CHAPTER 1

INTRODUCTION

Moisture content in air is a continuously changing factor. The percentage of moisture present in air depends upon time and place. Altitude, distance from the sea and other large water surfaces, wind conditions and season are the other factors contributing to the variation of moisture content in air. Reducing the moisture content or dehumidification, as it is sometimes called, is one of the most important tasks which technologists and scientists undertake to-day. Dehumidification is an important process in many industrial and domestic applications.

Different industrial processes are carried out under controlled atmospheres. Many processes in textile, pharmaceutical and food processing industries require a very low humidity. For example, carding process in cotton industries is performed at 50 % RH and 70 F while chocolate enrobing is done at 55% RH and 64 F. Lithographic printing is done at 45 % RH and 69 F and cereal processing is carried out at 45.5 % RH and 73 F. [25]

Processing under low relative humidity has proved to be a faster and a more effective method for drying of chemicals, grains and similar hygroscopic materials.

Dehumidification of air is generally carried out by different methods, namely (a) Refrigeration, (b) Adsorption and (c) Absorption. A schematic representation of the different dehumidification processes are shown in Fig. 1.1.
FIG. 1.1. SCHEMATIC REPRESENTATION OF DIFFERENT DEHUMIDIFICATION PROCESSES IN SUMMER.

1. Refrigeration

2. Adsorption

3. Absorption

a. Initial condition of air
   30°C, 80% RH

c. 23°C, 100% RH

d. 42°C, 35% RH

0. Final condition of air
   40°C, 40% RH
1.1. REFRIGERATION

In the refrigeration method, the moisture content of air is reduced by lowering its temperature below the dew point. It is done either by using surface condensers or by cold water sprays. During this process the moisture in the air is condensed. From Fig. 1.1 it is clear that the system mainly consists of a regular refrigeration unit and a heater. The refrigeration unit is used to maintain the temperature of the cooling coils well below the dew point temperature of atmospheric air.

1.2. ADSORPTION

In the adsorption method, solid dessicants like silica gel, activated alumina, etc. which have great affinity for moisture are used. Air is passed through the powdered dessicant bed. The moisture in air condenses in the pores of the dessicant resulting in the release of heat of condensation which, in turn, raises the temperature of air and dessicant. As the solid dessicant adsorbs the moisture in air, its adsorption capacity begins to decrease with time and so the subsequent adsorption rates will be comparatively lower than it was initially. A schematic diagram of an adsorption system is shown in Fig. 1.1. The system consists of two chambers where the dehumidification and regeneration processes are carried out alternatively. Two way valves are used to control the flow of air. The process line, represented in the psychrometric chart (Fig. 1.2), has a slope less than that of the constant wet bulb line.
1.3. ABSORPTION

When a concentrated solution of any of the hygroscopic chemicals such as calcium chloride, lithium chloride, lithium bromide, glycol, etc. is brought into contact with air, moisture in the air attempts to assume the vapour pressure of the solution, resulting in the dehumidification of air by absorption. This method has inherent advantages like low pressure drop, rate of dehumidification independent of time, relatively low regeneration heat and capacity to handle large volumes of air.

A schematic diagram of the system is shown in Fig. 1.1. In the dehumidifier, concentrated dessicant solution is sprayed from the top of the chamber and air is sent in from the bottom. As they come in contact, moisture in air is absorbed by the solution which gets diluted. This solution is then heated and sprayed in the regenerator for removal of moisture.

The moisture absorption by the solution is taking place because of the vapour pressure difference. When the vapour pressure of water in air is more than the vapour pressure of the solution, moisture transfer takes place from air to solution. When the temperature of the air and solution varies, the vapour pressure also changes. This will affect the moisture transfer process.

When the solution is heated, the vapour pressure of the solution increases and when it is more than the vapour pressure of water in air, moisture will be transferred from the solution to air. This brings about regeneration of the dessicant solution.
1.4. COMPARISON BETWEEN REFRIGERATION, ABSORPTION AND ADSORPTION PROCESSES

Psychrometric representation of the three dehumidification processes are shown in Fig. 1.2. Representative values of 30° C and 80% RH and 40° C and 40% RH are chosen as the inlet and outlet conditions of the air during summer. While dehumidification of air is carried out by the three different methods explained earlier, the condition of air at different stages in the processes are indicated in Fig. 1.1. Psychrometric representation of the three dehumidification processes during winter (25° C and 90% RH) is also shown in Fig. 1.2.

In the refrigeration method, air at 30° C and 80% RH is passed through the cooling coil where it is cooled to 20°C. The excess moisture is removed through condensation and air comes out of the cooling coil at 23° C and with 100% RH. After passing through the heater, air reaches the required condition of 40° C and 40% RH. In this method energy has to be supplied for the refrigeration system, for the heater and for blowing air through the cooling coil.

In the adsorption method, air reaches 42° C and 35% RH as it undergoes dehumidification. A heat exchanger is used to cool the air to the required final condition of 40°C. Blowing air through solid desiccant beds and heating the desiccant solution for regeneration consumes energy. In the heat exchanger, the air has to be cooled or heated depending on the final conditions required.

In the absorption method, air reaches 40° C and 40% RH as it passes through the dehumidification chamber.
FIG. 1.2. PSYCHROMETRIC REPRESENTATION OF DIFFERENT DEHUMIDIFICATION PROCESSES.

**SUMMER**

- **abc** - Refrigeration
- **add** - Adsorption
- **ao** - Absorption

- **a** - Initial condition
  - 30°C, 80% RH
- **o** - Final condition
  - 40°C, 40% RH

**WINTER**

- **aeo** - Refrigeration
- **ago** - Adsorption
- **agho** - Absorption

- **a** - Initial condition
  - 25°C, 90% RH
- **o** - Final condition
  - 40°C, 40% RH
Energy is needed for blowing air, for heating the dilute dessicant solution and for pumping the solution.

Energy analysis of these systems reveal that energy consumed is the least for the absorption process as compared to the other two methods. Further, the use of liquid dessicants facilitates continuous operation of Absorption Dehumidification systems. Typical energy requirements of these systems for the summer and winter conditions of Madras City are furnished in Appendix - 1.

1.5. SPRAY, PACKED BED AND FLUIDIZED BED COLUMNS

Dehumidification by absorption can be accomplished in spray columns, packed bed columns or fluidized bed columns. In spray columns, even though the pressure drop is low, the carryover loss is very high and the diameter to length ratio is critical. If diameter to length ratio is small, the spray will reach the wall and the effectiveness will be reduced. If it is large, there will be axial mixing and full advantage of counter current flow cannot be achieved.

In packed bed columns, the problem of reduction in effectiveness, because of axial mixing, is absent. However the presence of slugging and by-passing introduces retarding effects. The heat and mass transfer rates are low as the area exposed for heat and mass transfer is low.

Many of the problems encountered in the spray and packed bed columns are minimized in a fluidized bed system. Fluidized bed systems can operate in either two phase or three phase. The two fluids used in a three phase fluidized bed may flow either parallel to or counter to each other.
1.6. TWO PHASE AND THREE PHASE FLUIDIZED BED SYSTEMS

In a fluidized bed system, the solid material in the bed is kept in a suspended state, by sending the fluidizing media at a high velocity. This in turn develops turbulence, which increases the area exposed for heat and mass transfer considerably. A two phase fluidized bed system undergoes a non-clogging performance. However, channelling and slugging are not totally absent. Formation and quick rupture of small bubbles in the bed increases the rate of heat and mass transfer. These bubbles also help in augmenting solid circulation in the bed.

Dehumidification can be carried out in a two phase fluidized bed system. Solids of hygroscopic salts can be used as the bed material. The size of the particles may be reduced so as to fluidize easily. Air to be dehumidified can be blown through the distributor plate into the column to fluidize the solid dessicant particles. This will result in more efficient dehumidification compared to the packed bed systems. However, the problem of regeneration, of the used dessicant, remains. Moreover, the fine dessicant particles will be carried away by the air as it flows out. This will reduce the quality of air coming out of the system. Erosion of the column wall will be another problem associated with such a system.

Having established the superiority of absorption over adsorption for dehumidification, a two phase fluidized bed bubble column can be used. The dessicant solution can form the bed and the air to be dehumidified can be blown using a blower. Air will pass through the dessicant solution in the form of bubbles. As it passes, moisture in air will be absorbed by the solution. In this, the moisture
transfer will not be effective because of channelling, slugging, etc.

On the other hand, a three phase fluidized bed system gets rid of slugging and channelling to a great extent [13]. The carryover losses are also minimized in counter current flow beds. In the case of cocurrent flow three phase fluidized beds, the energy consumption is low as both the fluids help in fluidizing the bed, and the bed expansion is high. In a counter current flow bed, the energy consumption will be slightly higher, the bed expansion lower and the heat and mass transfer rates very high.

Because of these advantages, a three phase counter current fluidized bed is used for dehumidification in the present work and the system is analysed theoretically and experimentally.

The methodology employed in the present work is represented in Fig. 1.3. To begin with, the exergy analysis of different dehumidification systems was carried out and the most energy efficient method is chosen. Then the various dessicant solutions were analysed and the one best suited is selected. The theoretical investigations on a static bed dehumidifier and regenerator were then carried out. In the case of a fluidized bed, the theoretical analysis was carried out for the emulsion and bubble phases separately and these were then combined to get the overall performance characteristics. An experimental set up has been designed, fabricated and experiments were conducted to find the heat and mass transfer rates and the hydrodynamic characteristics in the dehumidifier and regenerator. The experimental and theoretical results were then compared.
Exergy Analysis of diff. dehumidification systems

Selection of desiccant

Theoretical analysis of static bed dehumidifier

Analytical work on 3 Phase counter current fluidized bed dehumidifier

Emulsion phase Bubble phase

Design & Fabrication of the experimental set-up.

Experiments on 3 Phase counter current fluidized bed dehumidifier - Hydrodynamics and Heat, Mass transfer

Experiments with packed bed systems

Results & conclusions

FIG. 1.3. SCHEMATIC REPRESENTATION OF THE PRESENT WORK.