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EMISSION OF GASEOUS POLLUTANTS
FROM FIRING-UP BURNERS

Emission of toxic gaseous compounds from the firing-up burners installed in high-power boilers was determined. The tests were carried out at varied capacity of the burners whose variables of operation were considered to be optimal, i.e., emissions of soot, nitric oxide and carbon monoxide were kept at a minimum which allowed stable burner operation. At the beginning of the boiler operation some types of firing-up burners emitted toxic compounds. The start-up of high-power boilers lasts many hours, therefore we propose to control the pollutant emission from the firing-up burners. The necessity of establishing the emission standards for power boilers in their start-up phase should be recognized.

1. INTRODUCTION

The start-up of a high-power boiler poses numerous problems associated with the optimum operation of the firing-up systems [1]–[3]. Mazout (heavy oil), soft asphalt and tar, the cheapest fractions of liquid fuel, are most often used as firing-up fuel. Such fuels, however, seem to be extremely troublesome because of the way of their preparation for burning and the burning itself. They have to comply with many requirements imposed on their properties such as viscosity, spraying quality, evaporation of droplets, mixing of vapours of hydrocarbons with the air and making an air-fuel mixture. Fulfilling particular requirements partly depends on the position of the burner in a combustion chamber, but mainly on the burner design, and especially on the design of its lance head, which determines the way of fuel spraying and formation of an air-fuel mixture [4]–[7].

While the assurance of viscosity (at 2–3 °E) is exclusively associated with an appropriate technology of preheating and protection against cavitation, fulfillment of other requirements, especially a thorough mixing of a fuel with oxidizer, can be considered a complex physical process. We can take advantage of this process only for

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the burners whose thermal power is definitely determined, even if the techniques used are very sophisticated.

Thermal power of the firing-up burners, which sometimes are support burners in main burners [1], [2], has to reach at least about 25% of the total boiler power. It is difficult to fulfil such a criterion in the case of high-power boilers. For constructional reasons the number of firing-up burners installed in a boiler is limited, hence the power of individual burners has to exceed substantially 10 MW power.

In conventional power burners and double-fuel burners used till now, a thermal power ranging from 8 to 10 MW is a boundary value guaranteeing a thorough mixing of air with oil and thus a perfect and complete combustion. At higher values of this thermal power it is extremely difficult to combust heavy oil in a cool combustion chamber without emission of smoke and separation of oil droplets from a flame.

2. FIRING-UP BURNERS

Four types of firing-up burners are used most often, i.e., pressure burner, rotary burner, double-fuel burner and gas-dynamic burner. Their diagrams are presented in figure 1.
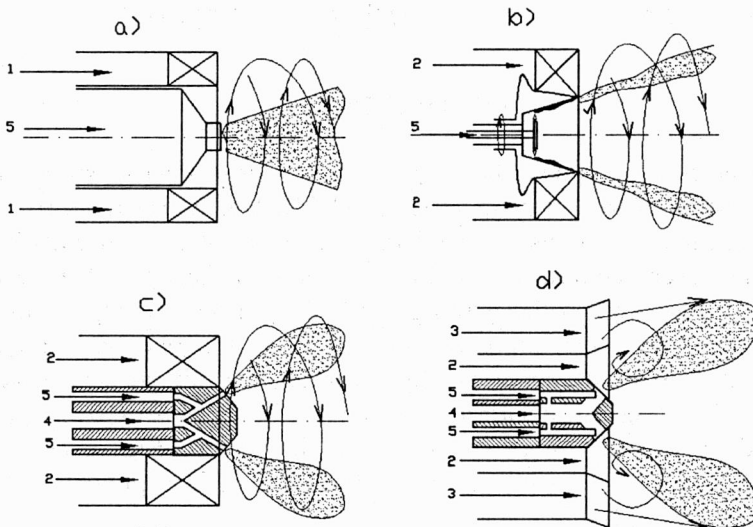

Fig. 1. The diagrams showing the firing-up burners of the following types: pressure (a), rotary (b), double-fuel (c), gas-dynamic (d), 1 – spraying air, 2 – primary air, 3 – secondary air, 4 – water vapour, 5 – mazout

In pressure burners, fuel under high pressure leaves a nozzle and mixes with swirling air outside the burner outlet, which results in producing a uniform solid of flame. The op-

eration of rotary burner is based on a similar principle – a fuel is sprayed on a vaned disc, the air-fuel mixture is formed at the burner outlet generating a single solid flame. In double-fuel burner, a fuel is mixed with water vapour in a nozzle. Then the mixture under low pressure leaves the nozzle and mixes with swirling air. In gas-dynamic burner, water vapour, i.e., spraying agent, and air are fed in a close vicinity of a head, which leads to the formation of the air-fuel mixture. This mixture contains mainly vapours of hydrocarbons which originate due to partial fuel evaporation inside the head and outside the burner. In such a way, a flame splits up facilitating an easy inflow of air to the inside of flame.

In double-fuel, rotary and pressure burners, the air ducts end in blade swirlers. The angle of inclination of the swirlers (20, 30, 40 and 50°) can be adjusted to the duct generatrix. In gas-dynamic burner, the air ducts end in diffusers. The flow of air through the duct has a rectilinear character, and the velocity field is equalized in the whole duct cross-section. The blade swirler and the duct system with a diffuser at the end create recirculation zones and in this way contribute to stabilization of a flame front.

In each of the above mentioned burners, the air-fuel mixture originates in different way, hence our expectation that they will emit various amounts of soot, carbon monoxide and nitric oxides during combustion is justified.

3. METHODS

The process of combustion was evaluated based on such parameters as emission of carbon monoxide, nitric oxides and soot number measured in pressure burner, double-

Table

Parameters of burner operation

Parameters of burner operation	Type of burner			
	Pressure burner	Double-fuel burner	Rotary burner	Gas-dynamic burner
Mazout capacity, kg/h	200–4000	200–4000	200–4000	200–4000
Mazout temperature, K	410	410	410	410
Mazout pressure, MPa	3.2–3.5	1.0–1.5	0.25–0.5	1.15–0.65
Pressure of spraying vapour, MPa	–	1.2–1.6	–	0.3–0.9
Temperature of spraying vapour, K	–	570	–	570
Rotor velocity, rpm	–	–	6000	–
Air excess number	1.25–1.5	1.25–1.5	1.25–1.5	1.05–1.1
Velocity of the primary air outflow, m/s	15–25	15–25	15–25	10
Velocity of the secondary air outflow, m/s	20–40	15–25	15–25	25

fuel burner, rotary burner and gas-dynamic burner with internal mixing. The burners operated within the optimum ranges of mazout and spraying vapour pressures. The parameters of the operation of burners are presented in the table.

The experiments were carried out using an OP-650 boiler under optimum conditions of the flame-front stabilization and the way of air being supplied to a given type of burner.
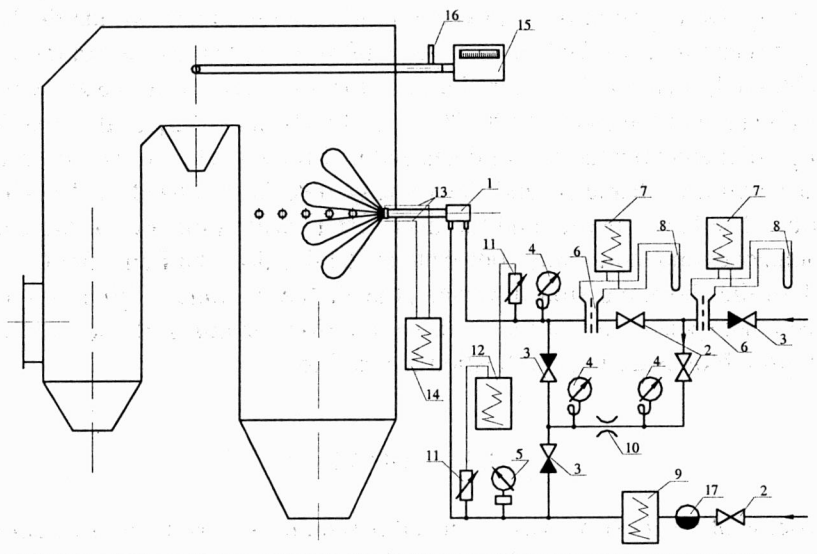

Fig. 2. The diagram of measuring system: *1* – burner, *2* – barrage valve, *3* – non-return valve, *4, 5* – manometers, *6* – measuring orifice, *7* – steam-flow meter with recorder, *8* – differential manometer, *9* – mazout flow-meter, *10* – throttling orifice, *11* – resistance thermometer, *12* – temperature indicator, *13* – thermoelement, *14* – temperature indicator of thermoelement, *15* – flue-gas analyzer, the Baharah analyzer, *16* – sampling probe, *17* – filter

The concentrations of carbon monoxide and nitric oxides in flue gas were measured using a gas analyzer, IMR-300 type, equipped with a special aspirator probe and a computer that analyzed the degree of a flame black (the Baharah number). The investigation was carried out in a post-flame zone. We made use of a standard apparatus (figure 2) in order to determine the amount of oil and spraying agent being combusted and their thermodynamic parameters.

4. RESULTS

The types of products obtained during combustion are closely associated with the time and degree of a fuel and oxidizer intermixing. A quick and thorough intermixing of the above components guarantees their perfect and complete combustion. An inap-
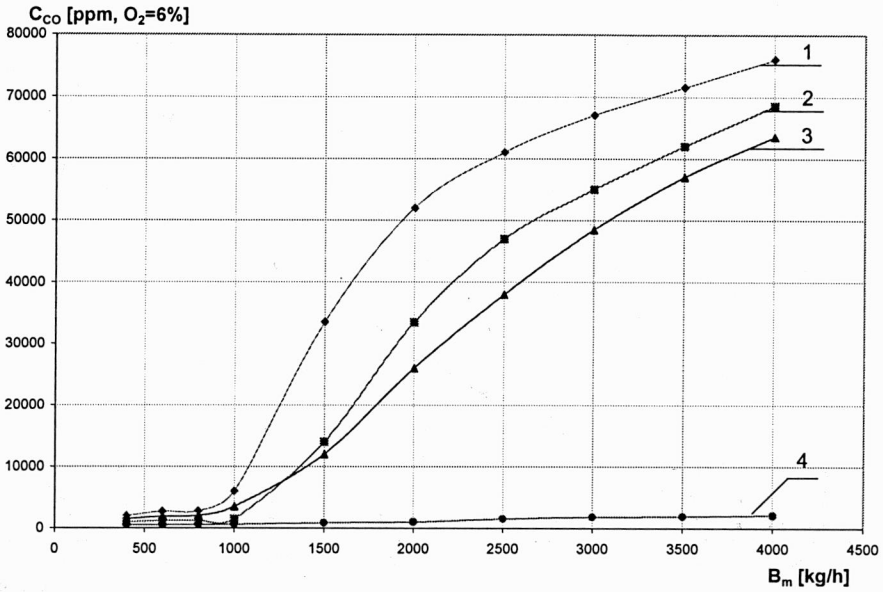
Fig. 3. Concentration of carbon monoxide in flue gas versus the burner capacity:
1 – pressure burner, *2* – rotary burner, *3* – double-fuel burner, *4* – gas-dynamic burner
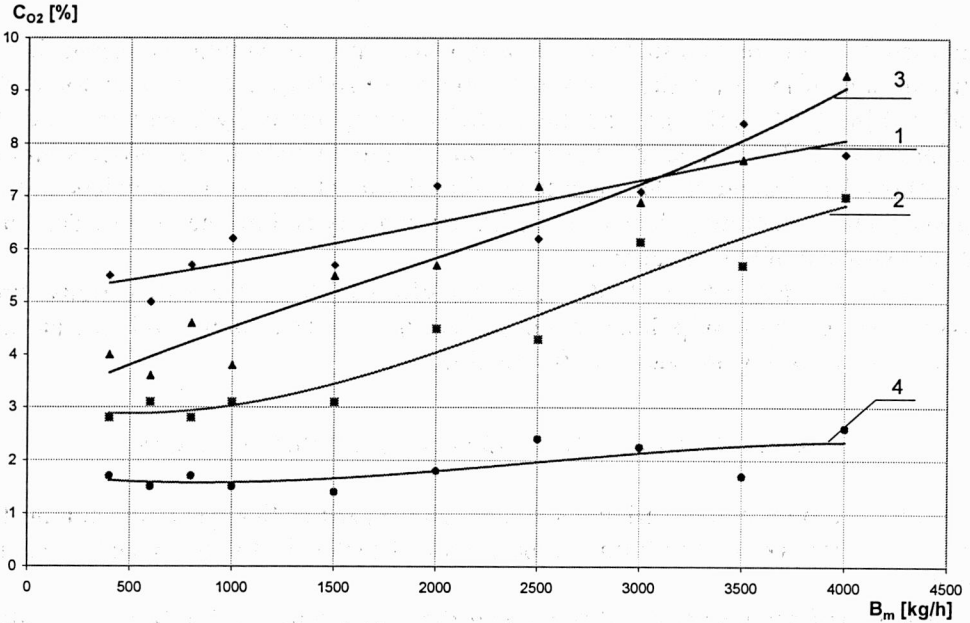

Fig. 4. Concentration of oxygen in flue gas versus the burner capacity:
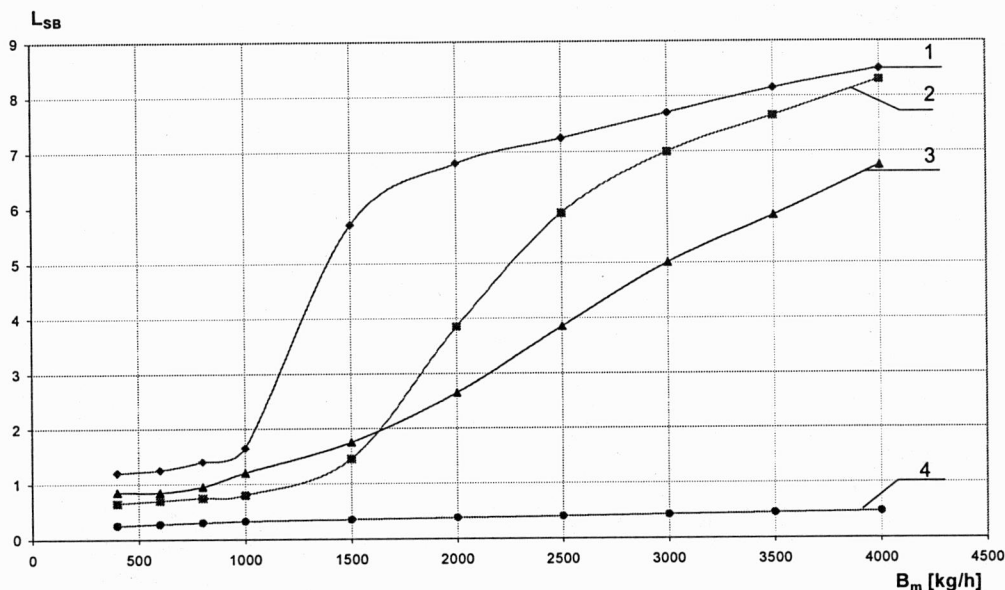*1* – pressure burner, *2* – rotary burner, *3* – double-fuel burner, *4* – gas-dynamic burner

Fig. 5. The value of soot number (L_{SB}) in flue gas versus the burner capacity:
1 – pressure burner, *2* – rotary burner, *3* – double-fuel burner, *4* – gas-dynamic burner

propriate intermixing of a fuel with oxygen, which takes much time, is responsible for the emission of mainly carbon monoxide, soot and PAHs (polycyclic aromatic hydrocarbons) [8]–[11]. In this process, the particles of vapours of hydrocarbons reach the periphery of a flame zone. A precise mixing of the air with these particles and the time this takes depend on the magnitude of a solid in which the fuel droplets undergo spraying and evaporating, hence on the burner capacity and on the magnitude, velocity and swirling of the air stream.

The results that allow us to determine the effect of the capacity of various burner types on the emission of pollutants released during mazout combustion in the phase of power boiler starting are shown in figures 3–5.

4.1. CONCENTRATION OF CARBON MONOXIDE IN FLUE GAS

The concentrations of carbon monoxide and oxygen in flue gas at the combustion chamber outlet versus the burner capacity are depicted in figures 3 and 4, respectively.

The experiments carried out prove that the concentration of carbon monoxide in flue gas depends on the burner type and capacity. Only in gas-dynamic burner, this concentration is virtually independent of the capacity. At the burner capacity smaller

than 1000 kg/h, carbon monoxide in flue gas occurs in trace concentrations in all types of burners. The highest (in the order of 200 ppm) and the lowest (in the range of 60–80 ppm) carbon monoxide concentrations are determined in the pressure burner of the Babcock type and the gas-dynamic burner, respectively. Intermediate concentrations of this compound are emitted from the rotary and double-fuel burners. If the burner capacity is higher than 1000 kg/h, emission of carbon monoxide increases very rapidly and reaches the values as high as about 67%, 6% and 7.5% for the rotary burner, double-fuel burner and pressure burner, respectively, at the maximum capacity of 400 kg/h. The concentration of carbon monoxide in flue gas emitted from gas-dynamic burner at its maximum capacity approaches 200 ppm.

Each burner operates under conditions of excess oxygen. Oxygen reaches its highest concentration in flue gas (figure 4) from the pressure burner. In a flue gas from the double-fuel and rotary burners, this concentration is lower, being the lowest for the gas-dynamic burner.

In spite of the fact that the air was dosed based on minimum concentration of carbon monoxide in flue gas and in a large excess of oxidizer, the concentration of carbon dioxide in some burners was surprisingly high. This can be explained as follows: under conditions of insufficient mixing of a fuel with an oxidizer, if a burner reaches its maximum capacity, a non-combusted fuel can originate. Moreover, a large flame produced under such conditions comes into contact with cool walls of a combustion chamber, which results in the combustion interruption.

4.2. SOOT IN FLUE GAS

The soot concentration is characterized by the Baharah soot number (L_{SB}). The values of L_{SB} presented in figure 5 refer to the post-flame zone at the outlet of a combustion chamber, where a temperature of gaseous medium is relatively low and where the process of soot after-burning is completed. The curves in figure 5 represent the concentration of soot in flue gas versus the burner capacity. The curves prove that the value of the soot number is heavily dependent on the capacity of the pressure burner, rotary burner and double-fuel burner.

The pressure, rotary and double-fuel burners operate within two distinct ranges of combustion, which depend on the burner capacity. At the capacity lower than 1000 kg/h we deal with highly efficient combustion, i.e. close to a perfect and complete combustion. This is corroborated by the value of the soot number being close to unity. At the burner capacity exceeding 1000 kg/h, the combustion process rapidly deteriorates which results in an increase in the LSB value to ca. 6 (the pressure burner at $B_m = 1500$ kg/h) and even to 7.8 at the capacity of 400 kg of mazout per 1 h (the pressure and rotary burners).

The value of the soot number is almost independent of the capacity of gas-dynamic burner. It varies in the range from 0.2 to 0.4, provided that capacity also

varies in the range of 400–4000 kg of mazout per 1 h. These figures provide clear evidence of a perfect and complete combustion in the ranges of the burner capacity being tested.

There is a high probability that soot will be emitted together with aromatic hydrocarbons, and their concentration will vary in the way similar to variation of the soot number, depending on the burner capacity.

4.3. CONCENTRATION OF NITRIC OXIDES

Nitric oxides (NO_x) obtained during combustion of liquid fuels are mostly formed in the reaction of the atmospheric nitrogen oxidation. The rate of their formation depends mainly on the flame temperature and the excess air number. Figure 6 proves that in the flue gas emitted from the pressure, double-fuel and rotary burners, the concentrations of NO_x are similar and increase with the increase of the burner capacity from the value of 400–500 mg/m³ at the capacity of 400 kg/h to 600–700 mg/m³ at the capacity of 4000 kg/h.
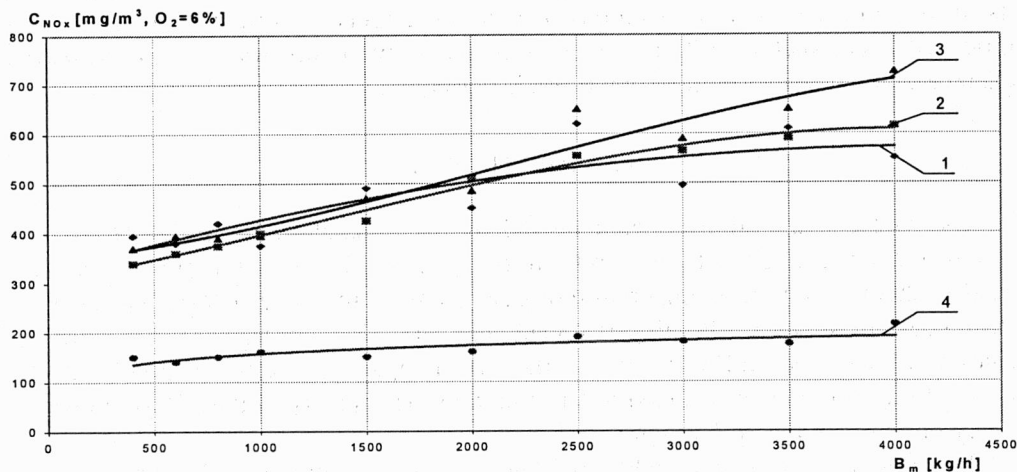

Fig. 6. Concentration of nitric oxide in flue gas versus the burner capacity: 1 – pressure burner, 2 – rotary burner, 3 – double-fuel burner, 4 – gas-dynamic burner

The concentration of NO_x in the flue gas from gas-dynamic burner ranges from 150 mg/m³ at the capacity of 400 kg/h to 200 mg/m³ at the capacity of 4000 kg/h. The character of a flame in such a burner, lacking in areas of extremely high temperature at the oxidizer excess (8), (11), is considered to be responsible for these concentrations.

6. CONCLUSIONS

Some types of firing-up burners emit toxic compounds of high concentrations at the beginning of operation of high-power boilers. The burners under investigation are characterized by a low level of emission of toxic compounds (carbon monoxide, soot, nitric oxides) in a flue gas only if their loading is low. The loading of burners exceeding 1500 kg of mazout per 1 h is responsible for a substantial increase in the concentration of toxic compounds in flue gas. Of all the burners tested only the gas-dynamic one satisfies the requirements for low-emission firing-up burner operating in the range of high loading.

The flame of a single-solid shape characteristic of the pressure burner, double-fuel burner (stabilized by swirling air) and rotary burner under high loading does not allow the air to mix with fuel, which leads to imperfect and incomplete combustion. The zones of extremely high temperature in these burners are also responsible for a high NO_x emission.

The burners with the flame being split up offer much better aerodynamic conditions for an appropriate inflow of oxidizer and its mixing with fuel. Moreover, in such burners, independently of their capacity, the high-temperature zones are not developed. It should be stressed that for combustion of such fuels as mazout, soft asphalt or tar, water vapour is used as a fuel-spraying medium. Water vapour accelerates the formation of a homogenous air-fuel mixture, ignition and combustion, but it is considered to be one of the factors that reduce pollutant production.

The process of starting operation of high-pressure boilers lasts many hours, therefore we postulate the control of pollutant emission from the firing-up burners. The necessity of establishing the emission standards for power boilers in their start-up phase should be recognized.

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EMISJA ZANIECZYSZCZEŃ GAZOWYCH Z PALNIKÓW ROZPAŁKOWYCH

Emisję gazowych substancji toksycznych określono dla znanych konstrukcji palników rozpałkowych kotłów dużej mocy. Badania przeprowadzono przy zmiennej wydajności palników dla optymalnych parametrów ich pracy, to jest minimum emisji sadzy, NO i CO, zapewniając jednocześnie stabilną pracę palników. Stwierdzono znaczną emisję substancji toksycznych z niektórych typów palników rozpałkowych w fazie rozruchu kotłów. Mając na uwadze fakt, że proces rozruchu kotłów energetycznych dużej mocy jest wielogodzinny, postuluje się kontrolę emisji zanieczyszczeń z palników rozpałkowych. Rozważenia wymaga konieczność opracowania norm emisji dla fazy rozruchu kotłów energetycznych.