coal (98.0 %) already at 750 °C. And the CO concentration in the flue gas also makes up less than 0.01 % vol. (Table 2). The experimental data on the brown coal combustion in the regulated fluidized bed of catalyst IC-12-73 are listed also in Table 2. One can see, that locating the unmovable catalytic package of type *A* in the fluidized bed of the sand allows to achieve the same parameters of the brown coal combustion as at the use of the fluidized bed of the catalyst. This is confirmed also by close values of the concentrations of toxic compounds in the flue gas in both cases (Table 3).

Today, the selling price of spherical catalyst IC-12-73 makes up $15 000 per ton. The selling price of catalytically active Raschig rings, from which the catalytic package can be produced, makes up $7000 per ton. A commercial catalytic heat supply unit (CHSU) with useful heat power 1 Gcal/h needs 1 t of catalyst IC-12-73 for loading the reactor. The necessary quantity of the Raschig rings for CHSU with the same power would make up 0.3 t. A warranty assurance of catalyst IC-12-73 equals to 6 months of the continuous operation; accordingly, the annual operating cost of the catalyst will make up $30 000. If the life time of the unmovable catalytic package equals even to 1 year (the expected life time is 3 years), the annual operating cost of the catalyst like the above Raschig rings would be equal only to $2100.

CONCLUSION

Catalytic combustion of solid fuels in the fluidized bed of inert material in the presence of an un movable catalytic package allows to achieve the same parameters of the process as in the case of the fuel combustion in the regulated uniform fluidized bed of catalyst. At the same time, in the first case, the operating cost of the catalyst is reduced more than by the factor of 10. The suggested arrangement of catalytic processes can be recommended for accomplishing also some other exothermic catalytic reactions which require the maintenance of isothermal conditions.

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