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BOILERS FIRED WITH WASTE GAS FROM CARBON-BLACK PRODUCTION

The paper sums up the experience gained in the development, construction, operation, and maintenance of biolers equipped with convective steam generators of the package type. Burners designed by the Krzgizhanovsky Power Engineering Institute are fired by waste gas of the lowest heating value; the burners may be fired alternatively, if necessary, by natural gas or fuel oil.

In the recent years the problems of a rational utilization of natural resources and pollution control in the industry have become more and more important. Oil refining and petrochemical industries are among the greatest fuel and energy consumers. The development of these branches of industry is characterized by high dynamics of fuel, heat and electric power use, therefore utilization of secondary energy resources (SER) is one of the most urgent tasks. The priority is now attributed to the utilization of combustible waste gases since their emission to atmosphere not only contributes to the energy losses but also to severe air pollution. The following waste gases belong to SER in the petrochemical industry: absorption gases; waste gases of carbon-black plants; furnace gases from annealing of catalysts; by-product gases derived in thermal conversion of oil shale, coal or other fossil fuels; methane-hydrogen cuts of ethylene production; hydrocarbons from synthetic rubber manufacturing; etc. Combustible waste gases are currently used for firing process furnaces, industrial heating systems, industrial district heating and power plants, and other installations [3].

The utilization of combustible waste gases as a fuel does not impose any basic technological difficulties: it has already been introduced successfully in industry long ago and needs only improvements in the process control, elimination of flame pulsations, etc.

However, there are some combustible flue gases which are now wasted in great amounts polluting air around industrial areas and even in nearby settlements since the technology for burning them has reached only a stage of development or testing and demonstration [7]. Among those are waste gases of plants producing carbon-black having typically the following ultimate analysis (in % by vol.): H_2 — 11.7%; CO — 15.0%; CO_2 — 5.3%; CH_4 — 0.5%; N_2 — 67.5%. The moisture content of the raw gas is usually 38–40%.

The concentration of combustible matters (in the mixture of the undried gas and oxidant) is near the lowest limit of ignition while the normal velocity of flame propagation representing an implicit characteristics of combustion stability reaches almost its minimum. The lowest calorific value ranges from 350 to 550 kcal/m^3 for undried gas, the value being considerably lower than that typical of poorest gaseous fuels burnt in boilers.

When these gases are cooled down to 50–60° C in a foam or other scrubber-type units, their calorific value could be improved by half due to steam condensation. However, along with the above components, the gases contain also residual carbon-black whose concentration sometimes reaches 2 g/m^3. Being entrained by the condensate, the finely dispersed carbon-black pollutes wastewater and forms slurry which could not be readily separated in conventional settling tanks. The attempts to predry the gas (for example, at the Barnaul Black Carbon Factory) appeared to be a failure since water resources were polluted while protecting atmosphere.

To solve the problem radically it seemed to be appropriate to develop a method providing the stable combustion of great amounts of undried gas containing up to 40% of steam at 190–200° C. The Krzhizhanovsky Power Engineering Institute in cooperation with the Electrougly Black Carbon Works have proposed a method based on the premxing of undried gas and air with subsequent burning of gas–vapour–air mixture obtained in special design burners with a high stability of combustion process.

The combustion stability is dependent on the rate of mass transfer due to which a part of recycled combustion products enters the active flow and is mixed with gas-air stream. Bearing this in mind, the burner proposed [6] has such a rate of gas-air flow swirling that ignition can accur not only along the circumference but also at the near-axial recirculation zone. As a consequence, the flame appeared to have a much shorter length and the maximum of burning-out profile has approached the burner exit. Fig. 1 shows a possible construction of the burner. The gas to be burnt is fed to mixer *1* via spiral intake *2*, while air enters it through the inlet pipe *3*. The mixing initiates in annular cavity *4* where the air streams from orifices *5* enter the swirled gas flow. The diameter of the air orifices, their distribution and number may be determined [4] using the methodology based on concepts suggested by IVANOV [2] and AKHMEDOV [1]. At the exit of mixer *1* there is the gas-air flow swirler *6* to enhance the recirculation of combustion products near the root of the burning jet. The ratio of the diameters of swirler shroud and burner funnel (hub ratio) was assumed to be 0.54 which ensured the discontinuity of the swirled flow and suction of the hot combustion products into the core of flame stabilization zone. Ignition of the gas-air flow at the circumference takes place when the mixture enters the refractory-lined duct whose diameter is significantly greater than that of the funnel. The peripheral zone of combustion product recirculation is being formed in a shoulder whose width equals to 0.45 of the funnel diameter. When the waste-gas flow rate is decreasing, it is possible to hold the same heat release by feeding natural gas amounting up to 40% based on heat load. Natural gas is delivered through axial perforated tube *7*. The gas passes via orifices *9* into annular duct *8* while air flows through inlet *10*. The methane–air mixture is swirled

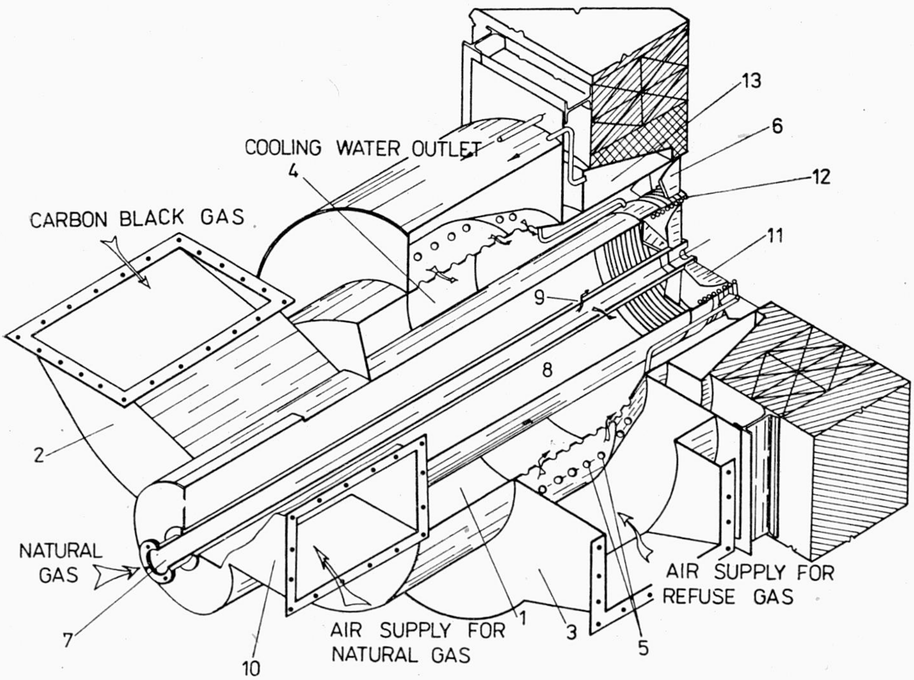

Fig. 1. Burner fired with waste gas of the carbon-black process operation (supplementary fuel — natural gas)

Rys. 1. Palnik do spalania gazu sadzowego (paliwo rezerwowe — gaz naturalny)

by vane *11* and is burnt at the exit of the water-cooled coil *12*. The funnel circumference is also cooled by water flowing through jacket *13*.

The flame stability depends on some regime parameters including in particular the temperature of mixture to be burnt, gas composition, excess air, as well as the velocity at the funnel exit. To ensure the complete burning out of the residual carbon-black, it is required to control closely preset values of the above characteristics, that is, the temperature in the combustion chamber should be in a range from 1150 to 1200°C, carbon-black particle residence time in the high-temperature zone 1.5–1.7 s, and the air to gas ratio about 1.15.

Another burner modification is designed to burn flue gases from regeneration units of annealing the catalysts for oil cracking. The gases containing up to 3% by volume of CO at 550°C enter the burner through a spiral intake. The air is supplied through orifices. The gas–air mixture, which is swirled by vanes, is ignited from two sides when it flows from funnel to refractory-lined duct. The air-flow rate is controlled by gate valves. Additional fuel (fuel oil or natural gas) is delivered to the burner through central tube, while the air needed for burning this fuel flows from annular duct.

To test the two-sided ignition technique at the carbon-black plants, the burners developed by the Krzhizhanovsky Institute and rated up to 10 and 30×10^3 m^3/hr of waste gas were installed in combustion chambers of existing steam generators (of DKVR and other types) fired earlier by commercial solid fuels. The experience gained in operation of these units fired by the 350–600 Cal/m^3 waste gas was taken into account by the Belgorod Power Engineering Plant when developing SK and PKK steam generators* designed to operate with waste gas from carbon-black process operation, the supplementary fuel being natural gas or fuel oil. The plant has started quantity production of PKK steam generators rated at 30.75 and 100 t./hr with steam pressures of 2.4 and 4.4 MPa (or 24

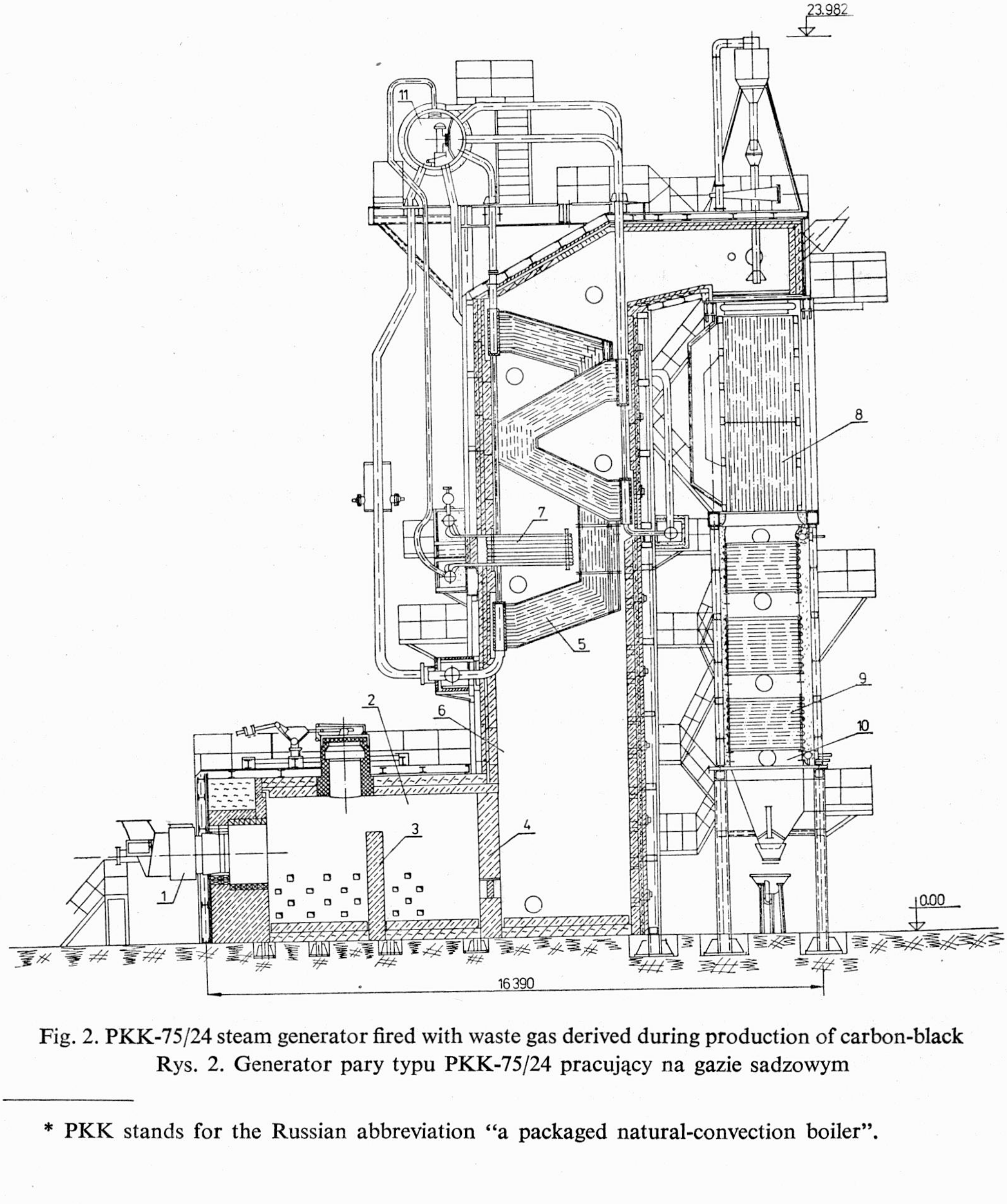

Fig. 2. PKK-75/24 steam generator fired with waste gas derived during production of carbon-black
Rys. 2. Generator pary typu PKK-75/24 pracujący na gazie sadzowym

* PKK stands for the Russian abbreviation "a packaged natural-convection boiler".

and 45 kg/cm²) [5]. The predicted efficiency is about 0.84 at the lowest gas calorific value.

Fig. 2 shows the PKK-75/24 steam generator. Burners *1* developed by the Krzhizhanovsky Institute and the Belgorod Plant are installed in separate precombustion chamber *2* having no heat screen. The chamber is divided by brickwork latticed baffles *3*, *4*. Convective evaporating surface *5*, constructed as tube banks, are mounted in a top section of upflow duct *6*. Steam generating coil *7* is housed in a fold between the adjecent tube sections. Air preheater *8* and economizer *9* are located in downflow duct *10*. Two-staged evaporation occurs in drum *11*. The evaporator salt section occupies the left-hand part of the drum, while the opposite part is for the pure water. The number of evaporation coils in each section is dependent on the total capacity needed. Cyclones built into the salt section serve for separation; the second section is provided with a mechanical multilouver separator. Outer tube surfaces in the upflow duct are cleaned by the air flow from a fan while the tubes in the downflow duct are scaled off by a special bead-blasting system.

Tests carried out with boilers at carbon-black plants demonstrated that PKK generators could ensure infinitely prolonged fault-free operation when fired with 450–550 Cal/m³ undried waste gas derived in carbon-black process operation. Also, the tests confirmed that main process parameters given above should be maintained to guarantee highly effec-

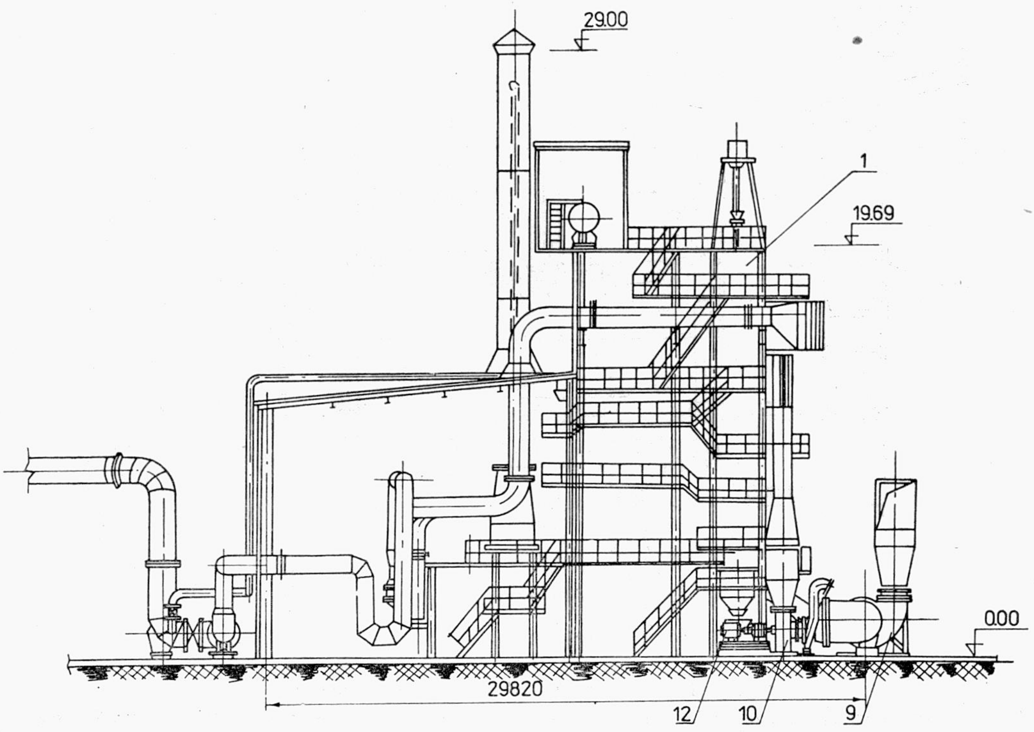

Fig. 3. Partially-enclosed boiler plant with PKK-30 /45-70 steam generators, side view
Rys. 3. Półotwarte rozwiązanie kotłowni wyposażonej w generatory pary typu PKK-30/45-70, przekrój

tive and intestive burning-down of harmful gaseous pollutants and residual carbon-black. When the steam generator load ranges from 0.75 to 1.20 of the nominal one, the concentration of carbon-black in flue gases does not exceed 30 g/m^3. The air delivered to the burner is preferably to be heated in recovery units up to 300–350° C. The required level of boiler capacity is sustained by controlling the proportion between the flow rates of waste gas and supplementary fuel (natural gas or fuel oil).

The arrangement of boiler plants with PKK steam generators were developed by the Power and Chemical Engineering Institute in association with the Rubber Engineering Institute. The works headed by Yevdokimov* were carried out with due consideration

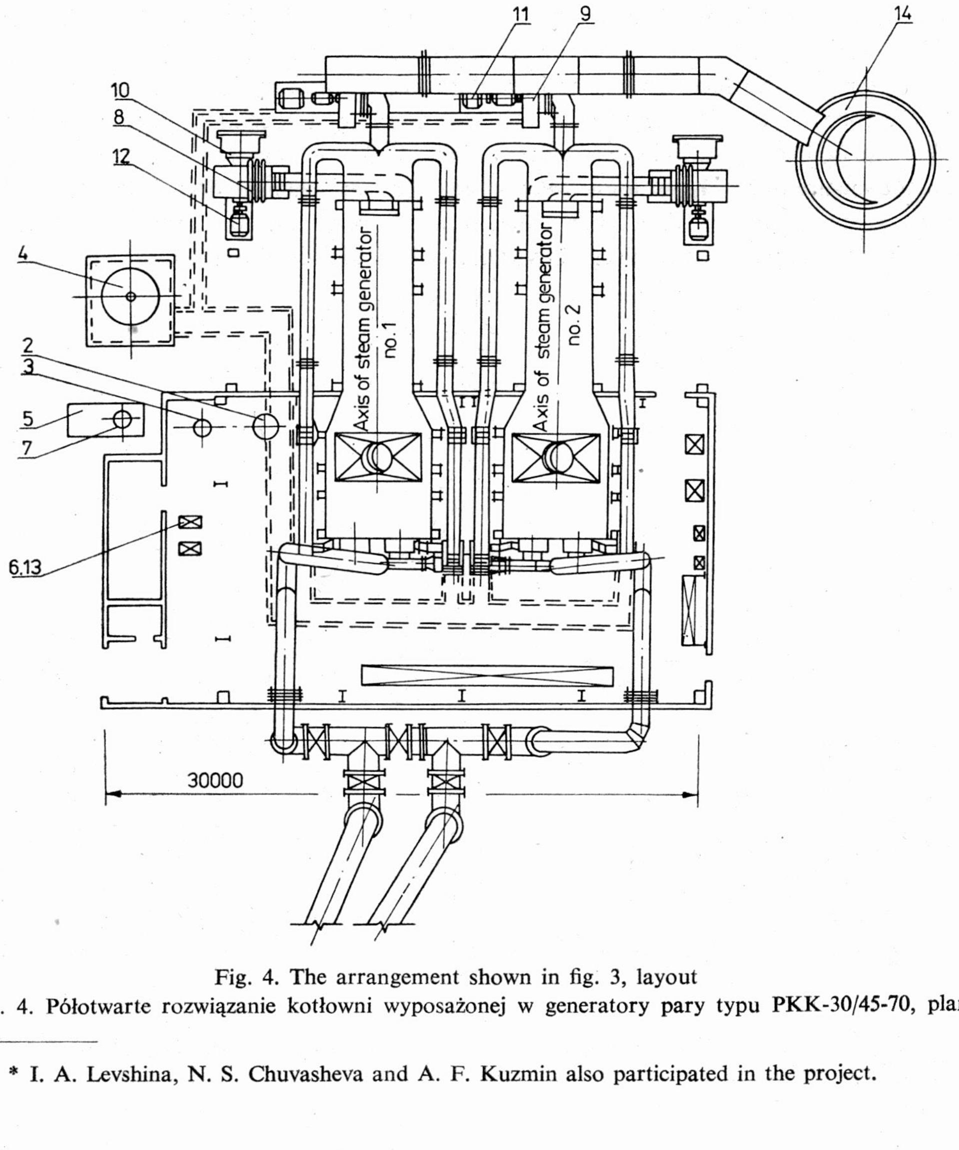

Fig. 4. The arrangement shown in fig. 3, layout
Rys. 4. Półotwarte rozwiązanie kotłowni wyposażonej w generatory pary typu PKK-30/45-70, plan

* I. A. Levshina, N. S. Chuvasheva and A. F. Kuzmin also participated in the project.

for standard erection procedures typical of mass construction and maximal utilization of prefabricated components. When finding the best plant design, the following goals were persued:

1. to ensure reliable operation, as well as easy and safe maintenance;
2. to do as short as possible pipelines and other conduits;
3. to minimize the floor space needed for main and auxilliary equipment, as well as for repair services and laboratories;
4. to lower to a possible minimum the operational staff by using automatic systems when they are cost-effective;
5. to permit separate installation of units and erection of new units without forcing the existing plant out of service;
6. to ensure an easy service, check inspection and cleaning of equipment and tubings, using the special loading devices and repair landings.

14	$Du = 2$m, $H = 80$ m	Smoke pipe	1	
13	$N = 4$ kVh $n = 2900$ rotations min^{-1}	Electric motor	2	ADL-2-32-2
12	$N = 110$ kVh $n = 980$ rotations min^{-1}	Electric motor AOZ-315-56	2	
11	$N = 110$ kVh $n = 600$ rotations min^{-1}	Electric motor AOZ-355-M-10	2	
10	$Q = 41200$ m^3/hr $H = 450$ kG /m^2	Fan WD-13.5	2	
9	$Q = 107200$ m^3/hr $H = 136$ kG /m^2	Smoke fan D-20	2	
8	$F = 53.3$ m^2	Heater KFB-9	12	
7	$\varphi = 426$	Compensation chamber	1	No. 7169 / 05-144
6	$\varphi = 10-30$ m^3/hr $H = 34.5$–24 m H_2O	Condensate pump 2K-6	2	
5	$V = 10$ m^3	Condensate tank	1	No. 7169 / 05-043
4	$V = 7.5$ m^3	Periodical blow-through separator φ 2000	1	BK-61752
3	$V = 0.7$ m^3	Pure drain expander φ 630	1	BK-61740
2	$F = 60$ m^2 $Q = 70$ m^3/hr	High pressure heater PW-60-4	1	
1	$D = 30$ t/hr $P = 40$ at $t = 440$°C	Steam generator PKK-30/45-70-5	2	
Item	Characteristics	Facility	Number	

Figs. 3 and 4 illustrate the arrangement of two PKK 30/45-70 steam generators installed at the Carbon-Black Plant in the town of Yaslo, Poland.

Bearing in mind relatively mild weather conditions prevailing at the site, the plant was designed as a partially enclosed structure; the burner maintenance zone (the operator's platform) has a rather poor insulation. The elevated enclosed section (24×15×14 m) contains precombustion chambers, superheater headers, high-pressure preheater and pump unit as well as electric switchboard, instrumentation and automatic control panels. At the ground level, a condensate tank, pumps, and an expansion tank for pure drained water occupy the space of 3×15×6 m. Ducts for evaporating and outlet heating surfaces, flue gas and air fans are mounted outside. The expansion unit of periodical blowdown system is placed in a hollow outside the boiler building.

Mainly, the boiler burns waste gas whose calorific value ranges from 450 to 550 Cal/m^3. Natural gas is used as a supplementary fuel. The process waste gas flows to the steam generator through the header. When the process operation is interrupted, the header intake shuts down and then the unit is fired exclusively by natural gas. When there is a damage of steam generators, the safety valve opens automatically while the waste and natural gas ducts shut off.

To prevent sulfur corrosion of the steam-generator outlet sections, the feed water

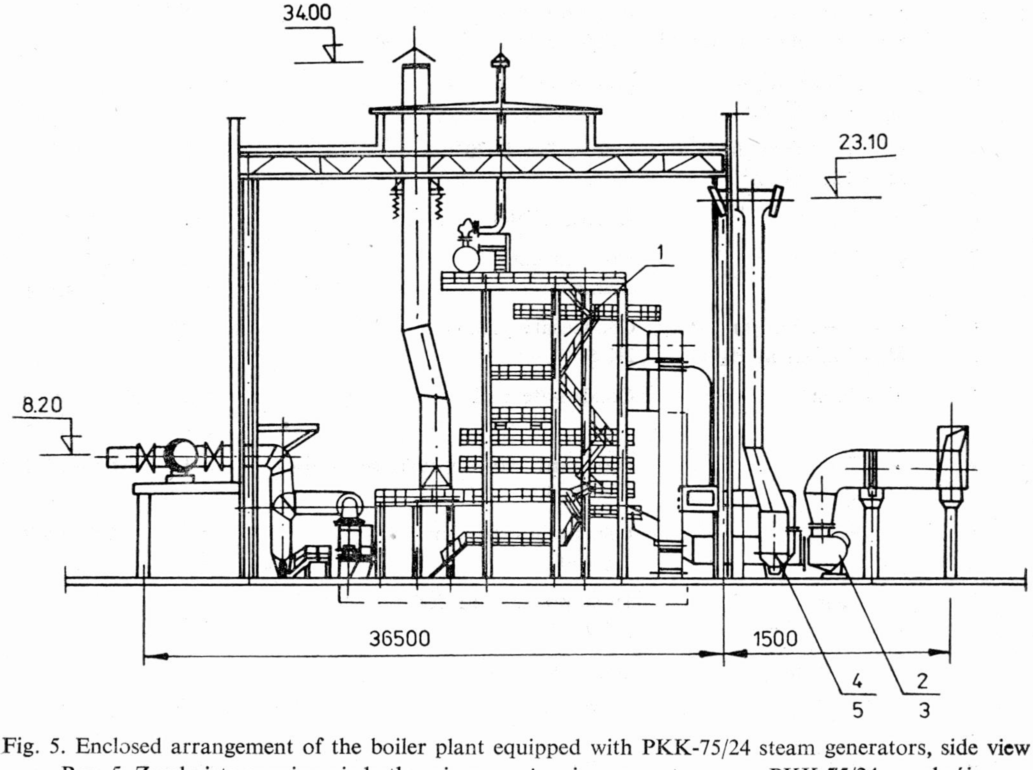

Fig. 5. Enclosed arrangement of the boiler plant equipped with PKK-75/24 steam generators, side view
Rys. 5. Zamknięte rozwiązanie kotłowni wyposażonej w generatory pary PKK-75/24, przekrój

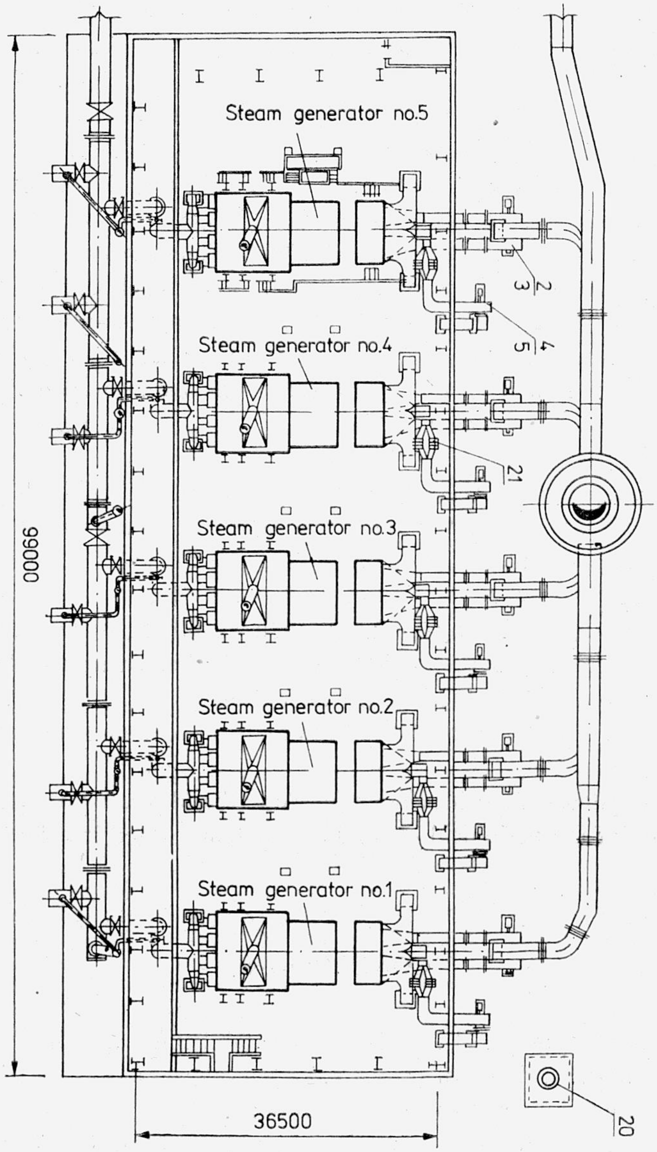

Fig. 6. The arrangement shown in fig. 5, layout
Rys. 6. Zamknięte rozwiązanie kotłowni wyposażonej w generatory pary PKK-75/24, plan

is heated up to 145°C in high pressure preheaters and air in the air heaters up to about 90°C, the heaters being installed downstream the air preheaters.

The draft unit consists of two D-20 exhaust fans, two VD-13.5 air fans, and six KFB-9 air heaters. The chimney stack is of 2 m diameter and 80 m height.

Reportedly, the boiler plant put in operation in 1975, operated smoothly at the required heat output and had no adverse influence on carbon-black process.

As an example of completely enclosed plant, figs. 5 and 6 present the arrangement of five PKK-75/24 steam generators rated up to 60 t/hr each and operating at a steam pressure of 24 kg/cm^2 and a steam temperature of 370°C. The installation was designed by the Rubber Engineering Institute for service at the Barnaul Black Carbon Plant. The waste gas is used as a main energy source, the balance fuel being low-sulfur fuel oil. The waste gas is supplied to steam generators from a single header. Each steam generator is equipped with a separate blowing plant, including a D-20$\times$2 exhaust blowers and VD-15.5 air fan. Two boiler plants (new and existing ones) have a common stack 120 m high and 5.1 m in diameter.

From the steam generators the superheated steam is delivered to the header and then to the reducing and cooling unit. At pressures of 11 and 22 kg/cm^2 the steam with a temperature of 250°C is supplied to users while the reduced steam at 7 kg/cm^2 and a temperature of 190°C covers the plant needs or is taken off to be sold.

The steam generators are fed by a mixture of chemically treated water and condensate. Before entering the steam generators the feed water is heated up to 145–150°C in high-pressure preheaters of the PV-150-3 type which eliminates the sulfur corrosion of water economizer surfaces. Continuous blowdown of the steam generators takes place in a special separator.

The steam separated is used in deaerators while the blowndown water is drained into an expansion tank of the periodical blowndown system located in a hollow at an outside area.

CONCLUSIONS

1. A new method is proposed to enhance the stabilizing capability of burners for ensuring the stable burning down of lowest calorific value waste-gases from carbon-black production and other industrial-process operations.

2. A set of packaged natural-convection steam generators has been developed and their fabrication has been commenced to use them for abating the waste-gas emission to atmosphere and energy usage of combustion products obtained.

3. Also, versions of boiler plants of partially and fully enclosed types have been designed using the packaged natural-convection steam generators proposed. The excellent reliability and performance of these plants have been confirmed by their prolonged operation when fired with waste gas of the carbon-black producing plants, the supplementary fuels being natural gas or fuel oil.

REFERENCES

[1] Akhmedov R. B., *Draft gas nozzle burners*, Moscow 1977.
[2] Ivanov R. B., *Gas nozzle burners*, Moscow 1972.
[3] Kosterin Yu. V., *Secondary fuel and energy resources and their utilization in oil refining and petrochemical industries*, Promyshlenaya Energetika, Vol. 11 (1977).
[4] Shimanovsky O. V., *Development and investigations on new methods of energy utilization and disposal of heavily dusted waste gases, the* author's summary of these applied for the diploma of the Cand. of Tech. Sci., Moscow, the Krzhizhanovsky Power Engineering Institute, 1972.
[5] Speisher V. A. et al., *Boilers fired by waste gases from black carbon producing plants*, Promyshlenaya Energetika, Vol. 7 (1975).
[6] Speisher V. A. et al., *The burner system*, The Official Bulletin of the State Committee on Inventions, Vol. 46 (1977).
[7] Speisher V. A., *Fire disposal of industrial wastes*, Moscow 1977.

KOTŁOWNIE PRACUJĄCE NA ODPADOWYM GAZIE Z PRODUKCJI WĘGLA TECHNICZNEGO

W artykule podsumowano doświadczenia uzyskane w zakresie projektowania, budowy i eksploatacji kotłów wyposażonych w konwekcyjne generatory pary typu PKK. Palniki tych kotłów, zaprojektowane w Krzyżanowskim Instytucie Inżynierii Energetycznej, są zasilane gazem odpadowym o niskiej wartości opałowej; w koniecznych przypadkach, jako paliwo, może być też stosowany gaz ziemny lub olej opałowy.

VERWENDUNG VON ABFALLGASEN AUS DER KOHLEVERARBEITUNG IN HEIZANLAGEN

Zusammengefasst werden Erkenntnisse, die zur Projektierung, Bau und Betrieb von Kesselanlagen mit konvektiven Dampfgeneratoren der PKK-Art dienen sollen. Die Brenner dieser Kessel werden mit Abfallgasen gespeist die einen niedrigen Heizwert haben; falls nötig, kann man auch Erdgas bzw. Heizöl als Brennstoff verwenden.

КОТЕЛЬНЫЕ, РАБОТАЮЩИЕ НА ОТРАБОТАННОМ ГАЗЕ ИЗ ПРОИЗВОДСТВА ТЕХНИЧЕСКОГО УГЛЯ

В статье подытожены опыты, достигнутые в области проектирования, строения и эксплуатации котлов, снабжённых традиционными парогенераторами типа РКК. Горелки этих котлов, запроектированные в Кшижановском институте энергетической техники, питаются отработанным газом с низкой теплотворной способностью; в необходимых случаях в качестве топлива может применяться природный газ или гарное масло.