July 6, 1948. H. R. McCOMBIE ET AL 2,444,613

LOW HUMIDITY METER

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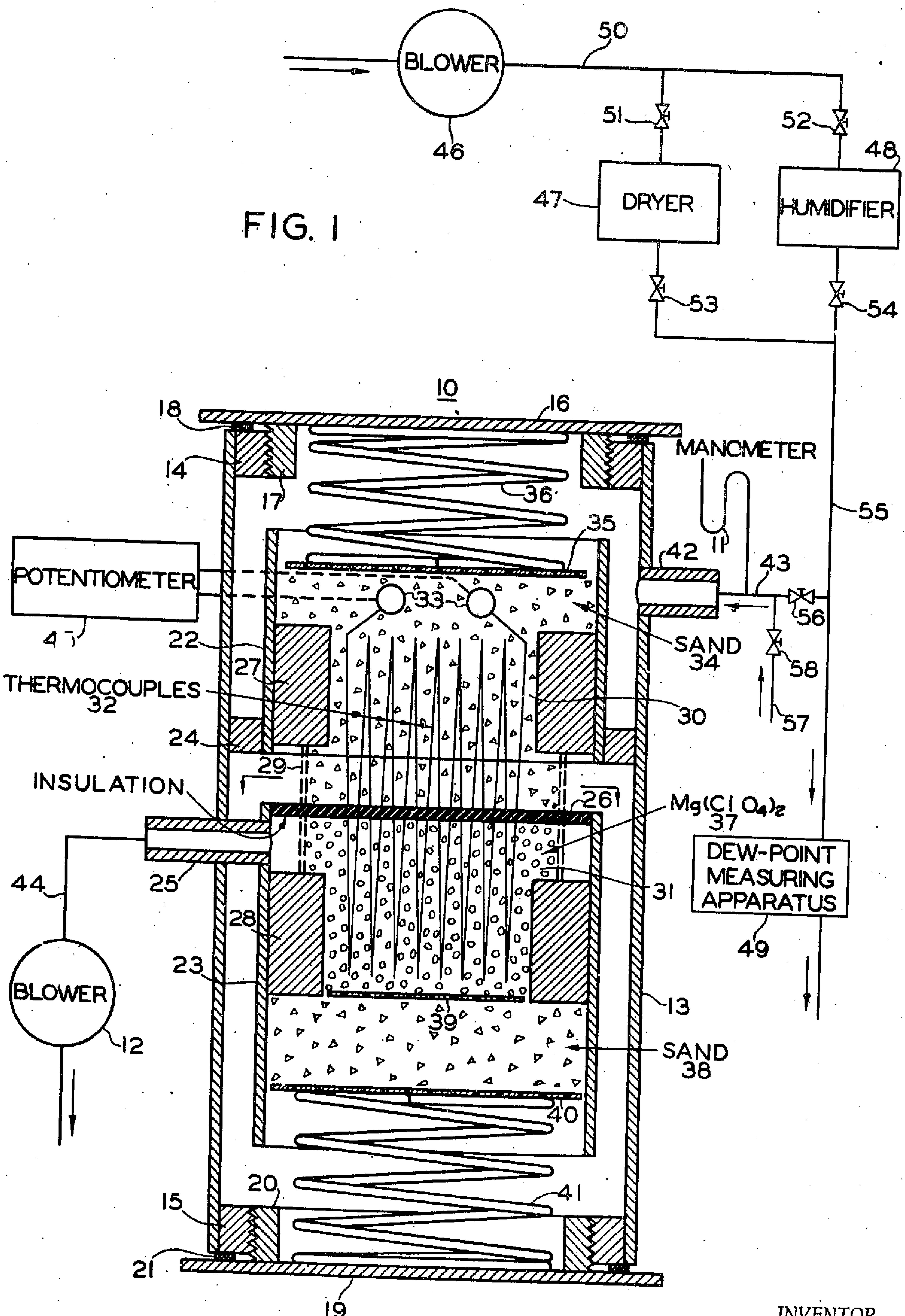

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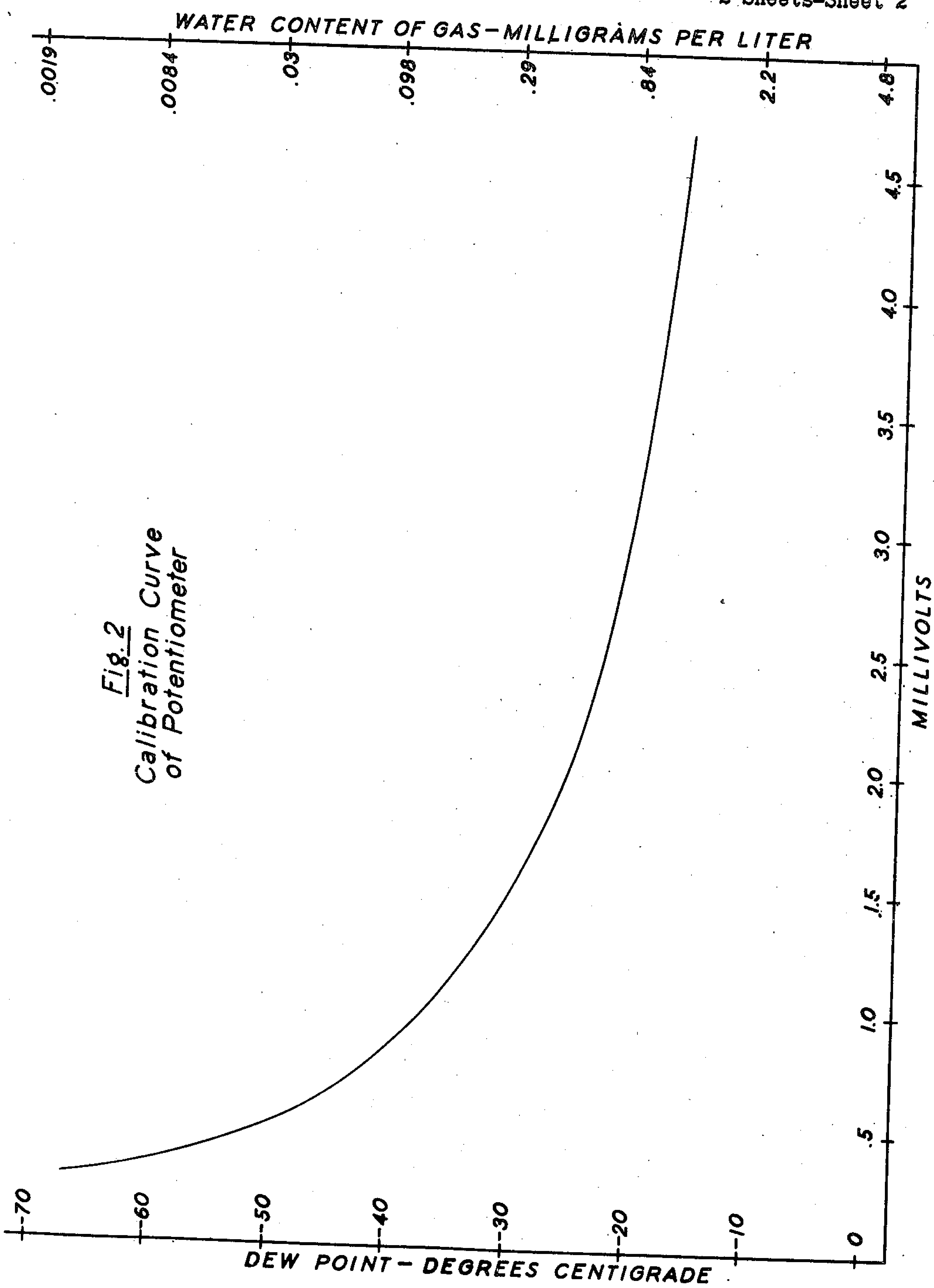

Fig. 2
Calibration Curve of Potentiometer

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LOW HUMIDITY METER

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The present invention relates to hygrometric processes and methods and more particularly to hygrometers.

It is an object of the invention to provide an improved hygrometric system and method which readily correlates the rate of flow of a gas and the water vapor content thereof.

Another object of the invention is to provide an improved hygometric system and method utilizing the heat-of-absorption or heat-of-solution effect of a dehydrating agent when it is contacted with a gas containing water vapor.

Another object of the invention is to provide an improved hygrometer comprising a moisture-responsive element containing a dehydrating agent having a finite heat of absorption.

Another object of the invention is to provide an improved hygrometer comprising a moisture-responsive element in the form of a porous packing containing a dehydrating agent having a finite and relatively high positive heat of absorption.

A further object of the invention is to provide an improved continuous reading hygrometer which is extremely sensitive, whereby the moisture content of a gas having dew-points of —30° C. and below may be readily measured.

A still further object of the invention is to provide a hygrometer of improved construction and arrangement which is capable of reading directly either very low dew-points or very small water vapor contents of test gases.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings, in which Figure 1 is a diagrammatic illustration of a hygrometric system and a longitudinal sectional veiw of a hygrometric element incorporated therein, which embody the present invention; and Figure 2 illustrates graphically the calibration curve of a potentiometer incorporated in the system shown in Fig. 1.

Referring now more particularly to Fig. 1 of the drawings, there is shown a hygrometric system comprising a hygrometric element **10**, an attached manometer **11**, and an associated pumping device or blower **12** of the constant speed

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type. In the particular embodiment of the hygrometric element **10** illustrated in Fig. 1 of the drawings, the parts are drawn to approximately twice scale; and the element **10** comprises an upstanding cylindrical casing **13** having internally threaded rings **14** and **15** suitably secured in the respective upper and lower ends thereof. Also, the element **10** comprises a removable upper cover **16** carrying an externally threaded ring **17** adapted to engage the threads carried by the ring **14**, a suitable gasket **18** being arranged between the upper cover **16** and the ring **14** in order to render the upper end of the casing **13** gas-tight; and a removable lower cover **19** carying an externally threaded ring **20** adapted to engage the threads carried by the ring **15**, a suitable gasket **21** being arranged between the cover **19** and the ring **15** in order to render the lower end of the casing **13** gas-tight.

Arranged within the casing **13** and spaced inwardly therefrom are upper and lower cylindrical baffles **22** and **23**, the baffles **22** and **23** being disposed in alignment and in spaced apart relation. The upper baffle **22** is secured in place by a ring **24** positioned between the outer surface thereof and the inner surface of the casing **13**; while the lower baffle **23** is secured in place by a tube **25**. The tube **25** extends through an opening provided in the side wall of the casing **13** and is supported thereby; and one end of the tube **25** is securely anchored in a cooperating opening provided in the side wall of the lower baffle **23**. The upper end of the lower baffle **23** is closed by a plate **26** secured therein, the plate **26** being formed of any suitable insulating material such as Bakelite. A ring **27** is secured within the upper baffle **22**; a ring **28** is secured within the lower baffle **23**; and an upstanding cylindrical reticulated screen **29** is embedded in the insulating plate **26** and extends between the rings **27** and **28** to which the opposite ends are suitably secured.

In view of the foregoing description of the construction and arrangement of the element **10**, it will be understood that the upper baffle **22**, the ring **27** and the reticulated screen **29** cooperate with the upper surface of the insulated plate **26** to define an upper compartment **30** within the casing **13**; while the lower baffle **23** and the ring **28** and the reticulated screen **29** cooperate with the lower surface of the insulating plate 26 to define a lower compartment 31 within the casing 13. The insulating plate 26 has a number of openings extending therethrough which are arranged in any suitable symmetrical pattern and in which a suitable number of thermocouples 32 are anchored. In the illustrated embodiment of the element 10 fifty-five thermocouples 32 are anchored in the openings provided in the insulating plate 26 and are arranged in series circuit relation, the intermediate portions of the thermocouples 32 being supported in the openings provided in the insulating plate 26 in such a manner that the insulating plate 26 is impervious to the seepage of gas therethrough. Preferably, the thermocouples 32 are of the Chromel-Alumel or iron-constantan types. In this arrangement, the upper ends of the thermocouples 32 arranged in the upper compartment 30 constitute cold ends; while the lower ends of the thermocouples 32 arranged in the lower compartment 31 constitute hot ends, as will be more fully explained hereinafter. As previously noted, the thermocouples 32 are arranged in series circuit relation and are terminated by two terminals 33.

The upper compartment 30 contains a porous packing 34 formed of sharp, clean sand, this sand being screened and sized such that it will pass a 20 mesh screen but will not pass a 30 mesh screen. The packing 34 arranged in the upper compartment 30 embeds the upper ends of the thermocouples 32 and is retained in place by a reticulated plate 35 positioned in the upper end of the upper baffle 22. The reticulated plate 35 is retained in place by a compressed coil spring 36 arranged between the upper surface of the reticulated plate 35 and the lower surface of the upper cover 16. The lower compartment 31 contains upper and lower porous packings 37 and 38, respectively, arranged in series, the packings 37 and 38 being separated by a reticulated plate 39 loosely positioned within the ring 28. The packing 37 is formed of a dehydrating agent, this dehydrating agent being screened and sized such that it will pass a 20 mesh screen but will not pass a 30 mesh screen. Preferably, this dehydrating agent comprises $Mg(ClO_4)_2$ in the form sold as Anhydrone. However, it may comprise other compounds of a class including $CaCl_2$ and P_2O_5, as explained more fully hereinafter. The packing 38 is formed of sharp, clean sand, this sand being screened and sized such that it will pass a 20 mesh screen but will not pass a 30 mesh screen. The packing 37 arranged in the lower compartment 31 embeds the lower ends of the thermocouples 32; and both the packings 37 and 38 are retained in place by a reticulated plate 40 positioned in the lower end of the lower baffle 23. The reticulated plate 40 is retained in place by a compressed coil spring 41 arranged between the lower surface of the reticulated plate 40 and the upper surface of the lower cover 19.

Finally, the element 10 comprises a tube 42, one end of which is anchored in a cooperating opening provided in the side wall of the casing 13 above the ring 24 and adjacent the upper end of the upper baffle 22. In the element 10 the tube 42 constitutes a gas inlet tube communicating with the upper compartment 30; while the tube 25 constitutes a gas outlet tube communicating with the lower compartment 31. The gas inlet tube 42 is connected to a pipe 43, to which the manometer 11 is also attached; while the gas outlet tube 25 is connected to a pipe 44, extending to the blower 12.

Considering now the general flow of gas through the element 10, it is noted that when the blower 12 is operating a partial vacuum is established in the gas outlet tube 25 and gas may be drawn into the gas inlet tube 42 from the pipe 43. This gas flows from the pipe 43 through the gas inlet tube 42 into the upper portion of the casing 13, upwardly in the cylindrical space between the upper portion of the casing 13 and the upper baffle 22, and then downwardly through the open end of the upper baffle 22 through the reticulated plate 35 into the upper compartment 30. This gas is thoroughly diffused by the packing 34 arranged in the upper compartment 30 through and around the upper ends of the thermocouples 32, and then flows downwardly toward the insulating plate 26 and outwardly through the reticulated screen 29 toward the mid-section of the casing 13. The gas then flows downwardly in the cylindrical space between the lower portion of the casing 13 and the lower baffle 23, and then upwardly through the open end of the lower baffle 23 through the reticulated plate 40 into the lower compartment 31. This gas is thoroughly diffused by the packing 38 arranged in the lower portion of the lower compartment 31, and then passes through the reticulated plate 39 into the upper portion of the lower compartment 31. This gas is then thoroughly diffused by the packing 37 arranged in the upper portion of the lower compartment 31 through and around the lower ends of the thermocouples 32 and then flows upwardly toward the insulating plate 26 and outwardly through the reticulated screen 29 into the gas outlet tube 25. Finally, the gas in the gas outlet tube 25 is drawn through the pipe 44 by the blower 12 and exhausted to atmosphere. The volume of gas drawn through the element 10 may be readily determined by reading the manometer 11 attached to the pipe 43 adjacent the inlet tube 42, as the blower 12 is of the constant speed type.

In the construction and arrangement of the element 10, it is noted that the packing 34 disposed in the upper compartment 30 offers an impedance to the flow of gas therethrough which is equal approximately to the sum of the impedances offered to the flow of gas through the series-arranged packings 38 and 37 disposed in the lower compartment 31. This arrangement insures that the cooling effect produced by the gas as it is diffused by the packing 34 onto and around the upper ends of the thermocouples 32 is substantially equal to the cooling effect produced by the gas as it is diffused by the packing 37 onto and around the lower ends of the thermocouples 32; whereby the temperature of the gas exerts substantially equal and opposite effects upon both the upper and lower ends of the thermocouples 32, thereby rendering the operation of the element 10 substantially independent of the temperature of the gas and ambient temperature conditions.

Finally, associating with the element 10 is a galvanometer or potentiometer 45 which is electrically connected to the terminals 33 in any suitable manner. Preferably, the potentiometer 45 is of the well-known Leeds and Northrup type. Also, it is preferred that the element 10, the manometer 11, the blower 12, and the potentiometer 45 be arranged in a suitable external casing, thereby constituting a portable hygrometer.

As previously explained, the packing 37 arranged in the upper portion of the lower compartment 31 and embedding the lower or hot ends of the thermocouples 32, comprises a dehydrating agent of a group including $Mg(ClO_4)_2$, $CaCl_2$, and

P_2O_5, this class of dehydrating agents having the following specifications:

(1) Great affinity for water vapor;
(2) Very high positive heat of absorption or solution;
(3) Chemically inert to air and ordinary permanent gases;
(4) Solid granulated form such that a porous packing can be made therefrom.

Of the dehydrating agents in this class,

$Mg(ClO_4)_2$

is preferred in view of the fact that it has a very great affinity for water vapor; it has a finite and very high positive heat of absorption or hydration (approximately 25,000 calories per mole); it is chemically inert to air and ordinary permanent gases; it is sharp and clean, rendering it well suited to the formation of a porous packing therefrom; and it may be readily regenerated.

Considering now the operation of the element 10, it is noted that when a gas containing water vapor or moisture is drawn therethrough in the manner previously explained, a portion of the water vapor contained therein is absorbed by the packing 37, this packing being formed of the dehydrating agent previously mentioned. When the moisture in the gas passing through the packing 37 is absorbed by this dehydrating agent it forms a hydrated compound, producing a considerable amount of heat, the heat of hydration of $Mg(ClO_4)_2$ being approximately 25,000 calories per mole, as previously noted. Thus, the packing 37 becomes hot due to the chemical action of the moisture forming a hydrate with the dehydrating agent, whereby the lower ends of the thermocouples 32 are heated, causing a voltage to be produced which appears across the terminals 33 and may be measured by the potentiometer 45. It is noted that the voltage appearing across the terminals 33 and measured by the potentiometer 45 is controlled directly by the temperature of the packing 37, which temperature, in turn, is controlled directly by the amount of heat liberated in this dehydrating agent, while the amount of heat liberated in this dehydrating agent is controlled directly in accordance with the amount of moisture absorbed thereby from the gas diffused therethrough. Finally, the amount of moisture absorbed by the packing 37 is directly controlled jointly and principally by the rate of flow of gas through the element 10 and the moisture content of the gas flowing therethrough. Accordingly, by maintaining substantially constant the rate of gas flowing through the element 10, the amount of moisture absorbed by the packing 37 will be dependent substantially entirely upon the moisture content of the gas flowing therethrough. Hence, in the element 10 the potentiometer 45 meters a voltage which is proportional to the moisture content of the gas flowing therethrough.

Further considering the construction and arrangement of the hygrometric system, it is noted that in addition to the elements previously described, the system comprises a pumping device or blower 46, a drier 47, a humidifier 48, and dew-point measuring apparatus 49. The blower 46 is adapted to take in air at atmospheric pressure and to deliver it at any desired gauge pressure to a connected pipe 50, the pipe 50 being suitably connected by adjustable valves 51 and 52, respectively, to the drier 47 and the humidifier 48. The drier 47 and the humidifier 48 are respectively connected by adjustable valves 53 and 54 to a common pipe 55, which in turn is connected to the dew-point measuring apparatus 49. Also, the pipe 55 is connected by an adjustable valve 56 to the pipe 43. Finally, the pipe 43 is also connected to a sampling conduit 57 by way of an adjustable valve 58.

The drier 47 is of any suitable form, although it preferably comprises a series of H_2SO_4 bubblers and $Mg(ClO_4)_2$ drying columns, whereby the air from the pipe 50 may be delivered through the drier 47 in extremely dry condition to the pipe 55. The humidifier 48 is of any suitable form, although it preferably comprises a series of H_2O bubblers, whereby the air from the pipe 50 may be delivered through the humidifier 48 in extremely wet condition to the pipe 55. Thus it will be understood that by suitably adjusting the proportion of air flowing from the pipe 50 through the drier 47 to the pipe 55 with respect to the proportion of the air flowing from the pipe 50 through the humidifier 48 to the pipe 55, the air in the pipe 55 may be adjusted to any desired vapor content over a very wide range. The proportion of air flowing through the drier 47 may be readily determined by manipulating the adjustable valves 51 and 53; while the proportion of air flowing through the humidifier 48 may be readily determined by manipulating the adjustable valves 52 and 54. A portion of the air in the pipe 55 may be admitted through the adjustable valve 56 into the pipe 43 and consequently into the element 10, the adjustable valve 56 being manipulated in order to establish the desired flow of air from the pipe 55 through the element 10. Finally, the remaining portion of the air in the pipe 55 traverses the dew-point measuring apparatus 49 and is exhausted to the atmosphere.

By utilizing the arrangement described above, the element 10 may be readily calibrated with respect to the dew-point measuring apparatus 49. In this operation the valve 58 associated with the sampling conduit 57 is closed, and the adjustable valve 56 is manipulated with respect to the constant speed of operation of the blower 12, whereby the required standard flow of air from the pipe 55 traverses the element 10. Preferably the dew-point measuring apparatus 49 is of conventional construction and arrangement and comprises a silvered tube subjected to a bath of air from the pipe 55, cooling equipment for the silvered tube, and a thermometer associated with the silvered tube, whereby the dew-point of the air from the pipe 55 traversing the dew-point apparatus 49 may be readily measured. Under the conditions mentioned, the moisture content of the air in the pipe 55 may be established by appropriately controlling the drier 47 and the humidifier 48 in the manner previously explained. At this time the dew-point of the air in the pipe 55 is established by the dew-point measuring apparatus 49 and the potentiometer 45 is read. After obtaining these readings, the moisture content of the air in the pipe 55 is varied and the operations described above are repeated, whereby a series of dew-point measurements are produced by the dew-point measuring apparatus 49 and a corresponding series of millivolt readings are obtained from the potentiometer 45. Thus, the potentiometer 45 may be readily calibrated with respect to the element 10 and the dew-point measuring apparatus 49 to produce a calibration curve of the character of that illustrated in Fig. 2 for the particular standard of air flow adopted.

Referring now to Fig. 2, the calibration curve illustrated is plotted with respect to dew-points in degrees C., obtained from the dew-point measuring apparatus 49, and readings in millivolts obtained from the potentiometer 45. It is further noted that the dew-points in degrees C. may be readily translated into terms of water content of the gas in milligrams per liter from any standard reference book. After a calibration curve of the character of that shown in Fig. 2 is obtained, correlating millivolt readings of the potentiometer 45 with respect to dew-points in degrees C. and water content in milligrams per liter, appropriate scales may be made and directly attached to the normal millivoltage scale of the potentiometer 45, whereby both dew-points and water contents of test samples of air may be read directly on the potentiometer 45 in an obvious manner.

After the potentiometer 45 has been calibrated with respect to the element 10 in the hygrometric system in the manner previously explained, the adjustable valve 56 may be closed, whereby the hygrometer proper may be operated without reference to the pipe 55 and the associated apparatus. In fact, the hygrometer proper may constitute a portable instrument, in which case the adjustable valve 56 is closed and detached from the pipe 55. In this case, the test sample of air is obtained by attachment to the sampling conduit 57 and appropriate manipulation of the adjustable valve 58. Accordingly, in normal use the adjustable valve 58 is manipulated, whereby the desired standard flow of air from the sampling conduit 57 through the element 10 is obtained as previously explained, this condition being indicated by the manometer 11.

In conjunction with the calibration of the embodiment of the element 10 illustrated it is noted that the standard rate of air flow therethrough was maintained at about 0.07 cubic foot per minute, a vacuum of about 2 cm. of water being produced at the gas inlet tube 42 of the element 10 as indicated by the manometer 11. Also, between readings the element 10 was permitted to cool until the potential metered by the potentiometer 45 was zero. These cooling periods were from 3 to 5 minutes for dew-points above 25° C. and from 2 to 3 minutes for dew-points below 25° C. In checking the calibration curve of the element 10 in conjunction with the potentiometer 45 and the dew-point measuring apparatus 49 it was found that the readings were reproduced over a considerable period and that slight changes in the condition of the dehydrating agent $Mg(ClO_4)_2$ did not affect the readings.

In a life test conducted upon the element 10 air was passed through the cell for 40 hours, the air having a dew-point of −30° C. It was found that the reading at the end of this period was exactly the same as at the beginning and an examination of the dehydrating agent forming the packing 37 showed only a slight caking at the surface which apparently had no effect.

The total life of the packing 37 is very long but is entirely dependent upon the moisture content of the air diffused therethrough, and the element 10 is most satisfactory for measuring the moisture content of air containing less than 1.5 mg. of water per liter. In fact, the hygrometer should not be employed to measure the moisture content of air when it is known that such content is relatively high and appreciably greater than 1.5 mg. per liter, as the life of the packing 37 would be unduly short.

While the calibration and use of the hygrometer has been described in conjunction with the measurement of the moisture content of air, it will be understood that this hygrometer is very useful in measuring the moisture content of other permanent and relatively inert gases, such as nitrogen, hydrogen, etc. However, the hygrometer should not be employed to measure the moisture content of a highly chemically active gas having the characteristic of combining chemically with the dehydrating agent of which the packing 37 is formed, as such would be productive of large heats of chemical combination. However, in this regard some selectivity is permissible by appropriately correlating the known chemical reaction of the gas, the moisture content of which is to be measured, upon the dehydrating agent selected from the class mentioned of which the packing 37 is formed. In using the hygrometer it is suggested that the element 10 be calibrated with the potentiometer 45 in the manner previously explained in conjunction with the particular gas, the moisture content of which is to be measured, in order to obtain most satisfactory results.

From the foregoing it is apparent that an improved hygrometric system is provided which comprises an improved hygrometer including an improved hygrometric element, which is operative in accordance with an improved method utilizing the heat-of-absorption or heat-of-solution effect of the dehydrating agent.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that various modifications may be made therein and it is intended to cover in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A hygrometer comprising a casing, an element supported within said casing, said element having a porous structure and containing a dehydrating agent having a finite heat of absorption, means defining a passage through said casing including said element, means for establishing a substantially uniform and predetermined rate of flow of gas containing moisture through said passage, whereby the gas is diffused through said element into intimate contact with said contained dehydrating agent in order to control the temperature of said agent in accordance with the moisture content of said gas at said predetermined rate of flow, and an indicator controlled in accordance with the temperature of said agent and calibrated in terms of moisture content of the gas contacting said agent at said predetermined rate of flow.

2. A hygrometer comprising a casing, an element supported within said casing, said element having a porous structure and containing a dehydrating agent having a finite heat of absorption, a porous packing supported within said casing adjacent said element, means defining a passage through said casing including said element and said packing, means for establishing a substantially uniform and predetermined rate of flow of gas containing moisture through said passage, whereby the gas is thoroughly diffused first through said packing and then through said element into intimate contact with said contained dehydrating agent in order to control the temperature of said agent in accordance with the moisture content of said gas at said predetermined rate of flow, and an indicator controlled in accordance with the temperature of said agent and calibrated in terms of moisture content of the

gas contacting said agent at said predetermined rate of flow.

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