(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 108 586
A1

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 83306625.1

(22) Date of filing: 31.10.83

(51) Int. Cl.³: F 23 N 5/00
F 23 N 1/02

(30) Priority: 01.11.82 US 438216

(43) Date of publication of application: 16.05.84 Bulletin 84/20

(84) Designated Contracting States: DE FR GB IT

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(54) Reducing losses in combustion operations.

(57) A method of minimising combustion operation losses includes measuring (40) a load index for the combustion operation which is proportional to the fuel demand or the output thereof, measuring an amount proportional to the air heating losses of the combustion operation and measuring an amount which is proportional to the fuel loss of the operation. The air heating loss is measured by multiplying (34) a flue temperature (30) by an amount of unburned oxygen in the flue gas. This quantity is multiplied (42,44) by a cost factor for such air heating and the load index. The fuel loss is obtained by measuring (46, 48, 50) an amount of by-product in the flue gas as well as the opacity of the flue gas. These are multiplied (56, 58, 60) by appropriate cost factors which in the case of opacity is proportional to a fine that would be due for violating certain limits for the opacity. Minimum values are found for the fuel loss and air heating loss quantities, as air demand to the combustion operation is changed. A minimum for the sum of the fuel and air heating losses is also obtained with the air demand of the combustion operation being set so that all of the losses are as low as possible. In this way the costs of undesired air heating, unburned by-products as well as potential violation of flue gas characteristic limits are utilised in determining the most economical air demand for the combustion operation.

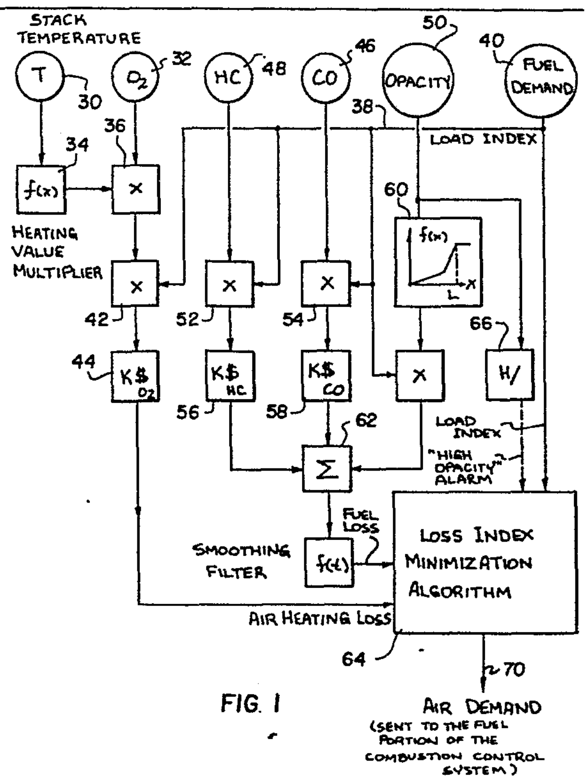

FIG. 1

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REDUCING LOSSES IN COMBUSTION OPERATIONS

This invention relates to methods of and apparatus for reducing losses in a combustion operation (e.g. in a boiler, heater, or other device) for burning fuel with air at a load level with the combustion operation producing flue gas having unburned by-product and oxygen and being at a stack temperature.

Techniques are known in the area of combustion control which involve the measurement of various products of combustion in the flue gases and the use of these measurements to adjust the amount of excess air (or air/fuel ratio) supplies beyond the stoichiometric level required for ideal combustion. The prior art recognises that there is a tradeoff between a high level of excess air, in which air heating losses predominate, and too low a level of excess air, in which unburned fuel losses predominate.

Prior approaches to optimising the combustion process fall into one of three categories, depending on what product or products of combustion are being measured in the flue gases: oxygen only, combustibles only, or a combination of the two. These are discussed separately in the following.

The oxygen only approach is used in Bailey Meter Company U.S. Patent No. 3 049 300, "Combustion Control for a Furnace Fired With Fuels Having Different Oxygen-Excess Air Characteristics," dated 14 August 1962. An anlyser is used to measure the oxygen in the flue gas, and the excess air is reduced until the measured oxygen reaches a preselected set point.

The combustibles only (Carbon monoxide-CO, hydrocarbons, and/or opacity) approach is used in Standard Oil Company (Indiana) U.S. Patent No. 4 260 363, "Furnace Fuel Optimiser," dated 7 April 1981, and a copending U.S. patent application of Econics Corporation, referenced in a technical paper by Keith Swanson, "An Advanced Combustion Control System Using Distributed Microcomputer Techniques", ISA Publication ISBN 0-87664-521-X, 1981. An analyser or analysers are used to measure one or more of these parameters, and excess air is adjusted until they reach a preselected set point. If more than one variable is measured and controlled, some switching between controlled variables is done to attain the most "conservative" value of excess air.

The combination of oxygen and combustibles approach is used in Measurex Corporation U.S. Patent No. 4 612 889, "Method and Apparatus for Control of Efficiency of Combustion in a Furnace," dated 31 July 1979, Westinghouse Electric Corporation U.S. Patent No. 4 231 733, "Combined O_2/Combustibles Solid Electrolyte Gas Monitoring Device," dated 4 November 1980 and a copending U.S. patent application of Bailey Controls Company "A system for CO and O_2 Control of Combustion Processes". In this case, both oxygen and combustibles are measured. In the Measurex patent and the copending application, the deviation of CO from its preselected set point is used to adjust the set point of an oxygen (O_2) controller in a cascade fashion. In the Westinghouse patent, excess air is adjusted to control, to a preselected combustibles set point, until the oxygen moves outside preselected limits. Then the control mode is switched to bring the oxygen back within limits, at which point combustibles control is resumed.

Shortcomings of the current approaches to combustion control are as follows.

All of the approaches attempt to control to arbitrary selected set points one or more of the products of combustion. There is, however, no guarantee that combustion conditions are such that these set points can be reached or that these set points are the best ones from an economic point of view.

In approaches that attempt to switch among multiple variables to be controlled, it is likely that limit cycling will occur as the various switch points are reached and the modes of control change. This leads to undesirable cyclic stresses on the process equipment.

None of the approaches attempts to directly minimise any explicit measure of economic loss, such as the cost of unburned fuel up the stack, the cost of heating the excess air, or the cost of violating governmental emission regulations.

The present invention provides a method of reducing losses in a combustion operation for burning fuel with air at a load level with the combustion operation producing flue gas having unburned by-product and oxygen and being at a stack temperature, the method comprising:

measuring a load index for the combustion operation which is proportional to the load level thereof; measuring an air heating loss for the combustion operation which is proportional to the stack temperature, an amount of excess oxygen in the flue gas, the load index, and a cost factor for air heating; measuring an unburned by-product loss for the combustion operation which is proportional to an amount of unburned by-product in the flue gas, the load index and a cost factor for the unburned by-product; measuring a characteristic loss for the combustion operation which is proportional to a characteristic of the flue gas (e.g. opacity), the load index and a cost factor for that characteristic (e.g. a fine exacted for exceeding set limits for that characteristic); adding the unburned by-product loss to the characteristic loss to obtain a total fuel loss for the operation; varying air demand to the combustion operation to obtain different value of the air heating loss, the fuel loss, and a summation of the air heating and fuel losses; and selecting an air demand point for the combustion operation at which the summation of air heating and fuel losses is as low as possible for a selected load level. An air demand signal can then be sent to and operates in conjunction with the fuel portion of the combustion control system.

The invention also provides apparatus for reducing losses in a combustion operation for burning fuel with air at a load level with the combustion operation producing flue gas having unburned by-product and oxygen and being at a selected stack temperature, the apparatus being characterised by:

a temperature transmitter for measuring the stack temperature;

an oxygen sensor for sensing unburned oxygen in the flue gas;

at least one unburned by-product sensor for sensing an amount of unburned by-product in the flue gas;

an opacity sensor for sensing the opacity of the flue gas;

means for establishing a load level for the combustion operation which is proportional to the load index thereof;

a first multiplier connected to the temperature transmitter and oxygen sensor for multiplying the values generated thereby together;

a second multiplier connected between the load level establishing means and an output of the first multiplier;

a first cost factor unit connected to an output of the second multiplier for generating an air heating loss value;

a third multiplier connected between the load level establishing means and the at least one unburned by-product sensor;

a second cost factor unit connected to an output of the third multiplier for generating a quantity proportional to an unburned by-product loss for the combustion operation;

a function generator connected to the opacity sensor for multiplying an amount of opacity sensed by the opacity sensor by an amount which increases to a fine that is exacted for reaching a limit in opacity;

a fourth multiplier connected to an output of the function generator and to the means for generating an opacity loss quantity;

a summing unit connected to an output of the second cost factor unit and the fourth multiplier for generating a total fuel loss for the combustion operation; and

a loss index minimising unit connected to an output of the summing unit, an output of the first cost factor unit and to the means for generating an air demand signal at which the fuel loss, the air heating loss, and a summation of the fuel loss plus air heating loss are minimised.

A preferred embodiment of the invention described hereinbelow differs from and seeks to improve upon the prior art in the following respects:

(1) The combustion control approach is based explicitly on minimising a penalty function that represents the sum of economic losses in running the combustion process.

(2) The control approach does not rely on selecting a set point for any one product of combustion parameter (e.g. CO, oxygen, or opacity) that may or may not be the best one under current operating conditions.

(3) The control approach takes into account the economic penalty of not meeting governmental emission regulations.

The preferred embodiment operates by effecting measurements of excess air and of each of the combustibles elements. These are multiplied by a boiler/heater load index to produce a "rate of loss" estimate for each element. These rates are multiplied by appropriate economic factors to convert them into the "dollars lost" per unit time of operation, and then added together to produce a combined loss index. The air/fuel ratio is then adjusted during on-line operation to search for the minimum value of this loss index. The economic impact of violating regulations on smoke emissions (e.g. those of the U.S. Government Environmental Protection Agency or "EPA") is taken into account by significantly increasing the rate of penalising the opacity component as it approaches the EPA limit.

The preferred apparatus described below is simple in design, rugged in construction, and economical to manufacture.

The invention will now be further described, by way of illustrative and non-limiting example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of apparatus embodying the invention for minimising loss in a combustion operation;

Figure 2 is a graph plotting the best previous air demand against a load index for the combustion operation; and

Figure 3 is a graph plotting the cost in dollars against the air demand and reflecting various losses in the combustion operation.

An embodiment of the present invention will now be described with reference to Figures 1 to 3. In this embodiment, the cost of heating excess air is estimated by using measurements of stack temperature from a transmitter 30 and oxygen from a transmitter 32 in flue gas produced by a combustion operation in which fuel is burnt with air at a load level. A function generator 34 and a multiplier 36 convert these measurements into an effective heat value of the excess air. This value is multiplied in a multiplier 42 by a boiler/heater load index provided on a line 38. In this case this value is fuel demand as measured in a fuel demand transmitter 40. It could also be steam flow in a boiler or product flow in a process heater. The multiplier 42 thus generates a heat loss rate, which is then multiplied by a K$ factor in a multiplier 44 to convert the loss rate into an air heating loss per unit time in dollars.

On the combustibles side, measurements are made in transmitters 46, 48 and 50 of carbon monoxide (CO), hydrocarbons (HC) and opacity. The CO and HC measurements are multiplied by the load index and the K$ factors in multipliers 52, 54, 56 and 58, to generate a fuel loss rate per unit time. The opacity measurement is handled in the same way, except that a function generator 60 is used instead of a simple K$ multiplication factor. The function generator 60 sharply increases the effective K$ factor when the opacity approaches an allowed EPA limit L, then settles out at the magnitude of the fine when the limit is reached or exceeded. All of the combustibles loss rates then are added together in a summing unit 62 and smoothed (filtered in time) in a smoothing filter to generate a total fuel loss rate in dollars per unit time. The summing unit 62 thus generates a total of the unburned by-product loss and loss due to a characteristic of the flue gas (opacity) which may cause a fine.

The air and fuel loss rates are fed into a "Loss Index Minimisation Algorithm" block 64 shown in Figure 1. A "high opacity alarm" is generated by a limit and alarm unit 66 when the opacity exceeds the EPA limit. This alarm and the load index are also fed into the minimisation algorithm block 64. Air demand is set by an optimum air demand value provided on a line 70 from the block 64.

The operation of the "Loss Index Minimisation Algorithm" block 64 is illustrated in Figures 2 and 3. The block 64 keeps track of the "best previous" values of air demand that have been found for each value of load index (Figure 2). Also, the corresponding dollar values of air heating loss, fuel loss, and total loss (the sum of the other two losses) are stored for each load index value (Figure 3). Under normal operating conditions (defined as occurring when the high opacity alarm is not active and the boiler/heater load is not changing), the minimisation algorithm then searches for the minimum value of the total loss parameter by adjusting the air demand output from the block. The algorithm increases or decreases the air demand, depending on the deviation of the current values of air and fuel losses from the corresponding "best previous" values stored. That is, if the fuel loss parameter is near its previous "best value" but the air loss is significantly higher, the algorithm will reduce the air demand. On the other hand, if the deviation in fuel losses predominates compared to the previous best values, the algorithm will increase the air demand. After waiting for a period of time equal to the time lag of the process, the algorithm then measures the new value of the total loss parameter. If it is less than the stored "best previous" value for the current load index, the new air demand replaces the old one as the "best previous" value. Also, the corresponding new loss parameters then replace the old ones and the search continues incrementally in the same direction until a minimum is found as shown at M in Figure 3.

The optimisation algorithm operates as described only under "normal" operating conditions as defined above. If the load index is changing, the optimisation operation is suspended and the air demand output is adjusted to match the "best previous" value stored for the current load index. If the load index is stable but the "high opacity" alarm is active, the loss minimisation operation still continues, but the "best previous" air demand and loss values found under these alarm conditions are discarded after the alarm becomes inactive. This is done because the fuel loss parameter is made artificially high during these alarm conditions. Therefore, its value is not relevant under normal operating conditions.

CLAIMS

1. A method of reducing losses in a combustion operation for burning fuel with air at a load level with the combustion operation producing flue gas having unburned by-product and oxygen and being at a stack temperature, the method being characterised by:

measuring a load index for the combustion operation which is proportional to the load level thereof;

measuring an air heating loss for the combustion operation which is proportional to the stack temperature, an amount of excess oxygen in the flue gas, the load index, and a cost factor for air heating;

measuring an unburned by-product loss for the combustion operation which is proportional to an amount of unburned by-product in the flue gas, the load index, and a cost factor for the unburned by-product;

measuring a characteristic loss for the combustion operation which is proportional to a characteristic of the flue gas, the load index, and a cost factor for that characteristic;

adding (62) the unburned by-product loss to the characteristic loss to generate a total fuel loss for the combustion operation;

varying air demand to the combustion operation to obtain different values of the air heating loss, the fuel loss, and a summation of the air heating and fuel losses; and

selecting (64) an air demand point for the combustion operation at which the air heating, fuel, and summation losses are as low as possible for a selected load index.

2. A method according to claim 1, including storing air demand points for various load indexes and utilising the stored air demand points as best previous air demand values.

3. A method according to claim 2, including supplying a best previous air demand point to the combustion operation, varying the air demand away from the best previous air demand point, and if reduced values for fuel loss, air heating loss, and the summation of fuel loss plus air heating losses is reduced, storing a new best previous air demand point.

4. A method according to any one of the preceding claims, including measuring (40) a fuel demand for the combustion operation, the load index being proportional to the fuel demand.

5. A method according to any one of the preceding claims, including generating an alarm (66) when a limit for the characteristic loss is reached.

6. A method according to any one of claims 1 to 5, wherein the characteristic of the flue gas is opacity, the cost factor of the characteristic being a fine for exceeding a selected limit for opacity.

7. A method according to any one of claims 1 to 5, including measuring (30) the stack temperature, calculating (34) a heating value which is proportional to the stack temperature, measuring (32) the amount of unburned oxygen in the flue gas, multiplying (36) the amount of unburned oxygen by the heating value, and multiplying (42) the outcome of this multiplication by the load index to obtain a load index weighted air heating measurement and multiplying (44) the air heating measurement by the cost factor for air heating to obtain the air heating loss.

8. A method according to claim 7, wherein the unburned by-product is carbon monoxide or hydrocarbons, including measuring (46, 48) the amount of unburned by-product in the flue gas, multiplying (52, 54) the measured amount of unburned by-product by the load index and multiplying (56, 58) the outcome by the cost factor for unburned by-product.

9. A method according to claim 8, including measuring (50) the opacity of the flue gas, which opacity comprises the characteristic of the flue gas, the cost factor of the characteristic increasing to a fine for reaching a selected value of opacity as the selected value for opacity is approached.

10. A method according to any one of the preceding claims, including smoothing the fuel loss using a smoothing filter to reduce irregularities in a change for the fuel cost over time.

11. Apparatus for reducing losses in a combustion operation for burning fuel with air at a load level with the combustion operation producing flue gas having unburned by-product and oxygen and being at a selected stack temperature, the apparatus being characterised by:

a temperature transmitter (30) for measuring the stack temperature;

an oxygen sensor (32) for sensing unburned oxygen in the flue gas;

at least one unburned by-product sensor (46, 48) for sensing an amount of unburned by-product in the flue gas;

an opacity sensor (50) for sensing the opacity of the flue gas;

means for establishing a load level for the combustion operation which is proportional to the load index thereof;

a first multiplier (36) connected to the temperature transmitter (30) and oxygen sensor (32) for multiplying the values generated thereby together;

a second multiplier (42) connected between the load level establishing means and an output of the first multiplier (36);

a first cost factor unit (44) connected to an output of the second multiplier (42) for generating an air heating loss value;

a third multiplier (52, 54) connected between the load level establishing means and the at least one unburned by-product sensor (46, 48);

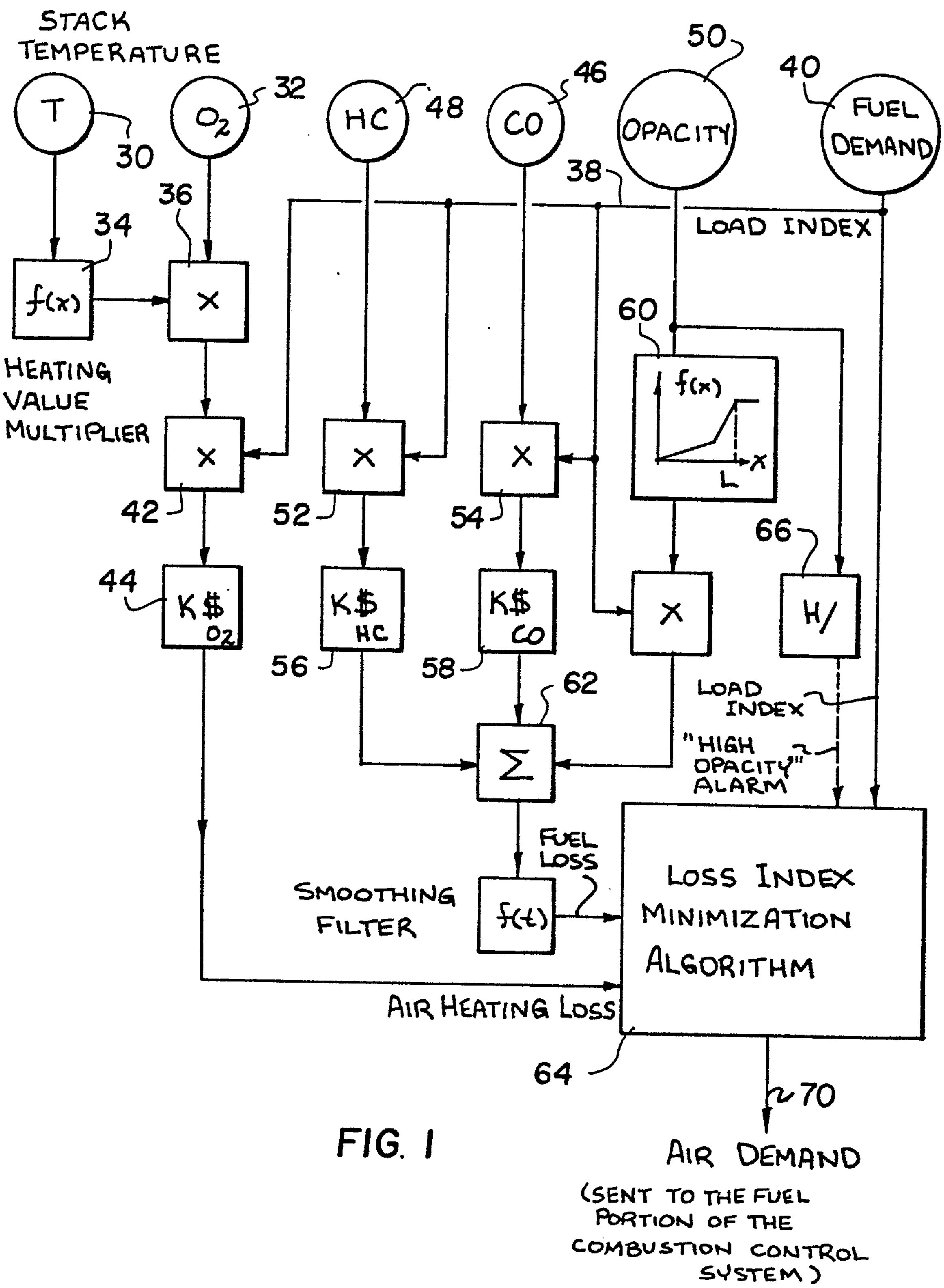
a second cost factor unit (56, 58) connected to an output of the third multiplier (52, 54) for generating a quantity proportional to an unburned by-product loss for the combustion operation;

a function generator (60) connected to the opacity sensor (50) for multiplying an amount of opacity sensed by the opacity sensor by an amount which increases to a fine that is exacted for reaching a limit in opacity;

a fourth multiplier connected to an output of the function generator (60) and to the means for generating an opacity loss quantity;

a summing unit (62) connected to an output of the second cost factor unit (52, 54) and the fourth multiplier for generating a total fuel loss for the combustion operation; and

a loss index minimising unit (64) connected to an output of the summing unit (62), an output of the first cost factor unit (44) and to the means for generating an air demand signal at which the fuel loss, the air heating loss, and a summation of the fuel loss plus air heating loss are minimised.



STACK TEMPERATURE
T
30
O2
32
HC
48
CO
46
OPACITY
50
FUEL DEMAND
40
38
LOAD INDEX
34
f(x)
36
×
HEATING VALUE MULTIPLIER
×
42
×
52
×
54
60
f(x)
x
L
44
K$ O2
K$ HC
56
K$ CO
58
×
66
H/
62
Σ
LOAD INDEX
"HIGH OPACITY" ALARM
FUEL LOSS
SMOOTHING FILTER
f(t)
LOSS INDEX MINIMIZATION ALGORITHM
AIR HEATING LOSS
64
70
AIR DEMAND
(SENT TO THE FUEL PORTION OF THE COMBUSTION CONTROL SYSTEM)

FIG. 1

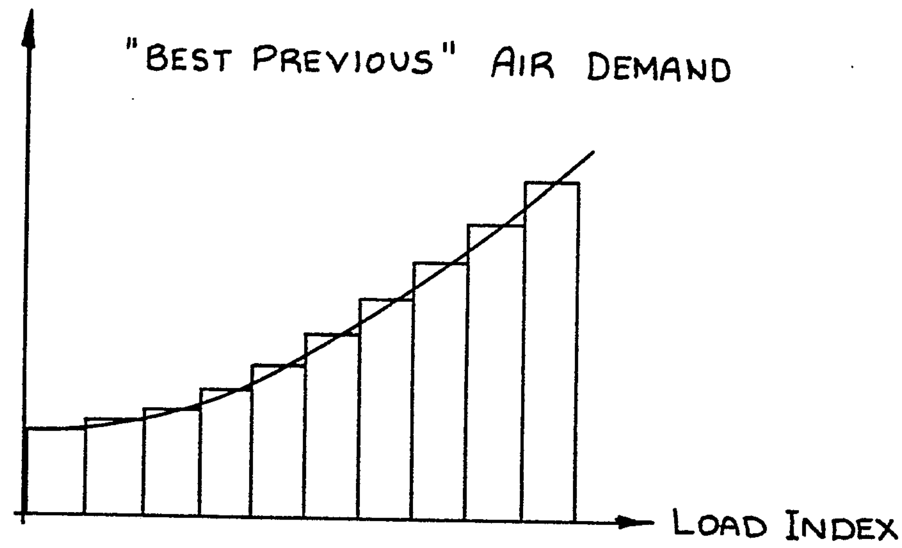

"BEST PREVIOUS" AIR DEMAND
LOAD INDEX

FIG. 2

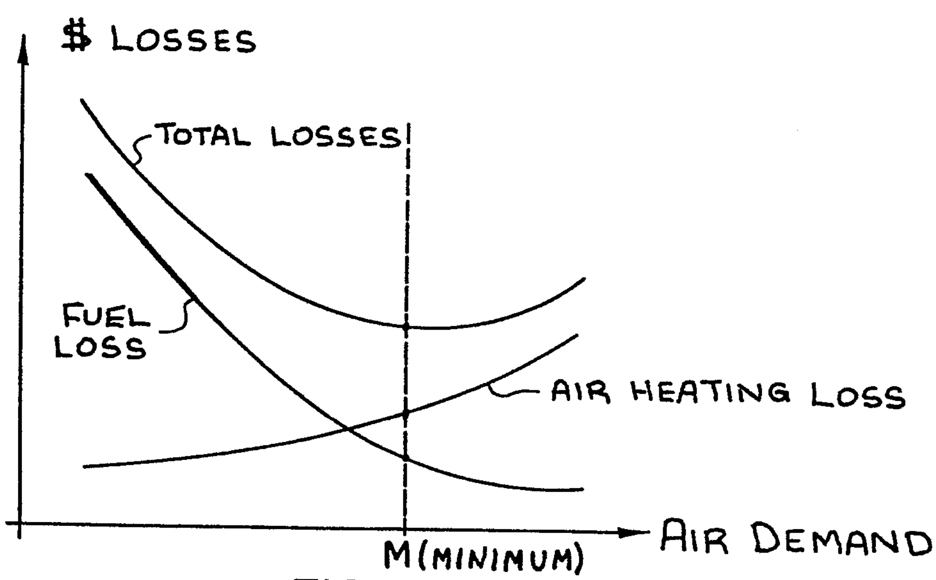

$ LOSSES
TOTAL LOSSES
FUEL LOSS
AIR HEATING LOSS
AIR DEMAND
M(MINIMUM)

FIG. 3

0108586

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 83 30 6625

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
E	EP-A-0 081 980 (THE BABCOCK & WILCOX CO.) * Figures; page 3, line 21 - page 8, line 24 * ---	1,11	F 23 N 5/00 F 23 N 1/02
A	GB-A-2 064 780 (NEOTRONICS LTD.) * Abstract; figure 1; page 1, line 63 - page 2, line 33 * ---	1,7,11	
A	POWER, vol. 125, no. 1, January 1981, pages 41-44, Concord, New Hampshire, US H. ZIMMER: "How to cut fuel costs by using a computer to distribute boiler loads for peak efficiency" * Page 42, left-hand column - middle-column, paragraph 1 * ---	1,11	
			TECHNICAL FIELDS SEARCHED (Int. Cl. 3)
A	GB-A-2 021 815 (LAND PYROMETERS LTD.) * Abstract; figures * ---	2,3	F 23 N
A	INSTRUMENTS & CONTROL SYSTEMS, vol. 50, no. 11, November 1977, pages 35-41, Radnor, PA., US S.G. DUKELOW: "Combustion controls save money" * Page 40, right-hand column, paragraphs 2,3; figure 8 * ---	1,3,11	
A	GB-A-2 088 091 (ECONICS CORP.) -----		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24-01-1984	THIBO F.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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