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(54) **Methods of and apparatus for determining maximum spray flow limits of attemperators.**

(57) A maximum spray flow limit for an attemperator is determined by using attemperator steam inlet pressure measured by a pressure sensor (10) and temperature measured by a temperature sensor (12) to calculate enthalpy. The enthalpy contributed by water spray flow to the attemperator is derived from a spray temperature sensor (40) and may be used in the calculation to determine enthalpy per unit load. The enthalpy per unit load is multiplied in a multiplication block (36) by the actual load of the boiler being serviced by the attemperator to produce a maximum spray flow limit on a line (44) for the attemperator.

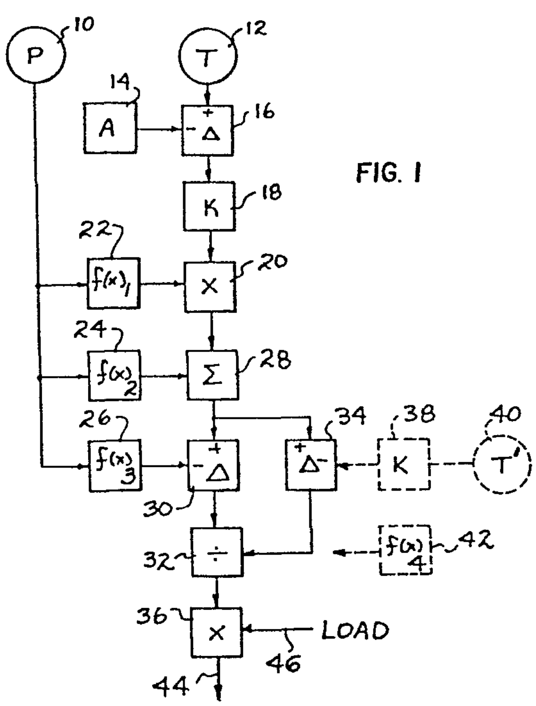



FIG. I

Croydon Printing Company Ltd

# METHODS OF AND APPARATUS FOR DETERMINING MAXIMUM SPRAY FLOW LIMITS OF ATTEMPERATORS

This invention relates to methods of and apparatus for determining maximum spray flow limits of attemperators.

It is known to utilise attemperators to reduce or control the temperature of superheated steam generated in a boiler. See STEAM, ITS GENERATION AND USE, 39th ed., 1978 by The Babcock and Wilcox Company, a McDermott Company.

The use of a microprocessor to calculate and display margin to saturation in the reactor coolant system of a nuclear reactor is disclosed in "DESIGN AND QUALIFICATION OF A MICROPROCESSOR SUBCOOLED MARGIN MONITOR", IEEE TRANSACTIONS ON NUCLEAR SCIENCE, Vol. NS-28, No. 1, Feb. 1981 by R.M. Caruso and R.P. Daigle. This article discloses how pressure and temperature readings from the reactor coolant system can be used in conjunction with steam tables programmed into the microprocessor to provide an indication of margin to saturation (that is the safety factor remaining before the coolant is saturated with steam), which determination can be utilised to activate an alarm or other suitable equipment.

U.S. Patent No. US-A-3 428 557 discloses an apparatus for controlling the amount of chemical additives added to water being supplied to the boiler, and the blowdown rate for the boiler (rate of removing liquid from the boiler) depending on the measured conductivity of a sample of boiler water tapped from the blowdown line of the boiler. This reference is relevant for its showing of an electronic mechanism for controlling at least one parameter of a boiler.

The limits for spray flow of spray water to known attemperators have in the past been determined by measuring the steam temperature leaving the attemperator. This requires establishing a spray flow limit above saturation temperature since, once saturation temperature is reached, the temperature does not change as spray flow is increased. Problems have also been experienced in reading the temperature due to cooling effects of the thermowell by spray water.

According to a first aspect of the present invention there is provided a method of determining the maximum spray flow limit of an attemperator having a spray flow thereto, the method being characterised by:

measuring the inlet temperature of steam to the attemperator;

measuring the inlet pressure of steam to the attemperator;

calculating the enthalpy added to the attemperator by the spray flow;

calculating a temperature correction to enthalpy based on the measured inlet steam temperature;

obtaining a base enthalpy quantity for steam at a known temperature as a function of the inlet steam pressure;

adding the base enthalpy quantity to the temperature correction to generate a steam inlet enthalpy quantity;

obtaining a saturated steam enthalpy quantity as a function of the inlet pressure;

subtracting the saturated steam enthalpy quantity from the steam inlet enthalpy quantity to obtain a first difference value;

subtracting the spray flow enthalpy from the steam inlet enthalpy quantity to obtain a second difference value; and

dividing the first difference value by the second difference value and multiplying the result by a load through the attemperator to generate the maximum spray flow limit.

According to a second aspect of the present invention there is provided apparatus for determining the maximum spray flow limit of an attemperator having a spray flow thereto, the apparatus being characterised by:

a first temperature sensor for sensing the temperature of inlet steam to the attemperator;

a pressure sensor for measuring the pressure of the inlet steam to the attemperator;

a first constant block containing a value corresponding to a selected operating temperature;

a first difference taking block connected to the first constant block and to the first temperature sensor for taking the difference between the actual inlet temperature of steam to the attemperator and the selected operating temperature;

a second constant block connected to the first difference taking block for multiplying the output of the first difference taking block by a selected constant which is a characteristic of the attemperator;

a first function block connected to the pressure sensor for generating a multiplication factor which is a characteristic of the attemperator and is a function of the inlet steam pressure;

a first multiplication block connected to the second constant block and the first function block for generating a temperature correction for enthalpy;

a second function block connected to the pressure sensor for generating a steam enthalpy for steam selected operating temperature as a function of the inlet steam pressure;

a summing block connected to the first multiplication block and the second function block;

a third function block connected to the pressure sensor for generating a quantity corresponding to the enthalpy of saturated steam;

a second difference taking block connected to the summing block and the third function block for generating the difference between actual steam enthalpy and steam enthalpy for saturated steam;

an enthalpy measuring means for measuring enthalpy of the spray flow to the attemperator;

a third difference taking block connected to the summing block and to the enthalpy measuring means for taking the difference between the actual steam enthalpy and enthalpy of the spray flow;

a division block connected to the second and third difference taking blocks for dividing an output of the second difference taking block by an output of the third difference taking block; and

a second multiplication block connected to the division block and having an input for receiving a value corresponding to a load on the attemperator and for multiplying a value from the division block by the load value to generate the maximum spray flow limit.

According to a third aspect of the present invention there is provided a method of determining the maximum spray flow for an attemperator, the method being characterised by measuring the inlet temperature and pressure of the attemperator, using the inlet pressure to determine a base steam inlet enthalpy for steam at a known temperature, using the base enthalpy and a correction factor based on the inlet temperature to establish a corrected base enthalpy, subtracting the corrected base enthalpy from actual steam inlet enthalpy calculated as a function of the inlet pressure to obtain an enthalpy difference, dividing the enthalpy difference by a spray inlet enthalpy difference which is obtained by subtracting the corrected base inlet enthalpy from the spray inlet enthalpy representing enthalpy of spray flow on the attemperator, and multiplying the result of the division by a value corresponding to the main steam flow to obtain the maximum spray flow limit.

A preferred embodiment of the present invention described hereinbelow is intended to solve or at least alleviate the prior art problems in controlling the maximum spray flow limit. According to the preferred embodiment, the spray flow limit is calculated from inlet temperature and pressure readings as well as flow measurements. These measurements are utilised to indicate the steam and water enthalpies (heat contents) entering the attemperator. The limit is based on design information and does not require field information. Determination of maximum spray flow is based on a heat balance calculation around the attemperator. Since the outlet of the attemperator is known from design information, to make the calculation, only measurements to determine inlet conditions are required. The ratio of spray flow to outlet steam flow is the same ratio as inlet steam enthalpy minus limit enthalpy divided by inlet steam enthalpy minus spray medium enthalpy. For attemperators using water as the spray medium, only a temperature measurement is required to determine enthalpy. This is because the effect of pressure is small. Spray water enthalpy may also be established as a function of load from the plant heat balance information, which information is available from the manufacturer of a turbine to be powered by the boiler. This is acceptable because spray water enthalpy does not have a major effect on the heat balance calculation around the attemperator. The limit enthalpy can be determined from only a pressure reading since the desired temperature can be established in the design stage of the unit. The limit can be taken from a curve relating actual temperature to saturation temperature or, if required, the limit could be lowered to below the saturation curve for the fluid passing through the attemperator. The limit can be reduced because it does not require making the attemperator outlet temperature measurement. A lower limit in the design stage would result in a cost reduction since some units may not require two stages of attemperation if additional spray can be placed through the first attemperator. The determination of steam enthalpy entering the attemperator requires both a temperature and a pressure measurement. By assuming either a constant temperature or enthalpy, a base enthalpy can be established as a function of the other measurement (e.g. pressure). Actual enthalpy is then determined by modifying the base enthalpy for actual temperature and pressure. The accuracy of the enthalpy is a function of the factors used to modify the base enthalpy.

The preferred embodiment comprises a combination of interconnected simple function blocks for achieving multiplication, summation, division and subtraction functions.

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 showing an apparatus embodying the invention;

Figure 2 is a graph showing a first function which is related to attemperator inlet pressure and which can be used as a correction value for obtaining a base steam inlet enthalpy value;

Figure 3 is a graph showing a second function which is related to attemperator inlet pressure and which establishes a base enthalpy value for steam at a known temperature;

Figure 4 is a graph relating attemperator inlet pressure to a third function corresponding to a limit enthalpy; and

Figure 5 is a graph relating unit load or main steam flow in percent to a fourth function which can be used to obtain the spray water enthalpy.

Referring to Figure 1, the apparatus illustrated therein is operable to determine a maximum spray flow limit for an attemperator, which limit is outputted on a line 44, on the basis of inlet parameters for the attemperator including attemperator inlet pressure and temperature. The inlet pressure P of the attemperator is taken by a pressure sensor 10 and the inlet temperature T is taken by a temperature sensor 12. An element 14 provides a constant A corresponding to a preselected temperature, in this case 399$^{0}$C (750$^{0}$F), which is utilised to obtain a base enthalpy quantity as will be explained later. The value of 399$^{0}$C (750$^{0}$F) is subtracted from the actual temperature supplied by the temperature sensor 12, in a comparator or subtraction unit 16. The result of the subtraction is multiplied by a constant $K_1$ in a function block 18. This constant $K_1$ is a function of the attemperator structure and in the present case is 0.0065 when measurements are taken in SI units (1.5 when enthalpy is given in Btu/lb, pressure is given in $lbf/in^2$ gauge, and temperature is given in $^oF$, hereinbelow referred to as non-metric units). The output of the function block 18 represents a correction for temperature and is multiplied by a first function $f(x)_1$ which is outputted by a function block 22. As shown in Figure 2, the function block 22 will output a quantity up to 1, depending on the pressure value supplied to the function block 22 by the pressure sensor 10. The multiplication takes place in a block 20 and the output of the block 20 corresponds to a corrected temperature influence on the actual enthalpy.

The temperature influence is supplied to a summing block (function block) 28, as is a second function $f(x)_2$ outputted by a function block 24. The output $f(x)_2$ of the function block 24 is illustrated in Figure 3 and is related to the attemperator inlet pressure. The second function $f(x)_2$ corresponds to a base enthalpy for the preselected temperature of $399^oC$ ($750^oF$).

A limit enthalpy function $f(x)_3$ is generated by a third function block 26 from the inlet pressure and is chosen to be that for saturated steam. The difference between the saturated steam enthalpy and the base enthalpy is taken in a second subtracting unit 30.

Spray water enthalpy is determined by multiplying a spray water temperature T' from a second temperature sensor 40, in a constant factor function block 38. The spray water temperature is multiplied by a constant $K_2$, which is a characteristic of the attemperator. The constant $K_2$ in the present case is 0.00426 when measurements are taken in SI units (0.91 in non-metric units).

The value from the function block 38 is subtracted from the base enthalpy from the summing block 28 is a third subtracting unit 34, and the results from the subtracting units 30 and 34 are divided in a division unit (function block) 32.

An alternative way of incorporating the influence of the spray water is by using a fourth function block 42 which provides a fourth function $f(x)_4$ and can be connected directly to the division unit 32. The curve of Figure 5 shows how the unit load or main steam flow (in percent) is related to the fourth function $f(x)_4$ and can result in the spray water enthalpy.

The result of the division in the division unit 32 is multiplied in a multiplication block 36 by the unit load or main steam flow which is provided on a line 46. The results in a maximum spray flow which is outputted on the line 44.

A specific example of the above-described embodiment follows.

EXAMPLE

For a main steam flow of 2.02 x $10^5$kg/s (1,600 Mlb/h), a pressure of inlet steam of 13.8 MPa (2,000 lbf/$in^2$ or PSI) gauge was assumed. A temperature of inlet steam was assumed at 427°C (800°F) and a spray water temperature was assumed at 149°C (300°F). The pressure and temperature readings are assumed from field measurements.

For 13.8 MPa (2,000 lbf/$in^2$) gauge attemperator inlet pressure, the three functions yielded values as follows:

$f(x)_1$ = 0.6

$f(x)_2$ = 3.005MJ/kg (1,292 Btu/lb)

$f(x)_3$ = 2.621MJ/kg (1,127 Btu/lb)

Attemperator inlet temperature -399°C (750°F) = 28C° (50F°). This calculation is achieved in the function block 16.

Correction to base steam inlet enthalpy is
(28C°) (0.00625) (0.6) = 0.105MJ/kg ((50F°) (1.5) (0.6) = 45 Btu/lb)

This results from the use of the function blocks 18,20 and 22 with the 0.105MJ/kg (45 Btu/lb) being outputted from the summing block 20.

The steam inlet enthalpy is obtained in the summation box 28 as:
3.005 + 0.105 = 3.110MJ/kg (1,292 + 45 = 1,337 Btu/lb)

Spray flow enthalpy as calculated by the function blocks 40 and 28 is:
(154) (0.00426) = 0.656MJ/kg ((310)(0.91) = 282 Btu/lb).

Maximum spray flow can thus be calculated by the function blocks 26,30,32,34 and 36 as well as the value on the line 46 (representing the load of $2.02 \times 10^5$Kg/s (1,600Mlb/h)) as follows:

$$2.02 \times 10^5 \text{Kg/s} \left( \frac{3.110 - 2.645}{3.110 - 0.656} \right) \quad \left(1600\text{Mlb/h} \left( \frac{1337 - 1137}{1337 - 282} \right) \right).$$

The maximum spray flow limit thus is equal to $3.82 \times 10^4$kg/s (303 Mlb/h). This value is outputted on the line 44.

The acceptability of the procedure according to the preferred embodiment can be determined by calculating the actual outlet steam condition and comparing it to the saturation curve which was assumed to be the limit enthalpy. Inlet steam at 427°C (800°F) and 13.8 MPa (2,000 lbf/in$^2$) gauge pressure produces an actual enthalpy of 3.105MJ/kg (1,335 Btu/lb). Spray water at 154°C (310°F) produces an actual enthalpy of 0.660MJ/kg (284 Btu/lb). Attemperator heat balance is thus

$$\frac{1.634 \times 10^5 \text{kg/s})(3.105\text{MJ/kg}) + (0.382 \times 10^5 \text{kg/s})(0.660\text{MJ/kg})}{2.02 \times 10^5 \text{kg/s}} = \text{outlet steam enthalpy}$$

$$\left( \frac{(1{,}297\text{Mlb/h})(1{,}335\text{Btu/lb}) + (303\text{Mlb/h})(284\text{Btu/lb})}{1600 \text{ Mlb/h}} = \text{outlet steam enthalpy} \right)$$

Outlet steam enthalpy is calculated to 2.642 MJ/kg (1136 Btu/lb) which agrees quite well with the saturation enthalpy at 13.8 Pa (2,000 lbf/in$^2$) gauge of 2.644 MJ/kg (1137 Btu/lb).

## CLAIMS

1. A method of determining the maximum spray flow limit of an attemperator having a spray flow thereto, the method being characterised by:

measuring the inlet temperature (T) of steam to the attemperator;

measuring the inlet pressure (P) of steam to the attemperator;

calculating the enthalpy added to the attemperator by the spray flow;

calculating a temperature correction to enthalpy based on the measured inlet steam temperature (T);

obtaining a base enthalpy quantity ($f(x)_2$) for steam at a known temperature as a function of the inlet steam pressure (P);

adding the base enthalpy quantity ($f(x)_2$) to the temperature correction to generate a steam inlet enthalpy quantity;

obtaining a saturated steam enthalpy quantity ($f(x)_3$) as a function of the inlet pressure (P);

subtracting the saturated steam enthalpy quantity ($f(x)_3$) from the steam inlet enthalpy quantity to obtain a first difference value;

subtracting the spray flow enthalpy from the steam inlet enthalpy quantity to obtain a second difference value; and

dividing the first difference value by the second difference value and multiplying the result by a load through the attemperator to generate the maximum spray flow limit.

2. A method according to claim 1, wherein a main steam flow passes through the attemperator, the method including using the main steam flow as the load which is multiplied by the division result to obtain the maximum spray flow limit.

3. A method according to claim 1 or claim 2, wherein the spray flow enthalpy is obtained by sensing the temperature (T') of the spray flow and multiplying the temperature of the spray flow by a constant ($K_2$).

4. A method according to claim 1 or claim 2, wherein the spray flow enthalpy is obtained as a function ($f(x)_4$) of the attemperator load.

5. Apparatus for determining the maximum spray flow limit of an attemperator having a spray flow thereto, the apparatus being characterised by:

a first temperature sensor (12) for sensing the temperature (T) of inlet steam to the attemperator;

a pressure sensor (10) for measuring the pressure (P) of the inlet steam to the attemperator;

a first constant block (14) containing a value corresponding to a selected operating temperature (A);

a first difference taking block (16) connected to the first constant block (14) and to the first temperature sensor (12) for taking the difference between the actual inlet temperature (T) of steam to the attemperator and the selected operating temperature (A);

a second constant block (18) connected to the first difference taking block (16) for multiplying the output of the first difference taking block (16) by a selected constant ($K_1$) which is a characteristic of the attemperator;

a first function block (22) connected to the pressure sensor (10) for generating a multiplication factor ($f(x)_1$) which is a characteristic of the attemperator and is a function of the inlet steam pressure (P);

a first multiplication block (20) connected to the second constant block (18) and the first function block (22) for generating a temperature correction for enthalpy;

a second function block (24) connected to the pressure sensor (10) for generating a steam enthalpy ($f(x)_2$) for steam selected operating temperature as a function of the inlet steam pressure (P);

a summing block (28) connected to the first multiplication block (20) and the second function block (24);

a third function block (26) connected to the pressure sensor (10) for generating a quantity ($f(x)_3$) corresponding to the enthalpy of saturated steam;

a second difference taking block (30) connected to the summing block (28) and the third function block (26) for generating the difference between actual steam enthalpy and steam enthalpy for saturated steam;

an enthalpy measuring means (38,40;42) for measuring enthalpy of the spray flow to the attemperator;

a third difference taking block (34) connected to the summing block (28) and to the enthalpy measuring means (38,40;42) for taking the difference between the actual steam enthalpy and enthalpy of the spray flow;

a division block (32) connected to the second and third difference taking blocks (30,34) for dividing an output of the second difference taking block (30) by an output of the third difference taking block (34); and

a second multiplication block (36) connected to the division block (32) and having an input (46) for receiving a value corresponding to a load on the attemperator and for multiplying a value from the division block (32) by the load value to generate the maximum spray flow limit.

6. Apparatus according to claim 5, wherein the enthalpy measuring means comprises a second temperature sensor (40) for sensing the temperature (T') of spray flow to the attemperator and a third constant block (38) for multiplying the temperature of the spray flow by a constant ($K_2$) which is a characteristic of the attemperator.

7. Apparatus according to claim 5, wherein the enthalpy measuring means comprises a fourth function block (42) which yields a value ($f(x)_4$) corresponding to the enthalpy of the spray flow as a function of the load on the attemperator.

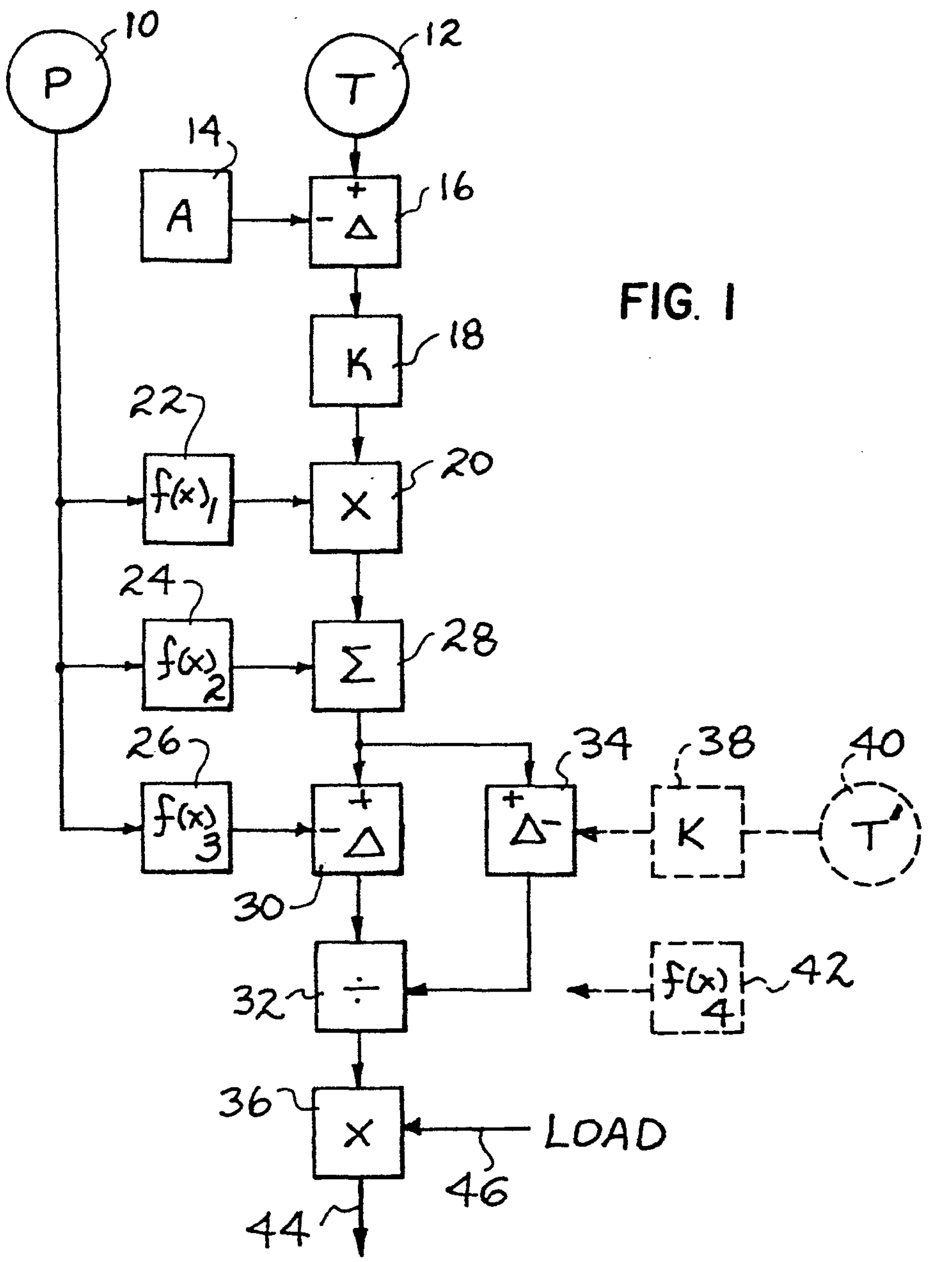
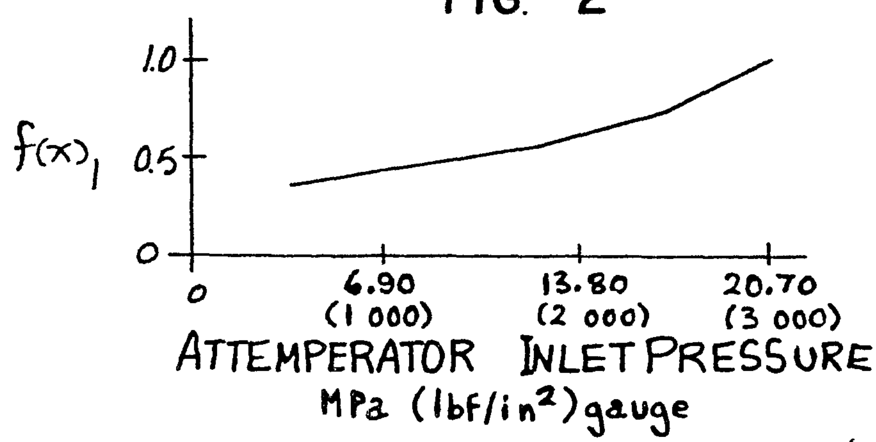

P
10
T
12
14
A
16
FIG. 1
K
18
22
f(x)1
X
20
24
f(x)2
Σ
28
26
f(x)3
Δ
30
34
Δ
38
K
40
T'
32
÷
f(x)4
42
36
X
LOAD
46
44

FIG. 2


f(x)1
1.0
0.5
0
0
6.90
(1 000)
13.80
(2 000)
20.70
(3 000)
ATTEMPERATOR INLET PRESSURE
MPa (lbf/in2) gauge

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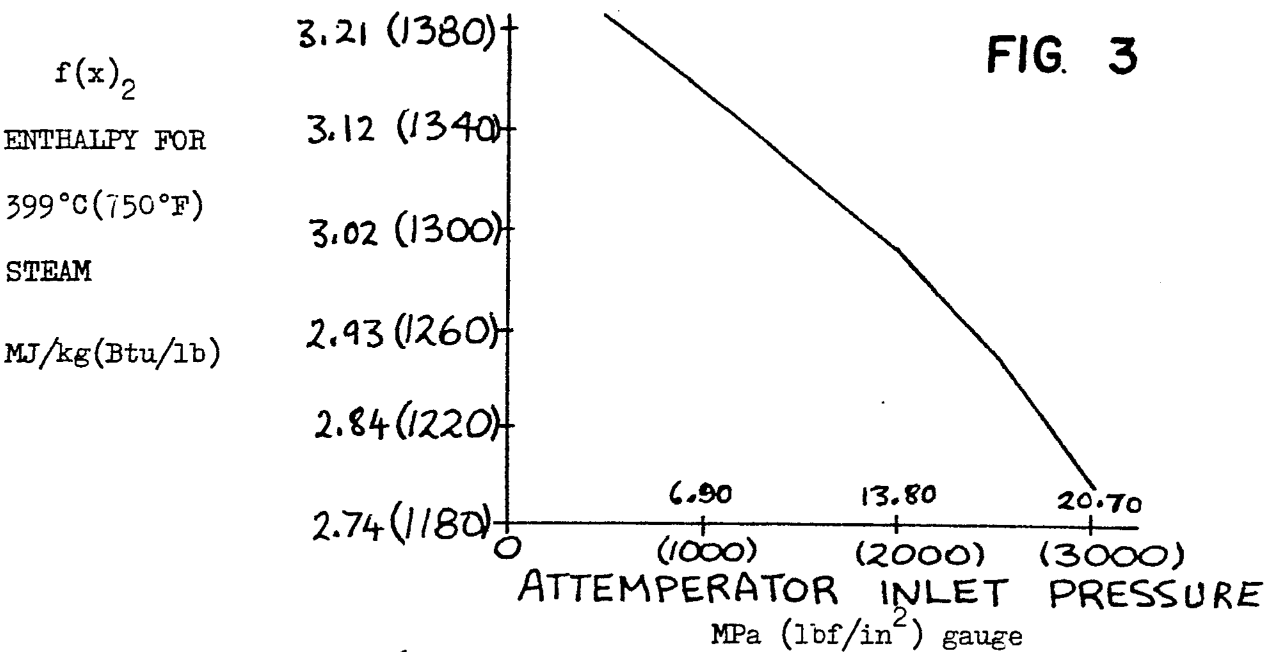


FIG. 3

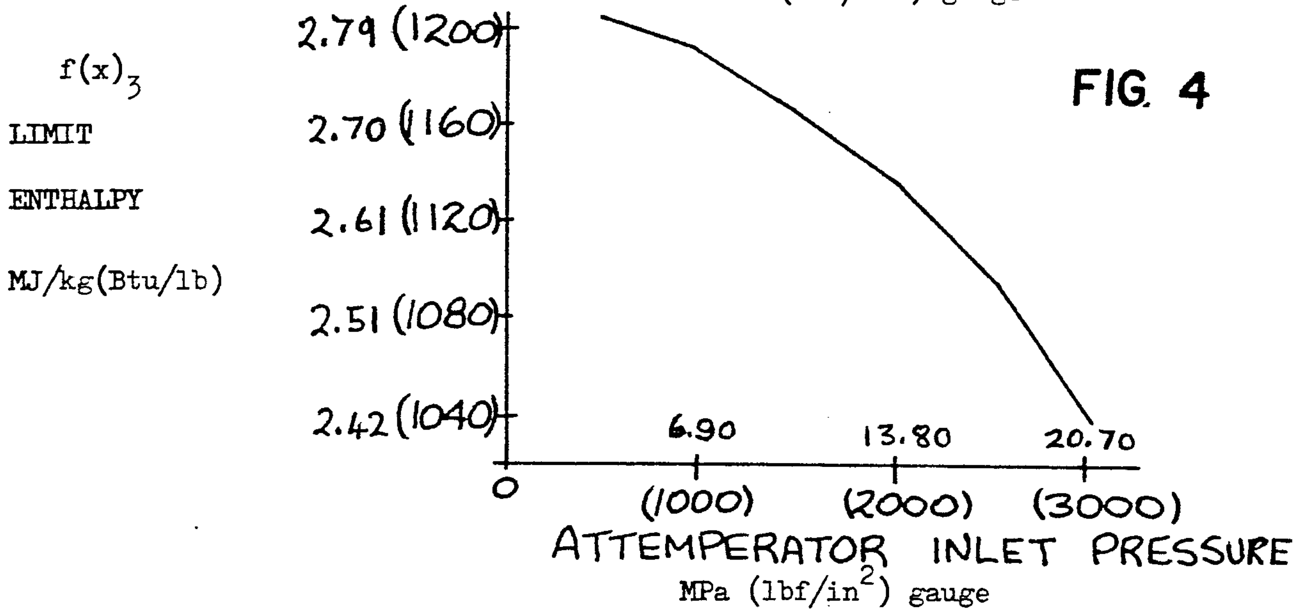


FIG. 4

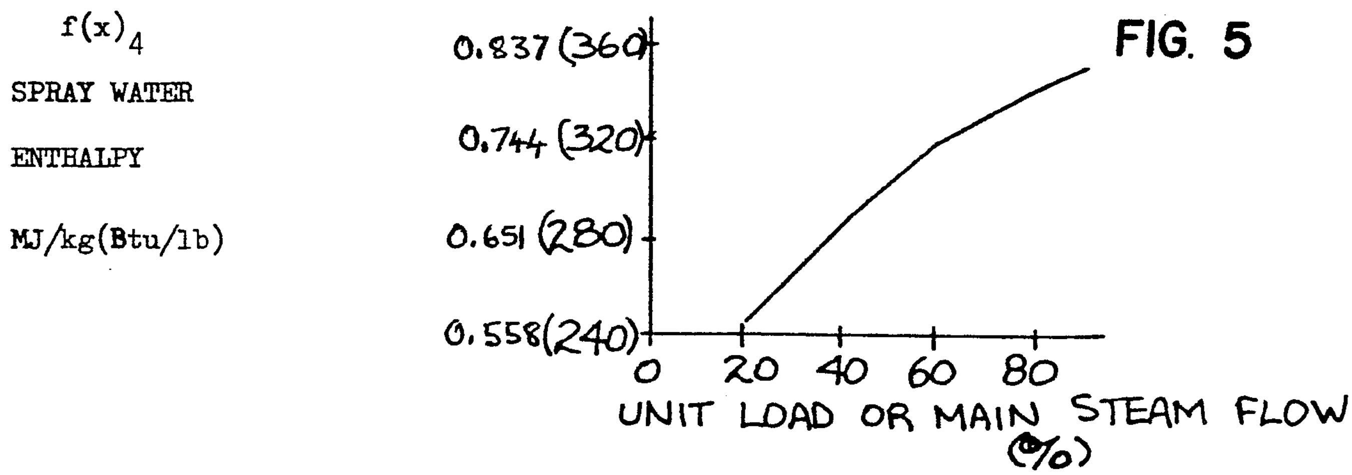


FIG. 5

European Patent Office

# EUROPEAN SEARCH REPORT

0184334
Application number

EP 85 30 8068

## 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.4) |
|---|---|---|---|
| X | DE-A-3 121 442 (STEAG AG)<br>* whole document *<br>--- | 1-3,5, 6 | F 22 G 5/12<br>G 21 C 17/02 |
| D,A | IEEE TRANSACTIONS ON NUCLEAR SCIENCE, vol. NS-28, no. 1, February 1981, pages 891-896; R.M. CARUSO et al.: "Design and qualification of a microprocessor subcooled margin monitor"<br>* page 891, chapter "Description", reference figure 1; page 892, figure 1 *<br>----- | 1,5 | |
| | | | **TECHNICAL FIELDS SEARCHED (Int. Cl.4)** |
| | | | F 28 F 27/00<br>F 22 B 35/00<br>F 22 G 5/00<br>G 21 D 3/00 |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| BERLIN | 05-02-1986 | BEITNER M.J.J.B. |

CATEGORY OF CITED DOCUMENTS

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