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Industrial experience of heat supply by catalytic installations

A.D. Simonov, N.A. Yazykov, P.I. Vedyakin, G.A. Lavrov, V.N. Parmon*

Boreskov Institute of Catalysis, Novosibirsk 630090, Russia

Abstract

A new technology of fuel combustion, offered by the Boreskov Institute of Catalysis in industrial scale, allows avoiding many disadvantages of the high-temperature fuel combustion. The technology is based on a combination of four principles: use of heterogeneous catalysts for complete oxidation of combustibles; combustion of fuels in a fluidized bed of catalyst particles; combustion of fuels without a significant excess of air; overlapping the processes of heat release and removal within the same fluidized bed. Based on the new technology, a variety of apparatuses for heating and evaporation of liquids, for drying and heating of materials, for detoxification of industrial emissions (gaseous, liquid, and solid), and for a number of other processes have been designed. Pilot catalytic heat supply units (CHSUs) are being used since the early 1980s to heat the auxiliary and constructed buildings. Since 1993, 30 industrial CHSUs operate successfully and reliably at different facilities in Novosibirsk, Russia, and all working parameters correspond to the design values. Automatic feedback between the temperature of circulating water and fuel feed allows minimizing the fuel consumption with regard to the heat yield and temperature of the outside air. The content of toxic substances in the CHSU flue gases does not exceed sanitary norms. An important advantage of catalytic combustion in the fluidized catalyst bed is the possibility to burn efficiently the solid fuels (coal, peat) as well.

Keywords: Heterogeneous catalysts; Fluidized bed; Combustion of fuel; Coal; Peat; Heat supply installations

1. Introduction

At the present stage of development of the power industry, the economy of power production and its environmental impact becomes a problem of critical importance. Traditional power installations based on the flame combustion of fuels are among the major sources polluting the environment with heat and harmful substances (CO, nitrogen oxides, sulfur, benzopyrenes and others). The cost of equipment for detoxification of the exhaust gases is similar to the cost of basic process equipment of power installations. The new technology of fuel combustion, offered by the Boreskov Institute of Catalysis in industrial scale [1,2], avoids many disadvantages of the high-temperature fuel combustion. The technology is based on a combination of four principles: use of heterogeneous catalysts for complete oxidation of combustibles; combustion of fuels in a fluidized bed of catalyst particles; combustion of the fuel without a significant excess of air; overlapping the processes of heat release and removal within the same fluidized bed. The catalytic combustion differs essentially from the burning in traditional understanding, since the fuel is oxidized on the surface of solid catalysts without flame formation [3]. The catalyst action during the complete oxidation (or heterogeneous burning) of the fuel–air mixture is based on the interaction of the fuel components with superficial oxygen of the catalyst and on regeneration of a restored catalyst surface by oxygen from the gas phase. Depending on the catalyst activity, the process

* Corresponding author. Fax: +7-383-2-34-32-69.
E-mail address: parmon@catalysis.nsk.su (V.N. Parmon)

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of complete oxidation of many combustibles can proceed even at 250–300°C. Compared with the known combustion methods, the catalytic combustion allows:

- to lower the temperature of organic fuel combustion from 1200–1600°C to 300–700°C;
- to mitigate requirements for thermochemical stability of constructional materials and reduce their erosion;
- to diminish heat losses through apparatus's wall;
- to improve explosion safety of the installations;
- to reach higher values of power loading of the fuel oxidation and thus decreasing significantly the design size, weight and metal consumption;
- to exclude secondary endothermic reactions forming toxic products.

Based on the new technology, a variety of apparatuses have been designed for the heating and evaporation of liquids, drying and heating of materials, detoxification of industrial emissions (gaseous, liquid and solid), and so on.

In this work we discuss our present experience in the development of low scale CHSUs and their industrial operation.

2. Reactor for CHSUs

The current design of a reactor for a CHSU is based on the long-standing experience of operation of the fluidized bed catalytic reactors as well as on original R&D work performed at the Boreskov Institute of Catalysis.

A general view of the reactor is shown in Fig. 1. The reactor consists of a cylinder body (1) bottomed with a detachable air distributor (2). In order to reduce the reactor height, the air is introduced sideways (3) and distributed through a circular gap (4) into horizontal perforated tubes (5), which work as a gas-distributing grid. Fuel (6) is fed directly into catalyst bed through four injectors (7). The fuel is sprayed by air (8). The injectors are fitted with a needle (9) for cleaning them during the CHSU operation. Starting from the height of 250 mm from the gas-distributing grid, the fluidized bed is staged by wire grids (10) with a mesh size of $30\times30\,mm^2$, distance between grids 30 mm, and a block (11) of six grids of mesh size $10\times10\,mm^2$. Thermocouples (12) are introduced both in the staged and free fluidized bed sections.

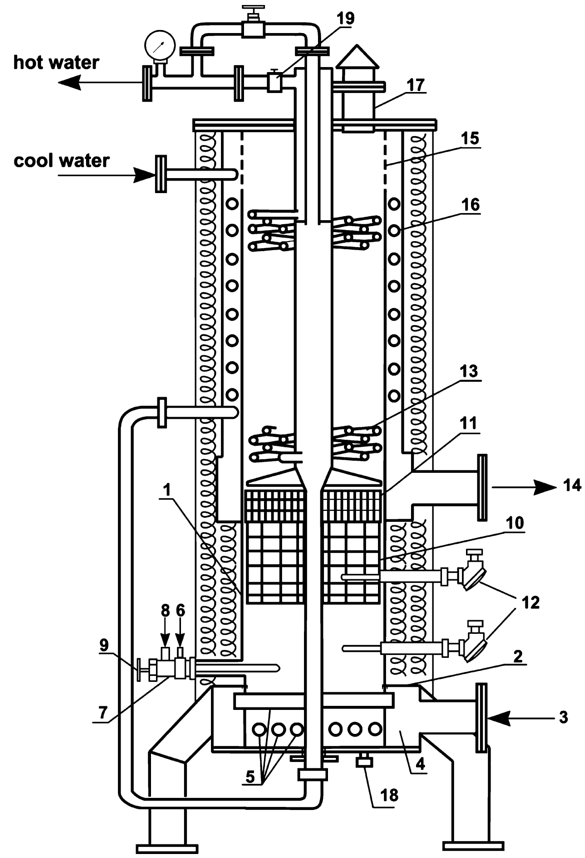

Fig. 1. Layout of CHSU reactor.

Free fluidized bed in the injectors' zone serves for fuel distribution and mixing with air. The fuel burns out in this zone approximately by 80%. Complete oxidation of the fuel occurs in the staged bed (10) due to the disintegration of large bubbles and intensive inter-phase transfer. Since the longitudinal heat conductivity of the staged bed changes insignificantly, the bed remains almost isothermal [4].

An important feature of this reactor is the use of a non-isothermal fluidized bed [5]. That is, the bottom part of the bed is kept at the optimum temperature for the fuel oxidation, while the top part of the bed is kept at any preset temperature (by means of heat removal) (Fig. 2). The bed remains continuous along the height. Its non-isothermicity is provided by grids (11), which reduces inter-zone particles transfer. The temperature gradient between top and bottom zones is governed by the size ratio of the grid mesh and the catalyst

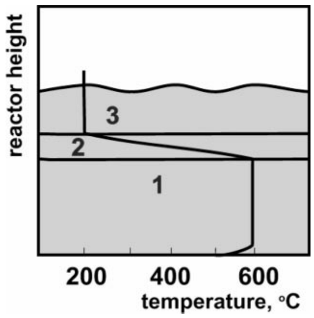

Fig. 2. Temperature profile along the height of the catalyst fluidized bed: (1) zone of fuel combustion in the zone of free fluidized bed (isothermal zone); (2) zone of fluidized bed with packing (non-isothermal zone); (3) zone of free fluidized bed (isothermal zone).

particle and is described by empirical equations. The existence of a non-isothermal bed between the fuel combustion and heat removal zones facilitates the start of the reactor and its operation.

A coiled heat exchanger (13) with staggered-corridor tubing [6] provides the maximum coefficients of bed-to-tubes heat transfer. Such configuration smoothes possible heterogeneity (large bubbles) and prevents formation of catalyst "caps" on the upper tube surface in contrast to staggered tubing. Nearly 10% of the heat exchanger submerges in the bed, the remaining over-bed part acts as economizer.

Flue gases (14) pass through a baffle gauze (15) preventing particles carry-off reactor and then through a heat-exchanger (16) at the outer shell thus providing cooling of the body and decreasing heat losses. The reactor is fitted with a relief valve (17), a socket (18) to discharge catalyst and a safety valve (19) at the hot water pipe.

3. Catalysts for heat supply installations

Presently, CHSUs operate with the use of catalyst IC-12-73 produced commercially by Joint-Stock Company "Katalizator", Novosibirsk, Russia. The catalyst consists of spherical alumina grains of 1.5–2.0 mm in diameter, impregnated with up to 10 wt.% of active component in the form of complex Cu–Mg–Cr oxide system. The price of IC-12-73 ranges from USD 5000 to 10 000 per ton.

When operating in CHSUs, the catalyst undergoes combined action of high temperature, reaction mixture and mechanical contacts, causing its attrition and carry-off from the reactor. Since IC-12-73 may contain up to 1 wt.% of active, but toxic component CrO_3, and assuming CrO_3 tolerance concentration equals 1.5×10^{-3} mg/m^3, the catalyst attrition must not exceed 0.5 wt.% daily (the dust suppression in the cyclone being 90%). The mechanical strength of IC-12-73 is determined by the strength of its support — γ-alumina. The Boreskov Institute of Catalysis designed a liquid molding technology to produce the strengthened alumina [7]. Attrition of the catalyst, prepared from the strengthened alumina, equals 0.3 wt.% daily; as a result, the catalyst service life attains 12 months.

It should be noted that the Boreskov Institute of Catalysis has designed a technology for producing catalyst IC-12-74 with the active component on the base of iron oxide. This catalyst is similar to IC-12-73 in activity and mechanical strength, but contains no toxic compounds.

The catalyst in CHSUs serves two functions: it catalyzes the fuel combustion and acts as a solid heat-carrier. It has been shown recently [8] that grains of an inert material (say, river sand) introduced into catalyst bed do not reduce the efficiency of the fuel combustion, even if the bed contains only 15–20 vol.% of the catalyst. Catalyst attrition in this case decreases several times (Fig. 3); this allows an essential decrease in the operational costs of the CHSUs.

4. Principle of the CHSU operation

Operational principle of CHSU consists of the following (Fig. 4). After the pumps are switched on and supply of water into the heating system starts, the air is blown into the starting electric heater, heated to 500–700°C and then fed into the catalyst bed through the gas-distributor. As the temperature of the catalyst bed reaches 300–500°C required to start the fuel catalytic oxidation, the fuel dosing into the catalyst bed is started by the fuel injector pump. As the catalyst bed temperature attains 600°C, the electric heater switches off and the installation operates in an autothermal mode. The start-up time depends on the electric heater power and does not exceed 30 min with a

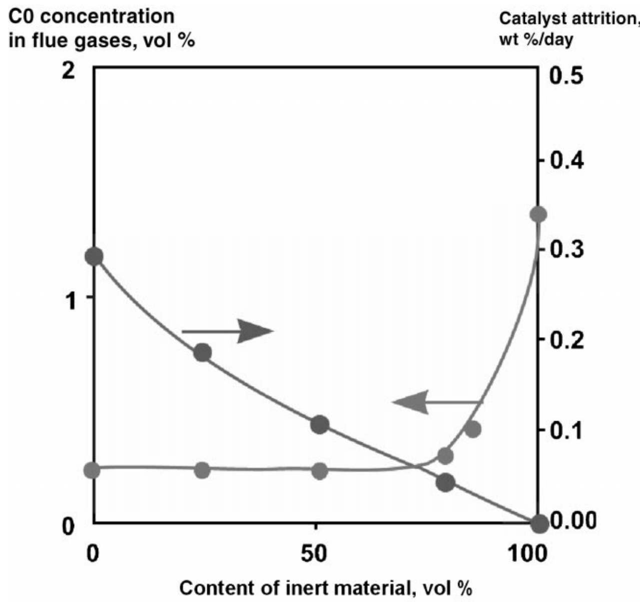

Fig. 3. Effect of inert admixtures on the strength and catalytic performance of IC-12-73 in diesel fuel oxidation.

20 kW heater. Flue gases, finally cooled in the special heat exchanger and cleaned from the catalyst dust in the cyclone, are released into the atmosphere. The catalyst dust collected in the cyclone bin is sent for processing in the plant "Katalizator" (Novosibirsk). If the temperatures of the catalyst bed or the reactor outlet water exceed, respectively, 600 and 95°C, fuel feed is stopped automatically; if circulating water is heated above 45°C, fuel and air feeding is switched off automatically. Shut-down situation is caused by the decrease of the catalyst bed temperature below 350°C, absence of water circulation in heat-exchanging contour, or break of air feed. The required amount of the catalyst should be loaded into the reactor manually (no more often than once monthly).

Thus, the installation operates in automatic mode and requires no special control, except the starting and the catalyst loading steps.

Pilot CHSUs capable of 170–230 kW, designed in the early 1980s for heating of auxiliary premises and buildings under construction, represented the first application of this fuel combustion technology. In 1993, a company "Arsenal-2" (Novosibirsk) started commercial production of 230–460 kW CHSUs, operating on diesel and other liquid fossil fuels, under the license

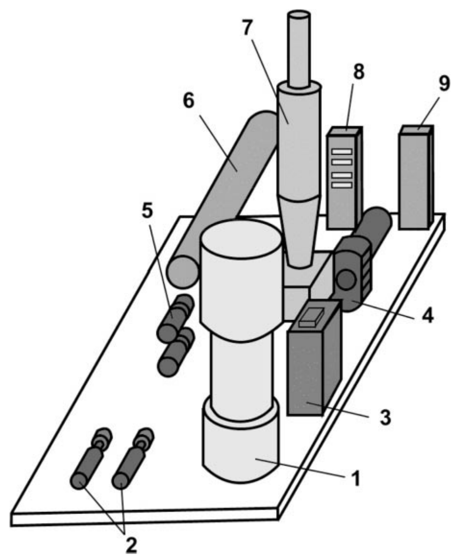

Fig. 4. Scheme of operating-transport block of a commercial CHSU fueled with liquid fuels: (1) catalytic reactor; (2) pumps; (3) starting air-heater; (4) blower; (5) fuel station; (6) flue gas–air heat-exchanger; (7) cyclone and bin; (8) control case; (9) power case.

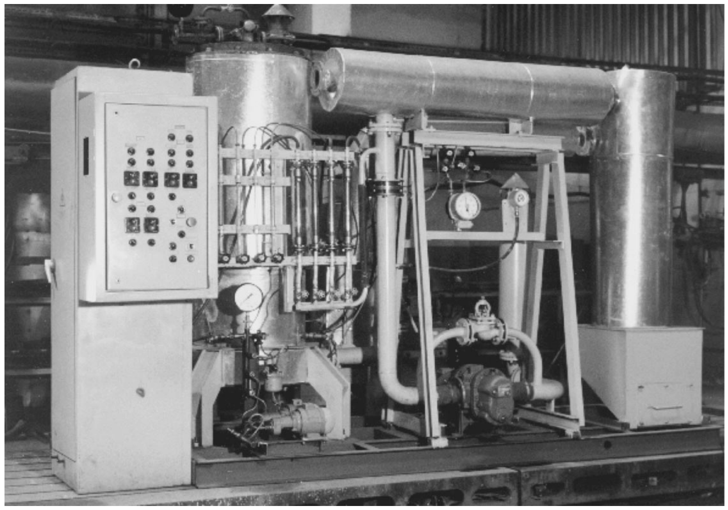

Fig. 5. The view of the operating-transport block of a commercial mobile version of CHSU.

agreement with the Boreskov Institute of Catalysis. Technical specifications of some commercial CHSU operating-transport units are shown in Fig. 4 and Table 1.

Since 1993, 30 commercial CHSUs are operating with various facilities in Novosibirsk (Fig. 5). Continued operation during five heating seasons proved their reliability and good compliance with the design characteristics. The automatic feedback between the temperature of circulating water and feed fuel allows minimum fuel consumption with regard to heat yield and outside temperature. The content of toxic compounds in flue gases of CHSU is constantly low (CO emission less than 50 mg/m^3, NO_x emission less than 5 mg/m^3, SO_x emission less than 10 mg/m^3). No information on CHSUs-related emergency cases or reclamation is yet available.

Table 1
Technical specifications of CHSU-200 operating on diesel and fossil fuel

(1)	Reactor dimensions	
	Diameter (without heat insulator) (m)	0.42
	Height (m)	1.93
	Surface of heat exchanger (m^2)	3.3
(2)	Heat capacity (kW)	230
(3)	Fuel efficiency (%)	93–94
(4)	Temperature in combustion zone (°C)	600–700
(5)	Temperature of flue gases (after cyclone) (°C)	100–120
(6)	Water temperature (°C)	
	Input	45
	Output	95
(7)	Water consumption at ΔT=50°C (m^3/h)	4
(8)	Maximum fuel consumption (kg/h)	22
(9)	Air consumption (Nm^3/h)	250
(10)	Fixed current collector capacity	
	Electric heater (kW)	20
	Water pump (kW)	4.0
	Fuel injector pump (kW)	0.27
	Blower (kW)	4.0
(11)	Catalyst load (l)	100

5. CHSUs operating on solid fuel

An important advantage of catalytic combustion consists in the possibility to burn efficiently the solid fuel and wastes as well [9]. Both lab and bench tests proved 85–90% carbon burning capacity even for bituminous coal, provided the contact time was 0.8 s and temperature of the catalyst bed was 700–750°C. The carbon burning capacity of brown coal and various wastes (including activated sludge and domestic wastes) exceeds 99% under the same conditions. The ash produced is carried out of the reactor to the cyclone by flue gases in the pneumatic transport regime.

Layout of CHSU operating with solid fuel is shown in Fig. 6; it differs from the liquid-fueled CHSU only by feed system.

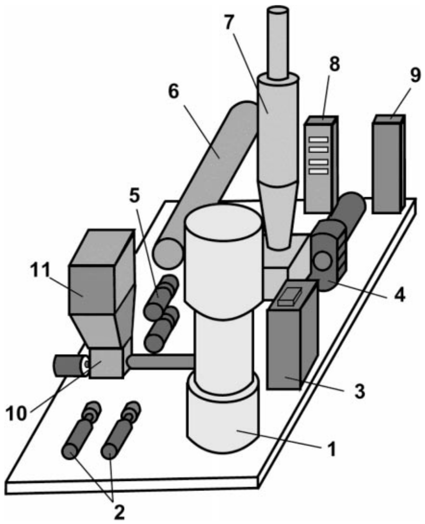

Fig. 6. Scheme of operating-transport block of CHSU fueled with solid fuels: (1) catalytic reactor; (2) pumps; (3) starting air-heater; (4) blower; (5) fuel station; (6) flue gas–air heat-exchanger; (7) cyclone and bin; (8) control case; (9) power case; (10) screw feeder; (11) solid fuel bin.

Table 2 contains comparative characteristics of CHSU and solid-fueled hot-water boilers with layer furnace produced at Cherepanovski Boiler Plant (Novosibirsk). Characteristics of “Tsukisima Kikai” (Japan) furnace with fluidized bed of sand for burning pulp-paper wastes compared with respective characteristics of CHSU are shown in Table 3. For CHSUs, we used design characteristics, data of bench tests, and the trial data of demonstrative catalytic hot-water boiler (10 MW) fueled by Kansk-Achinsk brown coal and operating at the Electric Thermal Power Plant “TETs-2” in the city of Krasnoyarsk (Siberia). Besides, the tables include test data of commercial CHSU, which is used to burn sludge wastes at plant “Grigishkes” (Lithuania) producing card- and fiber-boards. Hourly capacity of this unit attains 1 t of dry sludge.

Thus, the new combustion technology is more efficient than conventional one for burning solid fuels and wastes.

Table 2
Operating data of hot-water boiler KV-50 with layer furnace produced at Cherepanoski Boiler Plant and CHSU

		KV-50	CHSU
(1)	Heat productivity (kW)	50	50
(2)	Temperature of output water (°C)	95	95
(3)	Fuel consumption (Q=5000 kcal/kg) (kg/h)	11.9	9.9
(4)	Power efficiency (%)	72–78	87–93
(5)	Boiler volume (m^3)	2.85	0.09
(6)	Power consumption blower (kW)	0.3	0.65
(7)	Catalyst load (kg)	–	10
(8)	Content of toxic compounds in flue gases (mg/m^3)		
	No_x	Up to 2000	50–150
	CO	Up to 1000	50–100
	So_x	Up to 500	1–50

Table 3
Comparison of working characteristics of “Tsukisima Kikai” furnace (Japan) for combustion of solid wastes in fluidized bed of sand (base) operating at Ust-Ilimsk timber and new furnace based on catalytic combustion

		Base[a]	Catalytic[b]
(1)	Furnace productivity (t/h)		
	Dry sludge	2.3	2.3
	Evaporated moisture	11.2	11.2
	Wet sludge	13.5	13.5
(2)	Furnace dimensions		
	Hearth area (m^2)	32.2	8.2
	Furnace volume (m^3)	510.0	41.0
(3)	Specific load of furnace by solid wastes		
	Per hearth area (kg/h m^2)	71.5	280.0
	Per furnace volume (kg/h m^3)	4.5	56.1
(4)	Specific load by evaporated moisture		
	Per hearth area (kg/h m^2)	348.0	1365.0
	Per furnace volume (kg/h m^3)	22.0	273.0
(5)	Power consumption by blower (kW h/t ads[c])	271.1	190.0
(6)	Consumption of equivalent fuel (t/t ads[c])	0.405	0.219
(7)	Specific heat of combustion of dry sludge (kcal/kg)	3420	3420
(8)	Sand load (t)	100	–
(9)	Catalyst load (t)	–	12.2
(10)	Unit weight (t)	90	5.9
(11)	Content of toxic compounds in flue gases (mg/m^3)		
	No_x	Up to 800	50
	CO	Up to 1500	60
	SO_x	Up to 1000	5

[a] Operating data of the existing plant.
[b] Characteristics were obtained by extrapolation of operating data for the plant with dry sludge capacity 1 t/h.
[c] Absolutely dry substance.

6. Conclusion

CHSUs are very efficient for local heat supply both in rural and urban areas. Particularly, their emissions are ecologically safe. Regardless of the type of the fuel used (gas, liquid, or solid) and even its quality, the composition of toxic admixtures and their content in emissions are constantly low.

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