

PATENT SPECIFICATION

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(54) FURNACE CONTROL

(71) We, SHELL INTERNATIONAL RESEARCH MAATSCHAPPIJ B.V., a company organised under the laws of The Netherlands, of 30 Carel van Bylandtlaan, The Hague, The Netherlands, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The invention relates to a process and to an apparatus for the control of a furnace with at least two parallel coils of tubes over which the flow of matter to be heated and/or evaporated is distributed.

In principle, industrial furnaces consist of a system of tubes grouped around one or more flames. Through the system of tubes flows the matter to be heated and/or evaporated. This is often a liquid, such as an oil or an oil product. Besides its use for heating or evaporation, a furnace is also used for chemical conversions in the matter to be passed through. An example is cracking naphtha to form ethylene. The heat is transferred by radiation and by convection.

As a rule the system of tubes consists of two or more parallel coils. The incoming matter is distributed over the coils; at the ends of the coils the flows are combined again. The various flows can be controlled individually by valves. In doing this it is important to choose such a distribution of the matter that local overheating of a tube and/or of the matter flowing through it is prevented. It is also desirable to distribute the heat load evenly over the coils. This promotes an economic use of the furnace and prolongs its life. Industrial furnaces are usually kept in continuous operation for very long periods. With such furnaces it is not sufficient merely to maintain a pre-selected distribution of the flow of matter over the coils, because there are influences which call for adjustments in this distribu-

tion. Examples of such influences are changes in the distribution of fuel and air supply to the burners, changes in the position(s) of the flame(s), clogging of part of the tubes, weather conditions.

The invention enables measures to be taken by which the above-mentioned wishes can be satisfied.

The invention relates to a process for the control of a furnace having at least two parallel coils of tubes over which the flow of matter to be heated and/or evaporated is distributed, whereby

a) the temperature T_i of the matter is measured at the end of each coil and the average value

$$\bar{T} = \frac{1}{n} \sum_{i=1}^n T_i \text{ is calculated,}$$

b) each difference $\bar{T} - T_i$ is used to produce a signal by which the flow of matter through the coil concerned is adjusted so as to cause the said difference $\bar{T} - T_i$ to decrease,

c) of the temperatures T_i the highest $T_{i \max}$ is chosen and the difference $T_{i \max} - T_s$ (where T_s is a set value related to temperature T_o of the combined flow of matter leaving the furnace) is used to produce a signal by which the heat generation in the furnace is adjusted so as to cause the said difference $T_{i \max} - T_s$ to decrease.

This control system continuously aims at eliminating differences in temperature at the end of the coils. For this purpose the average of temperatures T_i is used, not the temperature of the combined flows leaving the furnace. The latter temperature is a weighted average and it may deviate from the arithmetic average $\bar{T}$. A deviation may also occur through evaporation of matter after the point where T_i is measured and before the point where T_o is measured. Therefore the control system according to the invention always enables temperatures

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Ti to be equalized, irrespective of differences in magnitude of the flows of matter through the coils.

The control of the heat generation in the furnace is based on the highest temperature occurring in a coil. The important result is that this highest temperature will never exceed the permissible temperature. Moreover, the furnace can now actually be operated at its maximum load, because all temperatures Ti are continuously made to approach the maximum permissible temperature.

As a consequence of the control according to the invention as described hereinbefore the total flow of matter through the furnace does not remain constant. In a number of cases, however, it is important to keep that flow constant or to be able to control it. According to another characteristic feature of the invention this requirement can be met when each signal produced as described hereinbefore under b) is made to adjust the set value for the control of the flow of matter through the coil concerned in proportion to the difference $T - T_i$. Now the total flow of matter does remain constant, because the sum of the deviations from the (arithmetic) mean $\Sigma_i (T - T_i)$ is always zero and hence the sum of changes which are each proportional to the deviation concerned is also zero.

There are also situations in which a variable supply of matter to the furnace has to be reckoned with. That may be the result of a non-constant supply of matter, e.g. from another plant, or of a variable demand for the end product of the furnace. The invention meets this situation by computing for each coil the ratio $\Delta R_i = \frac{C(T - T_i)}{F_s}$, where C is a constant and F_s the set value for the total flow of matter through the furnace, this ratio ΔR_i being used to control the flow of matter through the coil concerned. In this way each coil gets its share F_i of the flow matter supplied, while the advantages of the control system according to the invention are retained.

The ratio $R_i = \frac{F_i}{F_s}$. A frequently encountered situation involving a variable incoming flow of matter is one in which an incoming liquid flow comes from a space in which a specified liquid level must be maintained, for instance at the bottom of a distilling column. The set value F_s can then be derived from that liquid level. When the liquid level changes F_s is adjusted such that the liquid level goes back to the desired value.

An interesting improvement of the process according to the invention is achieved

when the difference $T_o - T_i$ is used for non-linearizing the control of the heat output in the furnace, namely by increasing the proportional control factor and the integral action time of the heat output control as the said difference becomes greater. The said increase can amount to at most a factor of 6. The result of this control is that upward deviations of $T_{i \max}$ are reduced.

The control according to the invention may be implemented using conventional controllers and dedicated computing elements, the latter, if desired, of the electronic type. It is also possible to set up the whole control system according to the principle of direct digital control or supervisory control. This alternative will be preferred in the case of large manufacturing plants where a digital computer or a number of microcomputers is already in use, e.g. to control other units of the plant and for the processing and presentation of data. The invention will now be further elucidated with reference to some figures and examples.

Figures 1, 2 and 3 are diagrammatic representations of a furnace with four parallel coils of tubes with variants of the control system according to the invention. Figures 4/8 show results of experiments with control systems according to the invention.

In Fig. 1 numeral 1 represents the flame that heats coils 2, 3, 4 and 5. Fuel for flame 1 is supplied at 6 and the rate of flow is controlled by means of valve 7. The matter to be heated and/or evaporated enters the system at 8 and is distributed by means of valves 9, 10, 11 and 12 over coils 2, 3, 4 and 5, respectively. The collected matter leaves the system at 50.

Each coil is equipped with a temperature meter (13, 14, 15, 16) and a flow meter (17, 18, 19, 20). The flow meters measure the quantity of matter passing through per unit time. A flow meter 21 measures fuel stream 6, a temperature meter 22 measures the temperature of the stream of matter 50 leaving the furnace. A temperature controller 23 generates the set value for fuel flow controller 24. Flow controllers 25, 26, 27 and 28 control valves 9, 10, 11 and 12, respectively.

The numerals used so far have the same meaning in Figs. 2 and 3.

In the scheme according to Fig. 1 the signals of temperature meters 13, 14, 15 and 16 go to a computing element 29 and to a selector 30. Computing element 29 computes the average value $\bar{T}$ of the temperatures measured,

so, in this case, $\bar{T} = \frac{1}{4} \sum_{i=1}^4 T_i$. The average value

$\bar{T}$ is the set value for controllers 31, 32, 33 and 34. In controller 31 $\bar{T}$ is compared with the temperature measured by meter 16 in coil 5. The output signal of controller 31 is the set value for flow controller 28. This control

aims at equalizing the temperature measured by meter 16 with average temperature $\bar{T}$. Similar elucidations are applicable to controllers 32, 33 and 34.

From the measured temperatures of coils 2, 3, 4 and 5 selector 30 selects the highest value $T_{i\max}$. In controller 35 $T_{i\max}$ is compared with a set value T_s resulting in an output signal which is the set value for controller 23. From the comparison with the measured temperature of stream 50 follows the set value for flow controller 24 for fuel stream 6. The temperature of stream 50 follows the set value for flow controller 24 for fuel stream 6. The temperature of stream 50 leaving the furnace is thus determined by the highest value $T_{i\max}$ occurring in a coil, which temperature $T_{i\max}$ cannot exceed set value T_s .

In the scheme according to Fig. 2 the task of computing element 36 is to control the streams through coils 2, 3, 4 and 5 such that total stream 8 (or 50) remains constant, while obviously the aforementioned task of controllers 25, 26, 27 and 28, which was to equalize each temperature T_i with average temperature $\bar{T}$, remains the same. To this end the signals of temperature meters, 13, 14, 15 and 16 are transmitted to computing element 36 and average temperature $\bar{T}$ is computed. Subsequently, $\bar{T} - T_i$ is determined for each coil. Then for each flow controller 25, 26, 27 and 28 a set value is now computed, based on the difference $\bar{T} - T_i$, which set value is now incremented in proportion to the difference $\bar{T} - T_i$. The desired value F_s for the total flow of matter 8 is taken into account here, which is indicated by arrow 37. Computing element 38 fulfils the tasks of selector 30 and controller 35 discussed with Fig. 1. Set value T_s is indicated here by arrow 39. Thus, computing element 36 controls the entire flow through the coils and the balance between them, while computing element 38 controls the balance between the desired and the maximum permissible temperature.

In Fig. 3 the incoming stream 8 is withdrawn from the bottom of a column 41 by a pump 40.

The liquid level in column 41 must remain within certain limits. For this purpose a level gauge 42 and a controller 43 are present. The output signal of level controller 43 goes to computing elements 44, 45, 46 and 47. Each computing element computes the ratio between the output signal of level controller 43 and the difference $\bar{T} - T_i$ computed for each coil by computing element 48. The amount of liquid allowed to leave the column, determined by level controller 43, is thus distributed over the various coils. Furthermore, on the basis of set value T_s (arrow 49), computing element 48 computes

the set value for controller 23 as described in relation to Fig. 2 for computing element 38.

Fig. 3 also shows a computing element 51 by which the proportional control factor and the integral action time of controller 23 can be adjusted to the difference $T_{i\max} - T_s$ computed by computing element 48.

The aforementioned control schemes may be realized with conventional controllers and dedicated computing elements, such as computing a ratio, computing an average, etc. However, it is also possible to use a digital computer for all computations. Finally, the functions of the controllers, too, can be performed entirely by a digital computer.

Example I

Through a furnace with four coils of tubes oil was passed at a mass velocity of about 3000 t/d. The maximum permissible temperature $T_{\max}$ was 390°C. Fig. 4A shows, for an arbitrary time interval of 120 minutes, the changes in temperature at the end of each of the coils 1, 2, 3 and 4 for the case where only manual control was used. There was a spread of about 11°C. The changes in temperature T_o of the combined outgoing stream is shown in Fig. 4B on the same temperature and time scale as used in Fig. 4A. The set value T_s is also shown. Owing to the wide spread a temperature of about 380°C had to be chosen for T_s , to avoid the risk of any of the coil temperatures exceeding $T_{\max}$.

Figs. 4C and 4D show the results upon application of the control system according to the invention for a constant oil supply. The temperature curves for coils 1, 2, 3 and 4 now coincide and the curve for T_o is identical with each of the curves 1, 2, 3 and 4. The set value T_s can now be chosen much closer to $T_{\max}$, viz. by a distance a as compared with the case of manual control. That distance was here 6.3°C.

Example II

The effect of changing the total oil throughput is shown for a furnace similar to that used in Example I with a control system according to the invention. Fig. 5A shows the changes in temperatures T_i and in the rate of flow F_i for the four coils of tubes in case of manual control. Temperature T_o of the combined outgoing stream is also given. This temperature T_o is lower than any of the temperatures T_i which is a result of evaporation between measuring points T_i and T_o . Line T_s shows the set value for temperature T_o .

Arrow b in Fig. 5B indicates the time at which the total oil supply was reduced by 292 t/d, arrow c indicates the time at which the supply was increased by 292 t/d. Figs. 6A and 6B show the results of these step-

wise changes when the control system according to the invention is used. Clearly, the initial disturbing effect on temperatures T_i and T_o is rapidly neutralized. The relative spreads in T_i are very small.

Example III

For a furnace similar to that used in the previous examples the effect of non-linearity of the fuel supply controller is measured as a function of the difference $T_o - T_s$ (controller 23 in Fig. 3).

There were four cases: I refers to the normal setting of the controller, II refers to multiplication of the proportional control factor and the integral action time by a factor of 2, III by a factor of 4 and IV by a factor of 6.

Fig. 7 shows the changes in temperatures T_i - which coincide each time for all four coils - for the cases I/IV when the difference $T_o - T_s$ exceeded 1°C . Fig. 8 shows setting VP of value 7 in the fuel line (Fig. 3).

The fluctuation in the temperatures T_i is found to decrease as the multiplication factor increases. The valve setting for cases III and IV is shown. Case III is more favourable than IV as regards minimizing the fluctuations in the fuel supply.

WHAT WE CLAIM IS:-

1. A process for the control of a furnace having at least two parallel coils over which the flow of matter to be heated and/or evaporated is distributed, characterized in that

a) the temperature T_i of the matter is measured at the end of each coil and the average value $\bar{T} = \frac{1}{n} \sum_{i=1}^n T_i$ is computed,

b) each difference $\bar{T} - T_i$ is used to produce a signal by which the flow of matter through the bundle concerned is adjusted so as to cause the said difference $\bar{T} - T_i$ to decrease,

c) of the temperatures T_i the highest $T_{i \max}$ is chosen and the difference $T_{i \max} - T_s$, (where T_s is a set value related to the temperature T_o of the combined flow of matter leaving the furnace) is used to produce a signal by which the heat generation in the furnace is adjusted so as to cause the said difference $T_{i \max} - T_s$ to decrease.

2. A process according to claim 1, characterized in that each signal produced according to 1-b is made to adjust the set value for the control of the flow of matter through the coil concerned in proportion to the difference $\bar{T} - T_i$.

3. A process according to claim 1, characterized in that for each coil the ratio $\Delta R_i = C \frac{\bar{T} - T_i}{F}$

is computed, where C is a constant and F_s the set value for the total

flow of matter to the furnace, this ratio R_i being used to control the flow of matter through the coil concerned.

4. A process according to claim 3, characterized in that for a liquid flow of matter F_s is derived from the level of the liquid flow to be supplied from a vessel.

5. A process according to any of claims 1 - 4, characterized in that the difference $T_o - T_s$ is used for non-linearizing the control of the heat output in the furnace, namely by increasing the proportional control factor and the integral action time of the heat output control as the said difference becomes greater.

6. A process according to claim 5, characterized in that the said increase amounts to at most a factor of 6.

7. A process according to claim 1 and as described hereinbefore, in particular with reference to the figures and the examples.

8. An apparatus suitable for carrying out the process according to claim 1 or 2, characterized by

d) a meter for the temperature of the matter at the end of each coil,

e) a meter for the flow of the matter through each coil,

f) a control device for the flow of the matter through each coil,

g) a computing element for computing $\bar{T} = \frac{1}{n} \sum_{i=1}^n T_i$

and $\Delta T_i = \bar{T} - T_i$ for each coil, for which purpose the computing element is connected to the meters mentioned under d)

h) a controller for each coil, of which controller the input for the measured value is connected to the corresponding meter mentioned under d) and of which the input for the set value is connected to the output of the computing element for the corresponding value of ΔT_i mentioned under g) and of which the output is connected to the corresponding control device mentioned under f)

i) a computing element for the difference $T_{i \max} - T_s$ for which purpose the computing element is connected to the meters mentioned under d),

j) a meter for the temperature of the combined outgoing stream,

k) a control device for the fuel stream to the burner of the furnace,

l) a controller of which the input for the measured value is connected to the meter mentioned under j) and of which the input for the set value is connected to the output of the computing element mentioned under i) and of which the output is connected to the control device mentioned under k).

9. An apparatus according to claim 8 suitable for carrying out the process accord-

wise changes when the control system according to the invention is used. Clearly, the initial disturbing effect on temperatures T_i and T_o is rapidly neutralized. The relative spreads in T_i are very small.

Example III

For a furnace similar to that used in the previous examples the effect of non-linearity of the fuel supply controller is measured as a function of the difference $T_o - T_s$ (controller 23 in Fig. 3).

There were four cases: I refers to the normal setting of the controller, II refers to multiplication of the proportional control factor and the integral action time by a factor of 2, III by a factor of 4 and IV by a factor of 6.

Fig. 7 shows the changes in temperatures T_i - which coincide each time for all four coils - for the cases I/IV when the difference $T_o - T_s$ exceeded 1°C . Fig. 8 shows setting VP of value 7 in the fuel line (Fig. 3).

The fluctuation in the temperatures T_i is found to decrease as the multiplication factor increases. The valve setting for cases III and IV is shown. Case III is more favourable than IV as regards minimizing the fluctuations in the fuel supply.

WHAT WE CLAIM IS:-

1. A process for the control of a furnace having at least two parallel coils over which the flow of matter to be heated and/or evaporated is distributed, characterized in that

a) the temperature T_i of the matter is measured at the end of each coil and the average value

$$\bar{T} = \frac{1}{n} \sum_{i=1}^n T_i \text{ is computed,}$$

b) each difference $\bar{T} - T_i$ is used to produce a signal by which the flow of matter through the bundle concerned is adjusted so as to cause the said difference $\bar{T} - T_i$ to decrease,

c) of the temperatures T_i the highest $T_{i \max}$ is chosen and the difference $T_{i \max} - T_s$, (where T_s is a set value related to the temperature T_o of the combined flow of matter leaving the furnace) is used to produce a signal by which the heat generation in the furnace is adjusted so as to cause the said difference $T_{i \max} - T_s$ to decrease.

2. A process according to claim 1, characterized in that each signal produced according to 1-b is made to adjust the set value for the control of the flow of matter through the coil concerned in proportion to the difference $\bar{T} - T_i$.

3. A process according to claim 1, characterized in that for each coil the ratio $\Delta R_i = C \frac{\bar{T} - T_i}{F}$

is computed, where C is a constant and F_s the set value for the total

flow of matter to the furnace, this ratio R_i being used to control the flow of matter through the coil concerned.

4. A process according to claim 3, characterized in that for a liquid flow of matter F_s is derived from the level of the liquid flow to be supplied from a vessel.

5. A process according to any of claims 1 - 4, characterized in that the difference $T_o - T_s$ is used for non-linearizing the control of the heat output in the furnace, namely by increasing the proportional control factor and the integral action time of the heat output control as the said difference becomes greater.

6. A process according to claim 5, characterized in that the said increase amounts to at most a factor of 6.

7. A process according to claim 1 and as described hereinbefore, in particular with reference to the figures and the examples.

8. An apparatus suitable for carrying out the process according to claim 1 or 2, characterized by

d) a meter for the temperature of the matter at the end of each coil,

e) a meter for the flow of the matter through each coil,

f) a control device for the flow of the matter through each coil,

g) a computing element for computing $\bar{T} = \frac{1}{n} \sum_{i=1}^n T_i$ and $\Delta T_i = \bar{T} - T_i$ for each coil, for which purpose the computing element is connected to the meters mentioned under d)

h) a controller for each coil, of which controller the input for the measured value is connected to the corresponding meter mentioned under d) and of which the input for the set value is connected to the output of the computing element for the corresponding value of ΔT_i mentioned under g) and of which the output is connected to the corresponding control device mentioned under f)

i) a computing element for the difference $T_{i \max} - T_s$ for which purpose the computing element is connected to the meters mentioned under d),

j) a meter for the temperature of the combined outgoing stream,

k) a control device for the fuel stream to the burner of the furnace,

l) a controller of which the input for the measured value is connected to the meter mentioned under j) and of which the input for the set value is connected to the output of the computing element mentioned under i) and of which the output is connected to the control device mentioned under k).

9. An apparatus according to claim 8 suitable for carrying out the process accord-





(14)

ing to claim 5, characterized by a computing element for computing a multiplication factor, for which purpose the computing element is connected to the output of the computing element mentioned under i) and to the meter mentioned under j) and of which the output is connected to an input of the controller mentioned under l) for setting the proportional control factor and the integral

action time of that controller.

10. An apparatus according to claim 7 and as described hereinbefore and in particular with reference to Figures 1, 2 and 3.

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