

ENGINEERING STANDARD
FOR
PROCESS DESIGN OF DRYERS

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0. INTRODUCTION

Drying is an important Unit operation concept in which water and other volatile liquids can be separated from solids and semisolid materials and from gases and liquids. Drying is most commonly used in Oil, Gas and Petrochemical (OGP) process plants for removal of water or solvents from solids by thermal means, dehydration of gases by condensation or absorption and drying of liquids by fractional distillation, or adsorption of fluids.

In drying, material is transferred from one phase to another, which is complicated by the need, to transfer heat and mass simultaneously, but in opposite direction. Heat is transferred first, usually in different external heat-transfer mode such as: Convection, Conduction, Radiation, Dielectric Heating etc. Then mass transfer occur, involving the removal of surface moisture and movement of internal moisture to the surface. Many dryers employ more than one of these modes. Nevertheless, most industrial dryers are characterized by one that predominates, heat transfer mechanism.

Industrial dryers may be classified according to the physical characteristics of the material being dried, the method of transferring the thermal energy to wet product, the source of the thermal energy, the method of physical removal of the solvent vapor, and the method of dispersion (in case of wet solids) in the drying operation.

As a consequence of dryer specialization, the selection of the type of dryer appropriate to the specific product to be dried becomes a critical step in the specification and design of the processing plant. The choice of the wrong type of dryer can lead to inefficient operation, reduced product quality, and loss of profit.

1. SCOPE

This Engineering Standard Specification is intended to cover minimum requirements for process design of dryers used in oil, gas, and petrochemical process plants.

Although, as a common practice, dryers are seldom designed by the users, but are brought from companies that are specialized in design and fabrication of drying equipment, the scope covered herein, is for the purpose to establish and define general principals on drying concept and mechanism, dryer classification and selection and to provide a cumulation design information and criteria required for proper selection, design and operation of solid, liquid and gaseous drying equipment (dryers).

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard. The applicability of changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor/Consultant.

IPS (IRANIAN PETROLEUM STANDARDS)

| | |
|--------------|--|
| IPS-E-PR-330 | "Process Design of Production & Distribution of Compressed Air Systems", Clause 5.4, "Air Dryers" |
|--------------|--|

ISO (INTERNATIONAL STANDARD ORGANIZATION)

| | |
|------------|---|
| 7183, 1986 | "Compressed Air Dryers-Specifications and Testing", Section 4, 1st. Ed., 15th March 1986 |
| 5388, 1981 | "Standard Air Compressors, Safety Rules and Code of Practice", 1st. Ed., 1981 |

BSI (BRITISH STANDARDS INSTITUTION)

| | |
|--------------------------------|---|
| BS 6757:1986/ISO 7183: 1986 | "Standard Specification and Testing of Compressed Air Dryers" |
|--------------------------------|---|

3. SYMBOLS AND ABBREVIATIONS

| | |
|------------------------------|--|
| A | Surface area for vaporization and heat transfer, in (m ²). |
| ABS | Acrylonitrile-Butadiene-Styrene. |
| c | Concentration of one component in a two-component phase of A and B. |
| C_T | Pressure drop coefficient, in (m.h ² /m ²). |
| D_{AB} | Binary diffusivity of the phase A-B. |
| d_c | Particle diameter, in (m). |
| D_p | Average drop diameter, in (μm). |
| $\frac{dw}{d\theta(\theta)}$ | Drying rate, in [kg liquid/(S kg dry material)]. |
| D_p | Effective particle diameter, in (m). |

| | |
|-------------------------|--|
| ε (epsilon) | External void fraction. |
| f_T | Friction factor. |
| FMC | Final Moisture Content. |
| G | Superficial mass velocity, in (kg/h.m ²). |
| H' | Henry's Constant. |
| H | Humidity at t, in (kg/kg). |
| HDPE | High Density Poly-Ethylene. |
| h_t | The sum of all convection, conduction and radiation, components of heat transfer, in [kW/(m ² .K)]. |
| i | A constant, that is independent of temperature. |
| IMC | Initial Moisture Content. |
| K | Function of the constant-rate drying period. |
| K'_a | Mass-transfer coefficient, in [kg/(s.m ² .kg/kg)]. |
| L | Length of dryer distance from bed entrance (adsorber), in (m). |
| ρ_L (rho) | Density of liquid, in (kg/m ³). |
| $L's$ | Latent heat of vaporization at t'_s , in (kJ/kg). |
| N | Rotations per minute, in (r/min) = (rpm) |
| θ (theta) | Diffusion retention time, in (h). |
| p | Partial pressure of vapor in the gas environment, in (kPa). |
| P_1 | Effective gage pressure of the compressed air, in (bar). |
| P | Electrical power, in kilowatt (kW). |
| ΔP (delta) | Pressure drop across dryers, in [(kg/m ²)= (9.80665 Pa)] and/or in (bar). |
| $\Delta P/L$ | Pressure drop per unit length of bed, in [(kg/m ² /m)]. |
| $P's$ | Liquid vapor pressure at t_s , in (kPa). |
| PP | Poly Propylene. |
| PVC | Poly Vinyl Chloride. |
| P_w | Pure water vapor pressure at the air temperature, in (kPa). |
| q_{m2} | Mass flow of compressed air (if required), in (kg/s). |
| q_v | Water (for cooling according to coolant temperature which is used at any heat exchanger of dryer), in (L/s). |
| $q_{v \text{ loss}}$ | Bleed air, dump losses, etc., max. and average, in (L/s). |
| q_{v1} and q_{v2} | Volume air flow rate related to the intake conditions, in (L/s) or (m ³ /s). |
| R_e | Reynolds number, (dimentionless). |
| S | Product mass rate, in (kg/h). |

| | |
|------------------|---|
| t | Air dry-bulb temperature, in kelvin (K) and average source temperature for all components of heat transfer. |
| t_1 | Temperature of compressed air, in ($^{\circ}\text{C}$). |
| t_2 | Temperature of dried compressed air, in ($^{\circ}\text{C}$). |
| t_{c1} | Coolant temperature, in ($^{\circ}\text{C}$). |
| t_{pd1} | Pressure dew point of compressed air, in ($^{\circ}\text{C}$). |
| t_{pd} | Highest pressure dew point under operating condition, in ($^{\circ}\text{C}$). |
| t'_s | Liquid surface temperature, in kelvin (K). |
| U | Overall heat-transfer coefficient, in ($\text{kW}/\text{m}^2\cdot\text{K}$) or $\text{W}/\text{m}^2\cdot^{\circ}\text{C}$. |
| $\mu(\text{mu})$ | Viscosity of liquid, in ($\text{kg}/\text{m}\cdot\text{h}$). |
| V | Dryer Volume, in (m^3). |
| \dot{V} | Volume Flow rate of air, in (m^3/s). |
| W | The moisture content of the drop, in (kg/kg of dry solid). |
| W_e | The equilibrium moisture content. |
| x | Moisture content, dry basis, in (kg/kg). |
| z | Distance in the direction of diffusion. |

4. DEFINITIONS AND TERMINOLOGY

Terms used herein are defined in accordance with ISO 7183, and other resources specified under Clause 2 as:

4.1 Moisture Content

The ratio of water and water vapor by mass to the total volume (gram per cubic meter).

4.2 Vapor Concentration (Absolute Humidity)

The ratio of water vapor by mass to the total volume (gram per cubic meter).

4.3 Partial Pressure

Absolute pressure exerted by any component in a mixture (millibar).

4.4 Saturation Pressure

Total pressure at which moist air at a certain temperature can coexist in equilibrium with a plane surface of pure condensed phase (water or ice) at the same temperature (millibar).

4.5 Relative Humidity (Relative Vapor Pressure)

Ratio of the partial pressure of water vapor (millibar) to its saturation pressure (millibar) at the same temperature.

4.6 Dew Point

Temperature, referred to a specific pressure (degree Celsius), at which the water vapor begins to condensate.

4.7 Constant-Rate Period

Is the drying period during which the rate of liquid removal per unit of drying surface is constant.

4.8 Critical Moisture Content

Is the moisture content of the material at the end of the constant-rate period. The critical moisture content is not a unique property of the material but is influenced by its physical shape as well as the conditions of the drying process.

4.9 Falling-Rate Period

The part of drying time which the drying rate varies in time.

4.10 Free Moisture Content

Is the liquid content that is removable at a given temperature and humidity. Free moisture may include both bound and unbound moisture, and is equal to the total average moisture content minus the equilibrium moisture content for the prevailing conditions of drying.

4.11 Equilibrium Moisture Content

The amount of moisture, in the solid that is in thermodynamic equilibrium with its vapor in the gas phase, for given temperature and humidity conditions. The material cannot be dried below its corresponding equilibrium moisture content.

4.12 Drying-Rate

The amount of water (kg) removed per square meter of drying area per hour. Or the volume flow rate of condensed gas at Standard Reference Atmosphere Condition of an absolute pressure of 101.325 kPa (1.01 bar) and a temperature of 15°C.

4.13 Adiabatic Drying

The drying process described by a path of constant adiabatic cooling temperature on the psychrometric chart.

4.14 Capillary Flow

Is the flow of liquid through the interstices and over the surfaces of a solid, caused by liquid-solid molecular attraction.

4.15 Adsorbate

The molecules that condense on the adsorbent surface e.g., water in the case of drying.

4.16 Adsorbate Loading

The concentration of adsorbate on adsorbent, usually expressed as kg adsorbate per 100 kg adsorbent.

4.17 Adsorbent

A solid material which demonstrates adsorption characteristics.

4.18 Adsorption

The phenomenon whereby molecules in the fluid phase spontaneously concentrate on a solid surface without undergoing any chemical change.

4.19 Adsorption Selectivity

The preference of a particular adsorbent material for one adsorbate over another based on certain characteristics of the adsorbate such as polarity or molecular mass.

4.20 Cycle Time

The amount of time allocated for one bed in an adsorption system to complete adsorption to a predetermined outlet specification level and to be reactivated.

4.21 Desiccant

An adsorbent that shows primary selectivity for the removal of water. All adsorbents are not necessarily desiccants.

4.22 Desiccant Fouling

Material adsorbed from the carrier stream may not be desorbed satisfactorily on regeneration. Some reaction may also occur on the adsorbent leading to products that are not desorbed. These reaction products may inhibit efficient adsorption and obstruct or "foul" capacity of the active surface.

4.23 Design Basis

A good design basis requires a sound knowledge of the stream to be processed as well as what the desired outlet specification is and how the system will be operated. The design conditions on which an adsorption system is based are not necessarily the actual operating conditions, nor the least or most stringent operating conditions.

4.24 Equilibrium Loading

The loading of an adsorbate on the given adsorbent, usually expressed in kilogram of adsorbate per hundred kilogram of adsorbent when equilibrium is achieved at a given pressure, temperature, and concentration of the adsorbate.

5. UNITS

This Standard is based on International System of Units (SI), except where otherwise specified.

6. WET SOLID DRYERS

6.1 General

In drying process the goal of many operations is not only to separate a volatile liquid, but also to produce a dry solid of specific size, shape, porosity, texture, color or flavor. So, well understanding of liquid and vapor mass transfer mechanism prior to design work is strongly recommended.

In drying of wet solids, the following main factors, which essentially are used in process design calculation of dryers should be defined in accordance with mass and heat transfer principles, process conditions and drying behavior:

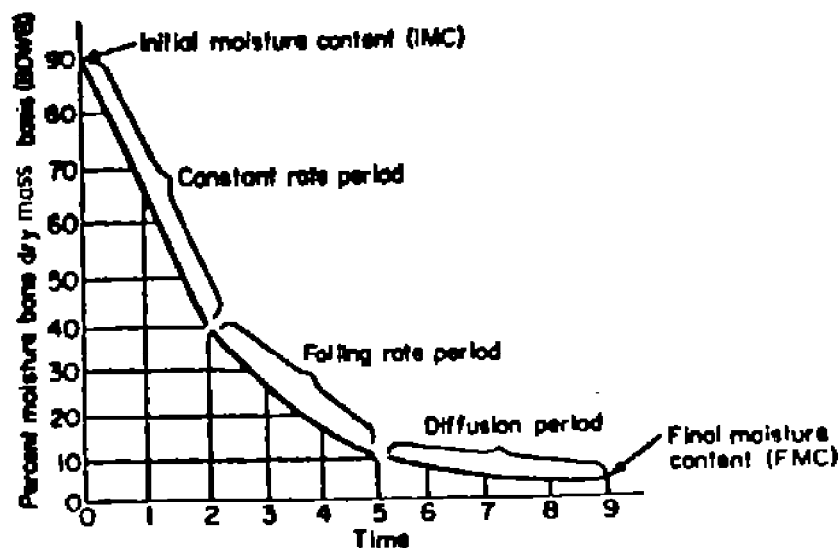
- a) Drying characteristics.
- b) Constant-rate period.
- c) Falling-rate period.
- d) Moisture content.
- e) Diffusion concept.

6.2 Drying Characteristics

6.2.1 The drying characteristics of wet solids is best described by plotting the average moisture content of material against elapsed time measured from the beginning of the drying process. Fig. 1 represents a typical drying-time curve. The experimental estimation of this curve must be made before one can begin the design calculations. The influence of the internal and external variables of drying on the drying-time curve should be determined in order that an optimal design can be developed.

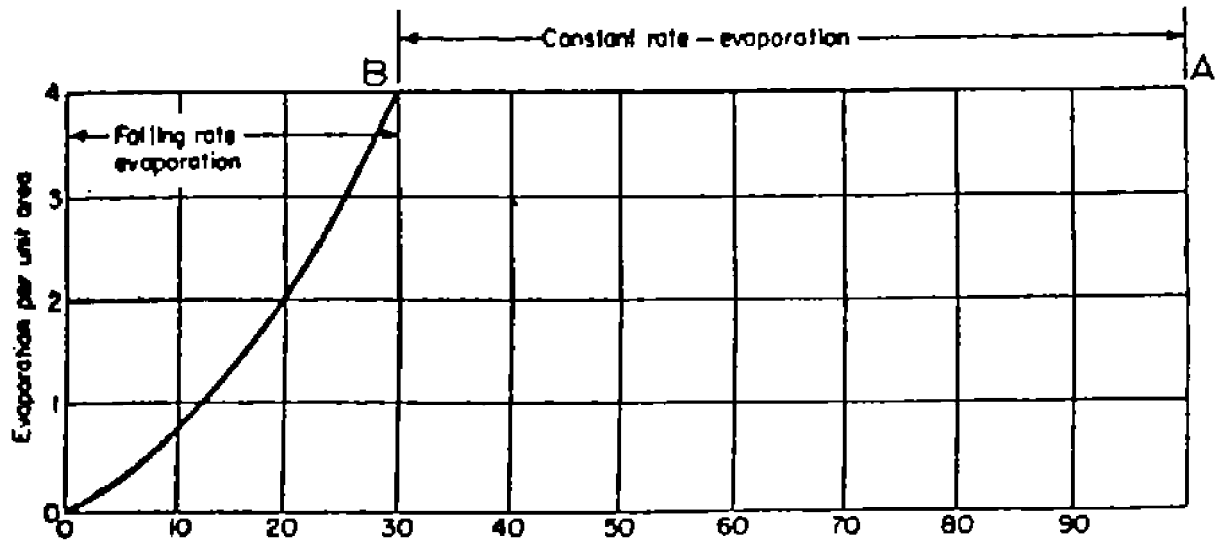
6.2.2 The drying-rate curve, Fig. 2, is derived from the drying-time curve by plotting slopes of the latter curve against the corresponding moisture content. The distinctive shape of this plot, shown in Fig. 2, illustrates the constant-rate period, terminating at the critical moisture content, followed by the falling-rate period. The variables that influence the constant-rate period are the so-called external factors consisting of gas mass velocity, thermodynamic state of the gas, transport properties of the gas, and the state of aggregation of the solid phase changes in gas temperature, humidity, and flow rate will have a profound effect on the drying rate during this period. The controlling factors in the falling-rate period are the transport properties of the solids and the primary design variable is temperature.

6.2.3 The characteristic drying behavior in these two period are markedly different and must be considered in the design. In the context of economics, it shall be costlier to remove water in the falling-rate period than it is removed in the constant-rate period, accordingly it is recommended to extend the length of the constant-rate period with respect to falling-rate as much practicable.



TYPICAL CLASSIC DRYING-TIME CURVE

Fig. 1



MOISTURE CONTENT, PERCENT BONE DRY MASS BASIS DRYING-RATE CURVE
Fig. 2

6.3 Constant-Rate Period

6.3.1 In Fig. 2, the horizontal segment AB which pertains to the first major drying period is called the constant-rate period. During this period, the solid is so wet that a continuous film of water exists over the entire drying surface, and this water acts as if the solid were not there. If the solid is nonporous, the water removed in this period is mainly superficial water on the solid's surface.

The evaporation from a porous material is subject to the same mechanism as that from a wet-bulb thermometer.

6.3.2 The drying rate in constant-rate period can precisely be calculated from Equation 1 which is a steady-state relationship between heat and mass transfer.

$$-\frac{dw}{d\theta} = \frac{h_t \cdot A}{L's} (t - t's) = K'a \cdot A (p's - p) \quad (\text{Eq. 1})$$

Where:

- $dw/d\theta$ is drying rate, in (kg/s);
- h_t is the sum of all convection, conduction, and radiation components of heat transfer, in [kW/(m².K)];
- A is surface area for vaporization and heat transfer, in, (m²);
- $L's$ is latent heat of vaporization at $t's$, in (kJ/kg);
- $K'a$ is mass transfer coefficient, in [kg/(s.m².kPa)];
- t is average source temperature for all components of heat transfer, in kelvin (K);
- $t's$ is liquid surface temperature, in kelvin (K);
- $p's$ is liquid vapor pressure at $t's$, in (kPa);
- p is partial pressure of vapor in the gas environment, in (kPa).

6.4 Critical Moisture Content

6.4.1 The critical moisture content is the average material moisture content at which the drying rate begins to decline. A prototype drying test should be conducted to determine the critical moisture content. In Fig. 2, the point B represents the constant-rate termination and marks the instant when the liquid water on the surface is insufficient to maintain a continuous film covering the entire drying area. The critical point (B) occurs when the superficial moisture is evaporated. In porous solids the point B of Fig. 2 is reached when the rate of evaporation become the same as obtained by the wet-bulb evaporative process.

6.5 Equilibrium Moisture Content

6.5.1 The equilibrium condition is independent of drying rate or drying method, but is a material property. Only hygroscopic materials have equilibrium moisture content under specific conditions of temperature and humidity. In prediction/estimation of equilibrium moisture content, the Henry's Law (Eq. 2) may be followed:

$$P = H' (x) \quad (\text{Eq. 2})$$

Where:

- p** is partial pressure of vapor in the atmosphere, in(kPa);
- H'** is Henry's constant;
- x** is Dry basis, moisture content, in (kg/kg). Henry's constant is a function of the pure liquid's vapor pressure.

$$H = i (p_w) \quad (\text{Eq. 3})$$

Where:

- i** is a constant that is independent of temperature;
- p_w** is the pure liquid's vapor pressure at any temperature, in (kPa) therefore;
- p** is $i (p_w)(x)$, and since percent relative humidity = $100 (p/p_w)$.

$$100 (p/p_w) = 100 i (x) \quad (\text{Eq. 4})$$

6.6 Falling-Rate Period

6.6.1 Estimation of the drying for the falling-rate period is primarily depends on experimental data. However, the drying rate during this period is considered to be a complex function of transport, physical, and thermodynamic properties of the solid phase, as well as of the same properties of the gas phase.

Since the mechanisms of internal liquid and vapor flow during falling-rate drying are complex, the falling-rate can rarely be described with mathematical precision. However, for evaluation of falling-rate drying, an integration of Equation 5 can be employed provided several assumptions are made:

- 1) diffusivity is independent of liquid concentration;
- 2) initial liquid distribution is uniform;
- 3) material size, shape, and density are constant;
- 4) the material's equilibrium moisture contents is constant.

$$\frac{dc}{d\theta} = D_{AB} \frac{d^2c}{dz^2} \quad (\text{Eq. 5})$$

The Equation 5 is the unsteady-state diffusion equation in mass transfer notation and,

Where:

- c** is concentration of one component in a two-component phase of A and B;
- θ (theta)** is diffusion time;
- z** is distance in the direction of diffusion;
- D_{AB}** is binary diffusivity of the phase A-B.

This equation applies to diffusion in solids, stationary liquids, and stagnant gases.

6.6.2 The shape of the falling-rate curve sometimes may be approximated by a straight line, with Equation 6, as:

$$-\frac{dW}{d\theta} = K(W - W_e) \quad (\text{Eq. 6})$$

Where:

- W_e** is the equilibrium moisture content;
- K** is a function of the constant-rate drying period.

6.7 Determining of Drying Time

6.7.1 Three following methods are generally used in order of preference for determining of drying time:

- 1) Conduct tests in a laboratory dryer simulating conditions in the commercial machine, or obtain performance data directly from the commercial machine.
- 2) If the specific materials is not available, obtain drying data on similar material by either of the above methods. This is subject to the investigator's experience and judgment.
- 3) Estimate drying time from theoretical Equation 1 or any such appropriate theoretical formulas.

6.7.2 When designing commercial equipment, tests are to be conducted in a laboratory dryer that simulates commercial operating conditions. Sample materials used in the laboratory tests should be identical to the material found in the commercial operation. Result from several tested samples should be compared for consistency. Otherwise, the test results may not reflect the drying characteristics of the commercial material accurately.

When laboratory testing is impractical, commercial drying can be based on the equipment manufacturer's experience as an important source of data.

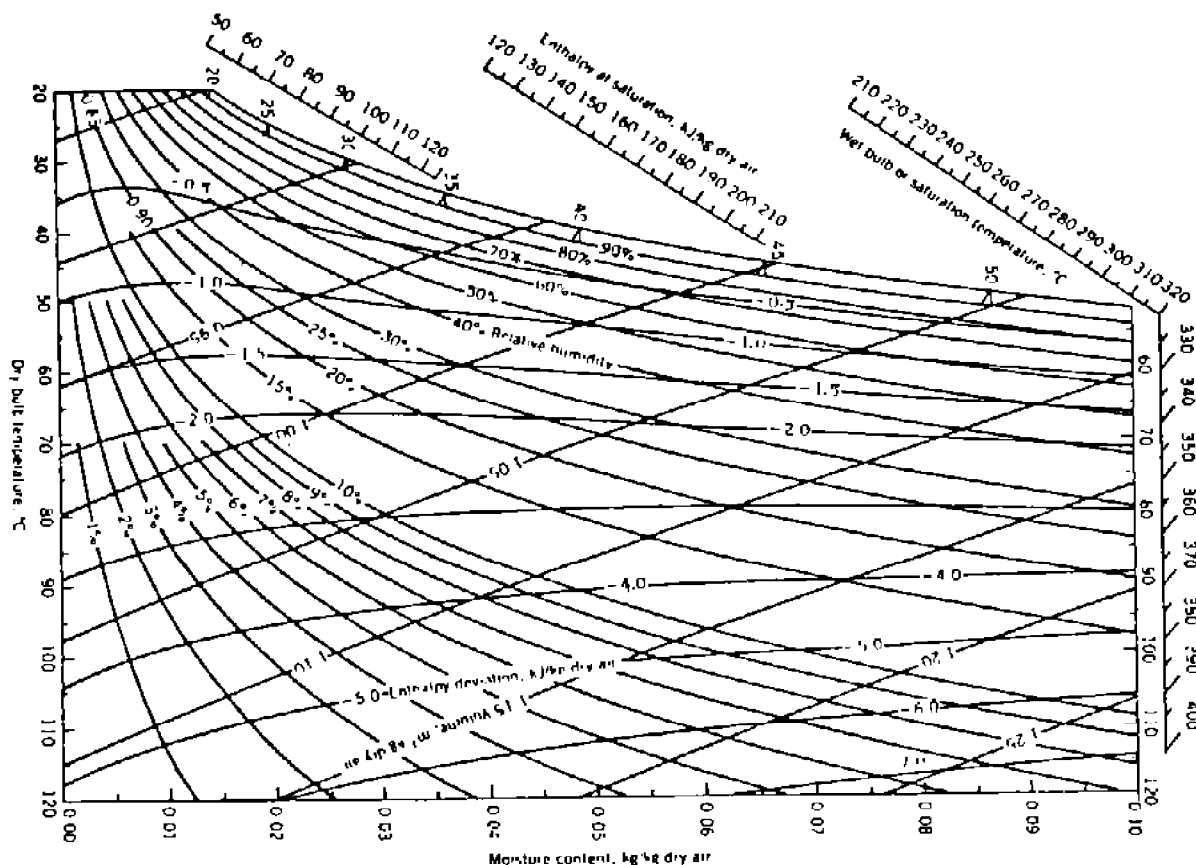
Since estimating drying time from theoretical equations are only approximate values, care should be taken in using of this method.

6.7.3 When selecting a commercial dryer, the estimated drying time determines what size machine is needed for a given capacity. If the drying time has been derived from laboratory test, the following should be considered:

- In a laboratory dryer, considerable drying may be the result of radiation and heat conduction. In a commercial dryer, these factors are usually negligible.
- In a commercial dryer, humidity conditions may be higher than in a laboratory dryer. In drying operations with controlled humidity, this factor can be eliminated by duplicating the commercial humidity condition in the laboratory dryer.
- Operating conditions are not as uniform in a commercial dryer as in a laboratory dryer.
- Because of the small sample used the test material may not be representative of the commercial material. Thus, the designer must use experience and judgment to correct the test drying time to suit commercial conditions.

6.8 Psychrometry

6.8.1 Before drying can begin, a wet material must be heated to such a temperature that the vapor pressure of the liquid content exceeds the partial pressure of the corresponding vapor in the surrounding atmosphere. The effect of atmospheric vapor content of a dryer on the drying rate and material temperature is conveniently studied by construction of a psychrometric chart. (See typical Fig. 3)



PSYCHROMETRIC CHART [AIR-WATER VAPOR AT 101.325 kPa (=1 atm.)]

Fig. 3

6.9 Classification of Industrial Drying

6.9.1 Industrial dryers may be classified according to the following categories:

a) Method of operation

This category refers to the nature of the production schedule. For large-scale production the appropriate dryer is of the continuous type with continuous flow of the material into and out of the dryer. Conversely, for small production requirements, batch-type operation is generally desired. A typical classification of dryers based on the method of operation is given in Table 1.

b) Physical properties of material

The physical state of the feed is probably the most important factor in the selection of the dryer type. The wet feed may vary from a liquid solution, a slurry, a paste, or filter cake to free-flowing powders, granulations, and fibrous and non-fibrous solids. The design of the dryer is greatly influenced by the properties of the feed; thus dryers handling similar feeds have many design characteristics in common.

Table 2, represents a typical classification of dryers based on physical properties of material.

Note:

A comprehensive classification of commercial dryers based on properties of materials handled, is given in Perry's Chemical Engineering Handbook.

c) Conveyance

In many cases, the physical state of the feed dictates the method of conveyance of the material through the dryer; however, when the feed is capable of being preformed, the handling characteristics of the feed may be modified so that the method of conveyance can be selected with greater flexibility. Generally, the mode of conveyance correlates with the physical properties of the feed.

d) Method of energy supply

Where the energy is supplied to the material by convective heat transfer from a hot gas flowing past the material, the dryer is classified as a convection type. Conduction-type dryers are those in which the heat is transferred to the material by the direct contact of the latter with a hot metal surface.

e) Cost

Cost effect of dryer selection influence the classification of industrial drying. When capacity is large enough, continuous dryers are less expensive than batch units. Those operating at atmospheric pressure cost about $\frac{1}{3}$ as much as those at vacuum. Once through air dryers are one-half as expensive as reciprocating gas equipment. Di-electric and freeze dryers are the most expensive and are justifiable only for sensitive and specialty products. In large scale drying, rotary, fluidized bed and pneumatic conveying dryers cost about the same.

f) Special process features

Special characteristics of the drying material together with particular features of the product is carefully considered in classifying of dryer and selection of dryer type. Hazardous, heat sensitive, quality sensitive products and cost effects can clearly dictate process consideration in classifications. A typical classification of dryers based on process special features is given in Table 3.

TABLE 1 - CLASSIFICATION OF DRYERS BASED ON METHOD OF OPERATION

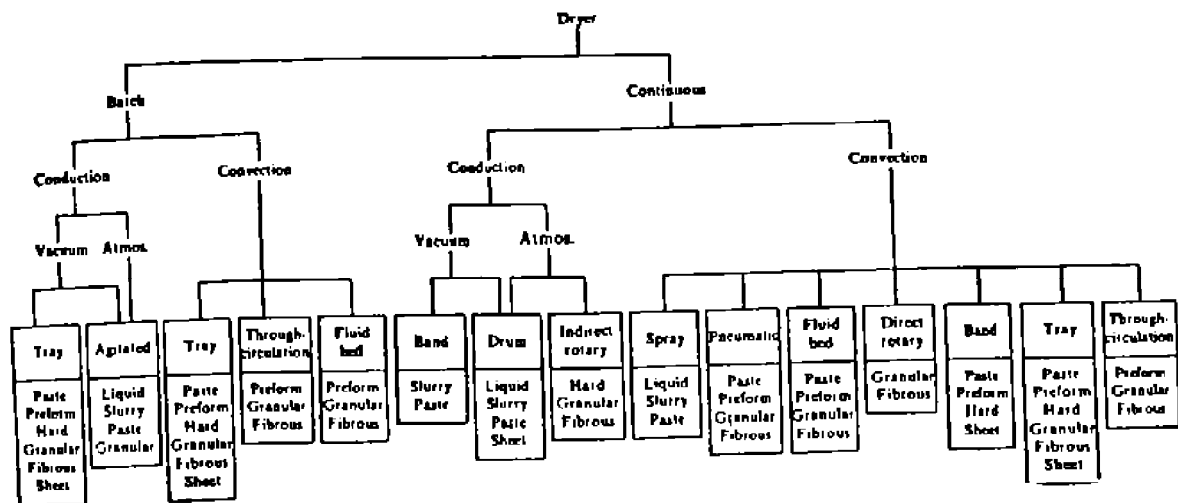


TABLE 2 - CLASSIFICATION OF DRYERS BASED ON PHYSICAL FORM OF FEED

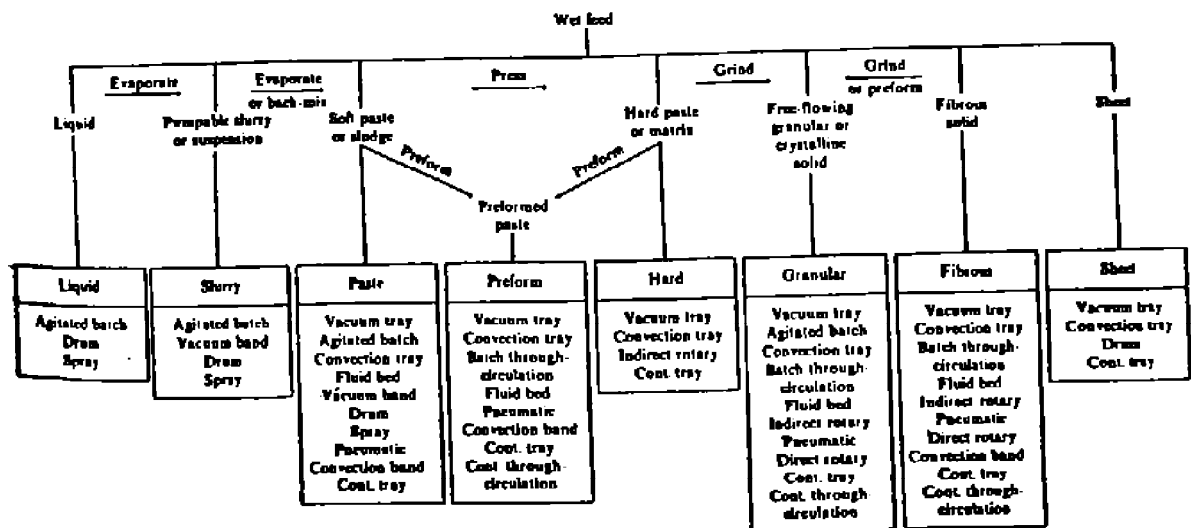
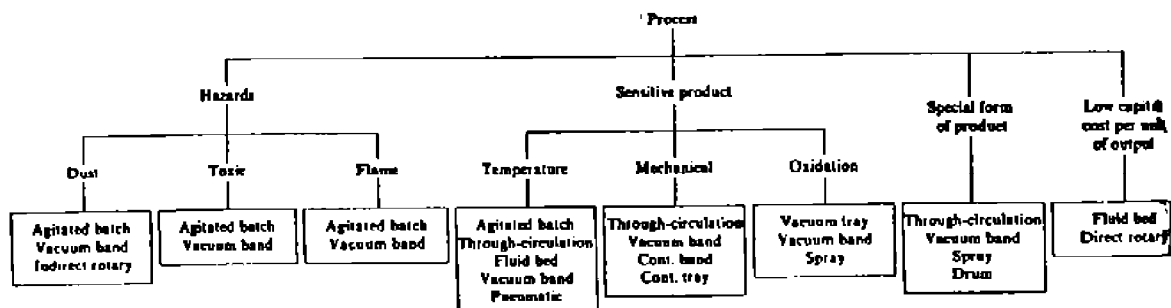


TABLE 3 - CLASSIFICATION OF DRYERS BY SUITABILITY FOR SPECIAL FEATURES



g) Specification forms

A listing of key information to be specified for a typical design is given in Table 4.

| | | |
|--|--|---|
| 1. Operation | mode | batch/continuous |
| | operating cycle | — h |
| 2. Feed | (a) material to be dried | — |
| | (b) feed rate | — kg/h |
| | (c) nature of feed | solution/slurry/sludge/granular/fibrous/ sheet/bulky |
| | (d) physical properties of solids: | |
| | initial moisture content | — kg/kg |
| | hygroscopic-moisture content | — kg/kg |
| | heat capacity | — kJ/kg°C |
| | bulk density, wet | — kg/m ³ |
| | particle size | — mm |
| | (e) moisture to be removed: | |
| | chemical composition | — |
| | boiling point at 1 bar | — °C |
| | heat of vaporization | — MJ/kg |
| | heat capacity | — kJ/kg°C |
| | (f) feed material is | scaling/corrosive/toxic/abrasive/explosive |
| | (g) source of feed | — |
| 3. Product | (a) final moisture content | — kg/kg |
| | (b) equilibrium-moisture content at 60% r.h. | — kg/kg |
| | (c) bulky density | — kg/m ³ |
| | (d) physical characteristics | granular/flaky/fibrous/powdery/sheet/bulky |
| 4. Design restraints | (a) maximum temperature when wet | — °C |
| | when dry | — °C |
| | (b) manner of degradation | — |
| | (c) material-handling problems, when wet | — |
| | when dry | — |
| | (d) will flue-gases contaminate product? | — |
| | (e) space limitations | — |
| 5. Utilities | (a) steam available at | — bar pressure (10^6 N/m^2) |
| | maximum quantity | — kg/h |
| | costing | — S/kg |
| | (b) other fuel | — |
| | at | — kg/h |
| | with heating value | — MJ/kg |
| | costing | — S/kg |
| | (c) electric power | — V |
| | frequency | — hz |
| | phases | — |
| | costing | — S/kWh |
| 6. Present method of drying | | — |
| 7. Rate-of-drying data under constant external conditions: | | — |
| | | — |
| | or data from existing plant | — |
| | | — |
| 8. Recommended materials of construction | | |
| | (a) parts in contact with wet material | — |
| | (b) parts in contact with vapors | — |

6.10 Selection of Dryer

6.10.1 General

6.10.1.1 The choice of the best type of dryer to use for a particular application is generally dictated by the following factors:

- a) the nature of the product, both physical and chemical;
- b) the value of the product;
- c) the scale of production;
- d) the available heating media;
- e) the product quality consideration;
- f) space requirements;
- g) the nature of the vapor, (toxicity, flammability);
- h) the nature of the solid, (flammability, dust explosion hazard, toxicity).

6.10.1.2 For application of factors specified under 6.10.1.1, in selection of process, a systematic procedure involving the following steps is recommended:

1) Formulating of drying problem as completely as possible:

In this step, the specific requirements and variables should explicit be identified; thus, the important information driven can be summarized as:

- a) indication of the product and it's purity;
- b) specification of initial and final moisture content;
- c) specification of range of variation of initial and final moisture content;
- d) specification and basis of production rate.

2) Collecting all available data related to the problem:

In this step, the previous experience related to drying of particular product of interest or of a similar material should be investigated.

3) Physical and chemical properties to be established:

The physical and chemical properties of feed and product including physical state of feed (filter cake, granulations, crystals, extrusions, briquettes, slurry, paste, powder, etc.) including size, shape, and flow characteristics; chemical state of the feed (pH, water of crystallization, chemical structure, degree of toxicity of vapor or solid, corrosive properties, inflammability of vapor or solid, explosive limits of vapor); and physical properties of dry product (dusting characteristics, friability, flow characteristics, and bulk density). Finally, available drying data in the form of prior laboratory results, pilot-plant performance data, or full-scale plant data on the drying of similar materials should be obtained.

4) Defining of critical factors, constraints and limitations associated with particular product and with available resources:

- Any particular hazards related to the handling of the product (wet or dry) should be specifically and quantitatively identified.
- Any characteristics of the product that present potential problems should be recognized.
- Degree of uniformity of drying will work as an important consideration in the selection process.

5) Making a preliminary identification of the appropriate drying systems:

In this Step, an identification of several dryer types that would appear to be appropriate should be made. This can be accomplished by simply comparing the properties and critical factors identified in Steps 3 and 4 with the characteristic features of the industrial dryers classified previously under Clause 6.9, of this Standard.

6) Selection of optimal drying system and determining it's cost effectiveness:

This step, is followed on the basis of forging, and the optimal dryer type is identified and the appropriate design calculations or experimental programs can be conducted. Thus, the ultimate choice is usually that which is dictated by minimum total cost. However, it should be noted that a detailed economic analysis might lead to a selection based on maximum profit rather than minimum cost.

6.10.2 When selecting a dryer, there are several questions that need to be answered for all types of dryers. Rotary dryers will be used to illustrate problems because they dry more material than any other dryer. A few of the problems are as follows:

1) What type of dryers can handle the feed? If the feed is liquid, dryers such as spray, drum, or one of the many special dryers that can be adapted to liquids may be used.

If the feed is quite sticky, it may be necessary to recycle much of the product in order to use a certain type of dryer. The best solution to the feed problem is to try the material in a pilot unit. The pilot unit for a spray dryer needs to be near the size of the production unit as scale-up is quite difficult in this case.

2) Is the dryer reliable? Is the dryer likely to cause shut-downs of the plant, and what performance history does this unit have in other installations? How long is the average life of this type of dryer?

3) How energy-efficient is this type of dryer? For example, a steam tube dryer may have an efficiency of 85% while a plain tube type of rotary dryer may have an efficiency of only 50%. However, production of the steam entails additional costs so the plain tube may be more efficient in overall production.

The higher the temperature of inlet gas stream, the higher the efficiency of the dryer in general. A fluid-bed dryer has a high back-mix of gas so it is possible to use a fairly high entering gas temperature.

Any dryer can use recycled stack gas to lower the inlet gas temperature and thus obtain a high efficiency for dryer. However, if there is any organic material in the stack gas, it may be cracked to form a very fine carbonaceous particulate which is almost impossible to remove from the stack. Recycle also increases the dew point of the incoming gas which lowers the drying potential of the dryer. This lowering of the potential is quite important when drying heat-sensitive material.

4) What type of fuel can be used for heating? Direct heating is usually the most efficient unit, and natural gas and LPG are the best fuels. However, both gases are getting more expensive and in many cases will not be available. The next best fuel is light fuel oil which can be burned readily with a "clean" stack.

This material is expensive, and in some cases may be in short supply. The third best fuel is heavy fuel oil which is usually available, but this oil requires special burners and may not give a sufficiently clean stack. Coal is dusty and hard to handle.

The stack gas usually is too contaminated for use in most installations.

5) Does the dryer have a dust problem? Steam tube units use very low air flow and have minor dust problems, while a plain tube uses high air rates and may have serious dust problems. In some cases the stack dust removal devices may cost more than the dryer.

6) How heat sensitive is the material to be dried? Most materials have a maximum temperature that can be used without the product deteriorating. This temperature is a function of the time of exposure as the thermal deterioration usually is a rate phenomena. Wet material can stand much higher temperatures in the gas due to the evaporation cooling.

As an example: A rotary dryer working with alfalfa can use 760°C entering gas in a cocurrent unit. A countercurrent unit at this temperature would burn the alfalfa. As the temperature of the entering gas determines the efficiency of the dryer, concurrent dryers, on the average, are more efficient than countercurrent dryers.

7) What quality of product will be obtained from the dryer? Freeze drying usually will give an excellent product, but the cost is prohibitive in most cases. A dryer needs to balance quality against cost of production of a satisfactory product.

8) What space limitations are placed on the installation? There are certain height limitations in some buildings, and floor space may be limited or costly.

9) Maintenance costs are often a major consideration. If moving parts either wear out or break down due to material "balling-up" or sticking, the plant may be shut down for repair, and repairs cost money. If this is problem, a record should be kept of the performance of the unit. It may be possible to get this information from a plant which is using this particular unit on a similar product.

10) What is the labor cost? A tray dryer has high labor costs, but it is the best dryer in many cases where only small amounts of material need to be handled.

11) Is a pilot unit available which can be used to get data to design the needed production facility? Nearly all new products need pilot plant data for a satisfactory design of a dryer.

In the case of spray drying an industrial size unit needs to be used. Drum and rotary units and most other dryers can be scaled-up with sufficient success from laboratory sized units.

12) What is the capital investment for the dryer and all the accessories?

13) What is the power requirement for the dryer? A deep fluid-bed dryer needs hot gas at a higher pressure than most other dryers: 0.47 m³/s of gas requires approximately 0.75 kW per 102 mm of water pressure.

14) What quantity of product is desired? For larger production a spray or rotary dryer should be considered. Rotary and spray dryers handle most large production demands, but in small production plants other dryers are often more economical.

15) Can the dryer perform over a wide range of production rates and still give a satisfactory product in an efficient manner?

16) Is a sanitary dryer needed? A sanitary dryer is one that has no grooves or corners that can trap product, and hence can be easily cleaned. If no corrosion can be allowed, most of the units should be made of stainless steel.

Once the above points have been examined, it is possible to select a few types of dryers that appear to be the best for the particular operation. Sufficient information and data should be obtained on these dryers to determine the size needed. Firm quotations should be obtained from the manufacturers. The most economical dryer now can be selected on the basis of quality of product and capital and operating costs.

6.11 Polymer Dryers

6.11.1 Polymer dryers may be classified and selected according to the mode of heat transfer, i.e., direct-heat and indirect heat dryers. Dryers combining both heat-transfer modes are often used for polymer drying.

6.11.2 Radiant-heat dryers are not commonly used, because most polymers are heat sensitive to some degrees and material temperature is difficult to control under radiant sources.

6.11.3 Within broad ranges, polymer dryers may be classified on the basis of material residence time as:

a) Short resident time: Spray dryers, pneumatic conveyors, drum dryers, and thin-film belt dryers, when the material residence time is less than one minute.

b) Medium residence time: Continuous-fluid-bed dryers, vibrating-fluid-bed dryers, steam-tube dryers, and direct-heat rotary dryers; when the residence time is up to one hour.

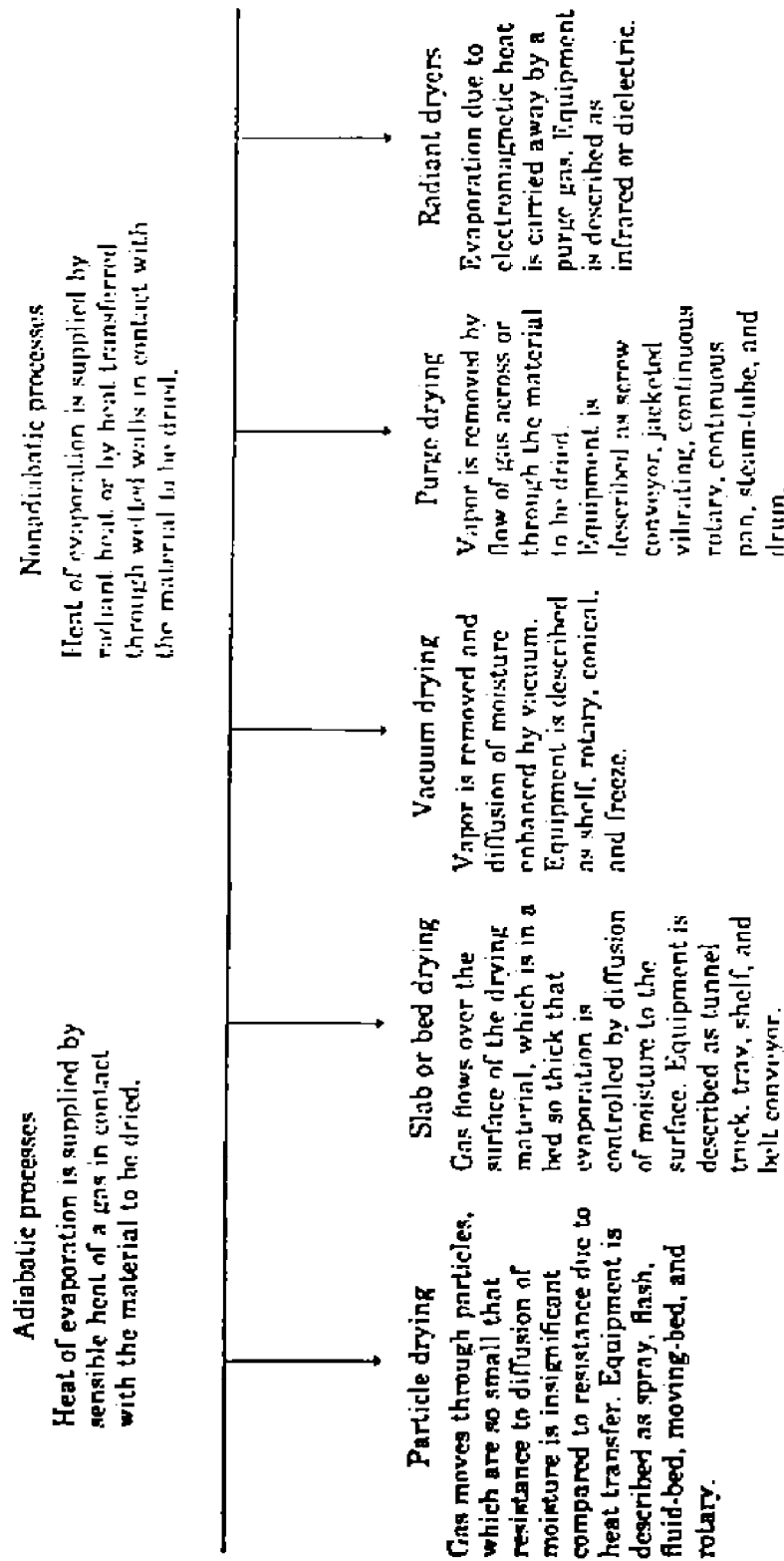
c) Long residence time: Batch fluid-bed dryers, batch or continuous-tray dryers, rotating-shelf dryers, hopper dryers, vacuum rotary and rotating dryers; when the residence times vary from one to several hours.

6.11.4 Short residence-time dryers are usually employed only for solutions and fine particle slurries during constant rate drying. The longer residence-time dryers are used for materials containing bound moisture and for operations involving capillary or diffusional drying. Solids flow control is difficult in continuous-fluidized-bed and rotary dryers.

6.11.5 A classification of polymer dryers according to adiabatic and nonadiabatic processes, is given in Table 5 is a general guide line for selecting a specific kind of equipment for particular product. However, a general classification for the purpose of choosing the correct dryer for a specific process is not suggested. Classifications are useful for review to ensure that all feasible alternatives are considered early in the selection process.

6.11.6 The specific operating characteristics of various dryers used for some important polymer drying and polymer grade by Competent Vendor is given herein below for further useful review and consideration in the selection process.

TABLE 5 - DRYER CLASSIFICATION BY PROCESS



a) Poly Vinyl Chloride (PVC):

a.1) Emulsion-grade PVC, is dried in spray dryers (see Fig. 4). Spray dryer, which is a direct-heat adiabatic dryer, is the first choice for this polymer grade. Centrifugal disk spray machines are usually chosen, because they are scalable to higher capacities and do not require high-pressure pumps. Cocurrent flow of spray gas and product permits a high inlet gas temperature.

a.2) Suspension-grade PVC can be centrifuged to a dry-basis moisture content of 25-35%. The cocurrent rotary dryer is still the most commonly chosen option and is installed in the manner depicted in Fig. 5. Dry product leaving the system carries less than 0.2% of moisture. Controlling system installed to measure the temperature loss to indicate the dryer is approaching overload. Cocurrent gas-solid flow is employed in such a way that the gas of the highest temperature contacts the wettest polymer, and overheating of dry product is avoided.

a.3) An alternative to the cocurrent rotary dryer is the two-stage arrangement of a pneumatic conveying dryer followed by a fluid-bed dryer shown in Fig. 6. This setup is tailored to accommodate the two drying periods, or phases, which are characteristic of several commodity polymers. A representative drying profile is shown in Fig. 7. During only a few seconds residence time, a properly sized pneumatic conveying dryer easily removes the surface moisture. A fluid-bed dryer with a residence time of about 30 min completes the drying process at a relatively low temperature during falling-rate drying of capillary moisture. Benefits include the reduced likelihood of adhesion of wet particles in the conveyor and longer residence time in the fluid bed, which allows a lower drying temperature, uniform product quality, and easy scale-up.

a.4) A third suspension-grade PVC drying arrangement employs a single fluid-bed, which combines direct with indirect-heat transfer by use of internal, indirect-heat, plate coil heating surface (see Fig. 8). This method minimizes dust recovery and gas-handling costs by reducing gas consumption to only that needed for fluidization and vapor removal, whereas most of the energy needed for evaporation is transferred indirectly from the heating surface. Total energy required is about 45% of that used by the cocurrent rotary dryer and 55% of that needed by the pneumatic conveyor-fluid bed combination. Residence time and plug-flow in the indirect heat fluid bed are controlled by arranging the plate coils to form internal baffles and plug-flow channels.

b) Polypropylene and High-Density Polyethylene (HDPE):

b.1) These polymers may be wet with water or an organic solvent. They are dried after centrifugation, and product temperature must not exceed 100-110°C, therefore, liquid vapor pressure has an overriding influence on dryer selection.

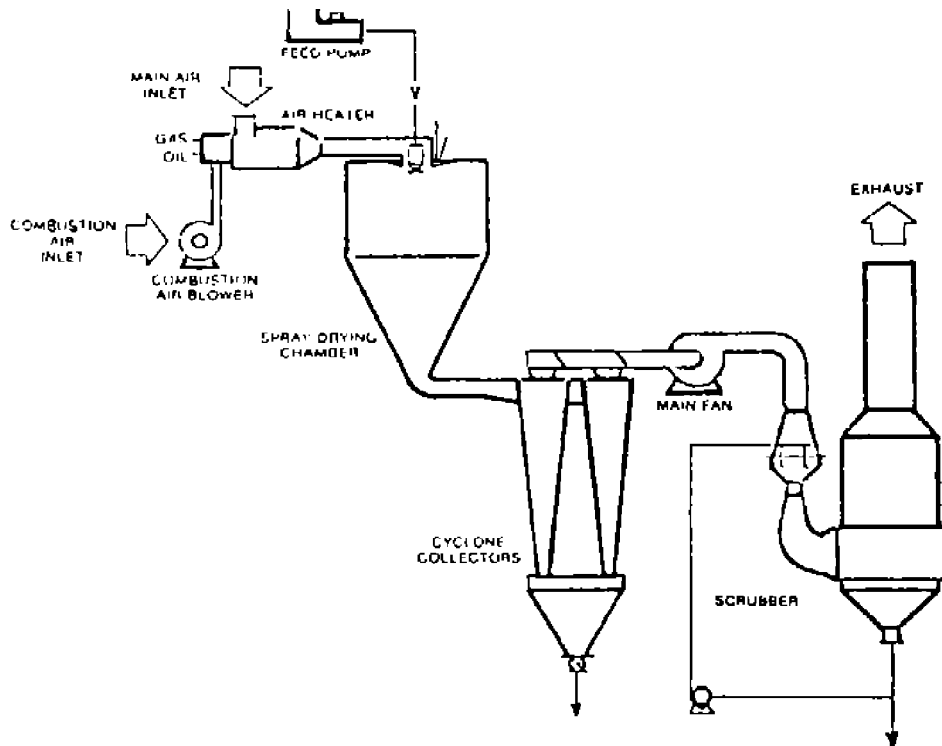
b.2) Direct-heat rotary dryer was used earlier, but now is proved to be a poor choice for organic solvent service. Large, expensive gas-tight rotary seals are needed between each end of the rotating dryer cylinder and its stationary end enclosures. Continuous maintenance is needed to ensure precise sealing.

b.3) Two-stage paddle agitator type dryers (see Fig. 9), is the preferred alternative. These paddle dryers are preferable to the rotary dryer because their cylinders are stationary. Shaft seals are very small compared to rotary cylinder seal. The first paddle dryer removes all surface liquid under constant-rate drying conditions. This stage is characterized by intense agitation, deagglomeration, rapid heat transfer, and short residence time. The second stage is designed for the removal of bound liquid and combines moderate agitation with a long residence time and a small temperature differential. Each drying stage includes an independent gas-recycle and solvent-recovery system.

b.4) A combination of pneumatic conveying-fluid bed dryers (see Fig. 10) incorporating closed-circuit inert gas recirculation are also employed. In these types, again constant-rate drying is separated from falling-rate drying which allows the use of higher gas temperature and solvent partial pressure in the first stage.

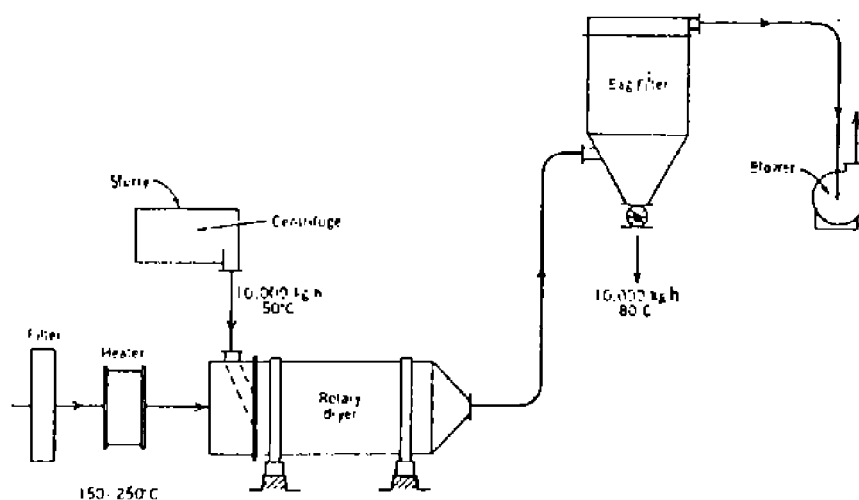
b.5) Multistage fluid-bed dryers have been used successfully for Polypropylene (PP) and High Density Polyethylene (HDPE) (see Fig. 11). As with aforementioned paddle-dryer system, energy efficiency will be improved by use of indirect heat plate coils in the fluid beds, especially in the first stage.

b.6) Efficiency may also be improved by installing three or more stage drying systems. Fluid beds are vulnerable in situations where, feed properties can not be controlled specifically for dryer performance. Fluid-beds are susceptible to defluidization if feed is sticky or cohesive such as Polypropylene copolymers.



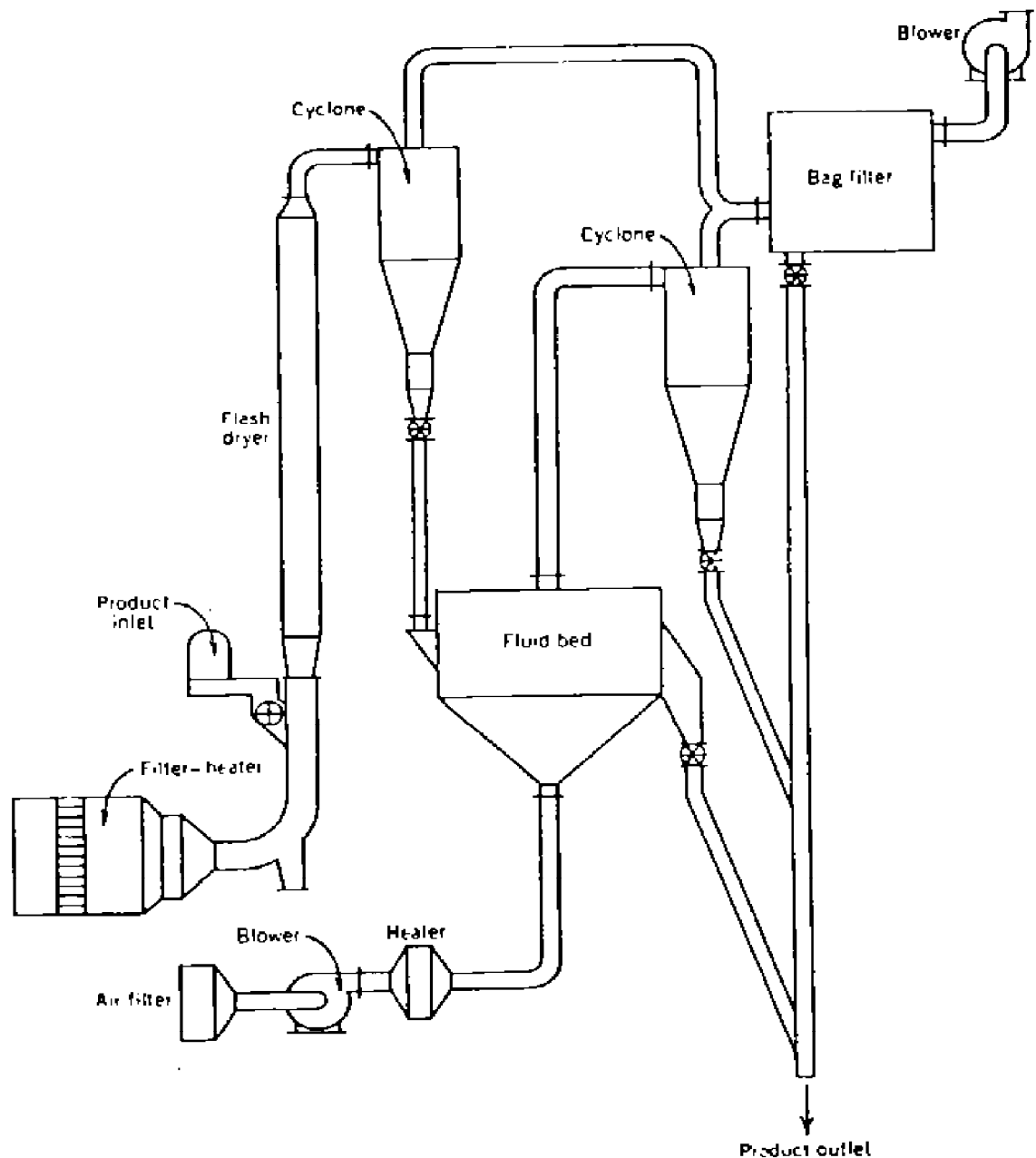
SPRAY DRYER FLOW DIAGRAM

Fig. 4



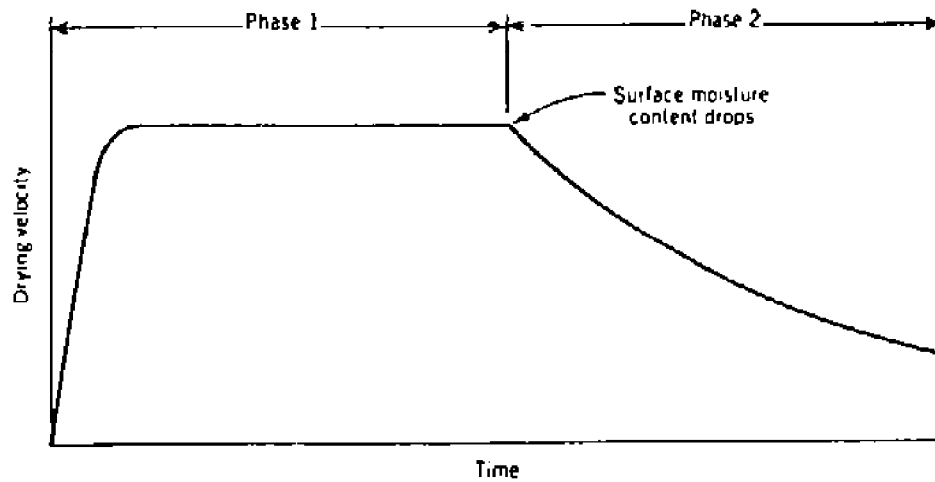
ROTARY DRYING OF SUSPENSION-GRADE (POLY VINYL CHLORIDE)

Fig. 5

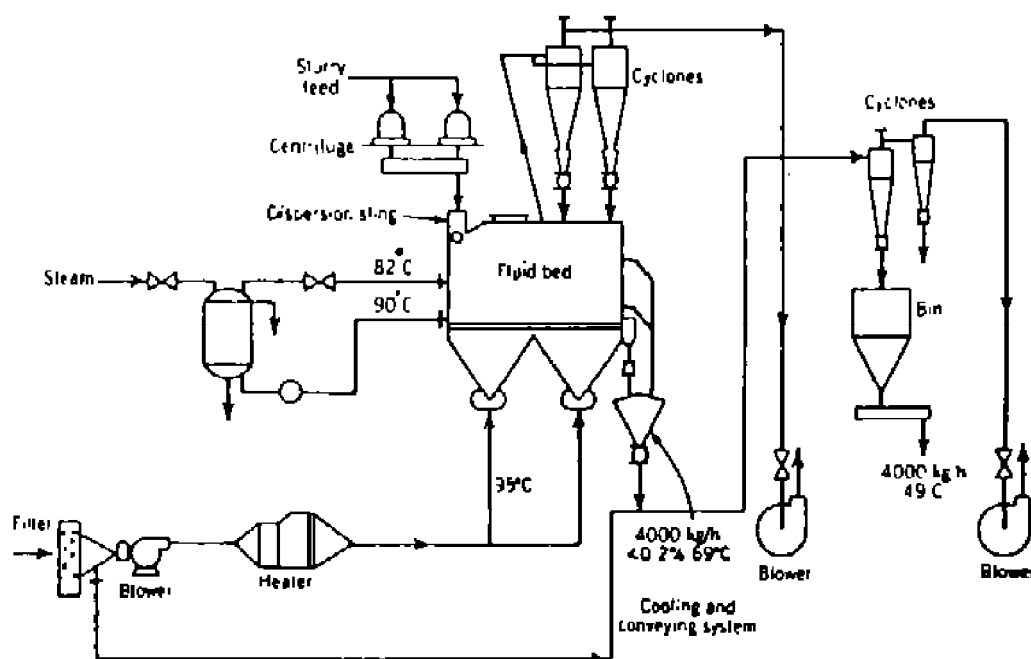


**TWO-STAGE DRYING SYSTEM (PNEUMATIC CONVEYING-FLUID-BED DRYER)
FOR SUSPENSION-GRADE (POLY VINYL CHLORIDE)**

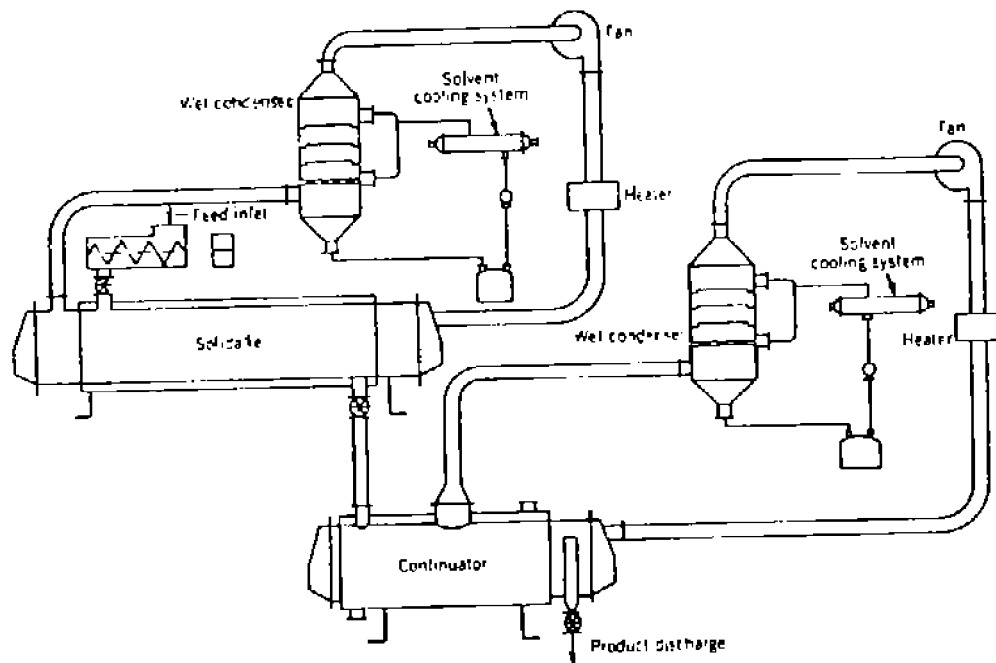
Fig. 6



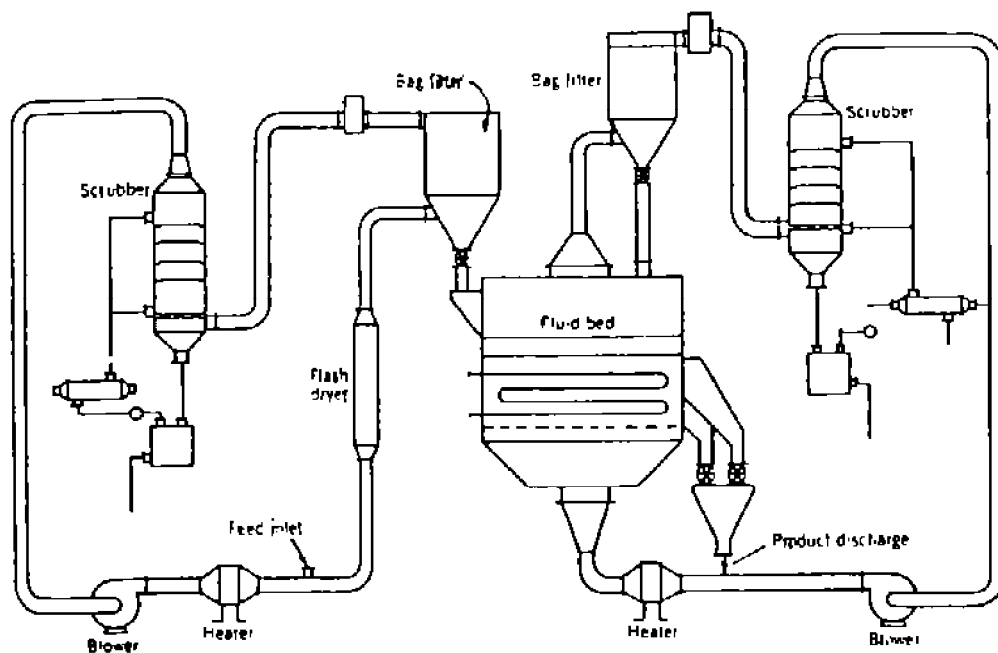
DRYING REQUIREMENTS OF POLYMERS
Fig. 7



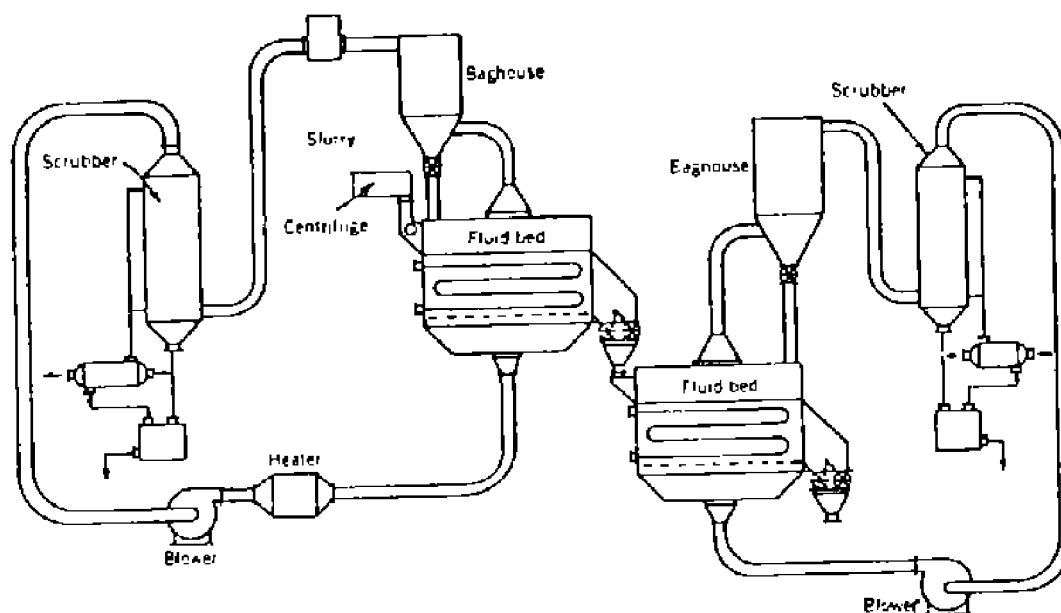
INDIRECT-HEAT FLUID-BED DRYER FOR SUSPENSION-GRADE
(POLY VINYL CHLORIDE)
Fig. 8



TWO-STAGE DRYING OF HIGH DENSITY POLYETHYLENE AND POLYPROPYLENE
Fig. 9



TWO - STAGE DRYING OF POLYPROPYLENE HOMOPOLYMER
Fig. 10



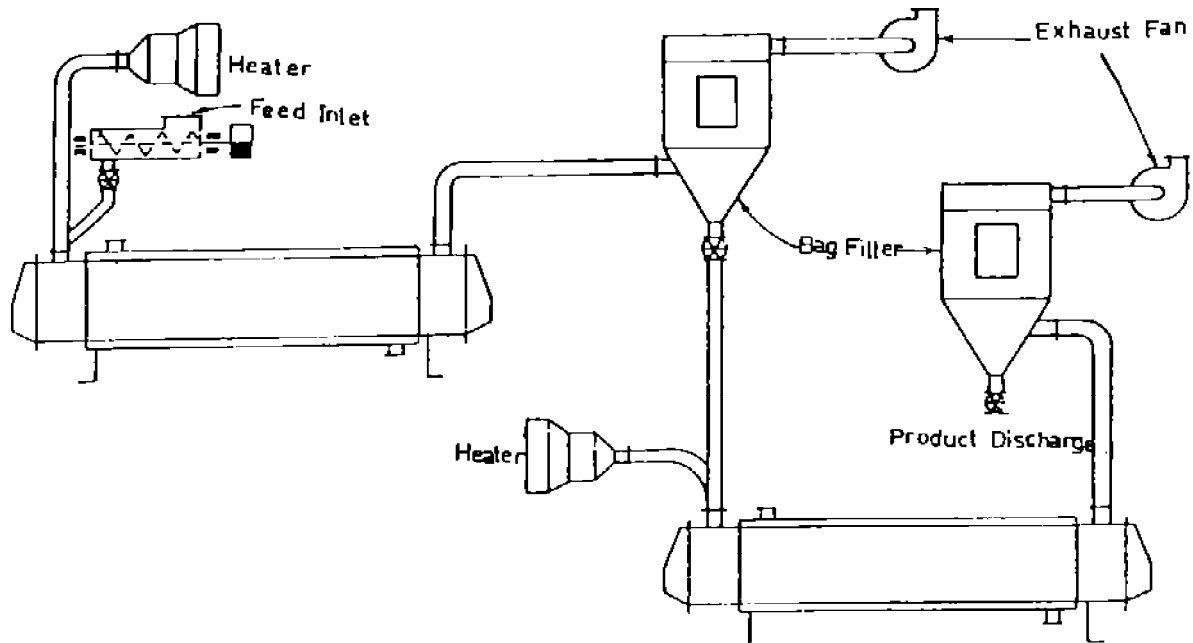
TWO-STAGE FLUID-BED DRYER FOR POLYPROPYLENE HOMOPOLYMER
Fig. 11

c) Acrylonitrile-Butadiene-Styrene (ABS) Polymers:

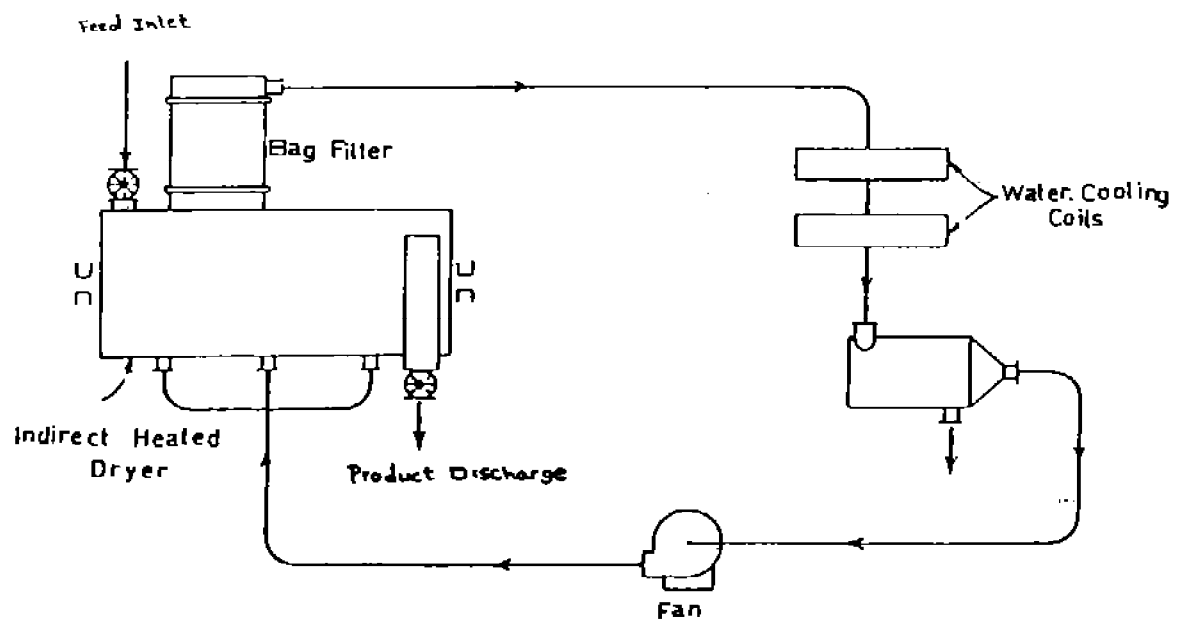
c.1) The drying characteristics of ABS Polymers vary with changes in composition. The usual requirement is to dry a centrifuge cake from 50% moisture to less than 1.0%. A product temperature of 100°C is about the maximum permissible. The pneumatic conveyor yields good thermal efficiency and is suitable for fine particles. The rotary dryer has a longer residence time and is suitable for these particles.

c.2) Using of a two-stage dryer with an arrangement similar to that shown in Fig. 12, with or without closed circuit gas recycle is a third choice which is free from those disadvantages implied for pneumatic conveyor and rotary types. In this type, each stage is designed for intense mechanical agitation, and particle lumps and agglomerates formed in the centrifuge are broken apart as drying proceeds. A product moisture content as low as 0.3% can be obtained in this manner.

c.3) A fourth alternative is the two-stage, pneumatic conveying fluid-bed dryer shown in Fig. 10. Closed-circuit inert-gas systems are installed on most new ABS polymer dryers to minimize polymer oxidation and the escape of styrene monomer, and increase the thermal efficiency of dryer. A closed circuit, inert-gas indirect-heat disk dryer for ABS is illustrated in Fig. 13.



**TWO-STAGE PADDLE-AGIATOR DRYER FOR
ACRYLONITRILE-BUTADIENE-STYRENE
POLYMER (ABS)**
Fig. 12



INDIRECT-HEAT DISK DRYER FOR ABS POLYMER
Fig. 13

d) Drying of hygroscopic polymers:

d.1) Nylon and polyester are prominent examples, of hygroscopic polymers drying of polyester pellets before solid-stage polymerization is carried out in generally called pellet-dryer. Both Nylon and polyester absorb moisture from the atmosphere during handling and storage. Presence of moisture will cause discoloration and viscosity degradation, in melting, extrusion, molding and spinning process.

d.2) Nylon may absorb 0.5 to 1.0% moisture and should be dried to less than 0.2% before melting. Because nylon is susceptible to oxidation and discoloration at elevated temperatures, most nylon pellet dryers are provided with closed-circuit inert-gas circulation. When dried with dehumidified air, the temperature should never exceed 80°C.

d.3) Polyester absorbs up to 0.5% moisture and must be dried to 0.005% to avoid viscosity loss during melting process. Polyester does not degrade in air and does not polymerize below 180°C, it may safely be dried in dehumidified air.

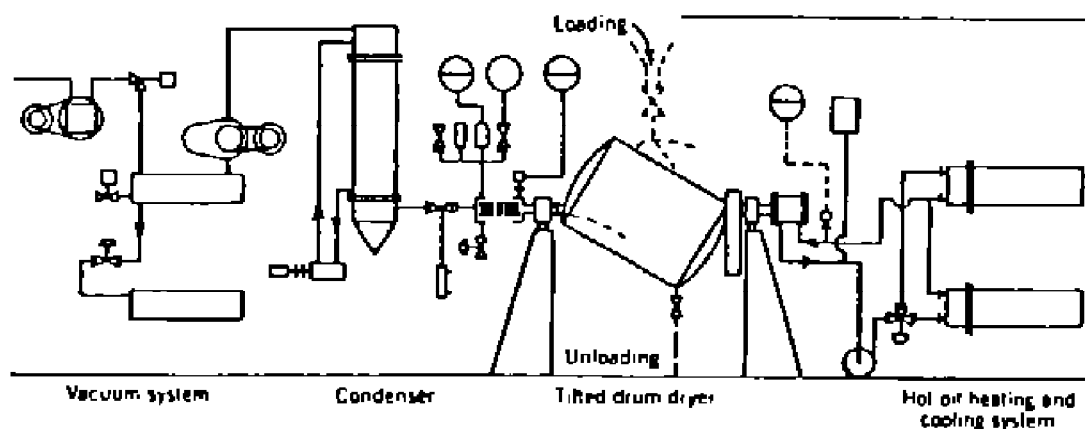
d.4) For small productions, batch drum-type and double-cone rotary vacuum dryers are employed (see Fig. 14). Internal pressure is 0.1 to 1.0 kPa (0.75 to 7.5 mm Hg) when drying nylon, and less than 0.1 kPa (0.75 mm Hg) for polyester. Jacket temperature is maintained with steam or hot oil at the desired final polymer temperature. Batch drying time for nylon and polyester is 8 to 24 hours, depending on the batch and dryer sizes. In larger pellet dryers, drying rate is limited by heat transfer.

d.5) Dryer heating surface to working volume ratios are low and vary inversely with nominal shell diameters. Installation of internal, heated tubes or plate coils in larger dryers alleviates deficiency of heat transfer, but not sufficiently as it is the limiting feature of most rotating vacuum dryers.

d.6) Continuous drying is the preferred method to avoid atmospheric exposure. Nylon and polyester are dried in fluid-beds, mechanically agitated hoppers, or simple moving-bed hoppers, where circulating dehumidified and heated air or inert gas through the bed heats the polymer and removes the moisture.

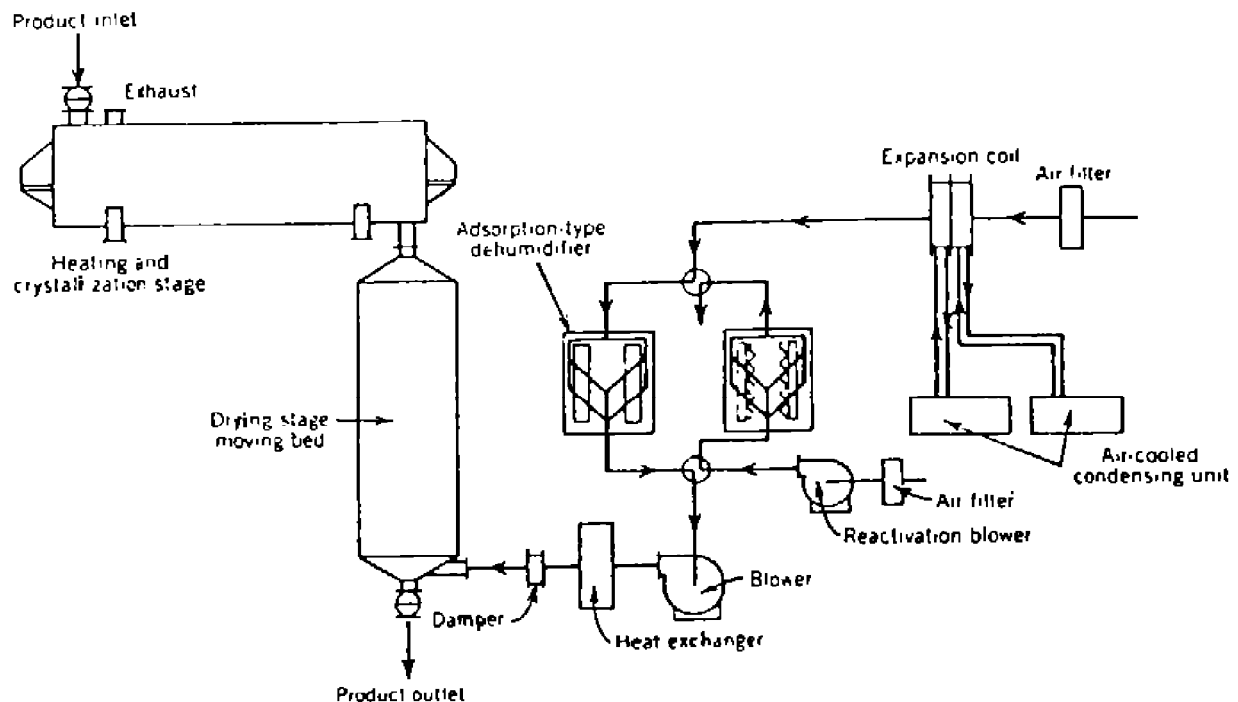
d.7) A moving-bed, hopper-dryer arrangement for polyester pellets is typically illustrated in Fig. 15.

d.8) When polyester is dried in a rotating vacuum dryer a separate crystallization step is usually not necessary because the heating rate is so low that crystallization takes place gradually over a period of several hours. In the hopper, temperature is controlled at 150-180°C by dehumidified air or inert gas with a dew point below -40°C.



FLOW SHEET OF A DRYING PLANT FOR NYLON AND POLYESTER CHIPS WITH HEATING AND COOLING SYSTEM DUST COLLECTOR AND VACUUM UNIT

Fig. 14



CONTINUOUS CRYSTALLIZATION AND DRYING OF POLYESTER CHIPS
Fig. 15

7. COMPRESSED AIR DRYER

7.1 General

7.1.1 Scope of process design of compressed air dryers is covered to the extent specified in IPS-E-PR-330. More general information and criteria relating to process requirement in proper selection, performance rating, specification and reference conditions are covered here in this Standard Specification.

7.1.2 Compressed air may be dried by:

- 1) absorption;
- 2) adsorption;
- 3) compression;
- 4) cooling;
- 5) combination of compression and cooling.

Note:

Mechanical drying methods and combined compression and cooling are used in large-scale operations. They are generally more expensive than those employing desiccants and are used when compression of the gas is a necessary step in the operation or when its cooling is required.

7.2 Rating Parameters and Reference Conditions

7.2.1 Reference standard conditions and rating parameters are both necessary in defining the performance of an air dryer and in comparing one make up dryer with another.

7.2.2 The reference conditions in Table 6 and performance rating parameters in Table 7, are to ISO 7183/1986, and shall form an invariable and variable parts of this statement respectively.

TABLE 6 - REFERENCE CONDITIONS

| QUANTITY | UNIT | VALUE ¹⁾ | | TOLERANCE |
|---------------------------------|------|---------------------|----------|-----------|
| | | OPTION A | OPTION B | |
| Inlet Temperature | °C | 35 | 38 | ±1 |
| Inlet Pressure | bar | 7 | 7 | ±7% |
| Inlet Pressure Dew Point | °C | 35 | 38 | ±2 |
| Cooling Air Inlet Temperature | °C | 25 | 38 | ±3 |
| Cooling Water Inlet Temperature | °C | 25 | 30 | ±3 |
| Ambient Air Temperature | °C | 25 | 38 | ±3 |

Note:

The choice between A and B will be influenced by the intended geographical location of the equipment.

TABLE 7 - PERFORMANCE RATING PARAMETERS

| QUANTITY | UNIT | VALUE |
|--------------------------------------|-------------|--------------|
| Outlet pressure dew point | °C | As specified |
| Outlet air flow | L/s or m³/s | As specified |
| Pressure drop across dryer | bar | As specified |
| Frequency of electrical power supply | Hz | As specified |

7.3 Specification

7.3.1 Important specification data together with relevant explanatory notes, essentially required in the period of design, enquiry and purchase and also for the use, when specifying and inspecting of compressed air dryers are tabulated in Table 8. For detailed specification and testing procedure see BS 6757 and ISO 7183.

7.3.2 In addition to the reference conditions (see Table 6, including options A and B) and the performance rating parameters (see Table 7), some other important performance data which should be concluded in process design of compressed air dryers and required for performance comparisons of the Vendors'/manufacturers' proposals is tabulated in Table 9.

TABLE 8 - SPECIFICATION

| ITEM | DESCRIPTION | SYMBOL | UNIT | REMARKS | EXPLANATORY NOTES |
|------|---|------------------|--------------------------|------------------------------|--|
| 1 | Compressor type | — | — | | State the type of compressor(s) (for example, displacement or turbo compressor), the type of lubrication (nonlubricated, minimum lubrication or oil flooded) and the type of coolant (air, water, oil). See ISO 5388. |
| 2 | Mode of operation of compressor plant | — | — | Continuous/ Intermittent | Details should be given of the operating intervals ("on periods") and the position of the compressed air dryer in the compressed air pipework system. |
| 3 | Volume of air receiver | V | L, m ³ | | State the volume of the air receiver. |
| 4 | Air volume flow rate related to the intake conditions in compliance with 4.10.1 | q _{v1} | L/s or m ³ /s | | The maximum compressed air volume flow accepted by the dryer under the reference conditions including air required for regeneration, pressurizing or cooling purposes. |
| 5 | Effective (gage) pressure of the compressed air | p ₁ | bar | | The inlet air pressure shall be stated. |
| 6 | Temperature of compressed air | t ₁ | °C | | The temperature of compressed air at the inlet of the dryer will affect its performance and shall be stated. |
| 7 | Pressure dew point of compressed air | t _{pd1} | °C | | If the dryer is installed immediately following the compressor aftercooler, the compressed air may be assumed to be saturated. However, the humidity of the air should be measured if the dryer is installed downstream of the air receiver or in the pipework remote from the aftercoolers. |
| 8 | Pressure drop across dryer | Δp | bar | | — |
| 9 | Oil presence in compressed air | — | g/m ³ | | The supplier should state the type and amount of compressor lubricant that can be expected at the dryer inlet. |
| 10 | Aggressive components in air | — | — | | Any pollution of incursive (aggressive) contaminants should be stated. |
| 11 | Coolant | — | — | Water/Air | |
| 12 | Coolant temperature | t _{c1} | °C | | The coolant temperature shall be measured. |
| 12.1 | Coolant quality | — | — | | Any aggressive component in the coolant should be stated. |
| 12.2 | Coolant pressure | — | bar | | |
| 13 | Position of air dryer | — | — | Before/After air receiver | When designing and specifying the air dryer the position of the air receiver is important and shall be stated. |
| 14 | Dryer location | — | — | Indoors/Out- doors | It is necessary to state the location of the dryer (for example: indoors, outdoors, hazardous area). |
| 15 | Ambient conditions (maximum and minimum) | — | — | | Any special ambient conditions shall be stated in the enquiry. |
| 16 | Power available | — | — | | To include supply voltage, frequency and number of phases. |

TABLE 9 - DATA FOR PERFORMANCE COMPARISONS

| DESCRIPTION | SYMBOL | UNIT | EXPLANATORY NOTES |
|---|---------------|--------------------------|--|
| Types of compressed air dryer | — | — | Specific details with regard to operation and design/type of the compressed air dryer should be given as well as a specification of the equipment included in the delivery. |
| Mode of operation of compressed air dryer | — | — | Details should be provided of the mode of operation of the compressed air dryer, for example, continuous operation, on/off operation (for refrigeration dryers) alternating operation (in the case of adsorption dryers) as well as automatic, semi automatic or manual. |
| Cycle time | — | s | — |
| Air volume flow rate related to the intake condition | q_{v2} | L/s or m ³ /s | The volume of air delivered by the dryer under the reference conditions i.e., after maximum bleed air, pressurizing air and cooling air flows have been deducted. |
| Mass flow of compressed air (if required) | q_{m2} | kg/s | If required, the manufacturer of the dryer should calculate in the mass of flow from the volume flow and state the value to the tender. |
| Temperature of dried compressed air | t_2 | °C | The temperature shall be measured. |
| Pressure drop across dryer | Δp | bar | If the dryer is delivered with integral filters, they shall be included in the pressure drop. |
| Highest pressure dew point under operating condition | t_{pd} | °C | The maximum pressure dew point shall be stated for operating conditions. |
| Nominal pressure dew point as requested by purchaser | t_{pd} | °C | — |
| Coolant flow | $q_{v\ c2}$ | L/s | — |
| Energy requirements: Electric power at dryer terminals including all components (this includes cooling air fans), max. and average | p | kW | — |
| Bleed air, dump losses, etc., max. and average | $q_{v\ loss}$ | L/s | — |
| Steam consumption | — | L/s(or kg/h) | — |
| Steam condition Pressure Temperature | — — | bar °C | — — |
| Water (for cooling according to coolant temperature which is used at any heat exchanger of dryer) | q_v | L/s | Pressure, quality inlet temperature and temperature should be stated. |
| Noise level of air dryer | — | dB | — |

Note:

For source of Specification Data reference is made to ISO 7183.

8. ADSORPTION DRYERS

8.1 General

8.1.1 The majority of industrial gases and liquids require some level of water removal between initial processing and final intended use. Unit operations and processes typically employed in drying industrial fluids include the following:

- Distillation (including azeotropic and extractive distillation).
- Mechanical Separation (including heat exchangers, evaporators, air coolers, vacuum freezing equipment, and injection of antifreeze).
- Adsorption (including liquid desiccants as dehydration media).
- Adsorption (including solid desiccant materials).

8.1.2 Drying with adsorbent discloses a number of the advantages on comparison with fractional distillation, wet scrubbing, or other processes, which necessitates its paramount importance use in OGP process plants.

These advantages include:

- Lower capital and operating costs.
- High reliability because adsorption performance is relatively unaffected by changes in flow rate or composition.
- Eliminates problems caused by azeotrope formation.
- Low maintenance because corrosion is not a problem.
- Simple process control and response, resulting in easy startup, shutdown, and a virtually unlimited turndown ratio.
- Handling and disposal problems associated with corrosive liquid chemicals are not a factor with inert solid desiccants.
- Fully automatic, unattended operation possible.

8.2 Solid Desiccant

8.2.1 Characteristics

8.2.1.1 Adsorbents used for removing water from a fluid stream are known as "solid desiccant". The characteristics of solid desiccants vary significantly depending on their physical and chemical properties. Many known solids have some ability to adsorb, but relatively few are commercially important. Some of the qualities that make a solid adsorbent commercially important are:

- 1) available in large quantity;
- 2) high capacity for the gases and liquids to be adsorbed;
- 3) high selectivity;
- 4) ability to reduce the materials to be adsorbed to a low concentration;
- 5) ability to be regenerated and used again;
- 6) physical strength in the designed service;
- 7) chemical inertness.

8.3 Criteria for Solid Desiccant Selection

8.3.1 In order to make the proper selection of solid desiccant, the following criteria should be considered:

- Cycled Capacity

The equilibrium loading is also known as the equilibrium capacity. This capacity gradually decreases during repeated adsorption regeneration cycles, essentially because of desiccant fouling and degradation. Consideration must be given to a desiccant's capacity over a long period of use rather than its capacity when freshly manufactured.

- Ability to Reach the Required Outlet Moisture Specification.

- Susceptibility to Deactivation in Specific Service

Ability to exclude certain side reactions as well as to maintain chemical inertness in the stream being dried is important (e.g., certain types of desiccant materials perform better than others in olefinic or acidic service).

- Cost

The initial cost of the desiccant, the operating cost, the recharge cost as related to change-out frequency, and the initial capital equipment cost should be evaluated in desiccant selection.

- Pressure Drop

Pressure drop is a function of desiccant particle size and type (e.g., beads or pellets), and is important on both adsorption and regeneration legs of the cycle.

- Regeneration Capability

The quantity and quality of regeneration gas available, as well as the temperature available to remove the moisture from the "loaded" desiccant.

- Service

The availability and capability of a desiccant supplier to provide needed service is very important in view of the complex processing that is often required.

Note:

The order given herein above, does not necessarily dictate the relative priority, that mainly depend on the user's particular circumstance.

8.4 Design Basis

8.4.1 Design and optimization of the adsorption process is a complex task; Vendor's/manufacturers advice shall save much time and effort. However, in order to design an optimum adsorption system, the design engineer must have an accurate design basis data, information and the variations and upsets which may occur in the processing stream. This type information shall also be required by adsorbent manufacturers in order to provide recommendations on specific applications. As a minimum, the following informations should be available:

1) Type of Fluid

Physical state (gas or liquid composition) and water level.

2) Operating Conditions

Flow rate, temperature, and pressure.

3) Outlet Water Specification.**4) Preferred Adsorption Cycle Time**

This time should be integrated into the operation and be consistent with the needs of the system. Switching vessels every 24 h or with change in operator shifts every 8 h is a fairly common way to designate this time.

5) Regeneration

The available fluid, its composition, quantity available, pressure, and maximum temperature available for regeneration, as well as contaminant levels (especially water concentrations), must be known.

6) Existing Equipment

In certain circumstances it is necessary or desirable to replace one type of adsorbent with another as processing conditions change. In most cases the same equipment can be used, but careful considerations must be given to interior vessel volume, vessel configuration and number, and adsorption and regeneration system flow.

8.5 Standard Configuration of Adsorber

8.5.1 Vertical cylindrical vessels filled with adsorbent are the simplest Fixed-bed adsorption system. Cylindrical adsorption vessels are usually arranged in two-bed or three-bed systems. Also, multiples of these basic systems, containing three, four, five, or more units, are not uncommon. As mentioned previously, one bed in the dual-bed system is adsorbing or drying. While the other is desorbing, or regenerating (see Fig. 16). In a three-bed system, one of the following three basic piping configurations is employed (see Figs. 17, 17a, b and c):

1) Two beds on parallel adsorption, one bed regenerating

This System is usually employed where a minimum pressure drop is required on adsorption, or where the use of small-diameter, multibed systems reduces vessel costs. In this arrangement, more efficient adsorption is obtained because flow is split in half and, therefore, mass transfer zone size per vessel is reduced.

2) Two beds on series adsorption, one bed regenerating

This System is usually employed when mass transfer zones are long. Each bed "moves" sequentially from:

- a) Trim, or downstream, adsorption to
- b) Lead, or upstream, adsorption and then to
- c) Regeneration.

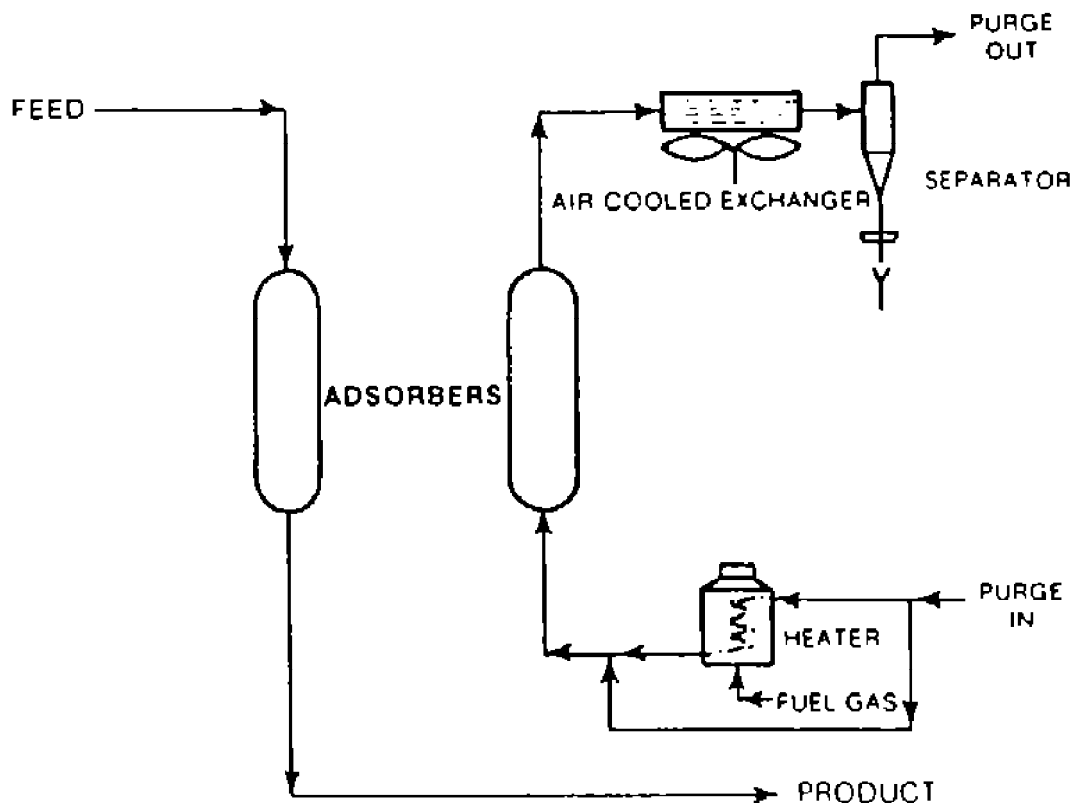
A bed spends $\frac{1}{3}$ of its cycle time in each of the three positions. The trim bed is long enough to contain a mass transfer zone, and it guards against water breakthrough into sensitive downstream equipment. In the lead position, nearly all of the adsorbent becomes loaded to equilibrium capacity.

3) One bed on adsorption, two beds regenerating in series

This system is usually employed where there is little regeneration gas available. Each bed "moves" from:

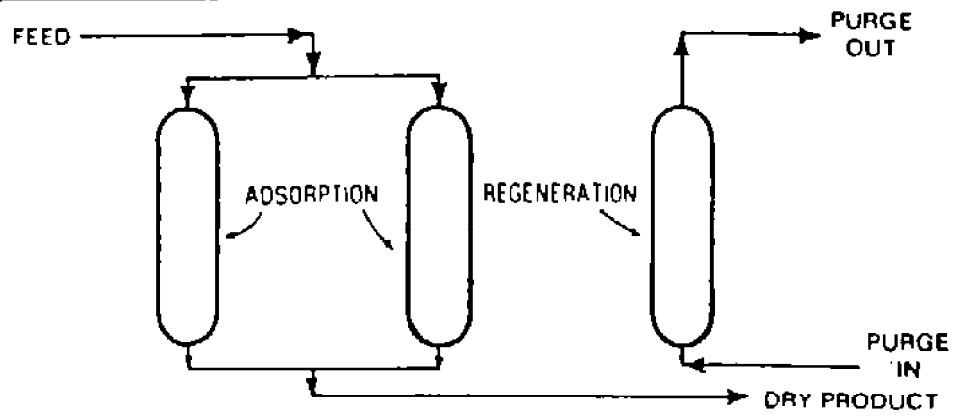
- a) Adsorption to
- b) Heating and then to
- c) Cooling.

Again, a bed spends $\frac{1}{3}$ of its cycle time in each of the three positions. In one arrangement, clean purge gas flows first to the bed to be cooled, next to a heater, then to the bed to be heated and desorbed, and finally to discharge. Many bed combinations are possible with the optimum arrangement being dictated by the basic processing constraints and economics. Three-bed systems offer many benefits to meet unique processing needs. However, they require more valves and more complicated piping than the dual-bed system. In some situations a one-bed system may be the only vessel required. This is usually the case in intermittent or batch-type operation where adsorption drying is not required on a continuous basis (see Fig. 18).

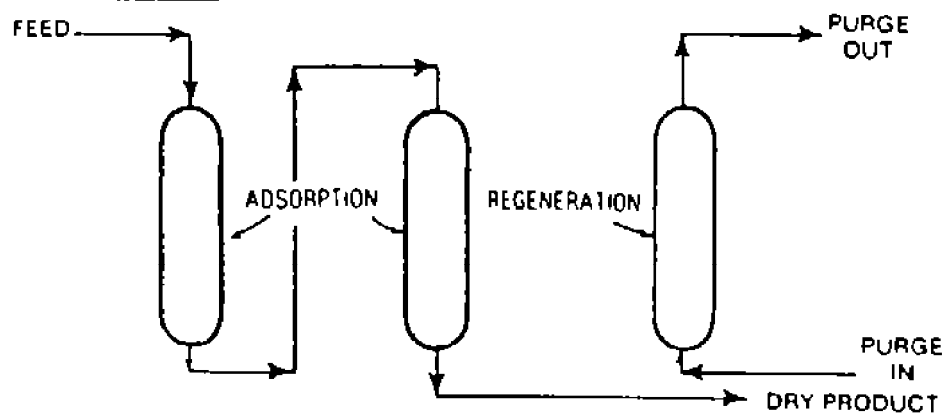


DUAL BED SYSTEM
Fig. 16

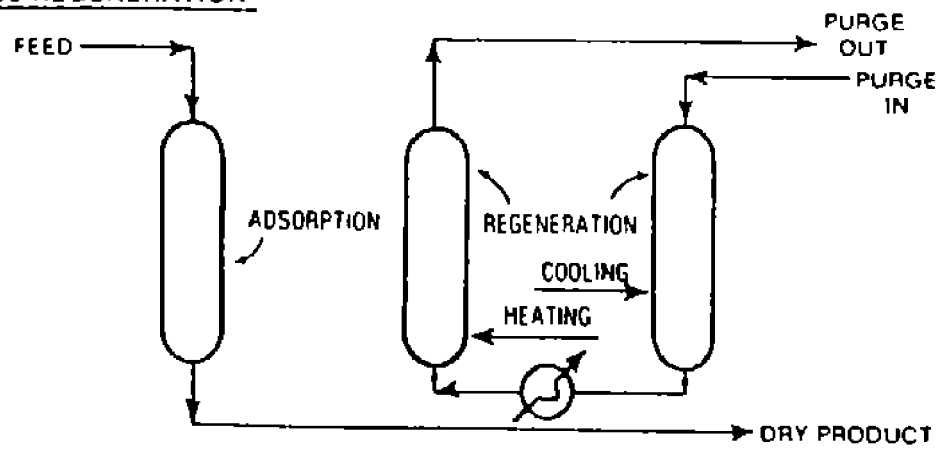
a) PARALLEL ADSORPTION



b) SERIES ADSORPTION

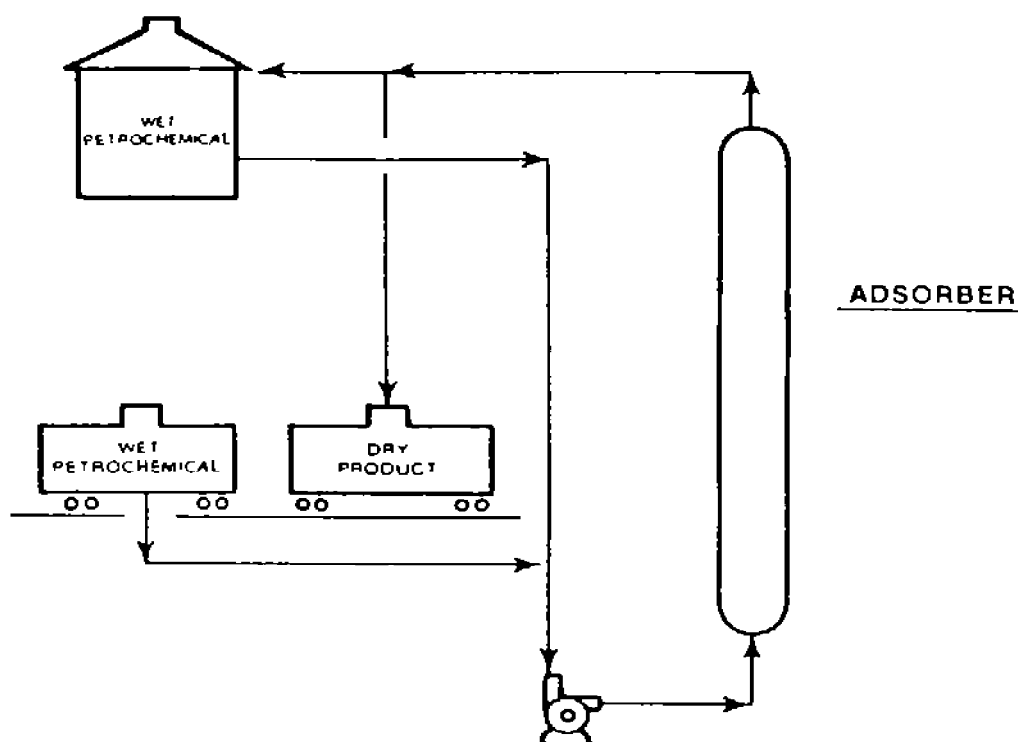


c) SERIES REGENERATION



MULTIPLE BED SYSTEMS

Fig. 17 a, b, c



SINGLE BED SYSTEM
Fig. 18

8.6 Design Criteria and Calculations

8.6.1 Flow velocity

Flow velocity, pressure drop, and adsorber bed diameter are all related. When any one of these parameters are fixed along with cycle time, the other two are also fixed. A limitation on pressure drop is usually the key parameter, and is generally the basis for fixing the other two. However, typical superficial linear velocities through beds of adsorbent are on the order of 10 to 20 m/min, for gases and 0.3 to 0.6 m/min, for liquids.

8.6.2 Bed diameter

Vessel costs tend to increase dramatically with diameter. This becomes more significant as the operating pressure (and consequently, wall thickness) goes up.

The minimum diameter for an adsorber bed is set by pressure drop limitations. A pressure drop analysis is required for each of the steps in the adsorption cycle, including the pressurizing and depressurizing steps.

8.6.3 Pressure drop

8.6.3.1 It will be necessary during various stages of dryer evaluation to determine the fixed-bed pressure drop in order to check fluidization limits, pressure drop variation with changes in fluid flow rate, utilization of existing equipment, etc.

8.6.3.2 The pressure drop through packed adsorbent beds may be determined by using the modifier. Ergun correlation which has proved to be very reliable.

The Ergun equation for the calculation of pressure drop in adsorbent beds is in good agreement with numerous pressure drop measurements on commercial adsorption Units for both gas-phase and liquid-phase operation.

The following form of this equation is suitable for calculating pressure drop through adsorbent beds:

$$\frac{\Delta p}{L} = \frac{f_T \cdot C_T \cdot G^2}{\rho \cdot D_p} \quad (\text{Eq. 7})$$

Where:

| | |
|--------------------|---|
| C_T | is pressure drop coefficient, in (m.h ² /m ²); |
| D_p^* | is effective particle diameter, in (m); |
| f_T | is friction factor; |
| G | is superficial mass velocity, in (kg/h.m ²); |
| L | is distance from bed entrance, in (m); |
| ΔP | is pressure drop, in (kg/m ²); |
| $\rho(\text{rho})$ | is fluid density, in (kg/m ³); |
| $\Delta P/L$ | is pressure drop per unit length of bed, in [(kg/m ²)/m]. |

Note:

The friction factor, f_T , is determined from Fig. 19 which has f_T plotted as a function of modified Reynold's number:

$$\text{MODIFIED Re} = D_p \cdot G/\mu \quad (\text{Eq. 8})$$

Where:

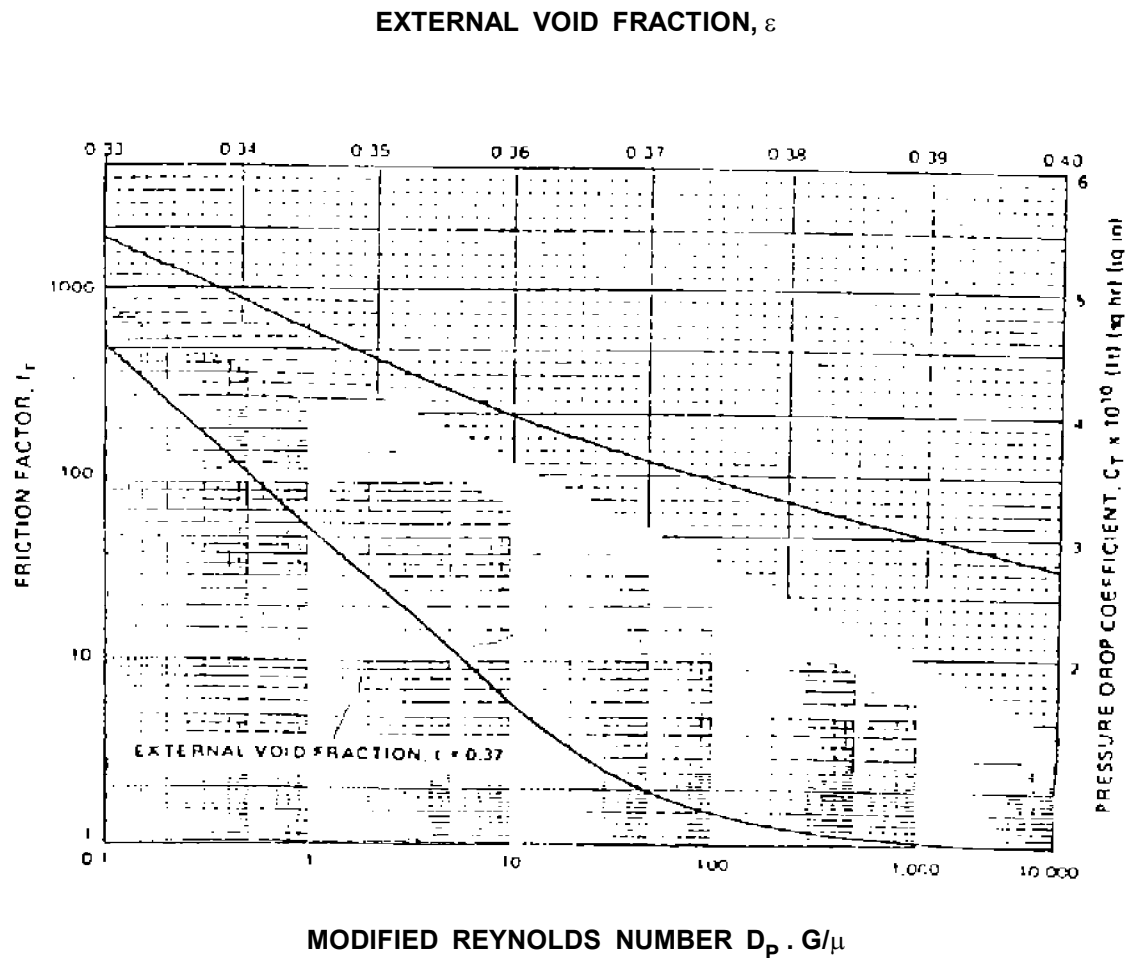
| | |
|------------------|----------------------------------|
| $\mu(\text{mu})$ | is fluid viscosity, in (kg/m.h). |
|------------------|----------------------------------|

Notes:

1) The pressure drop coefficient, C_T is determined from Fig. 19, which has C_T plotted as a function of external void fraction, ε (epsilon).

2) The suggested values for ε and D_p for various sizes of adsorbents are:

| | ε | D_p |
|-----------------------|---------------|---------|
| 0.32 mm pellets | 0.37 | 3.72 mm |
| 0.16 mm pellets | 0.37 | 1.86 mm |
| 14 × 30 mesh granules | 0.37 | 1.00 mm |



FRICTION FACTOR, f_T AND PRESSURE DROP COEFFICIENT, C_T FOR MODIFIED
ERGUN EQUATION

Fig. 19

8.6.4 Adsorption equipment

8.6.4.1 General guidelines and design criteria for auxiliary equipment of adsorption system such as blowers, heaters, heat exchangers, pumps, compressors, piping, valving and insulation are given in relevant referenced IPS and other Standards which should be considered in process design of adsorption system. The adsorber vessel design, however requires some attention to detail to achieve optimum desiccant performance.

8.6.4.2 Adsorber vessel design

Fig. 20, details one of the many acceptable adsorption vessel designs including it's, bed support system, nozzles, baffles, bed support media etc., all require special design review and consideration as:

a) Bed support system

The support system should be designed to hold the mass of the desiccant material, forces exerted by process pressure drop, and a substantial safety factor. A tight seal of specified mesh screen should be provided against the vessel walls. The I beams fastened to the supports and the vessel wall, should be free to move slightly during process heating and cooling of the system.

b) Nozzles

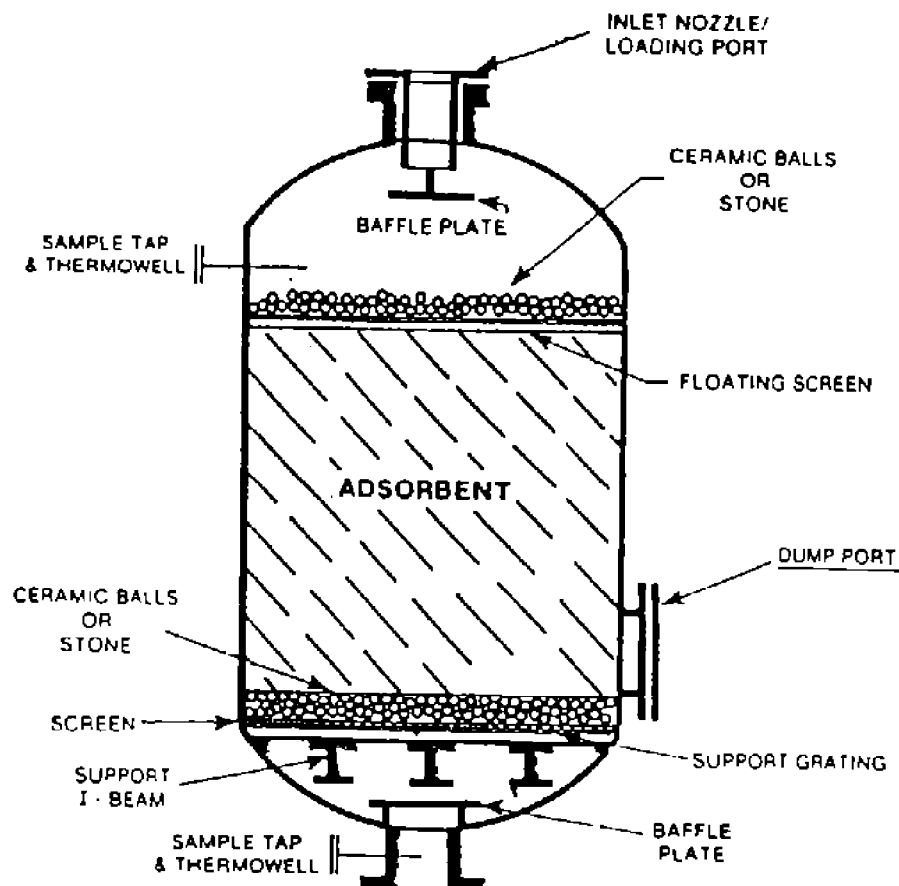
The inlet and outlet nozzles should be placed on the axis of the vertical vessel, to obtain proper flow distribution. The guidelines for the distance between the nozzle and the bed are:

- outlet nozzle, 2 pipe diameters;
- inlet nozzle, 5 to 6 pipe diameters;
- the ratio of the vessel diameter to the pipe diameter also has an affect. The larger this ratio is, the greater the distance should be from the bed to the nozzle.

c) Baffles

For proper flow distribution baffles should be installed in the inlet and outlet nozzles. Preferred baffle type and design shall be based on the Vendor/manufacture's experience. The goals, however, of any baffling should include:

- ensure low pressure drop past the baffle;
- prevent direct impingement on the desiccant bed;
- break up the flow into several directions not merely redirect the entire flow to another direction.



ADSORBER VESSEL DESIGN

Fig. 20

d) Bed support media

- A hard, mechanically strong, inert, high-density, inexpensive bed support that can take thermal cycling is desirable above and below the desiccant bed. The material on top acts as a guard layer, flow distribution media for the gas, and prevents desiccant particle movement caused by possible eddy currents from uneven flow distribution. The material is a relatively large size to minimize pressure drop and its own movement. A depth of 100 to 150 mm of 25 to 40 mm size material is typically required for the top support layer. A floating screen between the support media and the desiccant bed can be used to prevent migration into the desiccant bed.
- Support media is placed at the bottom of the bed in many systems to a depth of about 80 mm. Usually a 6 to 10 mm size material is necessary to prevent desiccant particles from slipping between the large support media. This material provides some additional baffling and is less likely to fall through small open spaces in the mechanical bed support.

e) Thermal wells

Should be placed for process requirements of temperature measure including inlet and outlet flows, hot gas into and out of the vessel and temperature near the wall of the vessel. Sample taps should be provided for the use as pressure taps when occasionally measuring of pressure drop across the vessel is required.

8.6.5 Equipment Vendor/adsorbent manufacturers consultation

It is recommended that prior to package-equipment selection and design, equipment Vendor and the adsorbent manufacturer to be consulted by the Contractor/Licenser, since their technical staff can provide considerable experience and input into the final process and mechanical design and equipment selection. The adsorbent manufacturer, who typically works with the equipment Vendor in setting final specifications, can assist in integration of the desiccant Unit into the process scheme for optimum efficient performance.