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The System of Plasma Ignition for Coal-Dust and Water-Coal Fuels Ignition

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ABSTRACT

In this paper a system of plasma ignition(SPI) which is applied for the ignition and stabilization of coal-dust fuel burning for decreasing fuel black oil consumption is described. The advantages of SPI are demonstrated, and the positive results of SPI which is operated at the thermal-clamping boilers installed in production and heating plants are described. The similar system was tested in demonstration and industrial installations to confirm the results. The improvement of economical, operating and ecological performances of the boiler are shown.

Key words : low-temperature plasma, plasma ignition of fuel, stabilization of fuel burning, thermal-clamping boiler, thermal-chemical preparation of fuel for combustion.

1. Introduction

The worldwide and Russian heat-power engineering utilizes natural gas or fuel oil to ignite coal-dust boilers and to stabilize burning(lighting) a coal-dust torch. More than 50 million tons of the boiler fuel oil is consumed per year all over the world. According to[1] every year the power stations of Russian joint-stock company "United Power Grids of Russia" only burn more than 5 million tons of the fuel oil.

The combined combustion of coal and boiler fuel oil which possesses the higher reactivity decreases the ecological and economical indices of boilers: the fuel underburning rises 10-15%, and gross efficiency de creases 2-5%, the high-temperature corrosion of screen surfaces rises, the operating reliability of the boiler equipment reduces and the outlet of nitrogen and sulfur oxides growths 30-40% (at the cost of higher contents of sulfur in the fuel oil), and the emission of carcino genic vanadium pent-oxide appear[1,2].

The application of natural gas as the major or extra fuel in spite of its higher ecological compatibility is not consistently available.

The problems mentioned are even more actual in the heat-power engineering which uses the boilers of lower power (the vapor capacity is 35-75 t/hour) with turbulent vortex coal-dust burners. The regimes with a variable heat load are typical for the heat-power boilers, and over 24 hours the load may vary from 50 to 100% of the total boiler capacity. In this case the fuel oil lighting of the coal-dust burners is demanded practically and constantly. The boiler fuel oil becomes not extra fuel but the second major one, especially in the cold season.

The worsening of ecological and economical characteristics of the boilers caused by combustion of two kinds of fuel becomes more clear at such high consumptions of the fuel oil. Thus, the carbon content in ash ranges up to 20-30%. In fact this ash might be returned into the boiler and burnt up secondly.

From the above the currently central problem of heat-power engineering is the decrease of fuel oil share in fuel balance of the coal-dust boiler units. There is a certain difference in this task for the energetic and heat-power plants. The energetic boilers need the systems guaranteeing a reliable fuel oil-less ignition of the boiler. On the other hand, the heat-power boilers demand the ignition and practically continuous lighting to stabilize boiler operation at the variable loads, and to increase ecological characteristics in total. The solution of the problem is impossible with traditional technologies of fuel utilization which have been mainly exhausted in a technical, ecological and economical view point.[1,2)

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2. Background

To solve the problem of high-efficiency utilization of poor quality solid fuels with minimum negative influence upon the surroundings, in 1983 the works for production of principally new plasma technology of powered fuel combustion with electric-arc heaters (plasma torches) were begun in a number of USSR scientific organizations. This project was offered by the key specialists in the area of plasma technique and technology, M. F. Zhukov, L. S. Polak et. al, and supported by The State Committee of science and technique. At about the same time the first foreign publications appeared which dealed with electric-arc plasma use in coal-dust torch ignition. Later on the systems of plasma ignition (SPI) of the coal-dust were widely taken up in energetic boiler units of the system "United Power Grids of Russia". The detailed experimental and theoretical investigations of the processes of coal-dust torch ignition and lighting were carried out, and a theory of thermal-chemical preparation of the fuel (TCPF) for combustion was elaborated. The detailed reviews of the works in this area are found in[1,2]. The conception of thermal-chemical preparation of a part of the coal-dust fuel in a pre-heating chamber situated in a coal-dust burner was distributed not only for plasma systems but also for the other systems of coal dust ignition[3,4]. Much less attention was given to the systems of TCPF in thermal-clamping boilers though the problem of saving of the black oil, and increasing of quality of coal combustion is even more pressing here.

3. Description of an inquiry subject

The works on fuel oil-less plasma ignition and burning sustain of the coal-dust torch in the thermal-clamping boilers are realized[5] in production and heating plant of Tashtagol Iron Mine (Kemerovo region, Russia) from 1997. There are five one-type boiler units of K-50-14/250 made by Belgorod boiler plant. The nominal output of the boiler is 50 tons/hour at the pressure of P=1.4 MPa and the temperature of T_{os}=250°C.

A boiler furnace is equipped with four turbulent coal-dust burners, which are situated on furnace side walls (two of them on each side). Black oil sprayers with vapor spraying are built in the central axis of the burners. Each boiler is equipped with two dust-systems with direct injection. The dust-system includes the following elements: a bowl mill, a scrapper feeder of raw coal with capacity of 0.67÷15 tons/hour, a mill ventilator with capacity of $(9\div13)\cdot10^3$ m^3/hour. The pulverized fuel pipes of each dust system are connec ting by pairs with the burners situated diagonally.

The major fuel for the boiler plant is bituminous coal. It possesses the following characteristics: ash content of A^p=15÷21%; humidity (in summer) of W^p=10÷11.5%; volatile matter of V=35÷38%; heat of combustion of $Q_H{}^p$ = 5,700 kcal/kg (23.94 MJ/kg). The black oil is used as an extra fuel to ignite and light a coal-dust torch. The flow rate of the black oil through one sprayer ranges up to 250-500 kg/hour. The black-oil sprayers are initiated in the following cases:

-the ignition of boilers. In the average about 15 ignitions of the cold boilers are realized in the cold season. As much as 15 tons of the black oil is consumed for each ignition;

-the lighting of a coal-dust torch at the work on lowered heat loads (with two coal-dust burners working);

-the lighting with coal humidity more than 16%;

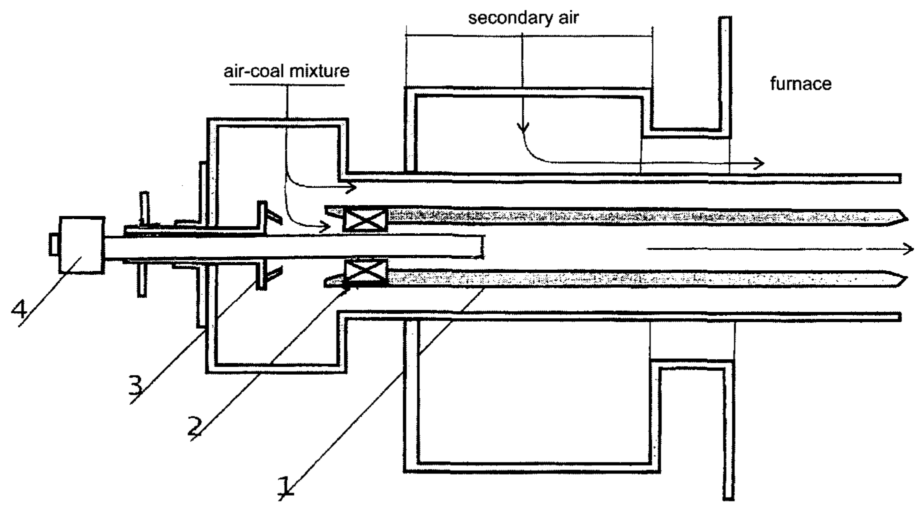
-the lighting with the temperature of an air-fuel mixture below 60°C.

In the cold season the total consumption of the black oil at plant runs up to 50-60 tons per day.

The given figures confirm again the necessity of looking for new ways of decrease of black oil con sumption.

What is the essence of plasma ignition of fuel? To ignite a flow of an air-fuel mixture in the burner, we suggest that a black oil torch should be changed for a torch forming at combustion of a part of the air-fuel mixture(10-20% from its total flow rate through the burner) with the help of a jet air or another plasma (heated up to 4-5 thousand K). The plasma is generated by an electric-arc gas heater-a plasma torch. A scheme of a turbulent burner with the system of plasma ignition is presented in Fig. 1.

According to this scheme, a muffle of the black oil burner is changed for a special muffle made from heat-resistant steel or cast iron lined with heat-insulating coating. In the enter part of the muffle there is a special



1- plasma burner muffle; 2-vortex machanism;
3-movable regulating cover; 4-plasma torch

Fig. 1. The scheme of turbulent burner with a system of plasma ignition of coal-dust fuel.

regulating device established in order to separate a part of the air-fuel mixture flow and to send it inside the muffle. The electric-arc gas heater plasma torch is coaxially situated with the muffle on the front flange of that. Before the burner igniting, the regulating device closes the enter part of the muffle. Neither the air-fuel mixture nor air comes into it. The plasma torch is switched on and at the power of 40-50 kW the internal surface of the muffle is heated up to 700-800°C. Then a system of regulation of the air-fuel mixture supply is open and the air-fuel mixture is supplied in the burner. The ignition and stable burning of air-fuel mixture in the muffle is supported by a regulation of a choke position on the muffle enter. The air-fuel mixture interacting with a high-temperature air jet and heated walls ignites inside the muffle. In this case not only its burning(with lack of oxygen) occurs but also gasifica tion and destruction of coal particles. This is so-called thermal-chemical preparation of the fuel for combus tion. In the exit of the muffle a stream of the hot air-fuel mixture containing a lot of active centers such as volatile hydrocarbons from coal, CO, hydrogen, coke, water vapors, atomic oxygen, radicals and etc takes place. Interacting with the major stream of the air-fuel mixture, and with secondary air stream, this torch of active particles ignites the air-fuel mixture and causes its burning not only in the burner zone but in the whole boiler. These processes are described more detail in monographes[1,2].

Fig. 2. Plasma torch EDP-327.

Upon the ignition and beginning of stable burning of the air-fuel mixture the power of the igniting torch may be decreased with regulation of air-fuel mixture flow rate through the muffle and plasma torch power decrease. The plasma torch may be switched off for a while in the regime of stable burning. It should be activated again only in the case of fall in temperature of the muffle, and unstable burning of the major stream of the air-fuel mixture. Since the plasma systems are easily controlled and fast, the activation of them in the regime of periodical lighting may be done automatically or by an operator in manual operation and control.

A specially developed for this burner plasmatorch EDP-327 is used as a source of high-temperature air (See Fig. 2). This is a one-chamber electric-arc gas heater of a linear scheme with an internal front electrode and output step electrode.

Performance specifications are:

Power, kW	-up 20 70
Arc current strength, A	-up to 250
Arc voltage, V	-up to 270
Air flow rate, nm^3/hour	-up to 25
Efficiency	-0.7-0.8.

The period of electrode life-time of the plasmatorch prior to the renewal is 50-100 hours. The plasmatorch design permits to change it for another in some minutes.

The special rectifiers are used as the power supply: $U_{no\text{-}load}$=315-320 V, $U_{operation}$≤280 V; I_{max}=250 A. The system of plasmatorch control includes: a remote console of operation and control of parameters, the system of blocking and signaling about technological regime trouble.

The systems of gas and water supply are connected to the technological lines of the boiler plant.

4. Experimental result

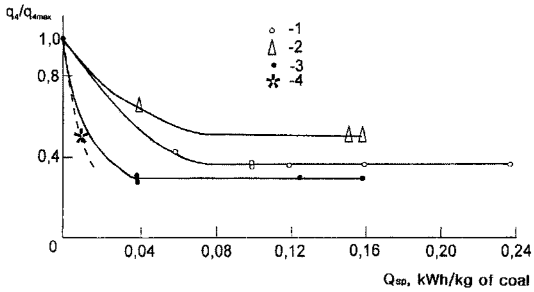
Plasma ignition of a boiler. The system of plasma ignition described in the previous part was set on the boiler No. 5. Two diagonally disposed burners of these boilers (No. 1 and No. 4) were equipped with plasma systems. The rest of them had black oil burners.

The ignition experiments for a heated boiler were carried out after testing the plasma systems. For this purpose muffles were heated up for about 40 minutes at the closed system of air-fuel mixture supply. For the burners No. 2 and No. 3, the air-fuel mixture supply was cut off. The black oil sprayers on these burners were activated. Since the muffles were heated up the regulating doors of the muffles were open and air-fuel mixture blowing was begun for the burners No. 1 and No. 4(with the plasma systems). At this air-fuel mix ture supply, fast and stable ignition was achieved in these burners and then in the burners No. 2 and No. 3, after the air-fuel mixture was supplied in them.

In the next experiment the black oil burners were switched off and ignition was realized with only plasma burners working. Stable and fast ignition of the air-fuel mixture was achieved in the plasma burners and then in the others(without black oil). The power of each plasma torch at the muffle heating up period was of 40 kW, in the process of ignition it was raised as much as 50 kW, then it was decreased up to 30 kW. The visualization of these experiments has shown that the plasma burners possess more even and stable burning of the torch than the black oil burners. The torch flame reaches the opposite wall of the boiler and results in air-fuel mixture ignition in the burners which have no plasma system.

After these experiments the boiler was shutdown and cooled(it was out of operation for more than three weeks) whereupon ignition of the cold boiler was realized with only plasma systems used. During 45-60 minutes the muffles of the burners No.1 and No. 4 were heated up and then secondary air was activated and the air-fuel mixture was supplied in these burners. The torches of these burners were ignited after the regulation of the air-fuel mixture flow rate in the muffles. The air-fuel mixture burning became stable for 10 minutes. The flame of the burners reached the opposite walls of the boiler i.e. one might observe the burning in the region of the burners No. 2 and No. 3, too. The temperature and pressure of vapor in the boiler began to grow. Then the air-fuel mixture supply was activated to the burners No. 2 and 3. The air-fuel mixture was ignited and its burning was stabilized in 5 7 minutes in the whole boiler. The black oil burners were not initiated in ignition.

It is impossible to compare the results obtained from the power-generating boilers because[1,2] there are the results of measurement in an experimental fire stand,



1 – culm; 2 – Borline coal; 3 – Ekibastuz coal, 4 - Kuznetzk coal (points 1 – 3, data from [1, 2]), and in the boiler K-50 (point 4).

Fig. 3. The relative decrease of the incomplete burning q_4/ q_{4max} in dependence on the specific plasma torch capacity with SPI use for stabilization of coal-dust burning in an experimental stand

and the data of real boilers concern with the ignition of cold boilers. We can do no more than the comparison in the relative decrease of the underburning on this experimental stand to our data. This comparison is presented in Fig. 3.

The data given showed, that the regimes of plasma lighting obtained in our experiment(point 4), are far from optimum. Raising the capacity should result in further decrease of the underburning. The optimum regimes of SPI work may be achieved at relatively low specific capacities of the plasmatorches. It is likely to be connected with coal quality. Further investigations (2000 2001 years) by analogous boilers with different constructions of SPI and different type of coals(brown coals, black coals by other composition and age) were shown that the conditions of ignition and stabilization of coal-dust burner work strongly depend on coal composition and many other factors. Only by experiment it is possible now to determine the rated duty of boilers with SPI. For ignition and stabilization of thermal-clamping boiler with 4-6 turbulent burners work it is enough two plasma ignition systems using.

One of the major problems at the application of the systems of plasma ignition and stabilization of coal-dust fuel burning is the life-time of plasma torches up to electrode renewal. According to the plasma torches features the electrode life-time is of 50-100 hours which is evidently deficient for continuous operation of SPI. For this stage of the experiments, the simples and most reliable in service model of a plasma torch was chosen. For the moment the increase of life-time is related to the meshing of a model and to plasmatorch cost increase. The experience has suggested that SPI continuous operation may be guaranteed with the exis ting plasma torches, too. At the course of prolonged experiments, the temperature of the muffle and its thermal lag allows to switch off the plasmatorch for 10-15 minutes and to renew it without cutting off of air-fuel mixture supply. The stable burning of the air-fuel mixture goes on up to the muffle cools down to the temperature below the coal dust ignition temperature. The availability of a reserve plasmatorch prepared to the work permits to renew either at electrode depleted or in the case of emergency burners No. 2 and No. 3. The air-fuel mixture was ignited and its burning was stabilized 5-7 minutes in the whole boiler. The black oil burners were not initiated in ignition

The following stages of the work were: adjustment of the regimes of plasma stabilization of coal-dust fuel combustion without the black oil, at various heat loads of the boiler, the preparation of technological order for the boiler work with plasma lighting, training of the stuff in the work with SPI.

Plasma sustain of burning. Then the experiments in long sustain of boiler burning were done with SPI application at various heat loads, when the black oil sprayers were initiated or cut off. The works were conducted at various ambient temperatures(up to-32°C) through the autumn and winter season, 1999. The experiments have demonstrated that with the aim of stable burning of the air-fuel mixture, the muffle should be heated up for 30-40 minutes at least. The stable burning of the air-fuel mixture in the boiler is settled in 3-5 minutes after the air-fuel mixture supply, and the burning temperature is higher in the burner region. In this case the burning stability, and the length of the torch grow in comparison to the case of the black oil lighting. In the case of air-fuel mixture supply in the cut off burners of the other mill(the black oil sp rayers were cut off too), the stable burning in them was also achieved in several minutes. These results also had obtained for the coal characteristics mentioned before i.e. for the humidity of about 10%. As the coal humidity increases, or the air-fuel mixture temperature falls the stable burning in the boiler is not always observed, especially if the other(without SPI) mill is cut off. In this case at least one black oil sprayer should be in work, to ensure the stable operation of the boiler.

The previous experiments with plasma ignition of boiler have shown the decrease of coal incomplete burning at plasma sustain of the burning. These experiments were continued with the work in the stabilization regime. The prolonged experiments were done with the boiler working at full capacity(both mills are in work and the black oil sprayers are out of work), and when the boiler heat load was decreased. The results of one experiment are presented in the Table 1. It is evident from the Table that the carbon content in ash (the incomplete burning) is 19-24% in the experi ments realized when the boiler works at full capacity without the black oil lighting. As the black oil sprayers are in work the incomplete burning may range up to 30% and

Table 1. The content of carbon in the ash emitted in experiments with SPI

Time	The content of combustibles in ash, %	Note
Night shift	23.1-23.9	The work at full capacity without black oil lighting. The comparative data prior to the experiment
10^{00}	19.2	Prior to the SPI activation, without the black oil lighting
11^{45}	12	SPI are activated, the mills A, B are in work, the black oil is cut off
12^{45}	13.8	- "-
13^{45}	13.2	- "-
14^{45}	9.9	- " -
15^{45}	13.6	The mill A is cut off, SPI is in work, one black oil sprayer is activated and the heat load is about 70%
16^{45}	26.2	SPI is out of work, two black oil sprayers of the A-mill are in work and the heat load is about 70%
22^{00}	20.0	The work at full capacity without the black oil lighting and SPI. The comparable data after the experiment

higher. In the regime given at two plasma burners activated, the hourly measurements of the carbon content in ash demonstrated its double the decrease: from 20% to 10%. It is likely to be connect ed with the refining of coal ignition condition in the burners with SPI, with the growth of air-fuel mixture temperature and burning stability.

At the decrease of the heat load(one mill cutting off) the capacity of SPI turned out to be lacking to sustain the combustion in the boiler. It corresponds to the results given in[1,2]. The activation of one black oil sprayer increased the incomplete burning about 1.5 times at once. The SPI switching off and transition to the work with the black oil sustain increased the incomplete burning as much as 26% i.e. twice, again. And finally the control measurement in several hours presented the same level of the incomplete burning as it was prior to the SPI activation.

Thus, using in optimum regime the systems of plasma ignition in the case of sustain of boiler burning allows not only to exclude or decrease black oil consumption but also to save a significant amount of coal two and more times due to the incomplete burning decrease.

5. Discussion

To explain the reasons of the boiler unstable opera tion at decreasing heat load certain heat evalua tions have been made. At the average plasmatorch power of 40 kW the contribution of the plasmatorch is 0.32% from the burner power, and as for the total plasma system it is 0.16% from the boiler power. According to[2] for the stable work of SPI at the similar coal characteristics, the plasmatorch power must be at least 0.5% from the burner power i.e. twice higher than the given one. Besides, let us compare the heat contribu tion of the black oil sprayers and the SPI muffle. The heat power of the black oil sprayer(at complete combustion) is 2.5 MW at black oil flow rate of 250 kg/hour. To guarantee the same power the coal flow rate through the SPI muffle should be about 400 kg/hour, i.e. about 20% from the total consumption through the burner. By our evaluation it is twice less now. Thus, to reach the stable regimes of the thermal-chemical preparation of the air-fuel mixture in SPI, and the stable burning without black oil attend, it is necessary to increase the plasma system power(in boiler ignition, and in working regime settling), and air-fuel mixture flow rate through the muffle. At plasmatorch power of 40 kW it will make 1.6% from the muffle burner power in the stable burning regime i.e. the muffle burner work will be guaranteed a fortiori. In the lighting regime the plasmatorch power decrease is possible but the regime ranges may be determined in the process of prolonged experiments only.

stop. Nevertheless, the works of plasmatorch modification and several times increase of electrode lifetime are being carried out based on the experience of SPI operation. Clearly that SPI operation in coal-dust boilers is effective at the uninterrupted supply of the air-fuel mixture in the boiler burners. In the case of outage of the supply in the SPI burners(mill stop, coal wedging) the plasmatorches are not able to keep up the heat state of the boiler. For this purpose the black oil sprayers are reserved in two burners. The sprayers are activated if necessary.

6. Plasma ignition of water-coal fuel

Increasing attention to the new type of ecologically clean fuel water-coal fuel initiated widening investiga tions of its effective utilization. Necessity in increasing of completeness of fuel combustion in small volume of boiler is required in the first reliable ignition and steady-stable burning of fuel. For this purpose the investigations of plasma ignition of water-coal fuel were carried out[5-8]. Recently a great experience in production and utilization of water-coal fuel is accumulated in Russia and other countries, such as Canada. Water-coal suspension, which consist of 30-50% of water and 70-50% of disperse coal dust is a peculiar fuel, analogous in many respects to viscous liquid fuel boiler black oil. Experience in it combustion at different boilers and experimental stands showed, that technology of water-coal fuel burning considerab ly differ from the same of solid dry and humid fuels. Such the temperature of ignition of water-coal fuel is twice less than of coal-dust fuel and it weakly depends on volatile matter of coal. Ratio of carbon combustion reached 98.5-99.5% for water-coal fuel. Burning of water-coal fuel in optimal conditions does not demand of heat supply from outside source for its stabilization. Thus, water coal fuel is the new type of fuel, combined many quality of liquid and solid fuels. The burner for combustion of water-coal fuel by using of plasma ignition system included the same main elements such a serial water- coal burner[7,8]: primary furnace muffle with heat insulating wall: plasma torch, which placed at the muffle for primary heating of muffle wall and ignition of spraying water-coal fuel; injector, which placed at front side of muffle for water-coal fuel injection; system of air injection. Plasma torch is used in this system instead of ignition black oil burner.

Ignition of water-coal burner with SPI using is carried out in the following way: at the first the plasma torch switched on and heating of muffle wall carried out. The fuel and air feeding systems are shutoff in this period. After the wall heating up to the temperature above the water-coal fuel ignition temperature the systems of air feeding and fuel injector switched on at low flow rates. After the ignition of water-coal fuel the working parameters of fuel and air injections are set. When the steady-stable burning of fuel will be reached the plasma torch power may be decreased or plasma torch may be switched off.

Experimental examinations of SPI at water-coal fuel burner were carried out in 1997[5,6]. Experimental burner was in work more than 2 hours at the condi tions: water-coal fuel composition was not optimal 53% of coal and 47% of water, fuel flow rate 150 kg/h, temperature of muffle end wall 1,000-1,100°C. SPI was in work only in the primary stages, in the case of steady-stable burning plasma torch was switched off.

At present the demonstration and industrial installa tions of water-coal fuel combustion with using of SPI are working in Kemerovo region. This elaboration is under the protection of Russian Federation patents [7,8].

7. Conclusion

1. The experiments carried out in the boilers K-50-14/250 with the systems of plasma ignition and stabilization of coal-dust fuel burning have shown the possibility and efficiency of application of these systems in thermal-clamping boilers.

2. Both economical problems(black oil consump tion and incomplete fuel burning) and ecological prob lems(sulfur, dioxide, nitrogen oxide, and other air pollution gases which are typical gases emitted from the coal combustion) may be solved. The final result of the work should be the exclusion or decrease of a black oil system.

3. The investigations of SPI were carried out in the real heat power stations for the different climate conditions of Siberia.

4. Analogous plasma ignition systems were elaborat ed and saved by RF patents for ignition and stabiliza

tion of the water-coal fuel burners.

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