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(54) **METHOD FOR OPTIMIZING THE COMBUSTION PROCESS OF A HYDROCARBON FUEL IN A BOILER**

(57) The invention relates to methods for combusting hydrocarbon fuel of variable composition. A method for optimizing the combustion process of a hydrocarbon fuel in a boiler comprises continuously measuring the fuel-consumption rate in the boiler and the heat flow rate in a heat transfer medium at the outlet of the boiler, determining deviations of the measured values from initially measured values and subsequently adjusting the air-consumption rate, and determining the specific fuel-consumption rate for generating 1 Gcal of heat, wherein a one-time discrete increase of the air-consumption

rate is carried out at the beginning of the optimization of the fuel combustion process, and, if the heat flow rate increases, the air continues to be increased until the point at which the heat flow rate begins to decrease, and, if the heat flow rate decreases, the air is decreased until the point at which the heat flow rate begins to decrease. Optimization of the combustion process of a hydrocarbon fuel in a boiler is achieved by minimizing the fuel-consumption rate for generating thermal energy transmittable to a heat transfer medium.

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Description

[0001] The invention relates to the methods for burning of hydrocarbon fuel having variable composition in heat power engineering, industrial heat-and-power engineering, industrial sectors, and housing and communal services. The invention is to be preferably used for burning the piped gas, hydrocarbon mixtures of undefined composition such as associated gas, and oil and gas production wastes.

[0002] RU Patent No. 2647940, IPC F23C 1/02, F23C 1/08, published on 21.03.2018, provides a method for automatic optimization of the burning process in a boiler, which is based on the continuous measuring the fuel consumption and the heat-carrier temperature at the heat-exchanger outlet of a fuel-burning apparatus; said method comprising one-time reduction of the fuel rate to ensure the feasibility of establishing specifically the tendency of the specific fuel combustion heat value otherwise unknown because of the arbitrary variable composition of the fuel used; further comprising the rate of heat exchanger outlet temperature change being synchronized with the change rate of the fuel rate, further comprising making simultaneous and/or non-simultaneous interconnected discrete changes in fuel consumption and air supply to the fuel-burning device according to one of the optimizing action algorithms implemented by a computer according to a predetermined program, making it possible to simplify the method for optimizing the fuel combustion process and increasing the accuracy of optimal parameters.

[0003] The disadvantage of the above technical solution is that the values of the heat-carrier temperature values at the outlet of the heat exchanger of the fuel-burning apparatus, as a parameter determining fuel consumption, do not reflect and are not an indicator of the required amount (consumed) of fuel, since the readings of only the heat-carrier temperature without measuring the amount thereof do not reflect the completeness of fuel combustion and, as a result, do not contribute to the minimization of fuel consumption.

[0004] A method for automatic optimization of hydrocarbon fuel combustion in the furnace of a drum steam boiler (RU patent No. 2425290, IPC F23N 1/02, published on 27.07.2011) was chosen as the closest analogue, said method comprising continuous measurement of parameters characterizing fuel consumption and the magnitude of heat transfer in the heat-carrier at the boiler outlet, and calculation of heat transfer introduced into the boiler furnace, determination of the deviations of the measured parameters from the optimal calculated values and the subsequent change in the air flow rate.

[0005] The indicator of the optimality of the combustion process in the above method is the boiler efficiency, which is determined by the measured values of the heat flow coming from the furnace to the boiler circulation circuit and the heat flow introduced by the fuel into the furnace. The disadvantage of the above technical solution

is that the correlation measurement of the time shift for said heat transfers and the synchronized ratio of said heat transfers do not reflect the completeness of fuel combustion and, as a result, do not contribute to the minimization of fuel consumption. Furthermore, the disadvantage of this method is the need for a large number of interrelated actions, the laboriousness and inertia of the process; further, adjustment is possible only in cases where both the gas composition and the specific heat of gas combustion are predetermined and known.

[0006] The **object** of the present invention is to develop a method for optimizing the hydrocarbon fuel combustion process.

[0007] The technical result is to optimize the hydrocarbon fuel combustion process in a boiler by achieving the minimum fuel consumption to generate thermal energy communicated (transferred) to the heat-carrier, thus ensuring the maximum possible completeness of fuel combustion.

[0008] The technical result is achieved by the fact that the method for optimizing the hydrocarbon fuel combustion in a boiler comprises: measuring continuously fuel consumption in the boiler and the magnitude of heat transfer in the heat-carrier at the outlet of the boiler, determining deviations of measured values from initially measured values, followed by changing air flow rate depending on the increase or a decrease in the rate of heat transfer, further comprising, on the basis of the measured values, determining the specific fuel consumption per 1 Gcal of heat by way of calculating the ratio of fuel consumption to the magnitude of heat transfer in the heat-carrier at the outlet of the boiler, further comprising, at the beginning of the optimization of the fuel combustion process, performing a one-time discrete increase in the air flow rate to determine the tendency of the value of the rate of heat transfer in the heat-carrier to increase or decrease, further comprising, to obtain an optimal fuel-air ratio, with an increase in the magnitude of heat transfer, continuing the increase in the air flow until the rate of heat transfer begins to decrease, and with a decrease in the magnitude of heat transfer, reducing the air flow until the rate of heat transfer begins to decrease.

Brief description of drawings

[0009] The invention will further be illustrated by the following drawings.

Fig. 1 is a schematic block diagram of the method for optimizing hydrocarbon fuel combustion process in a boiler.

Fig. 2 is a diagram of the method for optimizing hydrocarbon fuel combustion process with reduced specific consumption of hydrocarbon fuel per 1 Gcal of heat.

Fig. 3 is a diagram of the method for optimizing hy-

hydrocarbon fuel combustion process with increased specific consumption of hydrocarbon fuel per 1 Gcal of heat.

Fig. 4 is a schematic block diagram of the method for optimizing hydrocarbon fuel combustion process in a boiler, industrially implemented at the Kichuy boiler facility.

[0010] The schematic block diagrams shown in Fig. 1 and 4 use the following designations:

- 1-boiler;
- 2-fuel supply regulator;
- 3-fuel flow meter;
- 4-air flow regulator;
- 5-heat carrier temperature sensor at the inlet to the heat exchanger;
- 6-heat carrier temperature sensor at the outlet from the heat exchanger;
- 7-heat-carrier flow sensor;
- 8-heat meter for measuring the amount of heat;
- 9-personal computer with special software.

Embodiments of invention

[0011] The present method is implemented as follows: The method for optimizing the hydrocarbon fuel combustion in a boiler may use associated petroleum gas of variable composition as fuel, and atmospheric air as an oxidizing agent.

[0012] Prior to implementation of the present method for optimizing the hydrocarbon fuel combustion, the boiler 1 is adjusted to the power specified by the consumer in accordance with the boiler performance chart.

[0013] After the combustion process has begun and the required amount of heat is supplied to the consumer, with a constant initially set fuel supply, at the command of the computer 9, the air flow regulator 4 produces a one-time discrete increase in the air flow.

[0014] Next, using the measured values of the temperature of the heat-carrier at the inlet of the boiler 1 using the sensor 5 and at the outlet of the boiler 1 using the sensor 6, as well as using the values of the mass of the passing heat-carrier measured by the sensor 7, the heat meter 8 determines the deviation of the magnitude of heat transfer communicated to the heat-carrier from the initially set value.

[0015] Thus, the initial one-time discrete increase in the air flow rate makes it possible to assess the tendency

for the value of the rate of heat transfer to change relative to the initially set value, i.e. it allows one to determine the point from which the regulation process begins (Point 1 in Fig. 2 and Fig. 3).

[0016] Next, depending on the change (increase or decrease) in the magnitude of heat transfer, actions are taken to ensure the optimal performance of fuel combustion with the achievement of the minimum specific fuel consumption per unit magnitude of heat transfer.

[0017] Further, two options for changing the combustion process are possible.

[0018] If, after a one-time discrete increase in air flow, there is a decrease in the specific hydrocarbon fuel consumption per 1 Gcal of heat, the computer 9 issues a command to the air flow regulator 4 to step-by-step increase the air flow (Point 2 in Fig. 2), and each time the next increase in the air flow, the computer 9 calculates the specific fuel consumption and compares the change thereof with the previous value.

[0019] The increase in the air flow rate occurs until the computer 9 detects the beginning of the increase in the specific fuel consumption (Point 3 of Fig. 2).

[0020] At this moment, a command to stop the increase in the amount of supplied air is transmitted from the computer 9 to the air flow regulator 4, and thereafter a command to decrease the amount of supplied air by one increment (Point 4 in Fig. 2) is issued. The point 4 will be the point of the optimal fuel-air ratio at a given time when the maximum heating capacity of the boiler with a given amount of fuel consumed and the minimum specific hydrocarbon fuel consumption per 1 Gcal of heat are achieved.

[0021] If, after a one-time discrete increase in the air flow rate, there is an increase in the specific hydrocarbon fuel consumption per 1 Gcal of heat (Point 2 in Fig. 3), a command to stop the increase in the air supply and thereafter a command to step-by-step decrease the amount of supplied air are transmitted from the computer 9 to the air flow regulator 4. Further, the computer 9 each time calculates the specific fuel consumption and compares the change thereof with the previous value.

[0022] This process will continue until the specific fuel consumption starts increasing. At this moment, the computer issues to the air flow regulator 4 (point 3 in Fig. 3) a command to stop the decrease in the amount of air and to increase air supply by one increment, that is, to return to the point of optimal fuel-air ratio (point 4 in Fig. 3).

[0023] Further operation of the fuel-burning device is carried out taking into account the optimal fuel-air ratio as determined by the above actions (optimization of the combustion process), and, in case of any changes in the magnitude of heat transfer communicated to the heat-carrier, and, accordingly, in case of changes in the specific fuel consumption per 1 Gcal of heat, the fuel combustion optimization process is repeated.

[0024] Optimization of hydrocarbon fuel combustion process according to the present method may be carried out both automatically and manually with the help of an

operator.

[0025] Following implementation of the method for optimizing hydrocarbon fuel combustion process in a boiler, it may be necessary to adjust the value of the heat transfer of the heat-carrier to achieve a value desired by the consumer.

[0026] Accordingly, with an increase in the magnitude of heat transfer above the value desired by the consumer, at the command of the computer 9, the fuel supply regulator 2 first reduces fuel consumption to the value of heat transfer in the heat carrier as desired by the consumer, thereafter the air flow regulator 4 reduces air flow rate until the magnitude of heat transfer begins to decrease.

[0027] Accordingly, with a decrease in the value of heat transfer as desired by the consumer, at the command of the computer 9, the fuel supply regulator 2 first increases fuel consumption to generate the magnitude of heat transfer in the heat carrier as desired by the consumer, thereafter the air flow regulator 4 increases air flow rate until the increase in the magnitude of heat transfer stops. Further, the air supply is adjusted without measuring the amount of the air, i.e. without measuring the absolute magnitude of air flow.

[0028] After reaching the optimal fuel combustion performance, the boiler 1 continues to operate at the set amount of supplied fuel and air until the next change in the specific fuel consumption occurs, indicating that there have been changes in external conditions.

Example of implementation of the method

[0029] The method for optimizing hydrocarbon fuel combustion process is implemented on the boiler 1 (Fig. 4) DE 10-14 (OJSC TATNEFT, city of Kichuy).

[0030] First, the boiler 1 (Fig. 4) is fired up and brought to the required performance according to the boiler performance chart, which specifies the fuel-air ratio under various operating conditions of the boiler.

[0031] After bringing the boiler 1 to the desired power, the method for optimizing hydrocarbon fuel combustion is initiated. To this end, at the command of the computer 9, the air flow regulator 4 produces a one-time discrete increase in the air flow in the range from 0.01% to 2% of the total volume of the supplied air (while the fuel supply remains constant).

[0032] Next, the heat meter 8 (Krohne VHV 310) with the help of sensors 5, 6 and 7, which are set to measure the temperature values of the heat-carrier at the inlet of the boiler 1, at the outlet of the boiler 1, and to determine the mass of the passing heat-carrier, respectively, determines the current value of the magnitude of heat transfer communicated to the heat-carrier. This magnitude of heat transfer is transferred to the computer 9.

[0033] Then, in the event that, after a one-time discrete increase in the air flow rate, the magnitude of heat transfer has increased from the initial set value, a discrete increase in the air flow rate is carried out using the air

supply regulator 4 (Hyundai N300R11NF) at the command of the computer 9, until the magnitude of heat transfer decreases. Conversely, if the magnitude of heat transfer has decreased from the initial set value, a discrete reduction in the air flow rate is carried out by means of the air supply regulator 4 at the command of the computer 9, until the magnitude of heat transfer increases.

[0034] The computer 9 transmits an appropriate command to the air flow regulator 4 based on calculating the specific hydrocarbon fuel consumption per unit of heat (1 Gcal) communicated to the heat-carrier, and based on comparing this value with the previous calculation result (every 3 seconds). Thus, the optimal fuel-air ratio is determined.

[0035] Following implementation of the method for optimizing hydrocarbon fuel combustion process in a boiler, it may be necessary to adjust the value of the heat transfer of the heat-carrier to achieve a value desired by the consumer.

[0036] In this case, with an increase in the magnitude of heat transfer above the value desired by the consumer, at the command of the computer 9, the fuel supply regulator 2 first reduces fuel consumption to the value of heat transfer in the heat carrier as desired by the consumer, thereafter the air flow regulator 4 reduces air flow rate until the magnitude of heat transfer begins to decrease.

[0037] Accordingly, with a decrease in the value of heat transfer as desired by the consumer, at the command of the computer 9, the fuel supply regulator 2 first increases fuel consumption to generate the magnitude of heat transfer in the heat carrier as desired by the consumer, thereafter the air flow regulator 4 increases air flow rate until the increase in the magnitude of heat transfer stops. Further, the air supply is adjusted without measuring the amount of the air, i.e. without measuring the absolute magnitude of air flow.

[0038] The magnitude of fuel consumption is measured by the fuel consumption meter 3 (gas meter SG-800) and stored in the computer memory 9.

[0039] Tests have shown that the industrial application of the present technical solution has provided:

- reduction of hydrocarbon fuel consumption by 7% during the combustion of piped gas, and by 30% during the combustion of associated petroleum gas with oil refinery waste, depending on the supply of a particular fuel composition;
- increase in the completeness of fuel combustion (absence of combustion and underburning of fuel in boilers),
- reduction of labor intensity of the fuel combustion optimization process due to the reduction of the number of measurements and, accordingly, the reduction of the number of measuring instruments and auxiliary equipment used.

[0040] Significant reduction in the number of operations reduces the complexity of optimization, simplifies the optimization process, increases fuel efficiency (minimizes fuel consumption), expands the scope of application of fuel-burning devices for thermal utilization of industrial waste.

[0041] The fuel combustion optimization process is carried out continuously throughout the life of the boiler. The present method ensures the operation of the boiler under optimal performance with minimal environmental damage, as the fuel is completely combusted.

[0042] The present technical solution may be implemented in the operation of fuel combustion devices using gaseous, liquid and solid fuels. The method is implemented with the use of publicly available means of measurement and automation, personal computers.

[0043] A significant difference between the present technical solution and known ones is that the indicators of combustion process optimization are not the efficiency of the boiler and the temperature of the heat-carrier at the boiler outlet, but the ratio of the magnitude of fuel consumption to the magnitude of heat transfer in the heat-carrier at the boiler outlet to generate 1 Gcal of heat.

[0044] The method seeking a patent is simple and reliable in use, adapts to any existing systems, is based on simple and reliable devices of domestic production; is not subject to influence of: a condition of boilers, condition of air ducts, condition of chimneys and burning devices; allows to regulate the combustion for each burning device in multiburner boilers. Further, the method when in the automatic mode provides values of heat transfer of the heat-carrier (steam or hot water) set by the consumer.

Claims

1. A method for optimizing hydrocarbon fuel combustion process in a boiler, comprising: measuring continuously fuel consumption in the boiler and the magnitude of heat transfer in the heat-carrier at the outlet of the boiler, determining deviations of measured values from previous values, followed by changing air flow rate depending on the increase or a decrease in the rate of heat transfer, **characterized in that** it further comprises, on the basis of the measured values, determining the specific fuel consumption per 1 Gcal of heat by way of calculating the ratio of fuel consumption to the magnitude of heat transfer in the heat-carrier at the outlet of the boiler, further comprising, at the beginning of the optimization of the fuel combustion process, performing a one-time discrete increase in the air flow rate to determine the tendency of the value of the rate of heat transfer in the heat-carrier to increase or decrease, further comprising, to obtain an optimal fuel-air ratio, with an increase in the magnitude of heat transfer, continuing the increase in the air flow until the rate of heat transfer begins to decrease, and with a decrease in

the magnitude of heat transfer, reducing the air flow until the rate of heat transfer begins to decrease.

2. The method for optimizing hydrocarbon fuel combustion process in a boiler as claimed in Claim 1, **characterized in that** it further comprises, upon increasing the magnitude of heat transfer above the magnitude desired by the consumer, reducing the fuel consumption to generate the magnitude of heat transfer in the heat-carrier desired by the consumer and further reducing the air flow until the heat transfer is reduced, and, upon reducing the magnitude of heat transfer below the magnitude desired by the consumer, increasing fuel consumption to generate the magnitude of heat transfer in the heat-carrier desired by the consumer and further increasing air flow rate until the magnitude of heat transfer stops growing and the magnitude of heat transfer desired by the consumer is reached.
3. The method for optimizing hydrocarbon fuel combustion process in a boiler as claimed in Claim 1, **characterized in that** it further comprises, upon changes in the magnitude of heat transfer communicated to the heat-carrier occur, repeating the fuel combustion optimization process.

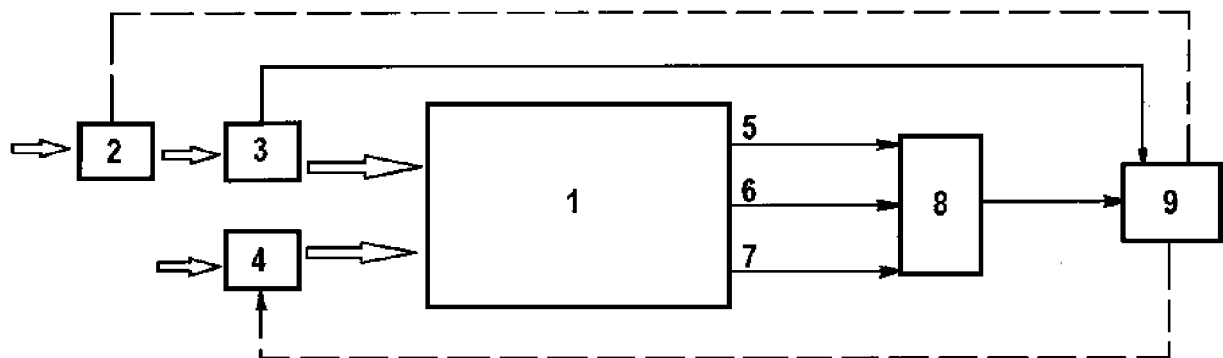


Fig. 1

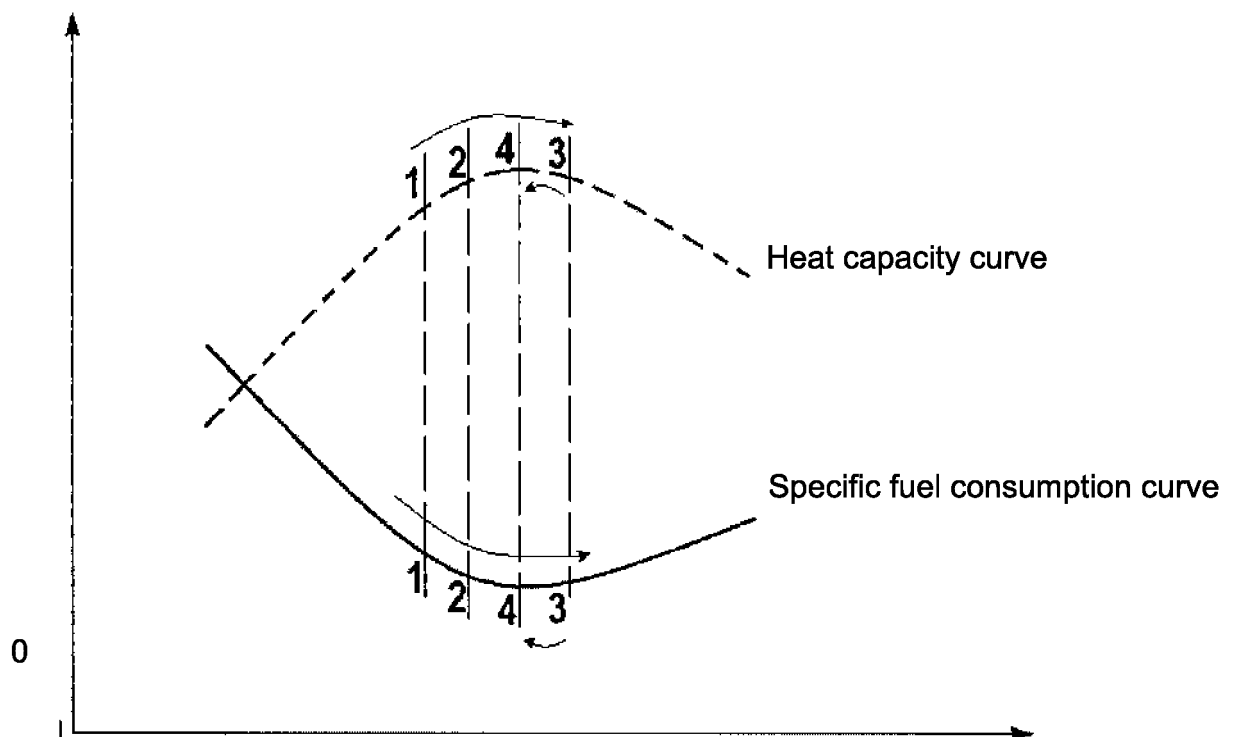


Fig. 2

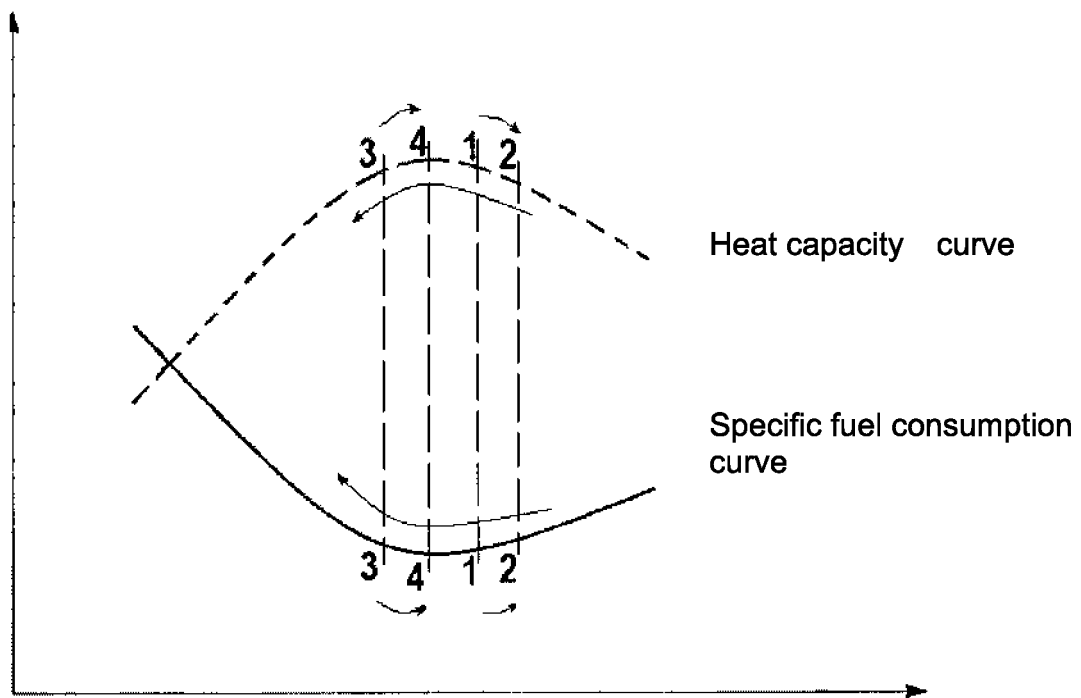


Fig. 3

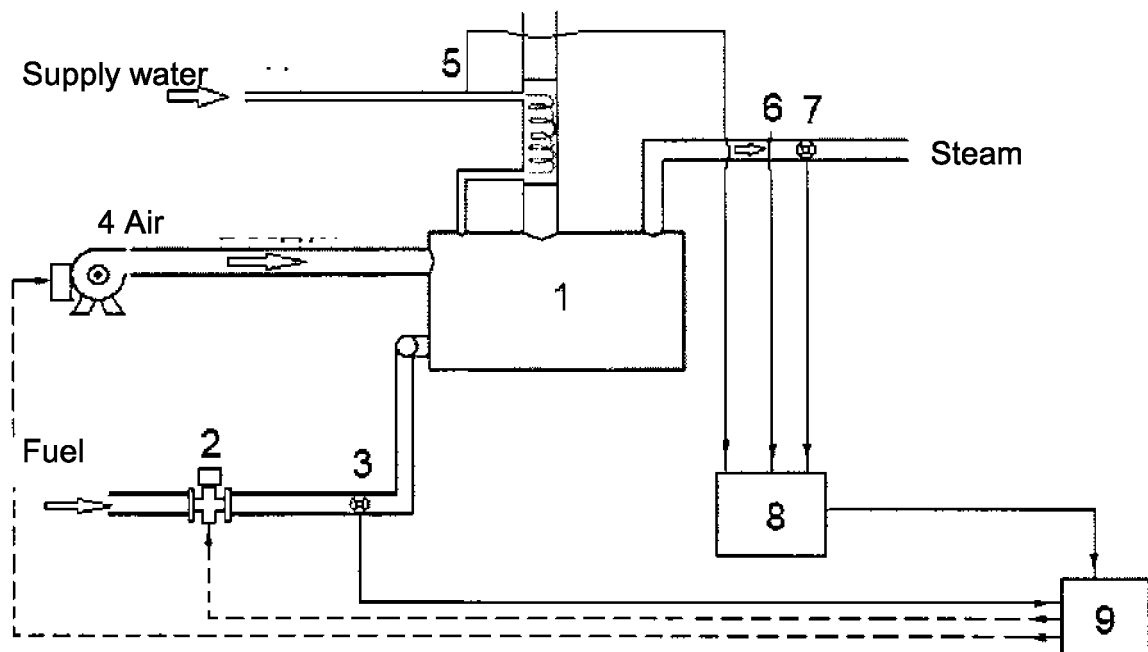


Figure 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/RU 2021/000081

A. CLASSIFICATION OF SUBJECT MATTER F23N3/00 (2006.01); F23N 1/00 (2006.01) According to International Patent Classification (IPC) or to both national classification and IPC															
B. FIELDS SEARCHED															
Minimum documentation searched (classification system followed by classification symbols) F23N 1/00, 1/02, 3/00, 5/00, 5/20 - 5/26															
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched															
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE															
C. DOCUMENTS CONSIDERED TO BE RELEVANT															
<table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>A, D</td> <td>RU 2425290 C2 (OTKRYTOE AKTSIONERNOE OBSHESTVO MAGNITOGORSKY METALLURGICHESKY KOMBINAT") 27.07.2011</td> <td>1-3</td> </tr> <tr> <td>A</td> <td>RU 2015131367 A (FEDERALNOE GOSUDARSTVENNOE AVTONOMNOE OBRAZOVATELNOE UCHREZHDENIE VYSSHEGO OBRAZOVANIYA "KAZANSKY (PRIVOLZHSKIY) FEDERALNY UNIVERSITET) 02.02.2017</td> <td>1-3</td> </tr> <tr> <td>A</td> <td>RU 2357153 C2 (OOO "ENERGOPROMNALADKA") 27.05.2009</td> <td>1-3</td> </tr> <tr> <td>A</td> <td>US 9506649 B2 (FISHER-ROSEMOUNT SYSTEMS, INC.) 29.11.2016</td> <td>1-3</td> </tr> </tbody> </table>	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	A, D	RU 2425290 C2 (OTKRYTOE AKTSIONERNOE OBSHESTVO MAGNITOGORSKY METALLURGICHESKY KOMBINAT") 27.07.2011	1-3	A	RU 2015131367 A (FEDERALNOE GOSUDARSTVENNOE AVTONOMNOE OBRAZOVATELNOE UCHREZHDENIE VYSSHEGO OBRAZOVANIYA "KAZANSKY (PRIVOLZHSKIY) FEDERALNY UNIVERSITET) 02.02.2017	1-3	A	RU 2357153 C2 (OOO "ENERGOPROMNALADKA") 27.05.2009	1-3	A	US 9506649 B2 (FISHER-ROSEMOUNT SYSTEMS, INC.) 29.11.2016	1-3
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☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.															
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"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family														
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Patent documents cited in the description

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- RU 2425290 [0004]