METHOD OF MEASURING THE DEW-POINT, NOTABLY OF COMBUSTION SMOKES, AND APPARATUS FOR CARRYING OUT THIS METHOD

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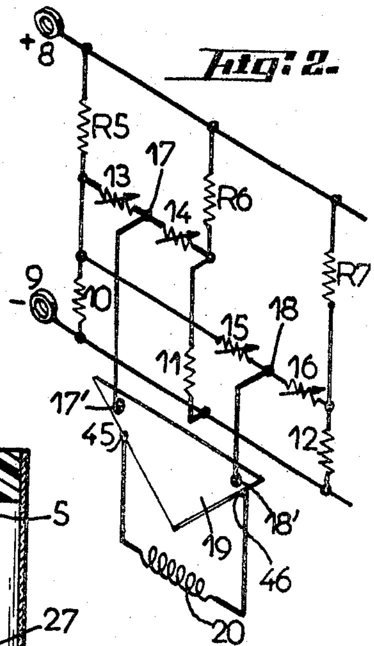

Fig. 2.

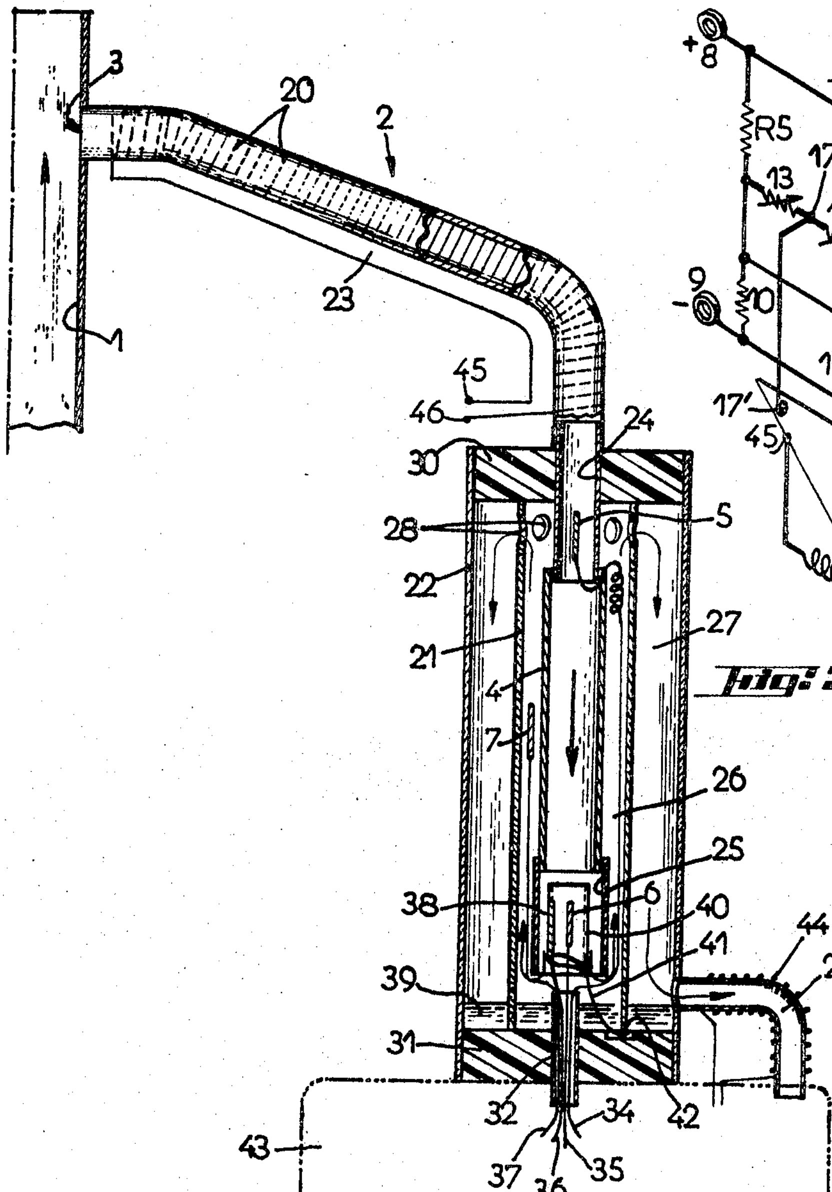

Fig. 3.

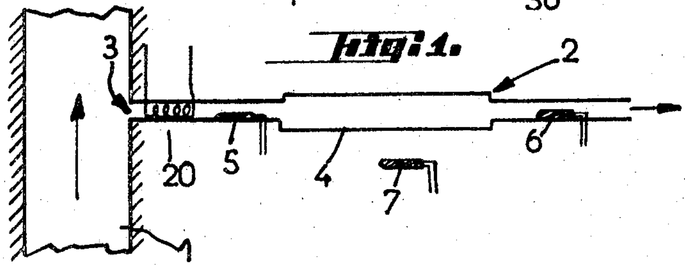

Fig. 1.

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3,491,583 METHOD OF MEASURING THE DEW-POINT, NOTABLY OF COMBUSTION SMOKES, AND APPARATUS FOR CARRYING OUT THIS METHOD

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ABSTRACT OF THE DISCLOSURE

The invention has for object an apparatus for measuring the dew-point of combustion smokes, remarkable notably in that it comprises a smoke pick-up hose, a device for cooling the picked up smokes which comprises a tube through which the smokes are caused to flow and which is surrounded by an external medium at a lower temperature and at least one thermometric probe disposed in said tube in the vicinity of its outlet for measuring the dew temperature. There is provided a heating for the smokes upstream of the tube to prevent any condensation before the outlet section of the tube and a humidifying device in the vicinity of said outlet section of the tube whereby the incipient condensations are blocked at the level of said probe.

The present invention has essentially for its object a method of measuring the dew-point, notably of combustion smokes of any installations, for example gas-operated systems, and also an apparatus for carrying out said method.

The apparatus further permits of continuously recording the temperature of the smokes produced by the combustion of gaseous or other fuels.

Many devices have already been proposed for making dew-point measurements, from the conventional psychometer to very complicated and costly electronic devices. In the smoke dew-point temperature range, notably of gaseous fuel combustion products, the standard device consists of a lithium chloride probe. The probe itself is relatively cumbersome and must be placed into the atmosphere of combustion products; this apparatus is delicate, liable to misadjustment and becomes rapidly sooted (after only a few hours' service) in a smoke chimney or duct. Moreover, the use of this probe is limited by the fact that it cannot withstand room temperatures in excess of a given limit; more particularly, it cannot be placed into the atmosphere of an oven.

This invention is concerned with a method of measuring dew-point values which is completely new and free of the inconveniences set forth hereinabove. More particularly, an apparatus for carrying out this method is constructionally very simple and permits the continuous recording of the dew-point of the smokes produced in all types of installations, irrespective of the original temperature of the smoke (taken for example from an oven or a

smoke duct), and irrespective of the smoke output. In addition, the apparatus of this invention has a good degree of precision, for example of the order of ±0.5° C. for a dew-point temperature range substantially from room temperature to about 100° C.

The method of this invention for measuring the dew-point of smokes is remarkable notably in that a continuous, light and substantially constant output is derived from the smoke circuit, the smokes thus picked up being cooled between two points by causing same to circulate through a device maintained externally at a lower temperature, water being caused to condense at a given point of said device while taking care that no condensation takes place upstream of this given point, the temperature prevailing at this point being measured and corresponding to the desired dew-point temperature, the smokes introduced into the device being heated sufficiently to prevent any condensation upstream of said given point.

According to another feature characterizing the method of this invention, an atmosphere of saturating humidity is maintained at the outlet of the aforesaid device, for example by using liquid water brought substantially to the temperature prevailing at the outlet of the device.

According to a complementary feature of the present invention, the heating of the smokes entering the device is reduced each time condensations tend to flow back downstream of the aforesaid point, and water is picked up from the means utilized for maintaining the aforesaid saturating humidity.

It is another feature of the method of the present invention to compare the temperature differences between the inlet and outlet sections of said device, with the temperature prevailing within the device, and any departure from these differences with respect to the differences contemplated which normally appear in the absence of any condensation or delivery or vaporization of water through the aforesaid means in said device, and the heating of smokes is increased or decreased before they penetrate into the device, according as a condensation aforesaid or a water vaporization aforesaid tends to take place, in order to correct or minimize this departure.

Thus, the water contained in the smokes is effectively constrained to commence its condensation at a well-defined point, the temperature obtaining at this point being therefore equal to the dew-point to be found. It may be adequate to remind that the dew-point, for example of smokes, is the temperature at which the condensation begins, under a given pressure prevailing in the smokes, which pressure is usually substantially equal to the atmospheric pressure.

An apparatus for carrying out the method of this invention is remarkable notably in that it comprises a duct of relatively small cross-sectional passage area for deriving one fraction of a smoke output, a device for cooling the smokes thus picked up, which comprises for example a tube through which the smokes are circulated, this tube being located in an external medium or atmosphere having a lower temperature than said smokes, and at least one thermometric probe such as a thermocouple or the like, secured in said tube in the vicinity of its outlet for measuring the dew-point; moreover, means are provided for heating the smokes upstream of said tube, that is, before the smokes penetrate into the tube, to prevent any condensation from taking place before the smokes reach the outlet section of said tube which is substantially level with said thermocouple.

According to another feature characterizing this invention, a humidifier operating under a substantially saturating water vapour pressure, which comprises for example a reserve of liquid water brought substantially to the temperature prevailing at the outlet of said device, is provided in the vicinity of the outlet section of said tube.

According to a preferred form of embodiment of an apparatus for carrying out the method of this invention, at least three thermometric probes are provided which read respectively the smoke temperatures at the inlet and outlet of said tube, and also the temperature of said external atmosphere; moreover, the apparatus comprises a comparator, for example of electronic type, for comparing the temperature discrepancies between said probes with the corresponding discrepancies produced in the absence of any condensation or water vaporization in the device; when possible corresponding departures or deviations from these temperature discrepancies appear, they are utilized for increasing or decreasing the heating in the aforesaid apparatus.

In fact, as will be explained more in detail hereinafter, a given relationship exists between the three temperatures measured by the three aforesaid thermometric probes, in the absence of any condensation or any water vaporization between the inlet and outlet sections of the tube in which the smokes are cooled; if water condenses or vaporizes between said inlet and outlet tube sections, the relationship previously existing between the three temperatures is no more true. Under these conditions, by constructing the apparatus in the manner broadly set forth hereinabove, the condensation products are prevented from circulating up and down the tube beyond the point whereat the dew temperature is measured. More particularly, by disposing the aforesaid humidifier in the outlet section of said tube, the condensation products are prevented from flowing down this tube; in other words, the first condensation products are caused to appear exactly in the outlet section of the tube and the smokes are efficiently and rapidly cooled; this arrangement also permits of controlling the aforesaid heating means by reducing its action when a corresponding variation in the temperatures measured by the probes becomes apparent, this variation being caused by the relatively intense cooling of the outlet section of the apparatus which is due to the water vaporization in the humidifier. It is thus clear that with the apparatus of this invention the incipient condensation is stopped in said outlet section of the tube. Therefore, reading the temperature prevailing in this section is like reading the dew temperature of the smokes.

According to a specific feature characterizing this invention, the aforesaid heating means comprises an electrical heating resistance receiving current from the power output stage of an amplifier incorporated in the aforesaid electronic device, the input signal of this amplifier being substantially proportional to the aforesaid deviations. This electronic device will advantageously utilize resistance probes, and under these conditions the smokes are heated automatically before they penetrate into said tube, the heating being constantly regulated by the smokes themselves which tend to start condensing at the very point where the dew temperature is measured, without causing neither any condensation upstream of this point, nor any water vaporization downstream of this point.

With the humidifier mentioned hereinabove if condensations tend to take place and flow down the tube, the humidifier will cause the water to evaporate in the outlet section of this tube, thus reducing the temperature along this section, and simultaneously reducing the heating action of said heating means; the cooling and heating of said tube are obtained automatically by stopping the first condensations, i.e. those taking place at the desired dew-point in the outlet section of said tube.

Other features and advantages of this invention will appear as the following description proceeds with reference to the accompanying drawings illustrating diagrammatically by way of example the principles and a typical form of embodiment of this invention. In the drawings:

FIGURE 1 is a diagram illustrating the general disposal of an apparatus constructed according to the teachings of this invention for carrying out the method of measuring the dew-point, notably of combustion smokes;

FIGURE 2 is a very simplified wiring diagram illustrating the automatic heating of the upstream section of the pick-up tube utilized in the construction of an apparatus according to this invention, and

FIGURE 3 is a sectional view showing on a larger scale a preferred form of embodiment of the apparatus.

Referring first to FIGURE 1 of the drawings, the reference numeral **1** designates diagrammatically an enclosure in which smokes circulate, this enclosure consisting for example of a chimney or like duct. According to this invention, a continuous light and substantially constant output is derived from the duct **1**, for example by means of a suction pump (not shown) connected to the upstream end of the branch circuit **2** connected at **3** to the main duct **1**. In this circuit **2** a device **4**, for example in the form of a tube or pipe, is mounted and adapted to receive therethrough the smoke picked up from the main duct **1**; this tube **4** is cooled by external means, for example the surrounding atmosphere, or any other suitable medium having the desired selected temperature. The reference numrals **5**, **6** and **7** designate three thermometric probes measuring respectively temperatures of the smoke at the inlet and outlet ends of tube **4**, and of the cooling medium surrounding this tube **4**.

According to the laws governing the transfer of heat, in the absence of any condensation in the tube **4**, if

t_5, t_6 and t_7 are the temperatures measured respectively by probes **5**, **6** and **7**, and if
α is the means heat transfer coefficient between the smokes circulating in the tube **4** and the air surrounding this tube,
C_p being the specific heat of the smokes, and
Q the smoke output

the following relation is obtained:

$$\alpha\left\{\frac{t_5+t_6}{2}-t_7\right\}=C_pQ\,(t_5-t_6) \qquad (1)$$

This relation may be written in a simplified form:

$$\Delta=K_1(t_5-t_6)-K_2(t_5-t_7)=0 \qquad (2)$$

K_1 and K_2 being constants depending on the values of α, C_p and Q.

From the foregoing, it will be seen that if care is taken to supply a substantially constant smoke output Q to the tube **4**, the specific heat of the smokes being substantially constant and α being constant for a given apparatus and a given output, the relation (2) should be obtained in all cases as long as no condensation or additional water vaporization takes place in the tube **4**.

If a condensation or a vaporization is produced in the tube **4**, the latent heat of vaporization of the water condensed or vaporized is recovered or dissipated in the tube **4**, thus altering the law previously connecting the temperatures t_5, t_6 and t_7 to one another. Under these conditions, the above relation (2) is no more valid. In other words, variations Δ other than zero appear in the system.

In FIGURE 2 a simplified wiring diagram is illustrated to set in sharper contrast the above-defined variation Δ. The device permitting of evidencing this variation is mounted across the positive and negative terminals **8** and **9** of a suitable source of current; mounted across the terminals **8** and **9** of the supply circuit are series resistances R_5—10; R_6—11 and R_7—12 respectively. Resistances 10, 11 and 12 may have the same characteristics and for example a very high value with respect to the other resistances R_5, R_6 and R_7. Three currents of substantially equal intensity will thus flow through the parallel branches R_5—10, R_6—11 and R_7—12. Resistances R_5, R_6 and R_7 actually consist respectively of the resistances of the thermometric probes 5, 6 and 7 which in this case are advantageously of the resistance type. Two bridge mountings, utilizing suitable variable resistances 13 to 16, are provided, their characteristics being such that voltages designated hereinafter with reference to the potential V_8 of terminal 8, can be derived from the intermediate points 17 and 18 of said bridges, respectively, as follows:

$$V_{17}-V_8=K_4(R_5-R_6) \quad (3)$$

and

$$V_{18}-V_8=K_5(R_5-R_7) \quad (4)$$

wherein K_4 and K_5 are constants depending on the selected values of resistances 13 to 16.

If a power amplifier 19 is connected at 17' and 18' to the aforesaid intermediate points 17 and 18 respectively, it receives a signal:

$$V_{17}-V_{18}=K_4(R_5-R_6)-K_5(R_5-R_7) \quad (5)$$

As the resistances R_5, R_6 and R_7 are preferably selected from the type varying linearly as a function of temperature, these resistances are linear functions of the aforesaid temperatures t_5, t_6 and t_7; eventually, the signal fed to the input of power amplifier 19 has the pattern:

$$\Delta'=K'_1(t_5-t_6)-K'_2(t_5-t_7) \quad (6)$$

constants K'_1 and K'_2 being a function of the choice of resistances 13 to 16.

The output stage of power amplifier 19 has its terminals 45, 46 connected to a heating resistance 20 disposed upstream of tube 4 in the smoke pick-up circuit 2.

If a signal Δ' other than zero is fed to the power amplifier 19, a power output signal will be obtained which will energize the heating resistance 20 and has the following form:

$$S=S_0+K_6\Delta' \quad (7)$$

wherein K_6 is a constant depending on the characteristics of the power amplifier.

If this signal Δ' is zero, the output signal delivered by the power amplified 19 is reduced to its means value S_o corresponding to a moderate heating of the smokes before they enter the tube 4.

It is clear that if the smokes are too cold when they enter the device, condensations are most likely to take place in the tube 4 i.e. upstream of the sensing probe 6, the outlet temperature t_6 tending to increase and the difference (t_5—t_6) to decrease. Then Δ' assumes a negative value and the heating is increased in resistance 20, if care is taken for example to give a negative value to K.

Similarly, if the smokes are abnormally hot when they penetrate into the device, a water vaporization tends to take place at the tube outlet, the outlet temperature t_6 tending to drop and the difference (t_5—t_6) to increase.

Under these conditions, Δ' assumes a positive value and the heating is reduced in resistance 20 from the very moment K_6 is negative.

The calibration of the device illustrated diagrammatically in FIGURE 2 is effected by simply adjusting the resistances 13 to 16 and visually limiting the formation of condensations at the base of tube 4 by observing the formation of mist on the wall of this tube. The apparatus may also be calibrated from smokes of which the dew-point is known with precision, by adjusting the resistances 13 to 16 until the dew temperature indicated by the corresponding probe of the apparatus is in harmony with the known dew-point.

This calibration obviously consists in identifying Δ and Δ'.

In FIGURE 3 there is shown more in detail the manner in which the apparatus illustrated in a purely diagrammatic form in FIGURE 1 is constructed. In this figure, the same reference numerals designate corresponding parts of the assembly shown in FIGURES 1 and 3.

In the specific and exemplary form of embodiment illustrated in FIGURE 3, it will be noted that the tube or pipe 4 is surrounded by a pair of coaxial concentric cylinders or ducts 21, 22. The smoke derived from the main duct 1 through the branch hose 23 penetrates into a first or inlet section 24 of this tube 4, and flows through the central or intermediate section of the tube before attaining the outlet section 25 thereof; then, the smoke rises in the annular space 26 formed between this tube 4 and the first concentric cylinder 21 (the aperture of the outlet section 25 of tube 4 being at a somewhat higher level than the lower edge of cylinder 21), and flows along the annular portion 27 formed between the concentric cylinders 21 and 22 after passing through orifices 28 formed through the wall of the upper portion of cylinder 21, the smoke being finally exhausted through a suction pipe 29 for example towards a suction pump (not shown). A pair of plugs 30 and 31 of adequate material is provided for sealing the upper and lower ends respectively of cylinders 21 and 22. Plug 30 has a central orifice formed therein, in which the inlet section 24 of tube 4 is fitted, and plug 31 has a smaller central orifice formed therein in which a slender tube 32 is fitted to permit the passage of electric wires 34, 35, 36 and 37 connected respectively to the resistance probes 5, 6 and 7 and also to a thermocouple 38 disposed in the outlet section 25 of tube 4.

As the smoke suction pipe 29 has its inlet end disposed above the top of the lower plug 31, a small reserve of condensed water 39 accumulates in the bottom of the device. The probe 6 is surrounded by a grid or like member 40 rigid with a wick 41 having its lower end immersed in the condensation water 39 filling the bottom of the apparatus. Furthermore, a cavity 42 is formed in said plug 31 to enable the water condensing mainly on the inner walls of the outer cylinder 22 to penetrate into the inner cylinder 21. Advantageously, the connecting wire 37 of thermocouple 38 constitutes the support of grid 40.

The complete device is mounted on a base 43 consisting for example of the casing or body of the smoke suction pump (not shown).

A heating resistance 44 is coiled about the pipe 29 to prevent any condensation of the outgoing smoke, and therefore protect the pump from possible damages.

The various cylindrical members or ducts 22, 21 and 4 as well as the inlet and outlet sections 24 and 25 of tube 4 are made of transparent material. Sections 24 and 25 are made of a glass having a poor heat conductivity, the central section 4 consisting of another transparent material having a better heat-conductivity, or of thinner glass.

The operation of the device illustrated in FIGURE 3 is clearly apparent from the foregoing and notably from the explanations given hereinabove in connection with the description of the preceding FIGURES 1 and 2. The resistance probe 7 is actually impregnated or soaked with the external medium provided for cooling the tube 4, but considering its position in the annular space 26 it is normally not subjected to the temperature variations of the surrounding atmosphere or any other medium external to the outermost cylindrical wall 22. The operation of the device is thus made more accurate. Advantageously, the probe 7 is disposed substantially intermediate the ends of tube 4.

As the resistance probes 5, 6 and 7 are mounted in an electronic comparator of the type shown diagramatically in FIGURE 2, this device is calibrated when starting the operation of the apparatus by so selecting the values of resistances 13 and 16 that the power amplifier 19 delivers a stronger current to the heating resistance 20 each time a condensation tends to develop in the central section 4 of the central tube and a weaker current each time a water vaporization 39 tends to take place in the same tube. This is obtained either by simply observing the formation of condensed droplets on the wall of said tube, since the various ducts 4, 21 and 22 are made of transparent material, or by utilizing smokes of which the dew-point is exactly known, and so adjusting the apparatus that the temperature measured by the thermocouple 38 be exactly the same as this dew-point.

Thus, any condensation is prevented from rising or descending along the tube 4.

More particularly, if the smoke temperatures at the inlet end of tube 4 is too high, so that condensations tend to occur downstream of the outlet section 25 of this tube 4, i.e. downstream of the sensing probe 6 the grid 40 will evaporate water and the smoke is cooled, and the heating of resistance 20 is reduced accordingly (by producing a positive input signal Δ' in the power amplifier 19). Therefore, the device is regulated automatically and the thermocouple 38 will indicate at any time the dew-point of the smoke to be analyzed.

The response time of the regulating means of this device may be controlled by varying the velocity of flow of the smoke along the tube 4. Of course, for a given rate of flow the electronic device shown in diagrammatic form in FIGURE 2 must be properly calibrated.

The advantage resulting from having the inlet and outlet sections 24 and 25 of tube 4 made of a material having a poor heat conductivity with respect to the central tube section 4, is due to the fact that the temperature measurements of the smoke inlet (probe 5) and smoke outlet (probe 6) is more accurate.

Many modifications may be brought to the form of embodiment described and illustrated herein without departing from the scope of the invention. Thus, more particularly, the section 23 upstream of tube 4 may be heated by non-automatic means, for example by using a device of the type shown diagrammatically in FIGURE 2 and responsive to the three probes 5, 6 and 7. In fact, if it is desired not continuously to record to dew temperature of the smokes to be analyzed, but simply to read this temperature with precision, from time to time, it is only necessary to observe the formation of condensation droplets in the tube and to cause these droplets to drop in said tube until they disappear by heating the smoke in the upstream section 23 of tube 4. Thus the temperature read by the thermocouple 38 at that time is the dew-point looked for.

As contrasted thereto, when it is desired to have a continuous record of the dew temperature of the smoke, it will be advantageous to use automatic regulation means of the type shown diagrammatically in FIGURE 2. Moreover, since all the ducts 4, 21 and 22 are transparent, the operator can constantly see the process taking place in the apparatus.

It may also be noted that the reserve of water 39 is fed by the water condensation taking place along the internal wall of duct 22 and the external wall of duct 21, so that the apparatus cannot fall short of the water medium necessary for its regulation, during its operation, even if the latter is protracted indefinitely. In fact, when the apparatus operates normally these walls are at a lower temperature than the dewpoint of the smoke derived from duct 1.

Of course, the invention should not be construed as being limited by the specific form of embodiment described and illustrated herein which is given by way of example, since many modifications and variations may be brought thereto without departing from the scope of the invention as set forth in the appended claims.

What we claim is:

1. A method of measuring the dew-point of combustion smokes by using a continuous, light and substantially constant output derived from the smoke circuit, causing the smokes picked up to flow and to cool between the

inlet and the outlet of a device kept externally at a temperature lower to that of said smokes, letting water to condense from the smokes in said device, and measuring the temperature at which the condensation takes place, wherein, in order that the condensation occurs at a given point of the device where the temperature is measured the smokes are heated upstream of said given point each time the condensation tends to go upstream of said given point and are cooled each time the condensation tends to go downstream of said given point, by measuring firstly the temperature t_5 prevailing at the inlet of the device, secondly the temperature t_6 prevailing at the outlet of the device and thirdly the temperature t_7 prevailing externally of said device, maintaining at said point a saturated atmosphere, providing means to heat the smokes upstream of the device, and increasing the heating of the smokes upstream of said point each time the difference (t_5-t_6) tends to decrease and the function $\Delta=[K_1(t_5-t_6)-K_2(t_5-t_7]$ tends to become negative, K_1 and K_2 being positive parameters dependent on the operative conditions and for which the function Δ is equal to zero when the condensation occurs at said given point, or reducing said heating of the smokes each time the difference (t_5-t_6) tends to increase and said function Δ tends to become positive.

2. A device for measuring the dew-point temperature of combustion smokes flowing in a duct, of the type comprising a branch duct of reduced cross-section for a continuous smoke pick-up output, at least a tube through which said output is caused to flow, said tube being surrounded by external medium having a temperature lower than that of said smokes, at least one thermometric probe disposed with in said tube in the vicinity of its outlet measuring the dew temperature, and humidifying means in the vicinity of said outlet comprising a reserve of water brought substantially to the temperature prevailing at the outlet of the device, comprising at the measuring point where said probe is disposed, means providing a saturated atmosphere vaporizing water from said reserve of water each time any water condensation tends to occur downstream of said measuring point, electrical heating means mounted upstream of said tube for heating said smoke output before its inlet in said tube in view to avoid any water condensation to rise upstream of said measuring point, control means for controlling said heating means, and pump means for pumping in said device a substantially constant output flow of smokes, three thermometric probes of the resistance type measuring respectively the smoke temperature at the tube inlet, the smoke temperature at the tube outlet and the temperature of said external medium, said control means including an electronic comparator which receives input signals from said thermometric probes for comparing the differences in temperature of said probes with the corresponding differences contemplated which appear in the absence of any condensation or water vaporization in the device, said heating means being constituted by electric resistances receiving current from the power outlet stage of an amplifier incorporated in said electronic comparator and of which the input signal is substantially proportional to said deviation.

3. A device according to claim 2, wherein said tube is disposed substantially vertically with its inlet at the upper end and its outlet at the lower end, this outlet opening in the vicinity of the bottom of a first coaxial duct surrounding said tube, said first duct presenting at its upper end, at a level near that of said tube inlet, openings communicating with the top of a second coaxial duct surrounding said first duct and having in the vicinity of its bottom an output orice for the exhaust of the smokes, said second duct being sealed at its bottom by a lower plug and at its top by an upper plug, said tube passing through a central opening of said upper plug, and said first duct abutting by its upper and lower ends against said upper and lower plugs, said outlet

orifice formed in said second duct being disposed slightly above said lower plug, and at least an opening being formed at the lower end of said first duct for the communication of the inner spaces between said first and second ducts, and between said tube and first duct respectively, forming on the lower plug said reserve of water, and wherein said thermometric probes are positioned respectively in the vicinity of the upper inlet end of said tube, in the vicinity of the lower outlet end of the tube and in the inner space comprised between said tube and said first duct.

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