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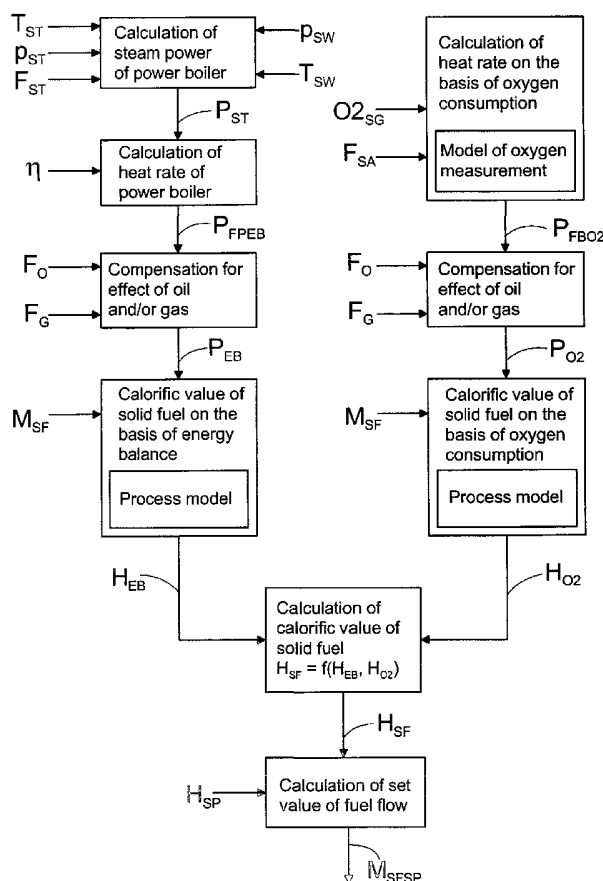
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(54) Title: METHOD AND APPARATUS IN CONNECTION WITH A POWER BOILER



(57) Abstract: A method and an apparatus in connection with a power boiler (1) for determining a variable expressing the fuel power of solid fuel (SF) to be fed to the power boiler (1). The variable expressing the fuel power of the solid fuel (SF) to be fed to the power boiler (1) is determined on the basis of the heat rate (P_{PB}) of the solid fuel (SF) determined from the energy balance (EB) of the power boiler (1) and the heat rate (P_{O2}) of the solid fuel (SF) determined from the oxygen consumption (O2) of the power boiler (1).



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METHOD AND APPARATUS IN CONNECTION WITH A POWER BOILER**FIELD OF THE INVENTION**

[0001] A method in connection with a power boiler, in which method a variable expressing the fuel power of solid fuel to be fed to the power boiler is determined.

[0002] Further, the invention relates to an apparatus in connection with a power boiler, which apparatus is arranged to determine a variable expressing the fuel power of solid fuel to be fed to the power boiler.

BACKGROUND OF THE INVENTION

[0003] The generation of electric and heat energy in power boilers of power plants is based on fuel burning taking place in power boilers. Fuels used in power boilers include oil, gas and solid fuels. Solid fuels include coal, peat, biofuels as well as different municipal wastes and sorted wastes. The operating principle of a power boiler can be based on combusting only oil, gas or solid wastes, but often different fuels can be combusted in the same power boiler. The combustion techniques of power boilers combusting solid fuels can vary. Presently, the most common combustion techniques of power boilers combusting solid fuels are pulverized fuel combustion, grate combustion and fluidized bed combustion.

[0004] Variations in the quality and the feed of solid fuel cause a problem in power boilers using solid fuel, resulting in variation in the fuel power of the solid fuel. Instead of the direct value of the fuel power, the fuel power of solid fuel can be expressed as the heat rate of solid fuel or the calorific value of solid fuel obtained on the basis of the heat rate and of the measurements of the amount of fuel to be fed. The amount of solid fuel to be fed to the power boiler is controlled on the basis of the fuel power of the fuel. Variation in the fuel power of the fuel makes it more difficult to control the amount of fuel to be fed to the boiler in such a way that the desired power is achieved. The variation in the quality of solid fuel may be due to the properties of the fuel sources, such as variation in the properties of different coal types. Also variation in the humidity of the fuel causes variation in the quality of the fuel. The humidity of the fuel can be measured in a laboratory, but it takes too long to determine the humidity in order to use this information in controlling the fuel feeding efficiently. Variations in the fuel feeding are, in general, due to disturbances in fuel feeding systems. Although the amount of fuel to be fed to

the boiler can be measured reliably, determining the fuel power of the fuel in a laboratory takes about 24 hours, which is again too long a time for efficient control of the fuel feeding.

[0005] The heat rate of solid fuel is calculated either on the basis of the energy balance of the power boiler or on the basis of the oxygen consumption of the power boiler. With neither manner of calculation is it possible, however, to determine the heat rate or calorific value of the solid fuel to be fed to the power boiler in such a way that the fuel feeding could be controlled accurately. When the heat rate or calorific value of the fuel is calculated on the basis of the energy balance of the power boiler, a problem is caused by the long delays due to the water store and heat exchange of the power boiler, whereby the final result must be filtered quite a lot so that the process dynamics would not affect the calculation. When the heat rate or calorific value of the fuel is calculated on the basis of the oxygen amount bound to the burning, the problem is the inaccuracy and unreliability of the determined final result.

[0006] US publication 4 909 037 discloses a method of controlling the fuel feeding of a coal boiler on the basis of the direct energy balance of the boiler. In the method, the boiler output is determined on the basis of the steam pressure, the amount of fuel to be fed to the boiler is measured, and the desired boiler output is determined for the boiler. On the basis of the measured boiler output and the desired boiler output, an error signal is calculated on the basis of which the fuel feeding is controlled. However, the problems caused for the use of power boilers by variations in the quality of the fuel or feeding disturbances are not taken sufficiently into consideration in the solution of the publication.

BRIEF DESCRIPTION OF THE INVENTION

[0007] An object of the present invention is to provide a novel and more accurate method and apparatus than previously for determining a variable expressing the fuel power of solid fuel.

[0008] The method according to the invention is characterized by determining the heat rate of the solid fuel fed to the power boiler on the basis of the energy balance of the power boiler; determining the heat rate of the solid fuel fed to the power boiler on the basis of the oxygen consumption of the power boiler; and determining the variable expressing the fuel power of the

solid fuel to be fed to the power boiler on the basis of the heat rate of the solid fuel determined from the energy balance of the power boiler and the heat rate of the solid fuel determined from the oxygen consumption of the power boiler.

[0009] Further, the apparatus according to the invention is characterized in that the apparatus is arranged to determine the heat rate of the solid fuel fed to the power boiler on the basis of the energy balance of the power boiler; to determine the heat rate of the solid fuel fed to the power boiler on the basis of the oxygen consumption of the power boiler; and to determine the variable expressing the fuel power of the solid fuel to be fed to the power boiler on the basis of the heat rate of the solid fuel determined from the energy balance of the power boiler and the heat rate of the solid fuel determined from the oxygen consumption of the power boiler.

[0010] According to an essential idea of the invention, the variable expressing the fuel power of the solid fuel to be fed to the power boiler is determined by determining the heat rate of the solid fuel fed to the power boiler on the basis of the energy balance of the power boiler; determining the heat rate of the solid fuel fed to the power boiler on the basis of the oxygen consumption of the power boiler; and determining the variable expressing the fuel power of the solid fuel to be fed to the power boiler on the basis of the heat rate of the solid fuel determined from the energy balance of the power boiler and the heat rate of the solid fuel determined from the oxygen consumption of the power boiler. The heat rate or calorific value of the solid fuel, for instance, can be used as the variable expressing the fuel power of the solid fuel. According to an embodiment of the invention, the amount of solid fuel to be fed to the power boiler is further controlled on the basis of the variable expressing the fuel power of the solid fuel to be fed to the power boiler. According to a second embodiment of the invention, the calorific value of the solid fuel to be fed to the power boiler is determined by determining the amount of solid fuel fed to the power boiler; determining the calorific value of the solid fuel fed to the power boiler on the basis of the heat rate of the solid fuel determined from the energy balance of the power boiler and the amount of solid fuel fed to the power boiler; determining the calorific value of the solid fuel fed to the power boiler on the basis of the heat rate of the solid fuel determined from the oxygen consumption of the power boiler and the amount of solid fuel fed to the power boiler; and determining the calorific value of the solid fuel to be fed to the power boiler on the basis of the calorific value of the solid fuel

determined from the energy balance of the power boiler and the calorific value of the solid fuel determined from the oxygen consumption of the power boiler. According to a third embodiment of the invention, the heat rate of the solid fuel fed to the power boiler is determined on the basis of the energy balance of the power boiler by determining the steam power of the power boiler and determining the heat rate of the power boiler on the basis of the steam power of the power boiler and the combustion efficiency of the power boiler. Further, according to a fourth embodiment of the invention, the effect of one or more fuels fed to the power boiler and having known fuel power on the heat rate determined from the energy balance of the power boiler is modelled; and on the basis of the modelling, the effect of one or more fuels fed to the power boiler and having known fuel power on the heat rate of the power boiler is compensated for. According to a fifth embodiment of the invention, the effect of the amount of solid fuel fed to the power boiler on the steam power of the power boiler is modelled; and on the basis of the modelling, the calorific value of the solid fuel fed to the power boiler is determined from the heat rate of the solid fuel fed to the power boiler. According to a sixth embodiment of the invention, the heat rate of the solid fuel fed to the power boiler is determined on the basis of the oxygen consumption of the power boiler in such a way that the oxygen consumption of the power boiler is determined on the basis of the oxygen content of flue gases, and the heat rate of the power boiler is determined on the basis of the oxygen consumption of the power boiler. Further, according to a seventh embodiment of the invention, the effect of one or more fuels fed to the power boiler and having known fuel power on the heat rate of the power boiler determined from the oxygen consumption is modelled, and on the basis of the modelling, the effect of one or more fuels fed to the power boiler and having known fuel power on the heat rate of the power boiler is compensated for. According to an eighth embodiment of the invention, the effect of the amount of solid fuel fed to the power boiler on the heat rate determined from the oxygen consumption of the power boiler is modelled; and on the basis of the modelling, the calorific value of the solid fuel fed to the power boiler is determined from the heat rate of the solid fuel fed to the power boiler.

[0011] An advantage of the invention is that the fuel power of the solid fuel to be fed to the power boiler can be determined quickly and accurately. The invention thus combines the advantages of the fuel power

determined on the basis of the energy balance of the power boiler and those of the fuel power determined on the basis of the oxygen consumption of the power boiler. The fuel power of the solid fuel determined from the energy balance is very accurate, and on the basis of the oxygen consumption, the fuel power of the solid fuel can be determined very quickly. By compensating for the effect of the fuels having known fuel powers on the heat rate of the power boiler, the solution can also be used in connection with such power boilers where not only solid fuel but also oil and/or gas, for example, is combusted. Modelling the effect of the amount of solid fuel fed to the power boiler on the steam power of the power boiler allows the delay relating to the fuel ignition, burning and boiler masses as well as the time constant in the heat exchange of the boiler to be taken into account. Correspondingly, modelling the effect of the amount of solid fuel fed to the power boiler on the heat rate determined from the oxygen consumption of the power boiler allows the delay relating to the fuel ignition and burning to be taken into account in the calorific value of the solid fuel calculated on the basis of the oxygen consumption. Further, on the basis of the quick and accurate fuel power of the solid fuel, the amount of solid fuel to be fed to the power boiler can be controlled accurately.

BRIEF DESCRIPTION OF THE FIGURES

[0012] The invention will now be explained in more detail with reference to the attached drawings, of which

Figure 1 shows schematically a side view of a power boiler; and

Figure 2 shows schematically a solution for determining the calorific value of solid fuel to be fed to a power boiler.

DETAILED DESCRIPTION OF THE INVENTION

[0013] Figure 1 shows schematically a side view of a power boiler 1, in connection with which the solution for determining a variable expressing the fuel power of solid fuel SF to be fed to a power boiler, such as heat rate P_{SF} [MW] or calorific value H_{SF} [MJ/JG], can be used. The calorific value H_{SF} of the solid fuel SF is a variable which is not an absolute value but which is proportioned to the feeding amount of fuel, i.e. to a signal expressing the fuel flow, whereby other typical units expressing the calorific value H_{SF} of the solid fuel SF include [MJ/kg], [MJ/%], [MJ/m³]. The power boiler 1 shown in Figure 1 is a fluidized bed boiler, in the furnace 2 of which there is a sand bed 3 functioning as the grate of the boiler 1. Further, the power boiler according to

Figure 1 comprises a drum 4, an evaporator 5, a superheater 6 and a flue gas duct 7. The solid fuel SF of the power boiler 1 is fed to the furnace 2 of the power boiler 1 above the sand bed 3 along a supply channel 8 for the solid fuel SF. The fuel can be fed to the power boiler 1 by using, for example, a feed screw 9, which is driven by a motor 10. A large variety of fuels of different types can be used as the solid fuel SF, for instance coal, peat, biofuels and different municipal wastes or sorted wastes. The solid fuel SF to be fed to the power boiler 1 may comprise only one fuel type, or the fuel to be fed may comprise several fuel types that have been mixed with each other or that have mixed with each other. In addition to the solid fuel SF, also oil or gas may be used as the fuel.

[0014] Further, the power boiler 1 comprises an air duct 11, along which burning air BA used for fuel combustion and blast air PA needed for fluidizing the sand bed 3 in the boiler 1 are conducted to the power boiler 1. The burning air BA required for combusting fuel is conducted above the sand bend along a first branch 11a of the air duct 11, the blast air PA fluidizing the sand bed 3 being conducted below the sand bed along a second branch 11b of the air duct 11. The blast air PA fluidizing the sand bed 3 naturally also functions as the burning air of the power boiler. The burning air BA and the blast air PA form together supply air SA to be fed to the power boiler 1, and the supply air SA is conducted to the power boiler 1 via a supply-air SA economizer 12 arranged in the flue gas duct 7, the supply-air (SA) economizer 12 using heat energy of flue gases SG generated in the fuel burning for heating the supply air SA. Further, the power boiler 1 comprises a supply water line 13 for feeding supply water SW to the drum 4. The supply water line 13 is conducted through a supply-water SW economizer 14 arranged in the flue gas duct 7, and the supply water SW is heated in the economizer close to the saturation point with heat energy of the flue gases SG. From the drum 4, the supply water SW is conducted in the direction of arrow A to the evaporator 5, where the energy generated when the fuel burns vaporizes the supply water SW into steam ST. From the evaporator 5, the steam ST returns to the drum 4. From the drum 4, the steam ST is further conducted through the superheater 6 arranged in the flue gas duct 7 along a steam channel 15 to a turbine outside the power boiler 1, which turbine rotates a generator. From the turbine, the steam ST is conducted to a condenser, where it condenses into water and from where it is usually further returned to the drum 4 as supply water SW. For

the sake of clarity, Figure 1 does not show the turbine, the generator or the condenser, nor one or more preheaters possibly comprised by the power boiler 1.

[0015] Figure 1 shows schematically the structure of one exemplary power boiler 1. The structure and operating principle of the power boiler 1 can vary in a plurality of ways. Instead of the fluidized bed boiler of Figure 1, for instance a circulating bed boiler can be used as the power boiler 1, in which case the blast air PA is fed as such an intensive flow to the furnace 2 of the power boiler 1 that it carries sand and fuel with it from the furnace 2, whereby the solid particles that have exited from the furnace with the blast must be separated in a particular separator and returned to the furnace. Any other boilers intended for combusting solid fuels can also be used as the power boiler 1. Further, the drum 4 in connection with the boiler can be replaced with flow-through of supply water SW, in which case the boiler is a once-through boiler. The structure and operating principle of different power boilers are known as such to a person skilled in the art, and they are not described in more detail here.

[0016] Figure 2 and the following example show schematically, in the form of a block diagram, one solution for determining a variable expressing the fuel power of the solid fuel SF to be fed to the power boiler 1. In Figure 2 and the example, the fuel power of the fuel is expressed as a calorific value H_{SF} of the fuel, which is determined by means of both the calorific value H_{EB} of the solid fuel determined from the energy balance EB of the power boiler 1 and the calorific value H_{O_2} of the solid fuel determined from the oxygen consumption O_2 of the power boiler 1.

[0017] When the calorific value of the solid fuel SF is determined on the basis of the energy balance of the power boiler 1, the first step is to determine the steam power P_{ST} [MW] of the power boiler 1. The steam power P_{ST} of the power boiler 1 is determined on the basis of the difference between the enthalpies of the supply water SW of the power boiler 1 and of the steam ST exiting from the power boiler 1, as well as the flow of the steam ST. The enthalpy of the supply water SW of the power boiler 1 is calculated on the basis of the temperature T_{SW} [°C] and the pressure p_{sw} [MPa] of the supply water SW. The temperature T_{SW} [°C] and the pressure p_{sw} [MPa] of the supply water SW are measured with temperature and pressure sensors known as such from the supply water line 13 before feeding the supply water to the

power boiler 1, i.e. in the case of Figure 1 before the economizer 14 of the supply water. The enthalpy of the steam ST exiting from the power boiler 1 is calculated on the basis of the temperature T_{ST} [°C] and the pressure p_{ST} [MPa] of the steam ST, which variables are measured with temperature and pressure sensors known as such from the steam channel 15 after the superheater 6. If the power boiler comprises one or more preheaters, their effect is taken into account also in the determination of the power P_{ST} of the steam ST. Multiplying the enthalpy difference of the steam ST and the supply water SW by the volume [kg/s] of the steam ST flow yields the steam power P_{ST} of the power boiler 1.

[0018] Dividing the steam power P_{ST} of the power boiler 1 with the combustion efficiency η yields the heat rate P_{FPB} [MW] of the power boiler 1 on the basis of the energy balance of the power boiler 1. The heat rate P_{FPB} of the power boiler 1 is thus the energy difference between the superheated steam ST and the supply water SW divided by the combustion efficiency η . The heat rate P_{FPB} of the power boiler thus encompasses the heat rate of all fuels fed to the power boiler 1. If, in addition to solid fuel SF, also oil and/or gas and/or another fuel having known fuel power, such as molasses or grinding dust, is/are fed to the power boiler 1, the portion formed by them must be compensated out of the heat rate P_{FPB} of the power boiler 1 to be able to determine the heat rate P_{EB} of the solid fuel to be fed to the power boiler 1. The effect of the fuels having known fuel power in the heat rate P_{FPB} of the power boiler 1 can be compensated for by means of a model expressing their combustion. For the sake of clarity, Figure 2 only shows the compensation for the effect of oil and gas, in which case the input variables of the model are the flow volumes F_O or F_G of oil and gas and the heat rate P_{FPB} of the power boiler.

[0019] The calorific value H_{EB} of the solid fuel determined on the basis of the energy balance is obtained by dividing the above-determined heat rate P_{EB} of the solid fuel by the amount M_{SF} of solid fuel fed to the power boiler 1. The amount of solid fuel fed to the power boiler 1 is obtained on the basis of the speed of rotation of the motor 10 rotating the feed screw 9, for example.

[0020] Since the delay and time constant relating to the drum 4 and heat exchange of the power boiler 1 are long, the heat power of the fuel fed to the power boiler 1 can be seen in the steam power P_{ST} of the power boiler 1 only after a long time. The duration of the delay is typically 30 to 150 seconds,

the time constant being typically a few minutes. Therefore, the effect of the delay and the time constant must be taken into account, i.e. compensated for, when the calorific value of the fuel is determined. The common effect of the delay and the time constant is indicated here by Δt . The effect Δt of the delay and the time constant can be compensated for by means of a process model expressing the operation of the power boiler 1 and the fuel combustion. By means of the process model, the steam ST temperature $T_{ST}(t_0)$ measurement, the flow volume $F_{ST}(t_0)$ measurement and the pressure $p_{ST}(t_0)$ measurement as well as the supply water SW temperature $T_{SW}(t_0)$ measurement and the pressure p_{SW} measurement $p_{SW}(t_0)$ corresponding to a certain moment of measurement are directed at that moment of time $t_0 - \Delta t$ when the solid fuel having generated the steam power $P_{ST}(t_0)$ corresponding to the measurements has been fed to the power boiler 1. Thus, Δt corresponds to the time that it takes from moment $t_0 - \Delta t$ at which a given amount of solid fuel SF has been fed to the power boiler 1 until the moment at which the steam power $P_{ST}(t_0)$ corresponding to this amount of fuel exits from the power boiler 1. Variable Δt comprises the time from the feeding of the fuel until its ignition, the combustion time of the fuel and the time until the heat power of the fuel has changed to power P_{ST} of steam ST at the outlet of the power boiler 1. The process model is a dynamic model expressing the dynamic behaviour of the operation of the power boiler 1. The process model allows determination of the calorific value H_{EB} of the solid fuel on the basis of the energy balance EB of the power boiler 1 when the amount M_{SF} of the solid fuel fed to the power boiler 1 at moment $t_0 - \Delta t$ and the heat rate P_{EB} of the solid fuel corresponding to moment t_0 are known.

[0021] When determining the calorific value H_{O_2} of the solid fuel SF on the basis of the oxygen consumption O_2 of the power boiler 1, the oxygen amount bound to the fuel combustion, correlating to a great extent with the heat power of the fuel, is determined.

[0022] The determination of oxygen consumption is not affected by the water store, bed material or heat exchange of the boiler, but only by the delays and time constants relating to the combustion and the oxygen measurement. When the heat rate P_{O_2} of the solid fuel based on the oxygen consumption of the power boiler 1 is determined, the total amount $F_{SA}[\text{kg/s}]$ of the supply air SA fed to the boiler 1 and the oxygen content $O_{2SG} [\%]$ of the flue gases SG exiting from the boiler 1 are measured. The total amount F_{SA} of

the supply air SA to be fed to the boiler 1 can be measured for example with venturi measurement known as such from the air duct 11, in the example of Figure 1 before the economizer 12 of the supply air SA. The oxygen content O_{2SG} of the flue gases SG exiting from the boiler 1 can be measured from the flue gas duct 7 with a ZrO_2 sensor, for example. On the basis of the measurements, the heat rate P_{O_2} of the power boiler 1 calculated on the basis of the oxygen consumption of the power boiler 1 can be calculated in a manner known as such to a person skilled in the art from the formula

$$P_{O_2} = (1 - O_{2SG}/21) * F_{SA} / k, \quad (1)$$

where k is typical oxygen consumption [kg/MW] for a fuel. By means of the oxygen measurement model, the delay and time constant between the total amount F_{SA} of supply air fed to the power boiler 1 and the measurement of the oxygen content O_{2SG} of the flue gas corresponding to it can be taken into account. Typically, the effect of the delay and the time constant is about 20 to 40 seconds and depends on the dimensioning and load of the boiler. If, in addition to solid fuel, also oil and/or gas and/or another fuel having known fuel power is/are used in the power boiler 1, their effect is eliminated from the heat rate P_{O_2} of the power boiler 1 in the manner described above, which yields the heat rate P_{O_2} calculated on the basis of the oxygen consumption of the solid fuel SF.

[0023] The calorific value H_{O_2} calculated on the basis of the oxygen consumption is obtained by dividing the heat rate P_{O_2} of the solid fuel, determined above, by the amount M_{SF} of the solid fuel fed to the power boiler 1. In the same way as when calculating the heat rate H_{EB} of the solid fuel on the basis of the energy balance EB of the power boiler 1, the process model makes it possible to take into account the delay and the time constant that it takes for the fuel fed to the furnace to ignite and burn and for the flue gases generated in the combustion to flow out of the boiler 1. This process model naturally deviates from the model that is used when calculating the calorific value of the solid fuel on the basis of the energy balance EB of the power boiler 1, since the drum, bed material or heat exchange of the boiler do not affect the oxygen consumption of the power boiler 1.

[0024] The calorific value H_{SF} of the solid fuel SF to be fed to the power boiler 1 is determined from the calorific value H_{EB} of the solid fuel

determined from the energy balance EB of the power boiler 1 and from the calorific value H_{O_2} of the solid fuel determined on the basis of the oxygen consumption O_2 of the power boiler 1 as a function of the two calorific values

$$5 \quad H_{SF} = f(H_{EB}, H_{O_2}), \quad (2)$$

which function can be linear or non-linear.

[0025] The solution combines the advantages of the calorific value determined on the basis of the energy balance of the power boiler and the
10 calorific value determined on the basis of the oxygen consumption of the power boiler. On the basis of the energy consumption EB, the calorific value H_{EB} of the solid fuel can be determined very accurately; in other words, the calorific value level of the solid fuel can be determined very accurately. On the basis of the oxygen consumption, in turn, the calorific value of the solid fuel
15 can be determined very quickly, and the value is not affected by the delays and time constants caused by the boiler masses. The calorific value determined on the basis of the oxygen consumption is not quite as accurate as the calorific value determined on the basis of the energy balance, but it allows easy detection of quick changes in the calorific value H_{SF} of the solid fuel SF to be
20 fed to the power boiler.

[0026] Detecting the accurate datum level of the calorific value H_{SF} of the solid fuel SF and the quick changes in the calorific value allows, when required, an accurate and quick reaction to changes in the amount M_{SF} of the solid fuel SF to be fed to the power boiler 1. Dividing the heat power desired of
25 the power boiler 1, i.e. the set value H_{SP} of the heat power, by the calorific value H_{SF} of the solid fuel yields the desired value, i.e. set value, M_{SFSP} for the amount of solid fuel SF to be fed to the power boiler 1. On the basis of the difference between the set value M_{SFSP} and measurement M_{SF} of the solid fuel to be fed to the power boiler 1, a control signal CO_{SF} is determined in a control
30 device 17, on the basis of which signal the rotation speed of the motor 10 operating the feed screw 9, for example, is controlled, the amount of solid fuel SF to be fed to the power boiler 1 being controlled at the same time.

[0027] The calorific value H_{SF} of the solid fuel SF determined according to an embodiment is used for controlling the amount of fuel to be fed
35 to the power boiler 1 in such a way that the calorific value H_{EB} of the solid fuel SF determined on the basis of the energy balance EB of the power boiler 1 is

set as the datum level for the calorific value H_{SF} of the solid fuel, on the basis of which the set value M_{SFSP} for the amount of solid fuel to be fed to the power boiler 1 is calculated. On the basis of the calorific value H_{O2} of the solid fuel determined from the oxygen consumption $O2$ of the power boiler 1 it is, in turn,
 5 determined how much the amount of fuel fed to the boiler 1 must be changed from the set value M_{SP} due to variations in the calorific value of the fuel.

[0028] On the basis of the solution, the amount of solid fuel to be fed to the power boiler 1 can be controlled very accurately both when the quality of the fuel varies and when there are disturbances in the fuel feeding.
 10 The solution can further be used for controlling the total air amount SA to be fed to the power boiler 1 or the amount of burning air BA , for controlling the amount of supply water SW or for controlling the temperature of the superheated steam. The determined calorific value of the solid fuel can be used for controlling the fuel feeding also in cases where the power of a group
 15 of several power boilers is controlled by adjusting the amount of fuel to be fed to one boiler. Further, the variable expressing the fuel power, determined in accordance with the solution, can be used for controlling steam consumption or electricity production.

[0029] If it is desirable to determine the fuel power of the solid fuel
 20 SF as the heat rate P_{SF} instead of the fuel calorific value H_{SF} , the heat rate P_{SF} of the fuel can be determined on the basis of the example shown in Figure 2 and described above as a function of the heat rate P_{EB} of the solid fuel determined from the energy balance of the power boiler and the heat rate P_{O2} of the solid fuel determined from the oxygen consumption of the power boiler

$$25 \quad P_{SF}=f(P_{EB}, P_{O2}). \quad (3)$$

When the fuel power of the solid fuel SF is determined as the fuel heat rate P_{SF} , the advantages and usability of the solution are the same as when the fuel
 30 power of the solid fuel is determined as the fuel calorific value H_{SF} .

[0030] The functions shown in the block diagram of Figure 2 are implemented with devices of the automation system of the power boiler 1, such as computers or other specific-purpose calculation and/or monitoring and control devices. Thus, the functions shown in the block diagram of Figure 2
 35 can be implemented in a centralized manner, for instance in a data-processing device 16 shown schematically in Figure 1, into which the functions of the

control device 17 can be integrated. The functions requiring calculation are preferably implemented by software. Each function of Figures 1 and 2 requiring calculation can naturally be implemented in separate calculation units or devices, but preferably all functions requiring calculation are implemented
5 together in a centralized calculation unit or device.

[0031] The drawings and the related specification are only intended to illustrate the idea of the invention. The details of the invention can vary within the scope of the claims. Thus, the invention can also be used in a corresponding manner in connection with power boilers intended for other solid
10 fuels. However, the presented solution provides significant advantages particularly in connection with power boilers based on fluidized bed combustion, because the technique of the fluidized bed combustion is particularly applicable to combusting fuels of poor quality, the combustion of which is not particularly successful with other combustion manners without
15 complex special arrangements. The fluidized bed combustion as such allows quick and even great variations in the fuel quality, but problems in controlling the amount of fuel to be fed to the power boiler and in the usability of the power boiler, caused by the quality variations, can be alleviated with the
20 presented solution.

CLAIMS

1. A method in connection with a power boiler, in which method a variable expressing the fuel power of solid fuel (SF) to be fed to the power boiler (1) is determined,

5 **characterized by**

determining the heat rate (P_{EB}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the energy balance (EB) of the power boiler (1);

10 determining the heat rate (P_{O2}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the oxygen consumption (O_2) of the power boiler 1; and

15 determining the variable expressing the fuel power of the solid fuel (SF) to be fed to the power boiler (1) on the basis of the heat rate (P_{EB}) of the solid fuel (SF) determined from the energy balance (EB) of the power boiler (1) and the heat rate (P_{O2}) of the solid fuel (SF) determined from the oxygen consumption (O_2) of the power boiler (1).

20 2. A method according to claim 1, **characterized** by further controlling the amount (M_{SF}) of solid fuel (SF) to be fed to the power boiler (1) on the basis of the variable expressing the fuel power of the solid fuel (SF) to be fed to the power boiler (1).

3. A method according to claim 1 or 2, **characterized** by the variable expressing the fuel power of the solid fuel (SF) being the fuel power of solid fuel (SF), the heat rate (P_{SF}) of the solid fuel (SF) or the calorific value (H_{SF}) of the solid fuel (SF).

25 4. A method according to claim 3, **characterized** by determining the calorific value (H_{SF}) of the solid fuel (SF) to be fed to the power boiler (1) by

determining the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1);

30 determining the calorific value (H_{EB}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the heat rate (P_{EB}) of the solid fuel (SF) determined from the energy balance (EB) of the power boiler (1) and the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1);

35 determining the calorific value (H_{O2}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the heat rate (P_{O2}) of the solid fuel (SF)

determined from the oxygen consumption (O_2) of the power boiler (1) and the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1); and

determining the calorific value (H_{SF}) of the solid fuel (SF) to be fed to the power boiler (1) on the basis of the calorific value (H_{EB}) of the solid fuel (SF) determined from the energy balance (EB) of the power boiler (1) and the calorific value (H_{O_2}) of the solid fuel (SF) determined from the oxygen consumption (O_2) of the power boiler (1).

5. A method according to any one of the preceding claims, **characterized** by determining the heat rate (P_{EB}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the energy balance (EB) of the power boiler (1) by

determining the steam power (P_{ST}) of the power boiler (1); and
determining the heat rate (P_{FBEB}) of the power boiler (1) on the basis of the steam power (P_{ST}) of the power boiler (1) and the combustion efficiency (η) of the power boiler (1).

6. A method according to claim 5, **characterized** by further modelling the effect of one or more fuels fed to the power boiler (1) and having known fuel power on the heat rate (P_{FBEB}) of the power boiler (1); and

compensating, on the basis of the modelling, for the effect of one or more fuels fed to the power boiler (1) and having known fuel power on the heat rate (P_{FBEB}) of the power boiler (1).

7. A method according to claim 5 or 6, **characterized** by determining the calorific value (H_{EB}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1) and the heat rate (P_{EB}) of the solid fuel (SF) fed to the power boiler (1) by

modelling the effect of the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1) on the steam power (P_{ST}) of the power boiler (1); and
determining, on the basis of the modelling, the calorific value (H_{EB}) of the solid fuel (SF) fed to the power boiler (1) from the heat rate (P_{EB}) of the solid fuel (SF) fed to the power boiler (1).

8. A method according to any one of the preceding claims, **characterized** by determining the heat rate (P_{O_2}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the oxygen consumption (O_2) of the power boiler (1) by

determining the oxygen consumption (O_2) of the power boiler (1) on the basis of the oxygen content (O_{2SG}) of flue gases (SG); and

determining the heat rate (P_{FBO2}) of the power boiler (1) on the basis of the oxygen consumption (O_2) of the power boiler (1).

5 9. A method according to claim 8, **characterized** by further modelling the effect of one or more fuels fed to the power boiler (1) and having known fuel power on the heat rate (P_{FBO2}) of the power boiler (1); and

10 compensating for the effect of one or more fuels fed to the power boiler (1) and having known fuel power on the heat rate (P_{FBO2}) of the power boiler (1).

10. A method according to claim 8 or 9, **characterized** by determining the heat rate (P_{FBO2}) of the power boiler (1) on the basis of the oxygen consumption (O_2) of the power boiler (1) by

15 determining the amount (F_{SA}) of total air (SA) fed to the power boiler (1);

determining the oxygen content (O_{2SG}) of the flue gases (SG) exiting from the power boiler (1);

20 modelling the effect of the amount (F_{SA}) of total air (SA) fed to the power boiler (1) on the oxygen content (O_{2SG}) of the flue gases (SG) exiting from the power boiler (1); and

determining, on the basis of the modelling, the heat rate (P_{FBO2}) of the power boiler (1).

25 11. A method according to any one of claims 8 to 10, **characterized** by determining the calorific value (H_{O2}) of the solid fuel (SF) fed to the power boiler (1) from the oxygen consumption (O_2) of the power boiler (1) on the basis of the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1) and the heat rate (P_{O2}) of the solid fuel (SF) fed to the power boiler (1) by

30 modelling the effect of the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1) on the heat rate (P_{FPO2}) of the power boiler (1); and

determining, on the basis of the modelling, the calorific value (H_{O2}) of the solid fuel (SF) fed to the power boiler (1) from the heat rate (P_{O2}) of the solid fuel (SF) fed to the power boiler (1).

12. A method according to any one of claims 5 to 11, **characterized** by the fuel having known fuel power being oil, gas, molasses or grinding dust.

13. A method according to any one of the preceding claims, **characterized** by the solid fuel (SF) being coal, peat, biofuel, municipal waste, sorted waste or a combination of two or more of these solid fuels.

14. A method according to any one of the preceding claims, **characterized** by the power boiler (1) being a fluidized bed boiler.

15. An apparatus in connection with a power boiler, which apparatus is arranged to determine a variable expressing the fuel power of solid fuel (SF) to be fed to the power boiler (1),

characterized in that the apparatus is arranged

to determine the heat rate (P_{EB}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the energy balance (EB) of the power boiler;

15 to determine the heat rate (P_{O_2}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the oxygen consumption (O_2) of the power boiler (1); and

20 to determine the variable expressing the fuel power of the solid fuel (SF) to be fed to the power boiler (1) on the basis of the heat rate (P_{EB}) of the solid fuel (SF) determined from the energy balance (EB) of the power boiler (1) and the heat rate (P_{O_2}) of the solid fuel (SF) determined from the oxygen consumption (O_2) of the power boiler (1).

16. An apparatus according to claim 15, **characterized** in that the apparatus is further arranged to control the amount (M_{SF}) of solid fuel to be fed to the power boiler (1) on the basis of the variable expressing the fuel power of the solid fuel (SF) to be fed to the power boiler (1).

17. An apparatus according to claim 15 or 16, **characterized** in that the variable expressing the fuel power of the solid fuel (SF) is the fuel power of the solid fuel (SF), the heat rate (P_{SF}) of the solid fuel (SF) or the calorific value (H_{SF}) of the solid fuel (SF).

18. An apparatus according to claim 17, **characterized** in that the calorific value (H_{SF}) of the solid fuel (SF) to be fed to the power boiler (1) is arranged to be determined in such a way that the apparatus is arranged to determine the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1);

to determine the calorific value (H_{EB}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the heat rate (P_{EB}) of the solid fuel (SF) determined from the energy balance (EB) of the power boiler (1) and the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1);

- 5 to determine the calorific value (H_{O_2}) of the solid fuel (SF) fed to the power boiler (1) on the basis of the heat rate (P_{O_2}) of the solid fuel (SF) determined from the oxygen consumption (O_2) of the power boiler (1) and the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1); and

- determining the calorific value (H_{SF}) of the solid fuel (SF) to be fed
10 to the power boiler (1) on the basis of the calorific value (H_{EB}) of the solid fuel (SF) determined from the energy balance (EB) of the power boiler (1) and the calorific value (H_{O_2}) of the solid fuel (SF) determined from the oxygen consumption (O_2) of the power boiler (1).

19. An apparatus according to any one of claims 15 to 18,
15 **characterized** in that the heat rate (P_{EB}) of the solid fuel (SF) fed to the power boiler (1), based on the energy balance (EB) of the power boiler (1), is arranged to be determined in such a way that the apparatus is arranged

- to determine the steam power (P_{ST}) of the power boiler (1); and
 to determine the heat rate (P_{FBEB}) of the power boiler (1) on the
20 basis of the steam power (P_{ST}) of the power boiler (1) and the combustion efficiency (η) of the power boiler (1).

20. An apparatus according to claim 19, **characterized** in that

- the apparatus further comprises a model arranged to express the
25 effect of one or more fuels fed to the power boiler (1) and having known fuel power on the heat rate (P_{FBEB}) of the power boiler (1); and that

- the apparatus is, on the basis of the model, arranged to compensate for the effect of one or more fuels fed to the power boiler (1) and having known fuel power on the heat rate (P_{FBEB}) of the power boiler (1).

- 30 21. An apparatus according to claim 19 or 20, **characterized** in that the apparatus comprises a process model arranged to express the effect of the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1) on the steam power (P_{ST}) of the power boiler (1); and that

- the apparatus is, on the basis of the process model, arranged to
35 determine the calorific value (H_{EB}) of the solid fuel (SF) fed to the power boiler (1) from the heat rate (P_{EB}) of the solid fuel (SF) fed to the power boiler (1).

22. An apparatus according to any one of claims 15 to 21, **characterized** in that the heat rate (P_{O2}) of the solid fuel fed to the power boiler (1), based on the oxygen consumption ($O2$) of the power boiler (1), is arranged to be determined in such a way that the apparatus is arranged

5 to determine the oxygen consumption ($O2$) of the power boiler (1) on the basis of the oxygen content ($O2_{SG}$) of flue gases (SG); and

to determine the heat rate (P_{FBO2}) of the power boiler (1) on the basis of the oxygen consumption ($O2$) of the power boiler (1).

23. An apparatus according to claim 22, **characterized** in
10 that

the apparatus further comprises a model arranged to express the effect of one or more fuels fed to the power boiler (1) and having known fuel power on the heat rate (P_{FBO2}) of the power boiler (1); and that

15 the apparatus is, on the basis of the model, arranged to compensate for the effect of one or more fuels fed to the power boiler (1) and having known fuel power on the heat rate (P_{FBO2}) of the power boiler (1).

24. An apparatus according to claim 22 or 23, **characterized** in that the apparatus comprises

20 means for determining the amount (F_{SA}) of total air (SA) fed to the power boiler (1);

means for determining the oxygen content ($O2_{SG}$) of the flue gases (SG) exiting from the power boiler (1);

25 a model arranged to express the amount (F_{SA}) of total air (SA) fed to the power boiler (1) on the oxygen content ($O2_{SG}$) of the flue gases (SG) exiting from the power boiler (1); and that

the apparatus is, on the basis of the model, arranged to determine the heat rate (P_{FBO2}) of the power boiler (1) from the oxygen consumption ($O2$) of the power boiler (1).

25. An apparatus according to any one of claims 22 to 24, **characterized** in that
30

the apparatus comprises a process model arranged to express the amount (M_{SF}) of solid fuel (SF) fed to the power boiler (1) on the heat rate (P_{FPO2}) of the power boiler (1); and that

35 the apparatus is, on the basis of the process model, arranged to determine the calorific value (H_{O2}) of the solid fuel fed to the power boiler (1) from the heat rate (P_{O2}) of the solid fuel (SF) fed to the power boiler (1).

26. An apparatus according to any one of claims 19 to 25, **characterized** in that the fuel having known fuel power is oil, gas, molasses or grinding dust.

5 27. An apparatus according to any one of claims 15 to 26, **characterized** in that the solid fuel (SF) is coal, peat, biofuel, municipal waste, sorted waste or a combination of two or more of these fuels.

28. An apparatus according to any one of claims 15 to 27, **characterized** in that the power boiler (1) is a fluidized bed boiler.

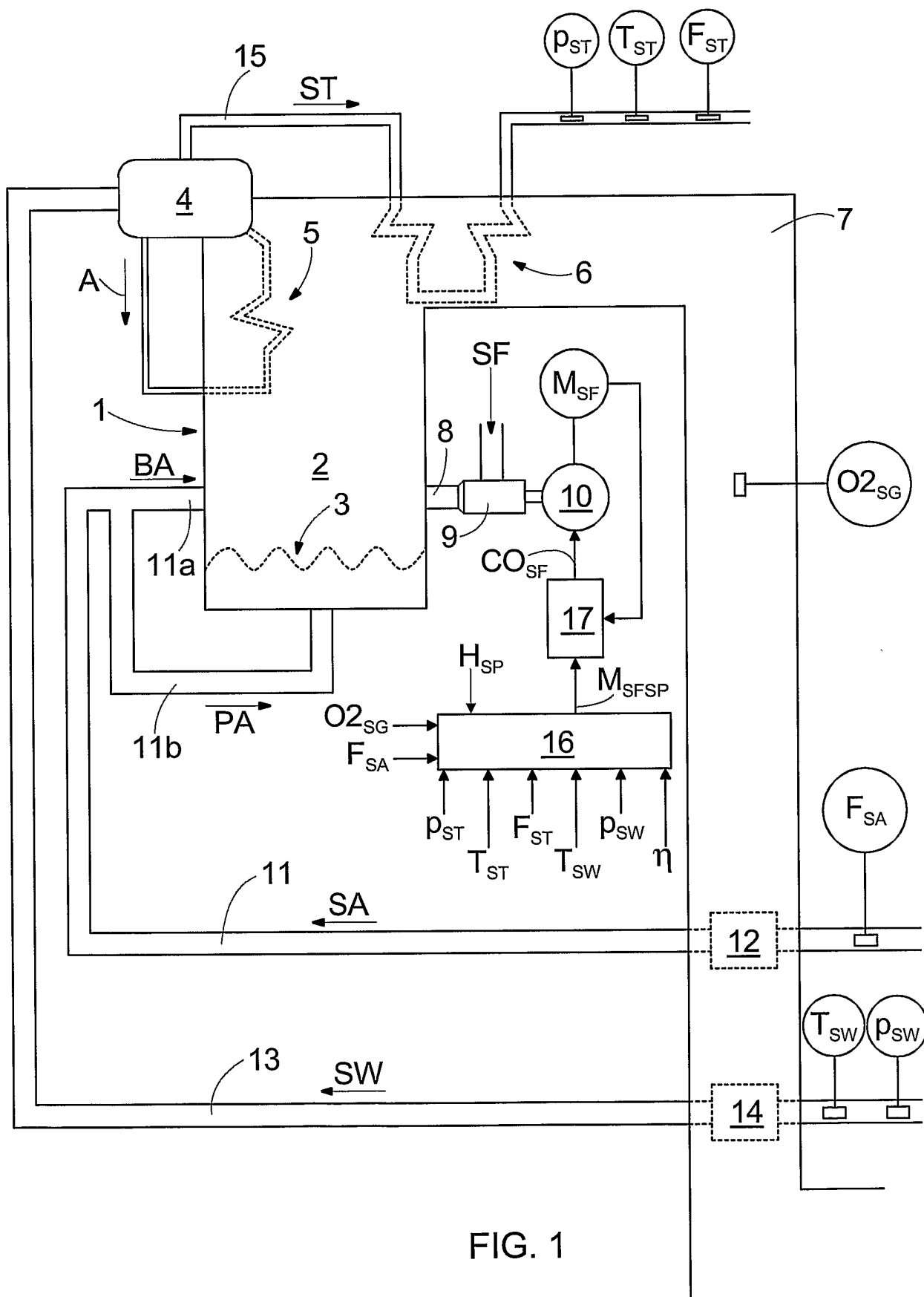


FIG. 1

2/2

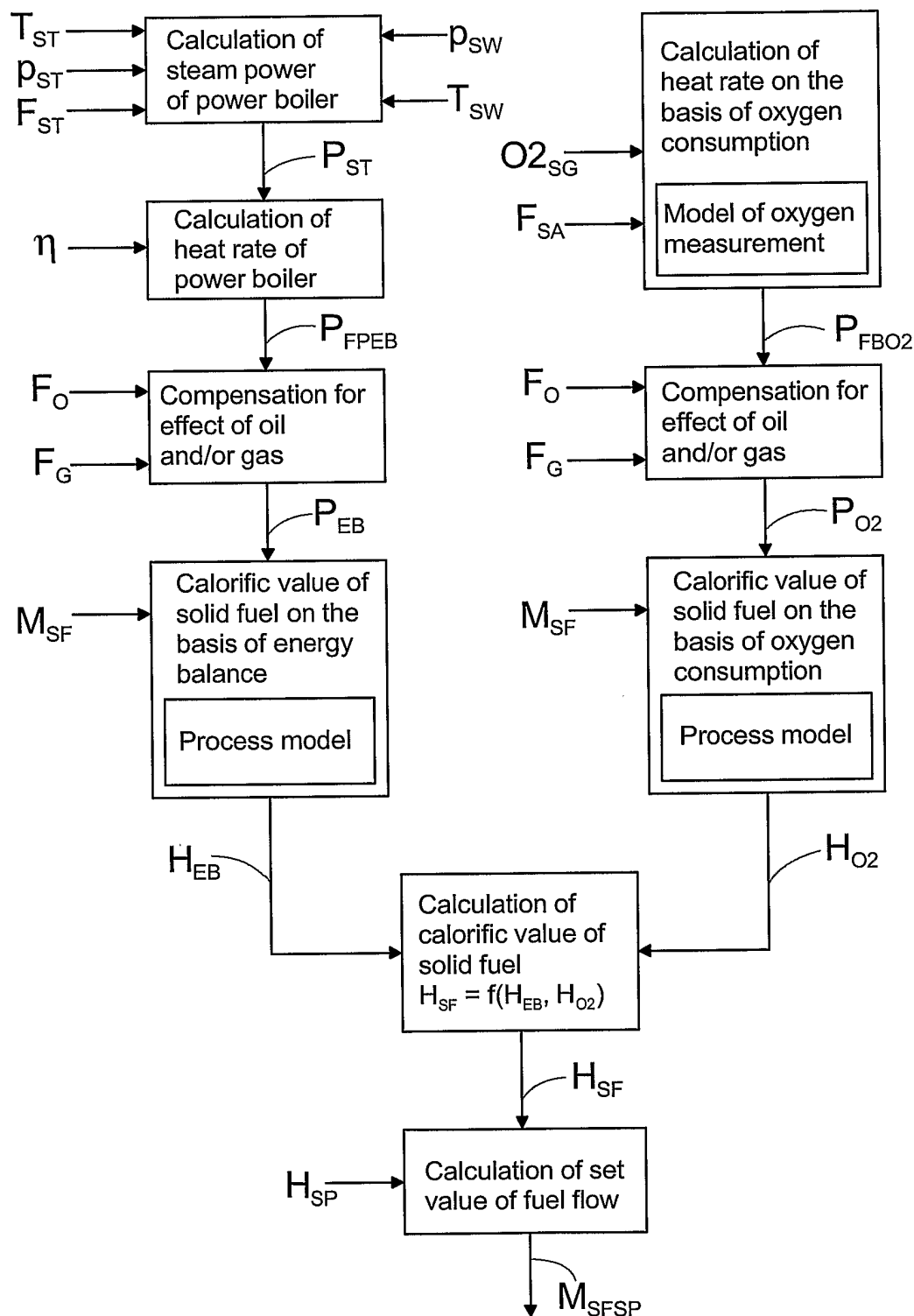


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI 03/00436

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: F23N 5/00, F23N 1/00, F23G 5/50

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)

IPC7: F23N, F23G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	WO 0125690 A1 (NEDERLANDSE ORGANISATIE VOOR TOEGEPASTNATURWETENSCHAPPELIJK ONDERZOEK TNO), 12 April 2001 (12.04.01), page 4, line 19 - page 6, line 5, claims, figure 1 --	1-28
X	WO 0229326 A1 (SWEDISH BIOBURNER SYSTEM AKTEIBOLAG), 11 April 2002 (11.04.02), page 5, line 2 - line 6, figure 1 --	1-28

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search

4 Sept 2003

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI 03/00436

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SCHOLZ, Reinhard, Abfallbehandlung in thermischen Verfahren, Stuttgart: Teubner - Reihe Umwelt, 2001, Vol. 1, ISBN 3-519-00402-X, pages 205, 207 and 413-416 --	1-28
A	US 4909037 A (ROBERT N. HUBBY), 20 March 1990 (20.03.90) -- -----	1-28

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International application No.

PCT/FI 03/00436

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