METHOD FOR DRYING

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This invention relates to methods of drying materials. More particularly it concerns an improved method for removing moisture from materials by bringing into contact therewith a relatively dry atmosphere of controlled temperature and humidity, this atmosphere being subsequently conditioned for re-use by contact with a hygroscopic liquid.

One of the objects of the invention is to provide a highly efficient method of drying moist materials. Another object is to define a cyclic process for conducting drying operations under conditions which are substantially adiabatic and largely independent of the surrounding atmosphere.

With these and other objects in view, the present invention contemplates passing a stream of air of predetermined temperature and relative humidity in a closed system into contact with materials to be dried and directly thereafter into contact with a hygroscopic solution of controlled temperature and concentration, whereby the air is brought to the proper condition for recirculation in the process without having to be rejected or replaced in part with fresh air. This continued re-use of the same air permits large heat savings in the process.

The invention may best be understood with reference to the accompanying drawing which illustrates diagrammatically a preferred embodiment of the invention.

In the apparatus illustrated, drying is conducted in a chamber 1 with shelves 2 for holding the materials to be dried. Air is circulated through the drier in a closed circuit comprising a motor-driven air-circulating fan 3, an air delivery duct 4 connecting the fan to the chamber 1, and an outlet duct 5 connected through a damper 6 to the air-conditioning chamber 7 and through a damper 8 to the by-pass 9, the opposite end of both the chamber 7 and the by-pass 9 being connected to a duct 10 and by it to the inlet side of the fan 3. The conditioning chamber 7 is part of a circulating system for the hygroscopic liquid, the system also comprising a reservoir 11, a liquid sump 12, and a pump 13 connecting the sump through lines 14 and 15, and a valve 16 to the reservoir 11. Both the air-circulating system comprising the chambers 1 and 7 and their associated ducts, and the liquid circulating system comprising pump 13 and connecting piping, are preferably provided with insulating lagging (not shown) to prevent transmission of heat into or out of the system.

Inasmuch as the hygroscopic solution in the liquid circulating system becomes diluted during operation, a small portion of the solution is withdrawn from the line 14 through a valve 17 and is conveyed through a line 18 and a heat-exchanger jacket 19 into an evaporator or regenerator 20 which is fired by a gas burner 21 controlled by a gas valve 22. The concentrated liquor from the bottom of the regenerator is then returned to the liquid circulating system through a heat-exchanger coil 23, or by a by-pass 24 controlled by a valve 25, and thence to a return line 26 leading to the sump 12. This line 26 is provided with a small heat exchanger 27 to which cooling water may be admitted as needed through a valve 28.

The concentration of the hygroscopic solution in the apparatus may be controlled by any desired means, suitably by varying the rate of evaporation in the regenerator 20, e. g. by adjusting the gas-flow to the burner 21. This control may be effected automatically by means of a density indicator 29 receiving hygroscopic liquid through a by-pass 30, the density-responsive plummet 31 of the device being connected to the burner valve 22 (as shown by the solid line) in such manner that the gas flow to the burner is varied in accordance with the indications of the plummet 31. The temperature and humidity of the air circulated through the driers are regulated by a thermostat 32 and a wet-bulb thermometer 33 located within the drying chamber 1, the thermostat 32 being adapted to actuate the valve 16 controlling the rate of circulation of the hygroscopic liquid, and the wet-bulb thermometer 33 being operatively connected to valve 24 controlling the by-pass 23 (as shown by the full line), and simultaneously or alternatively to the valve 28 controlling the cooler 27 (as shown by the broken line).

In operating the process according to the invention, the materials to be dried are placed upon the shelves 2 or otherwise conveyed into the drying chamber, and the fan 3 is set in motion causing the air in the system to circulate through the chamber 1 in contact with the material to be dried. In this chamber, since in operation the partial pressure of water in the air is less than the vapor pressure of the moisture in the material being dried, this moisture will evaporate into the air stream, such evaporation cooling the air and increasing its humidity. Inasmuch as the chamber 1 is thermally insulated, this evaporation and cooling occurs under essentially adiabatic conditions, and the air remains
at substantially constant total heat, i.e., at constant wet-bulb temperature.

The cooled moist air leaving the chamber \(1\) passes through the duct \(5\) and damper \(6\) into the conditioning chamber \(7\), the by-pass damper \(8\) being closed in this mode of operating. In the chamber \(7\) the moisture laden air is brought into contact with a hygroscopic liquid circulated by the pump \(13\), either in the form of a shower or spray, or in distributed form upon a suitable medium such as cotton strings suspended from the reservoir \(11\), as shown. In this air-liquid contact zone the hygroscopic liquid absorbs part of, usually most of, the moisture from the air, such absorption being accompanied by a liberation of the heat of condensation and solution of the water vapor, this heat raising the temperature of the hygroscopic liquid, which, in turn, transfers a part of this heat back to the air in contact therewith. The air, thus warmed and dried, is ready for recycling in the process through the duct \(10\) to the inlet of the fan \(3\). As operation is continued, the hygroscopic liquid being circulated into the chamber \(7\) and the heat generated in the chamber \(7\) continues to heat up, as explained, until it reaches and remains at some temperature above that of the incoming air, at which temperature the amount of heat transferred from the air to the liquid is exactly equal to the heat liberated in the dehumidification of the air. Now since the chamber \(7\) is thermally insulated and since, as will be expounded, the hygroscopic liquid circulating through the reservoir \(11\), sump \(12\), pump \(13\), and pipes \(14\) and \(15\) does not change in temperature appreciably and is maintained at constant composition, it is seen that the heating and dehumidification of the air occurring in the chamber \(7\) takes place under adiabatic conditions, i.e., the air remains at constant heat content and hence at a constant wet-bulb temperature.

As hereinbefore explained, the hygroscopic liquid being circulated through the chamber \(7\) is maintained at constant concentration by withdrawing a small portion, e.g., 5–10 per cent of the total, and removing water therewith, as in the evaporator \(20\), which is controlled by the density-responsive plummet \(31\). The reconcentrated liquor returned from the evaporator \(20\) through the pipe \(26\) should be at substantially the same temperature as the diluted portion withdrawn through the line \(18\) in order to avoid adding or subtracting heat from the otherwise adiabatic circulatory system for the hygroscopic liquid. This necessary temperature control may be effected by any desired means, as by operating the evaporator \(20\) under such a vacuum that the water is removed without heating the liquor. Alternatively, the evaporator \(20\) may be run hot at atmospheric pressure, the incoming diluted liquor being used to cool the reconcentrated liquor back to the temperature of the circulating liquor in a heat-exchanger \(23\), as illustrated. If the heat-exchanger \(23\), by reason of inefficiency, does not provide enough cooling, a further temperature reduction may be effected by running cooling water through the small heat-exchanger \(24\).

Although drying operations may be carried out satisfactorily in the process as thus far described, it has been found that unless means are employed to control the air-reconditioning step in the chamber \(7\) there is no assurance that the amount of water absorbed by the hygroscopic solution will precisely equal the amount of water given off by the material being dried. If a condition of inequality prevails, the temperature and humidity of the air passing into the drying chamber \(1\) will not remain constant, but will vary somewhat as the drying proceeds. In certain instances this variation is of no great consequence, but for the drying of materials especially heat-sensitive products, such as gelatine, it is highly desirable that the drying air be supplied at constant conditions of temperature and humidity.

In order to maintain a constant temperature and humidity of the drying air, it is necessary to insure: (1) that the air-circulation system remain essentially adiabatic, that is, at constant wet-bulb temperature, and (2) that the air-reconditioning step in chamber \(7\) be carefully controlled. These requirements will now be considered in detail.

(1) The process of the invention, since it involves closed cycles of both the air and the hygroscopic liquid, would of necessity remain adiabatic if it were not for the possibility of heat loss or gain in the liquid. An example of such a condition is shown in Fig. 20, for heat transfer by radiation between the room and the walls of the chambers \(1\) and \(7\) and connecting ducts and piping, and for slight frictional effects. In the preferred operation of the process, however, the condition of loss or gain to the regenerator circuit since the heat-frictional effects is avoided, the apparatus with heat insulation, it can rarely be entirely eliminated. To this end, a control instrument responsive to variations in the total heat content of the system, such as a wet-bulb thermometer \(33\), is placed in the drying chamber \(1\). When the apparatus is to be run at a temperature above that of its surroundings, so that the total heat content of the system tends to decrease because of radiation losses, the wet-bulb thermometer \(33\) is connected operationally to the valve \(25\) controlling the heat-exchanger by-pass \(24\), as illustrated; the valve \(28\) controlling the cooler \(27\) is kept closed. Then, when the total heat of the system falls, the thermometer \(33\) drops slightly in temperature, opening the valve \(25\), and allowing some of the reconcentrated liquor from the evaporator \(20\) to by-pass the heat-exchanger \(23\). Under this condition the reconcentrated liquor returns to the circulatory system through the pipe \(26\) at a higher temperature than the diluted liquor leaving through the line \(18\). Heat is accordingly added to the liquid circulatory system and is, of course, transferred to the air-circulatory system, since the two are in contact in the chamber \(7\), so that the total heat content of the entire apparatus rises until the value is reached, at which time the wet-bulb thermometer \(33\) operates to close the valve \(25\). On the other hand, when the drying apparatus is to be run at a temperature lower than that of its surroundings so that the total heat of the system tends to increase by radiation into the chambers \(1\) and \(7\), the wet-bulb thermometer \(33\) is connected operationally to the valve \(28\) controlling the cooler \(27\), and the by-pass valve \(25\) is closed. Thus, when the total heat of the system rises, the thermometer \(33\) operates to open the valve \(28\), cooling the reconcentrated liquor returning to the system in the pipe \(26\) to
a temperature below that of the diluted liquor leaving the pipe 18. Heat is extracted from the entire system until the desired heat content is attained, when the thermometer 33 closes the valve 28.

In an alternative structure of the apparatus, not illustrated, the heat-exchanger 23 may be omitted, in which case the small heat-exchanger 27 is connected so as to be either a heater or cooler in response to the demands of the wet-bulb thermometer 33. In fact, in the broadest sense of the invention, the wet-bulb thermometer 33 may be used to control make-up heating or cooling means located anywhere within the air or hygroscopic liquid circulating systems, since these systems are inter-communicating and are otherwise adiabatic. It is thus evident that the wet-bulb thermometer 33 is essentially a means responsive to variations in the total heat content of the air and hygroscopic liquid circulating systems and adapted to actuate means for increasing or decreasing the total heat content of the two systems.

As hereinbefore noted, if the drier is to be operated on air of constant temperature and humidity, not only must the system remain at substantially constant total heat, but in addition the air-reconditioning step in the chamber 7 must be carefully controlled so as to maintain constant conditions. That is, the air-hygroscopic liquid contacting step must be operated so that the effectiveness thereof, i.e., the quantity of moisture removed from the total quantity of air after each passage through the chamber, is such that the amount of water absorbed by the hygroscopic solution equals the amount of water given off by the material being dried. This effectiveness depends upon the rate of flow of air through the chamber 7, the rate of flow of hygroscopic solution from the reservoir 11 into the sump 12, and the concentration of the solution.

In the apparatus illustrated, the rate of air flow remains constant as long as the damper 8 is closed, and the fan 3 operates at constant speed; the concentration of the hygroscopic solution is held constant by the density-responsive plummet 31. The effectiveness of the reconditioning step is then dependent upon the rate of flow of hygroscopic liquid. Accordingly, to provide automatic control, the valve 16 governing this flow is connected operatively to a dry-bulb thermometer or thermostat 32, placed in the drying chamber 1, as shown, and set at the temperature desired. Then, when the temperature of the air entering the drier 1 changes due, say, to a variation in the rate of moisture evolution of the material being dried, the thermostat 32 operates to open or close the valve 16, thus varying the effectiveness of the air-reconditioning in the chamber 7 to just such an extent that the temperature of the reconditioned air returns to the desired value.

Instead of connecting the thermometer 32 to the valve 16 as shown, the same temperature control may be effected by connecting it to any other of the means for varying the effectiveness of the air-reconditioning step in chamber 7. Thus, if the valve 16 and density-device 29 be kept at a constant setting, the thermostat 32 may be connected so as to vary the speed of the fan 3, or to control the quantity of air passing through the chamber 7. The only necessary conditions, essentially, are that the relative positions of the dampers 6 and 8. Again, if the valve 16, fan 3, and dampers 6 and 8 are at a constant setting, the thermo-
may, if multiple-effect evaporation of the hygroscopic solution is employed, be markedly less than that theoretically required to dry the material charged. The heat economy and efficiency thus obtained are very high.

This application is a continuation-in-part of my co-pending application Serial No. 246,401, filed December 17, 1938, which, in turn is a continuation-in-part of my prior application Serial No. 13,968, filed March 30, 1935.

Other modes of applying the principle of the invention may be employed instead of those explained, change being made as regards the details disclosed, provided any of the steps or means stated in any of the following claims or the equivalent of such stated steps or means be employed.

I claim:

1. The method of removing a volatile liquid from a material wet therewith which comprises: circulating a body of an inert gas in a closed system through a drying zone wherein it is contacted with the wet material and removes part of the volatile liquid therefrom as vapor, then at least in part through a reconditioning zone wherein it is contacted with an absorbent liquor which removes part of the vapor of the volatile liquid and reconditions the gas for re-use, and finally back to the drying zone; circulating the absorbent liquor employed in the reconditioning zone into re-use in said zone; and withdrawing the reconditioned liquor from the liquor system, reconditioning the same to an extent sufficient to maintain the concentration of the entire body of absorbent liquor substantially constant, adjusting the temperature of the reconditioned liquor to a degree sufficient to compensate for small heat exchange effects between the gas and liquor circulatory systems and the surrounding atmosphere and thus to maintain both the said systems at substantially constant total heat content, and returning the reconditioned liquor to the liquor circulatory system.

2. The method of removing a volatile liquid from a material wet therewith which comprises: circulating a body of an inert gas in a closed system through a drying zone wherein it is contacted with the wet material and removes part of the volatile liquid therefrom as vapor, then at least in part through a reconditioning zone wherein it is contacted with an absorbent liquor which removes part of the vapor of the volatile liquid and reconditions the gas for re-use, and finally back to the drying zone; circulating the absorbent liquor employed in the reconditioning zone through a closed system into re-use in said zone; and withdrawing a small portion of the absorbent liquor from the closed liquor circulatory system, reconditioning the same to an extent sufficient to maintain the concentration of the entire body of absorbent liquor substantially constant, adjusting the temperature of the reconditioned liquor to a degree sufficient to compensate for small heat exchange effects between the gas and liquor circulatory systems and the surrounding atmosphere and thus to maintain both the said systems at substantially constant total heat content, and returning the reconditioned liquor to the liquor circulatory system.

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