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APPENDIX A

PRODUCTION AND MAINTENANCE OF VACUUM

A1 A plant which operates under vacuum is full of air when it is started up; and this has to be removed by some form of pump in order to establish a low absolute pressure, or vacuum. Some air leaks into the plant during normal operation and, in some cases, other non-condensible hases are evolved in the process. In most plants used in the detergents and related industries, water vapour, supplied as open steam or evaporated from the materials being processed,also needs to be removed continuously. Organic substances, such as fatty acids or glycerol, may be vaporized in the plant, but these are condensed substantially completely prior to the vacuum system, which will be assumed to have to deal only with water vapour and non-condensible gases described as air.

Vacuum, expressed in inches or millimetres of mercury, or other convenient units, is equal to the atmospheric pressure minus the absolute pressure at the relevant point in the plant. To avoid confusion, the discussion in the rest of this appendix will be in terms of absolute pressure rather than vacuum. It is , however, important to note that the absolute pressure at a given vacuum can vary considerably with the atmospheric pressure, if the latter differs widely from the approximate 760 mm Hg at sea-level, for example on the South African Rand which is some 5000 ft (1525 m) above sea-level.

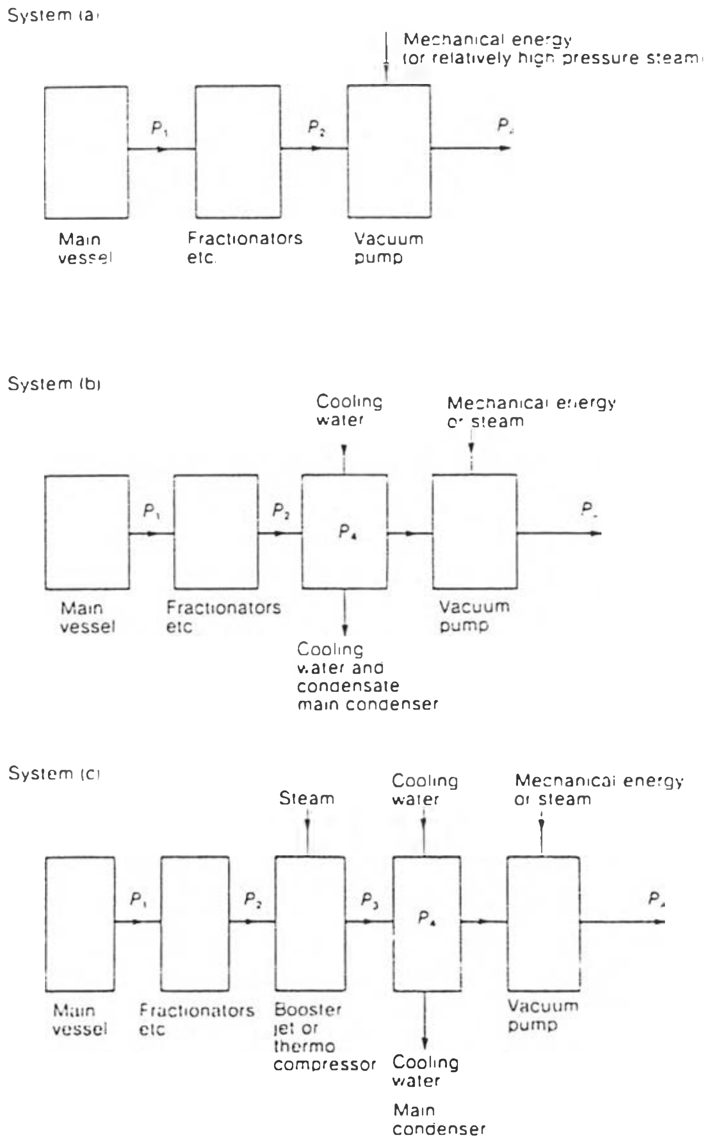


Fig. A1 Systems for maintenance of vacuum (Edger Woollatt, 1982)

A1.2 In principle, three systems can be used to raise the pressure of the gases and vapours leaving the plant to the level just above atmospheric pressure at which they can be discharged. These systems are shown diagrammatically in Fig. A1 (a), (b) and (c). In system (a), the whole of the gases and vapours are compressed in some form of pump from pressure P_2 at which they leave the plant to the discharge pressure P_A. This system is not normally used for the types of plant with which this book is concerned; it would be prohibitively expensive and probably impracticable.

In system (b) most of the water vapour is condensed by the use of cooling water. The condenser can be of the surface type in which the heat is transferred through walls and the condensate is recovered separately from the cooling eater. Unless the condensate is required, a direct contact condenser, in which the cooling water and the vapours come into contact, and the condensate and cooling water leave together in a mixed stream, is normally more convenient and economical. A condenser should do two things, carried out in separate zones, although these are often in the same shell. Its primary duty is to condense the bulk of the water vapour, so that it can be removed from the system as liquid condensate. The secondary function of the condenser is to cool the residual air plus water vapour, which reduces the volume of gas to be removed by the air pump. Efficient cooling of the air requires counter-current contact, so that the process is completed by the coolest available water. This is achieved in the upper part of a counter-current direct contact condenser to which the gases enter near the base and the cooling water at the top. Surface condensers should have an air cooling section in which the tubes use the fresh cooling water, which then goes to the main condenser in a multi-pass water flow arrangement.

The temperature to which the main condensate is cooled in the condensign zone is of major importance, as it controls the minimum pressure which can be achieved with system (b). This minimum pressure is the vapour pressure of water at the highest temperature at which the condensate is in contact with the condensing vapours, that is the condensate exit temperature. In the case of a direct contact condenser, the relevant temperature is that of the mixed condensate and cooling water stream. The exit condensate temperature is controlled by the inlet temperature of the cooling water and the mass used per init mass of water vapour to be condensed. In the case of a surface condenser, the area of cooling surface and the factors which affect heat transfer are important as these also influence the condensate temperature.

A vapour pressure curve for water is shown in Fig.6.3 and a skeleton table is;

temperature, C	vapour pressure, mm Hg
10	9
15	13
20	18
25	24
30	32

The total pressure in the condensign zone, P_4, equals $p_{w4}+p_{a4}$, where p_{w4} and p_{a4} are respectively the partial pressures of water vapour and air at point 4. p_{w4} is the vapour pressure of water at the highest temperature at which the condensate is in contact with the vapours is the condensing zone. With a given mass of air to the removed, p_{a4} is controlled by the performance of the air pump. A larger air pump reduces p_{a4}, which, in any case, should be relatively small, but it does not significantly reduce p_{w4}. Its only influence on pw4 is to carry away more water vapour with the air and so marginally to reduce the condensate temperature.

The total pressure in the air cooling zone is normally substantially the same as that in the condensign zone p_4; only a very small pressure difference being needed to induce flow from one zone to the other. The components p_w and p_a, however, vary, although $p_w + p_a$ continues to equal P_4. As the moist air is cooled, more water vapour is condensed. At any point

$$p_a/p_w \quad = \quad \text{(moles air)/(moles water vapour),}$$

or is proportional to (mass air)/(mass water vapour).

As water is removed from the gas phase as liquid, the ratio increases, so that p_a rises and p_w falls to maintain p_4 constant. Cooling of the air reduces the volumetric load on the air pump in two ways;

- it reduces the mass of water vapour to be removed with the air as just described.
- by the direct effect of temperature on gaseous volumes.

In view of the discussion regarding p_{w4} in the condensing zone, it may seem surprising that p_w falls to a lower value in the air cooling zone. The reason is that the condensate which separates in the air cooling zone is at a lower temperature than the main condensate: and this is the temperature which controls p_w at a point in the air cooling zone. It is important for the zones to be separated sufficiently for water from the main condensate not to re-evaporate into the air in the cooling zone.

Various designs of counter-current direct contact condenser are possible, including types with perforated trays and others with devices to produce curtains of water. As for other parts of a vacuum syste, condensers should be designed to minimize pressure drop.

Condensers can be low level or high level .The condensate ,and in direct contact types also the cooling water, is extracted from a low level condenser by a pump. High level condensers, now usual, are installed at least some 10.5 m above ground level; and the water runs out through what is knownas a barometric leg into an open seal tank, or hot well. This works as shown in Fig. A1.2 h_1 is the height of the column of water which, plus the absolute pressure in the condenser, just balances the atmospheric pressure on the water in the hot well. Some additional height, h_2, is needed to cause the water to flow down the leg at the required rate; and a little more is normally allowed to provide a margin of safety. If the barometric pressure is 760 mm Hg., the equivalent column of water equals 760/1000 x13.6 = 10.4 m. If the pressure in the condenser is zero (the situation in a barometer) h_1 = 10.4 m, but if the pressure is, say 30 mm Hg,equivalent to 0.4 m water, h_1 = 10.4 - 0.4 = 10.0 m.

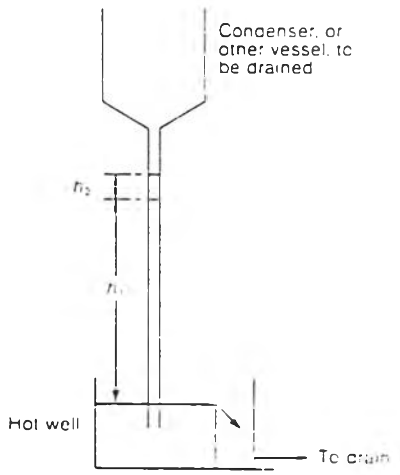


Fig. A2 Principle of the barometric leg (Edger Woollatt, 1982)

System (b) is normally used when it can achieve the required absolute pressure with the available cooling water. Under some circumstances a water chilling unit may be worthwhile, but this is more usual if very cold water is needed for duties such as plant cooling jackets.

When a lower pressure than that which could be achieved with system (b) is required, system (c) is used. In this, all the gases and vapours are compressed from P_2 to P_3, normally in a booster jet, or thermocompressor, in which mechanical energy is provided in the form of relatively high pressure steatn. The booster jet discharges into a main condenser which operates as discussed for system (b); thus system (c) is a combination of system (a) and system (b). When the ratio P_3 / P_2 to be provided by the booster jet is rather high, it may be necessary, or desirable, to use two, or even more, thermocompressor stages. The motive steam in the first booster stage then has to be compressed with the other gases and vapours in the next booster stage. The design of a booster jet is such that when the pressure required in the plant can be achieved using system (b), it is possible to shut off the steam to the booster jet, and to use the jet as a duct to the main condenser.

The vacuum pump used to compress to atmospheric pressure the moist air which leaves the condenser can be mechanical, or, now more usually, a two stage steam ejector unit, with an intermediate direct contact condenser to condense steam from the first stage. With either system (b) or system (c), a 'roughing jet' may be provided to reduce pressure more rapidly during start-up. Many years ago glycerine evaporators were sometimes equipped with large reciprocating pumps which extracted air, cooling water, and condensate together from a low-level condenser.

The vacuum maintenance system controls only the pressure at the point P_2.In many plants, such as glycerine stills, it is the pressure at P_1 which is particularly important. This depends upon the pressure change between P_1 and P_2, as well as upon the performance of the vacuum maintenance system itself. Careful design of ducts, condensers and other plant items, is necessary; but, in some cases, certain types of fractionation, or other equipment, cannot be used if the desired pressure P_1 is to be achieved.

A3. If the pressure in a plant deteriourates, or is not up to specification, and the cause is not immediately evident, it may be helpful to diagnose the fault systematically along the following lines;

- check P_1 andP_2.If the difference is unduly large, there is some blockage (such as a durty bed of packing), or the flow of gases and vapours is higher than expected.

- checkthe exit temperature of the condensate (the combined stream of cooling water and condensate in the case of a direct contact condenser) and note the corresponding vapour pressure of water. If the water temperature and the vapour pressure are high, the flow of water vapour to the condenser is high,or the supply of cooling water is sub-standard in quantity or temperature. This can be due to patial blockage of the water supply or the distribution system within the condenser, which is particularly liable to occur when the eater is taken from a creek, or other dirty source. In the case of a surface condenser heat transfer can be impaired by deposits of scale or dirt.

- if the difference between the vapour pressure of water and the total pressure, that is the partial pressure of air, is high, either the vacuum pump system is not working properly, or, more likely, there is an additional intake of air throuhg a leak in the plant. Such leaks can occur, for example, throuhg holes, joints, faulty valves, or valve glands.

- if the system (c) is in use and the pressure rise P_2 to P_3 is low, check the steam supply and the nozzles in the booster jet or jets.

Appendix B
Mechanical Separation

Practically every process operation requires the separation of entrained material. This may be either as a step in the purification of one stream, or a principal process operation.These separations may be:

1. liquid particles from vapor or gas
2. liquid particles from immiscible liquid
3. dust or solid particles from vapor or gas
4. solid particles from liquid
5. solid particles from other solids

These operations may sometime be better known as mist entrainment, decantation, dust collection, filtration, centrifugation, sedimentation, screening, classification, scrubbing, etc. They often involve handling relatively large quantities of one phase in order to collect or separate the other. Therefore the size of the equipment becomes very large. For the sake of space and cost it is important that the equipment be specified and rated to operate as efficiently as possible. This subject will be limited here to the removal or separation of liquid or solid particles from a vapor or gas carrier stream (1. and 3. above).

B1.Particle Size

The particle sizes of liquid and solid dispersoids will vary markedly depending upon the source and nature of the operation generating the particular particles. For design of equipment to reduce or eliminate particles from a fluid stream, it is important either to know from data the range and distribution of particle sizes, or be in a position to intelligently estimate the normal and extreme expectancies. Figure B1 gives a good over-all picture of dimensions as well as the descriptive terminology so important to a good understanding of the magnitude of a given problem. The significant laws governing particle performance in each range is also shown.

Particle sizes are measured in microns, u. A micron is 1/1000 millimeter or 1/25400 inch. A millimicron, mu, is 1/1000 of a micron, or 1/1,000,000 millimeter. Usually particle size is designated as the average diameter in microns, although some literature reports particle.

Table B1

Sizes of Common Dusts and Mists (Earnest E.Ludwig ,1964)

Dust or Mist	Average Particle Diameter, Microns
Human Hair (for comparison)	50-200
Limit of visibility with naked eye	10-40
Dusts	
Atmospheric dust	0.5
Aluminum	2.2
Anthracite Coal Mining	
Breaker air	1.0
Mine Air	0.9
Coal Drilling	1.0
Coal loading	0.8
Rock drilling	1.0

Dust or Mist	Average Particle Diameter, Microns
Alkali fume	1-5
Ammonium Chloride fume	0.05-0.1-1
Catalyst (reformer)	0.5-50
Cement	0.5-40-55
Coal	5-10
Ferro-manganese, or silicon	0.1-1
Foundry air	1.2
Flour-mill	15
Fly Ash (Boiler Flue gas)	0.1-3
Iron	
Flour-mill	15
Fly Ash (Boiler Flue gas)	0.1-3
Iron (Gray Iron Cupola)	0.1-10
Iron oxide (steel open hearth)	0.5-2
Lime (Lime Kiln)	1-50
Marble cutting	1.5
Pigments	0.2-2
Sandblasting	1.4
Silica	1-10
Smelter	0.1-100

Dust or Mist	Average Particle Diameter, Microns
Taconite Iron	
(Crushing & Screening)	0.5-100
Talc	10
Talc Milling	1.5
Tobacco smoke	0.2
Zinc oxide fume	0.05
Zinc (sprayed)	15
Zinc (condensed)	2
Mists	
Atmospheric fog	2-15
Sulfuric acid	0.5-15

Compiled from References 1,13,and 15

B2. Preliminary Separator Selection

The Sylvan Chart of Figure B2 is useful in preliminary equipment selection,although arranged primarily for dust separations, it is applicable in the appropriate parts to liquid separations.

B3. Impingement Separators

As the descriptive name suggests, the impingement separator allows the particles to be removed to strike some type of surface. This action is better accomplished in pressure systems where pressure drop can be taken as a result of the turbulence which necessarily accompanies the removal action.

Particle removal in streamline flow is less efficient than for turbulent flow, and may not be effective if the path of travel is not well baffled.

The "target" efficiency for impingement units expresses the fraction of the particles in the entraining fluid, moving past an object in the fluid, which impinge on the object.

The target efficiencies for cylinders, spheres, and rebbon like particles are given for conditions of Stokes Law in an infinite fluid by Figure B3.

If the particles are close enough together in the fluid to affect the path of each other, then Figure B3 gives conservative efficiencies. For particles differing considerably from those given in the curves, actual test data should be obtained.

There are basically three construction types for impingerment separators;

1. Wire mesh
2. Plates (curved, flat or special shaped)
3. Packed Impingement Beds

Table B2

Identification of Wire Mesh Types (Earnest E.Ludwig ,1964)

General Type	Density, Lbs./cu. ft.*	Surface Area Sq. ft./cu. ft.	Thickness, In.**	Min. Eff. Wt. %	Application
High Efficiency	12	115	4+	99.9+	Relatively clean, moderate velocity
Standard Eff.	9	85	4+	99.5+	General purpose
Optimum Eff. or VH Efficiency, and Wound type	13—14	120	4+	99.9+	For very high efficency
Herringbone, High through-put or Low Density	5—7	65±	4—6+	99.0+	For services containing solids, or "dirty" materials

*If the mesh is made of nickel, monel or copper, multiply the density values by 1.13, referenced to stainless steel.

** 4" is minimum recommended thickness; 6" is very popular thickness: 10" and 12" recommended for special applications such as fine mists. oil vapor mist.

B3.1 Knitted Wire Mesh

A stationary separator element of knitted smalldiameter wire or plastic material is formed of wire 0.003 in. to 0.016 in. (or larger) diameter into a pad of 4 inches, 6 inches or 12 inches thick and serves as the impingement surface for liquid particle separation. Solid particles can be separated, but they must be flushed from the mesh to prevent plugging. Although several trade name units are available they basically perform on the same principle, and have very close physical characteristics. Carpenter presented basic performance data for mesh units. Figure B1 shows a typical eliminator pad. Figure B1 Pictorially depicts the action of the wire mesh when placed in a vertical vessel.

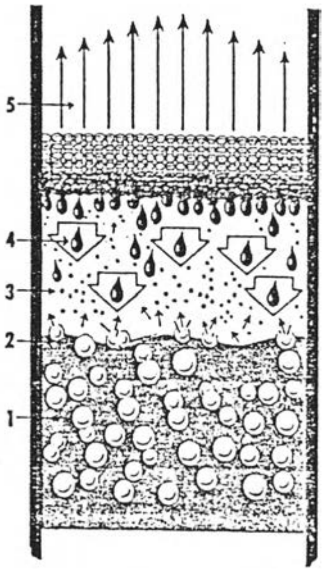


Figure B1. Diagram of actionof wiremeshinliquid-vaporseparation.
(Earnest E.Ludwig ,1964)

When a gas is generated in, or passes through, a liquid (1), the gas, on bursting from the liquid surface (2) carries with it a fine spray of droplets-liquid entrainment-which are carried upward in the rising gas stream(3). As the gas passes through the mist eliminator, these droplets impinge on the extensive surface of the wire, where they are retained until they coalesce into large drops. When these liquid drops reach sufficient size, they break away from the wire mesh (4) and fall back against the rising gas stream. In this way,the entrained droplets are literally "wiped out" of the gas which, freed from liquid entrainment, (5) passes on, unhindered through the mesh.

Referring to Figure B1, the typical situation represents a vapor disengaging from a liquid by bursting bubbles and creating a spray of liquid particles of various sizes. Many of these particles are entrained in the moving vapor stream. The largest and heaviest particles will settle by gravity downward through the stream and back to the bottom of the vessel or to the liquid surface. The smaller particles move upward, and if not removed will carry along in the process stream. With wire mesh in the moving stream, the small particles will impinge on the wire surfaces; coalesce into fluid films and then droplets, run to a low point in their local system; and fall downward through the up-flowing gas stream when sufficiently large. The gas leaving is essentially free from entrained liquid unless the unit reaches a flooding condition.

B3.1.1 Mesh Patterns

There are several types of mesh available, and these are identified by mesh thickness, density, wire diameter and weave pattern. Table B2identifies most of the commercial material now available. The knitted pads are available in any material that can be formed into the necessary weaves, this includes: stainless steels, monel, nickel, copper, aluminum, carbon steel, tantalum, Hastelloy, Saran, and polyethylene.

B3.1.2 Capacity Determination

The usual practice inselecting aparticular mesh for a given service is to determine the maximum allowable velocity and from this select a vessel diameter. In the case of existing vessels where mesh is to be installed, the reverse procedure procedure is used, i.e., determine the velocity conditions which will prevail and select a mesh to fit as close to the conditions as possible. The procedure is outlined below:

Allowable Vapor Velocity (Mesh in Horizontal Position)

$$Va = k / ((\rho_L-\rho_V)/ \rho_V)$$

Va= Maximum allowable superficial vapor velocity across inlet face of mesh, ft./sec.

K = Constant based on application, Table B3

ρ_L= Liquid density, Lb./cu.ft.

ρ_V= Vapor density, Lb./cu.ft.

The correlation factor, k, is a function of the liquid drop size, liquid viscosity, liquid load, disengaging space, type of mesh weave, etc. Certain values have been found satisfactory for systems described in Table B3.

Table B3

"k" Values for Knitted Mesh (Earnest E.Ludwig ,1964)

Bottom of mesh at least 12 inches above liquid surface		
Service Conditions	"k"	General Type Mesh
Clean fluids, moderate	0.35 to 0.36	Standard
liquid load, fits 90% of	0.35	High Efficiency
process situations	0.25	Very High Efficiency
High viscosity, dirty	0.40	Low density of
suspended solids		Herringbone, high through-put
Vacuum operations:		
2" Hg. abs.	0.20	Standard or
16" Hg.abs.	0.27	High Efficiency
Corrosive Chemical	0.21	Plastic coated wire, or plastic strand

Table B4

Variation of k with Disengaging Height (Earnest E.Ludwig ,1964)

Disengaging Height Above Mesh, Inches	Allowable k Value
3	0.12
4	0.15
5	0.19
6	0.22
7	0.25
8	0.29
9	0.32
10	0.35
11	0.38
12	0.40
13	0.42
14	0.43

*O.H. York, Reference .

Note: Values based on 12 Lb./cu.ft. wire mesh. Design practice normally does not exceed k of 0.4 even for higher disengaging height.

For conditions of high liquid loading, use caution in design. Use the high velocities for very fine mist to remove the small particles, and use two mesh pads in series with the second mesh operating at a lower velocity to remove the larger drops re-entrained from the first mesh. Systems involving high viscosity fluids should be checked with the various manufacturers for their case history experience. Lower k values are used for systems with high vacuum, high viscosity liquids, low surface tension liquids and systems with very bad fouling conditions. Table B4 indicates the effect of disengaging height on the allowable k value. Similar relations should hold for other mesh densities.

Velocity Limitations

Very low velocities will allow particles to drift through the mesh and be carried out with the leaving vapor. Also, very high velocities will carry liquid to the top of the mesh, establish a "flooding" condition, and then re-entrain the liquid from the surface of the mesh. For most situations very good performance can be expected for all velocities from 30-100 percent of the optimum allowable design velocity. The minimum allowable safe design velocity is 10 percent of the value calculated by the equation. The flooding velocity of the mesh is usually about 120 percent to 140 percent of the maximum allowable velocity.

Generally the maximum allowable velocities are lower under conditions of pressure, and higher under conditions of vacuum. The limits and ranges of each area being determined by the relative operating densities of the vapor and liquid, the nature of the entrainment, and the degree of sepqration required.

When the mesh is installed with the pad vertical or inclined, the maximum allowable velocity is generally used at 0.67 times the allowable value for the horizontal position.

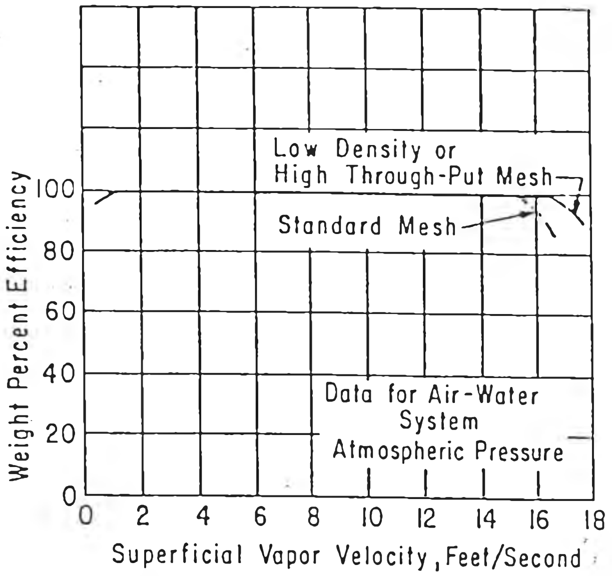


Figure B2. Typical wire mesh efficiency.(Earnest E.Ludwig ,1964)

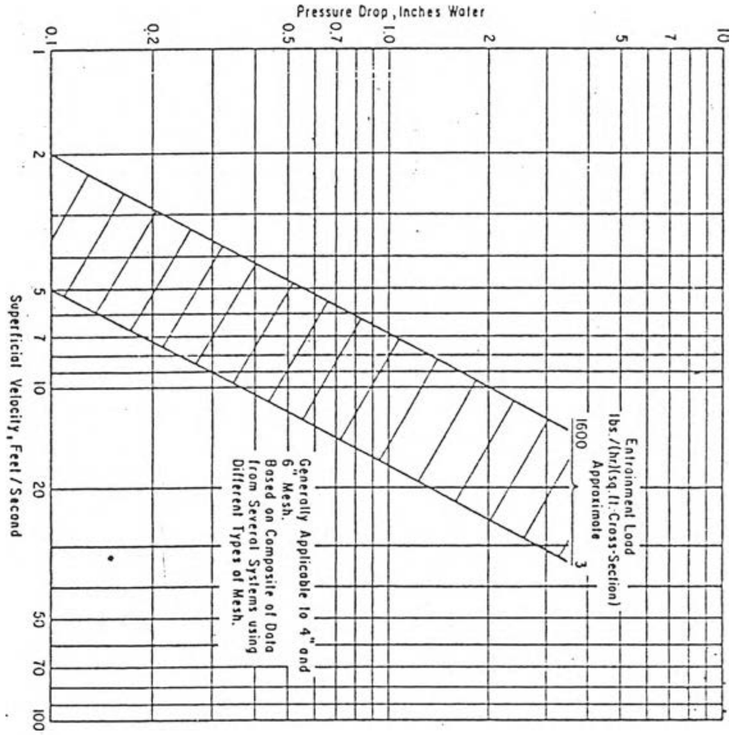


Figure B3. Typial pressure drop range for most wire mesh separators.

(Earnest E.Ludwig ,1964)

B3.1.3 Design Velocity

To allow for surges,variationsin liquid load and peculiarities in liquid particle size and physical properties, use:

$$Vd = 0.75\ Va$$

For the design of new separators. When checking existing vessels to accept wire mesh, some variation may have to be accepted to accommodate the fixed diameter condition, but this is no great problem since the range of good operation is so broad.

B3.1.4 Efficiency

For most applications the efficiency will be 98-99 percent plus as longasthe range of operating velocity is observed. The typical performance curve for this type of material is given in Figure B6. For hydrocarbon liquid natural gas system, guarantees are made that not more than 0.1 gallon of liquid will remain in the gas stream permillion cubic feet of gas. Special designs using a 3-foot thick pad reduce radioactive entrainment to one part per billion.

For the average liquid process entrainment the mesh will remove particles down to 5 microns. Particles smaller than this usually require two mesh pads. Carpenter shows the calculated effect of decreasing particle size on percent entrainment removed at various linear velocities. For water particles in air at atmospheric pressure, the 8μ particales are 99 percent removed at 3.5 ft./sec., the 7μ at 5 ft./sec., and the 6μ at 6.8 ft./sec.

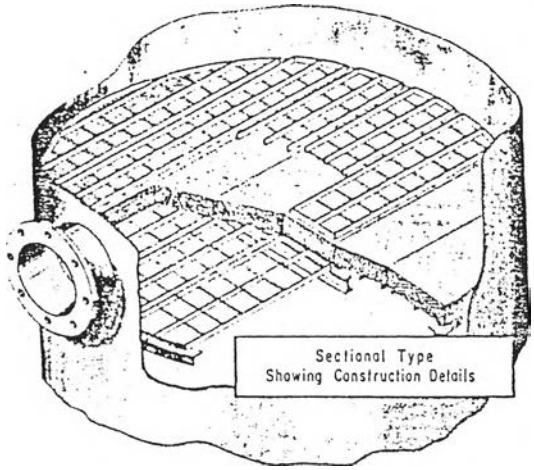


Figure B4.Thpical installation of meshstripsin vertical vessel.

(Earnest E.Ludwig ,1964)

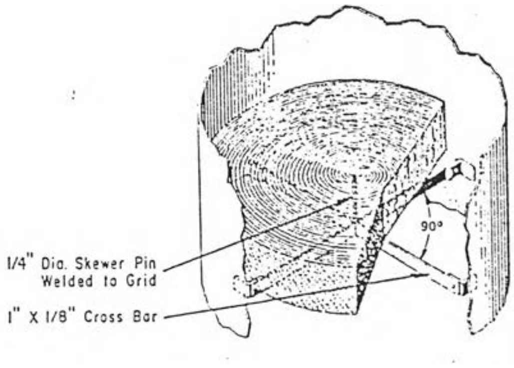
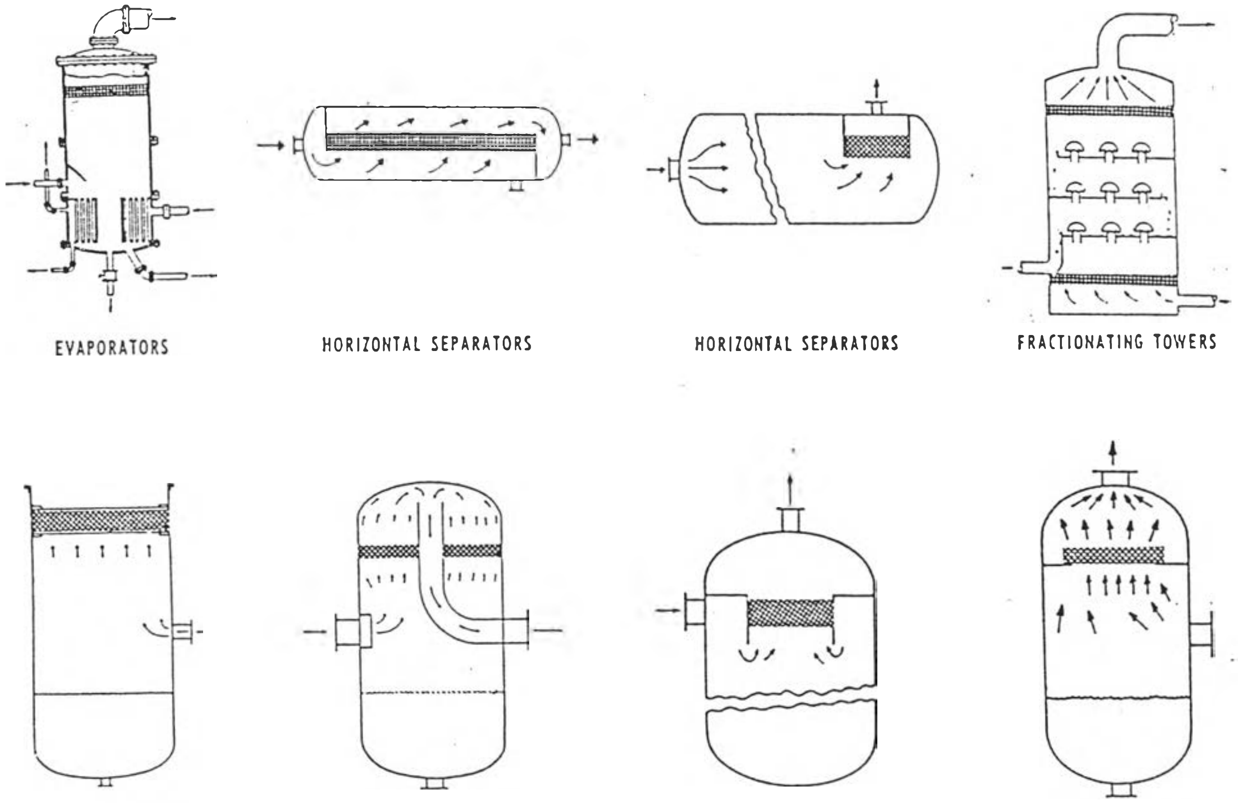


Figure B5.Typical installation of wound mesh pads in vertical vessel.

(Earnest E.Ludwig ,1964)



EVAPORATORS

HORIZONTAL SEPARATORS

HORIZONTAL SEPARATORS

FRACTIONATING TOWERS

OPEN SEPARATORS

IN-LINE GAS SCRUBBERS

OIL-GAS SEPARATORS

OVER-SIZE VESSEL

Figure B6.Typical mesh installations in process equipment.

(Earnest E.Ludwig ,1964)

B3.1.5 Pressure Drop

Pressure drop through wire mesh units is usually very low, in the order of 1-inch water gage for a 4-inch or 6-inch thick pad. For most pressure applications this is negligible. If solids are present in the particle stream, then solids build-up can become appreciable, and is usually the guide or indicator for cleaning of the mesh. A 12-inch pad may require a 3-inch water drop. Figure B7 presents the range of expected pressure drops for a spread of 3 to 1600 #/hr.-ft, fir kuqyud rates. Although this is for air-water system at atmospheric pressure it will not vary much unless the physical properties of the vapor and liquid deviate appreciably from this system, in which case the general Fanning equation can be used to approximate the pressure drop under the new conditions. Approximate values based upon air-water tests suggest these relations.

For the standard weave, 4 inches thick:

$$\Delta p = 0.2\ V_D^2 \rho_V, \text{ inches water} \qquad \text{(B1)}$$

For the low density weave (high through-put), 6 inches thick:

$$\Delta p = 0.12\ V_D^2 \rho_V \qquad \text{(B2)}$$

B3.1.6 Installation

The knitted mesh separator unit may be placed in a pipe in which case a round flat rolled unit is usually used or it may be placed in a conventional vessel. Although the vessel may be horizontal or vertical, the mesh must always be in a horizontal plane for best drainage. Some units in special situations have been placed at an angle to the horizontal, but these usually accumulate liquid in the lower portion of the mesh. Since the material is not self supporting in sizes much over 12 inches in diameter, it requires support bars at the point of location in the vessel. In most instances it is wise to also install hold-down bars across the top of the mesh in accordance with manufacturers' instructions as the material will tend to blow upward with a sudden surge or pulsation of vapor in the system. Many early installations made without the bars on top were soon found ineffective due to blowout holes, and wire particles were found in pipe and equipment downstream of the installation.Figures B4 and B5 show a typical installation arrangement in a vertical vessel. The mesh is wired to the bottom support bars and the hold-down on top.

A few typical arrangements of mesh in vessels of various configurations are shown in Figure B6.

Note that in some units of Figure B6 the mesh diameter is smaller than the vessel. This is necessary for best operating efficiency under the system conditions, and applies particularly when using an existing vessel.

When placing mesh in small diameter vessels it is important to discount the area taken up by the support ring before determining the operating velocity of the unit. For small 6-,8-, and 12-inch vessels (such as in-line, pipe-with-mesh inits) it is usual practice to use 6 ir 8-inch thickness of mesh for peak performance.

Provide at least 6- ti 12-inch minimum (preferably 18-inch min.) disengaging space ahead of the inlet face of the mesh, i.e., above any inlet nozzle bringing the liquid-carrying vapors to the vessel, or above any liquid surface held in the vessel. Leave 12-inch minimum of disengaging space above the mesh before the vapors enter the vessel vapor exit connection. The mesh may be installed in horizontal, vertical or slanting positions in circular, rectangular or spherical vessels. For locations where the liquid drains vertically through the mesh pad perpendicular or angular to its thickness dimension, care must be taken to keep velocities low and not to force or carry the liquid through to the downstream side of the mesh.

B3.2 Baffle Type Impingement

There are manybaffletype impingement separators.The efficiency of operation for entrainment is entirely a function of the contacting action inside the particular unit. There are no general performance equations which will predict performance for this type of unit: therefore manufacturers' performance data and recommendations should be used.

B3.2.1 Efficiency

The efficiency of this type of unit varies ,and is a function of the effectiveness of the impingement baffling arrangement. About 70 percent of separator applications can use the line-type unit; the other 30 percent require the vessel construction. The preferance of the designer and problems of the plant operator are important in the final selection of a unit to fit a separation application.

The efficiency for removal of liquid and solid suspended particles is 97-99 plus percent when handling 15-micron particles and larger. For steam service, a typical case would be 90 percent quality entering steam with 99.9 percent quality leaving.

Some units will maintain a reasonable efficiency of separation over a range of 60-120 percent of normal per-formance rating while other types will not. This flexibility is very peculiar to the internal design of the unit. Some units are guaranteed to reduce mechanical entrainment loss to less than 0.1 gallon per million standard cubic feet of entraining gas.

B3.2.2 Pressure Drop

Pressure drop in most units of this general design is very low,being in the order of 0.1 to 3 psig.

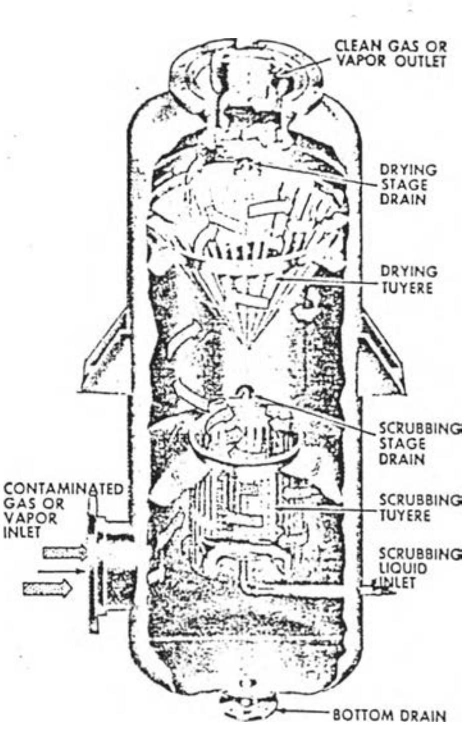


Figure B7. Scrubber with internal liquid feed. (Earnest E.Ludwig ,1964)

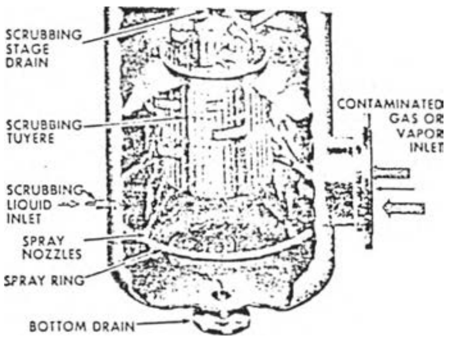


Figure B8. Scrubber with sprayring as. alternate arrangement for illustration B12.(Earnest E.Ludwig ,1964)

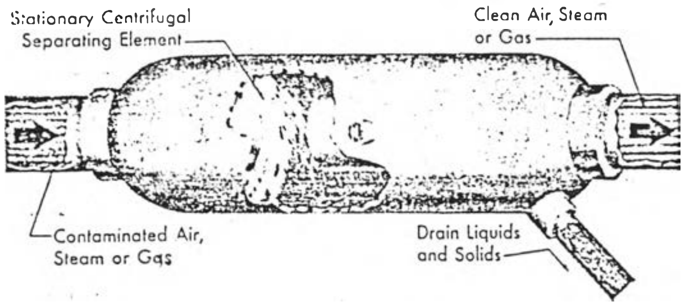


Figure B9. Line type centrifugal separator. (Earnest E.Ludwig ,1964)

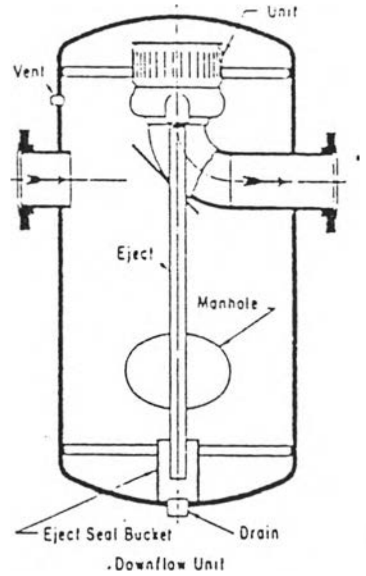


Figure B10. Centrifugal separator applications. (Earnest E.Ludwig ,1964)

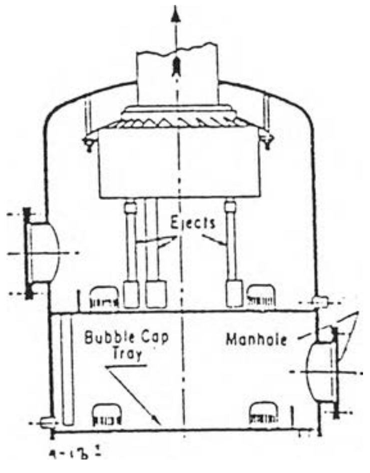


Figure B11. Centrifugal separator applications. (Earnest E.Ludwig ,1964)

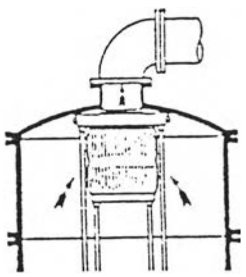


Figure B12. Centrifugal separator applications. (Earnest E.Ludwig ,1964)

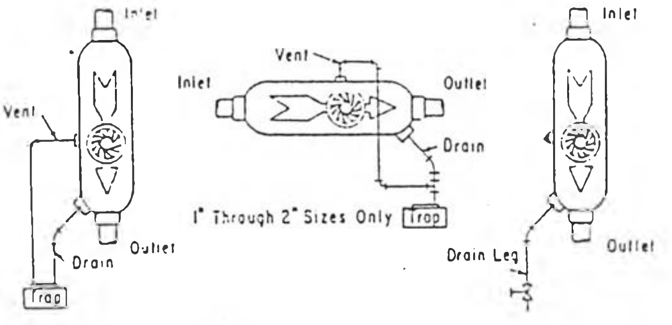


Figure B13. Centrifugal separator applications. (Earnest E.Ludwig ,1964)

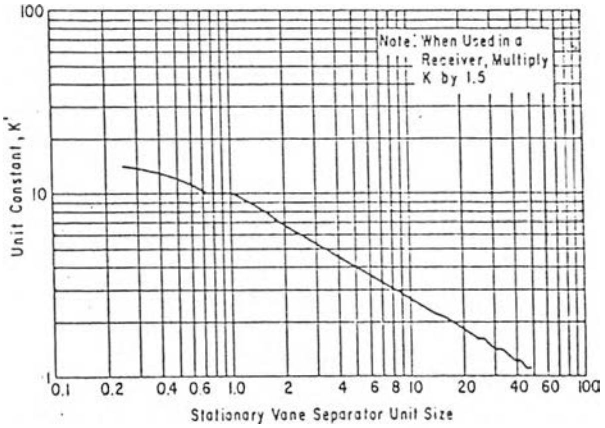
B3.3 Dry-Packed Impingement Beds

Although this type of unit is not used as frequently as most of the others discussed, it does have some specific applications in sulfuric acid mist removal and similar very difficult applications. The unit consists of a bed of granular particles or ceramic packing, sometimes graduated in size,operating dry as far as external liquid application to aid in the separation. The superficial velocities of 0.5 to 8-feet per second through the unit are rather low for most separators therefore the vessels become large. Dur to 0.5 the packed heights of 2 feet (min.) and higher, the pressure drop can be appreciable. Particle removal may be 0.5 to microns at 99 percent efficiency for a good design. These units will plug on dust service and must be back washed to regain operability at reasonable pressure drops.

B3.4 Centrifugal Separators

Centrifugal separators utilizecentrifugalaction for the separation of materials of different densities and phase They are built in (a) stationary and (b) rotary type various modifications of stationary units are used more than any other kind for separation problems.

The cost is moderate; it is simple in construction, and is reasonably flexible in service, being useful for gas-liquid or gas-solid systems. In addition to serving as finishing separators centrifugal units are also used to take a "rough cut" into a separation problem.They may be followed by some additional unit of special cyclone action or filtration through woven cloth pads, etc., to completely remove last traces of entrained particles.



FigureB14. Performance constant for stationary vane centrifugal separator. (Earnest E.Ludwig ,1964)

B3.4.1 Stationary Vane

The stationary vane type is quite popular and adapts to many applications.It is used in vessels or pipe lines as illustrated in Figure B7-B13.They are usually of high efficiency for both liquid and solid particles such as rust, scale, dirt, etc. When the system is dry with dust a special design is used.

B3.4.1.1 Performance

Figure B15 gives the performance selection for a unit handling air or gas with liquid plus dust entrainment. Figure B21 is for units handling steam as the carrier vapor. The size unit is designated as the inlet opening for the vapor, gas or steam. The safe operating range for entering vapor or gas velocities is given in Figure B17. Densities of several gases and vapors are placed on the chart for convenience in conversion.

B3.4.1.2 Pressure Drop

Pressure drop is usually reasonable , being from a few inches of water to about a maximum of 10 psig. Estimated drop can be determined.

$$P = K'\rho V^2/10^6 \qquad (B3)$$

where K' is a constant based upon the design of the separating element. This can serve as a general guide to the performance of this particular class of unit.K' values are given in B14. If the pressure drop is too high, a lower velocity can be selected. This will give a larger unit (sometimes) with a lower ΔP.

B3.4.1.3 Efficiency

The efficiency of centrifugal units is:

Type	Efficiency Range
High Velocity	99% or higher, of entering liquid.
Stationary Vanes	Residual entrainment 1 ppm or less
Cyclone	70-85% for 10 micron, 99% for 40 micron and larger. For high entrainment, efficiency increases with concentration.
Rotary	98% for agglomerating particles

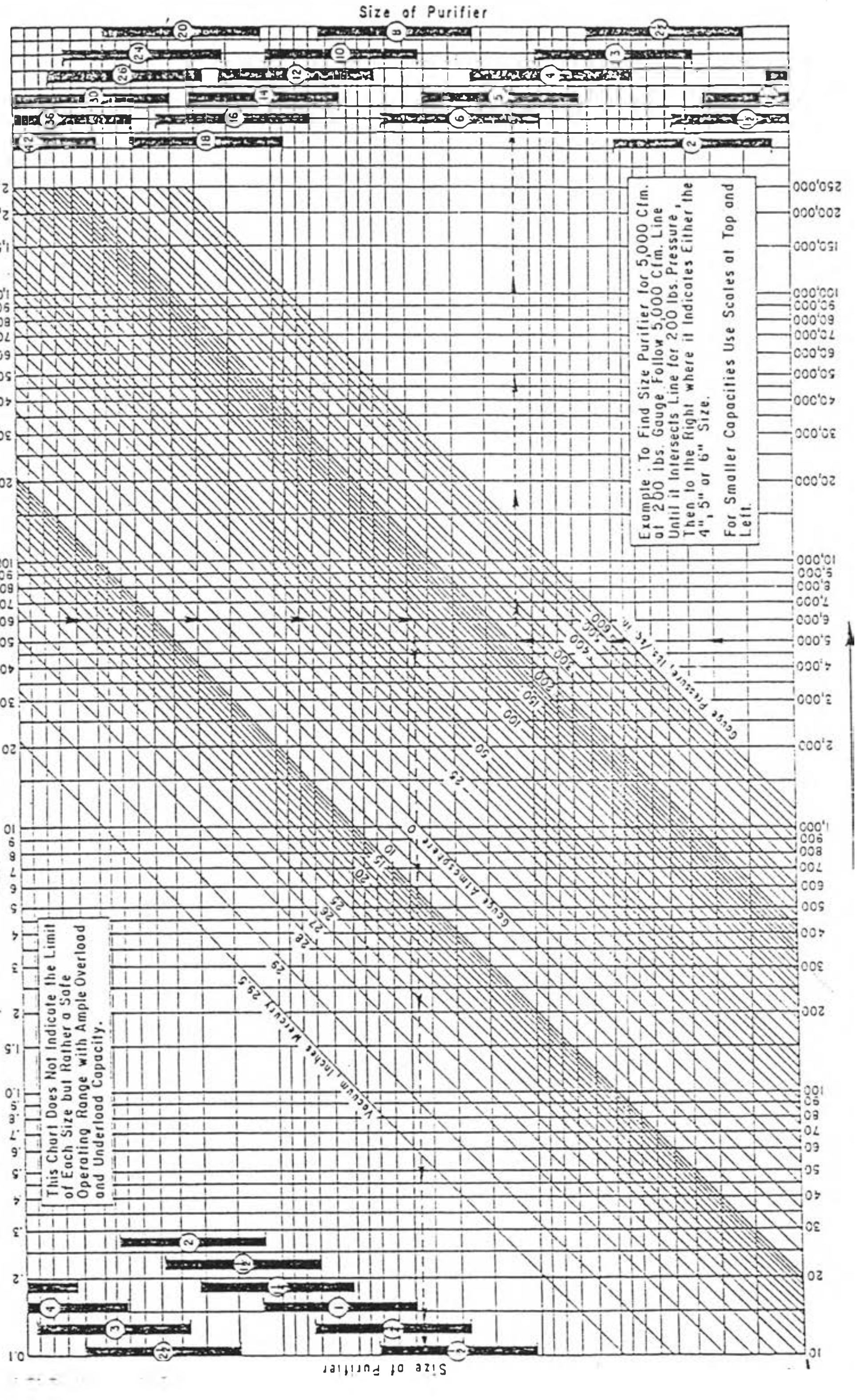


Fig.B15 Air and Gas capacity chart (Earnest E.Ludwig ,1964)

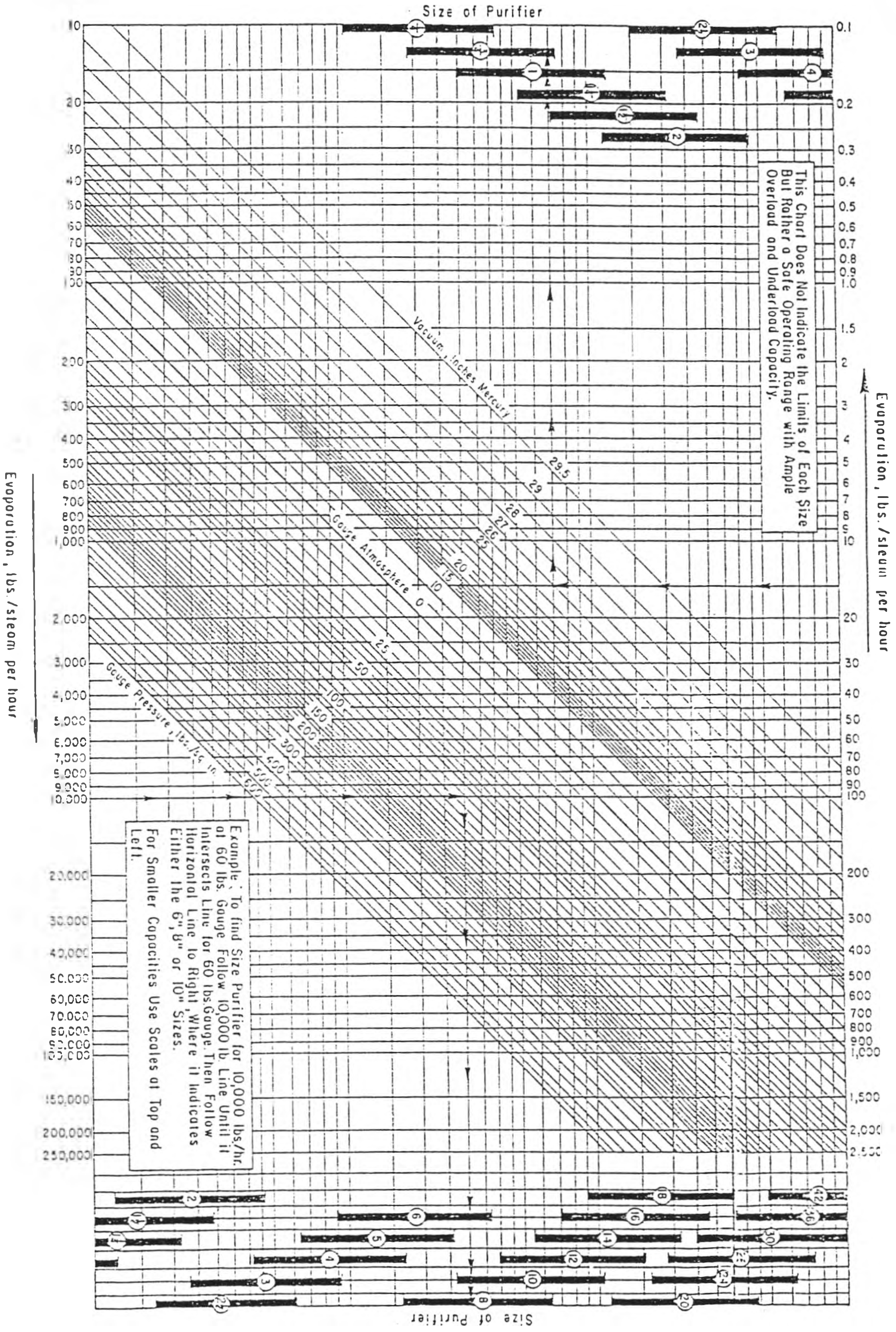


Fig.B16 Steam Capacity Chart (Earnest E.Ludwig ,1964)

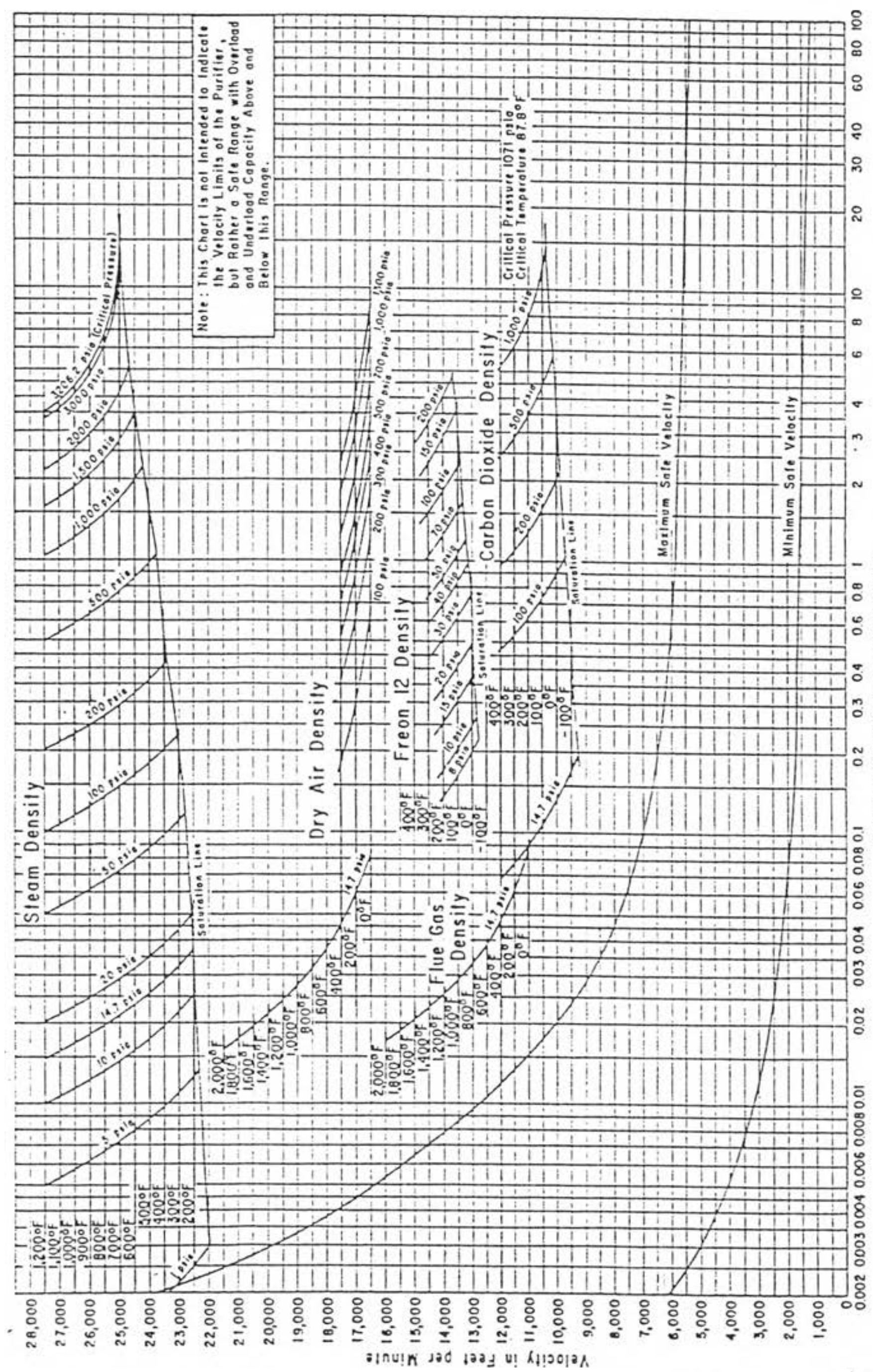
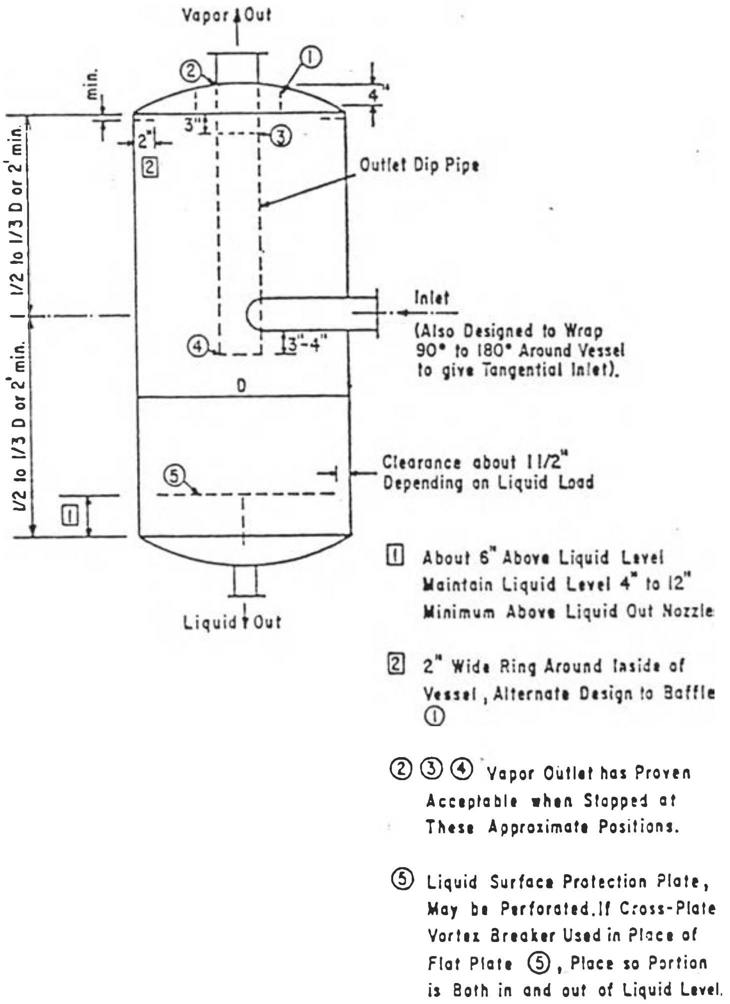


Fig.B17 Permissible Velocities for Stationary Vane Centrifugal Purifier

(Earnest E.Ludwig ,1964)



(Also Designed to Wrap 90° to 180° Around Vessel to give Tangential Inlet).

Clearance about 1 1/2" Depending on Liquid Load

1 About 6" Above Liquid Level Maintain Liquid Level 4" to 12" Minimum Above Liquid Out Nozzle

2 2" Wide Ring Around Inside of Vessel, Alternate Design to Baffle ①

② ③ ④ Vapor Outlet has Proven Acceptable when Stopped at These Approximate Positions.

⑤ Liquid Surface Protection Plate, May be Perforated. If Cross-Plate Vortex Breaker Used in Place of Flat Plate ⑤, Place so Portion is Both in and out of Liquid Level.

Fig.B18 Centrifugal Liquid Separator (Earnest E.Ludwig ,1964)

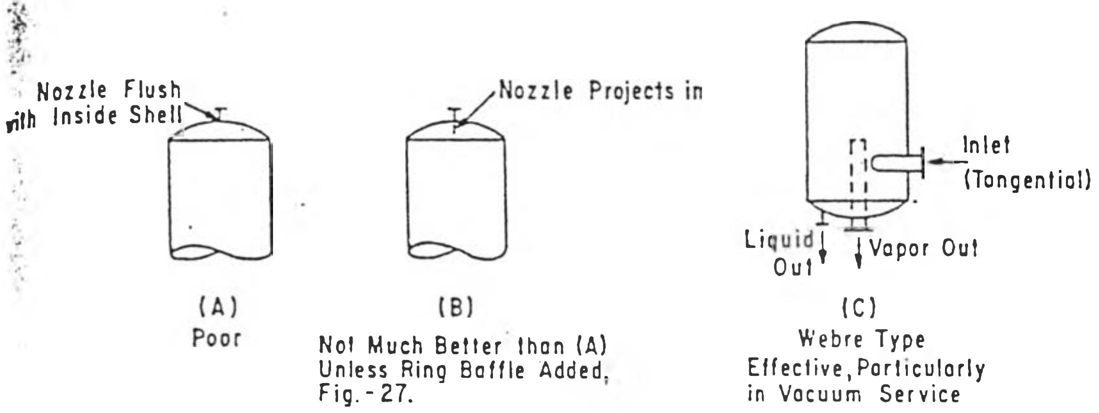


Fig.B19 Separator Outlets for Liquid-Vapour Service. (Earnest E.Ludwig ,1964)

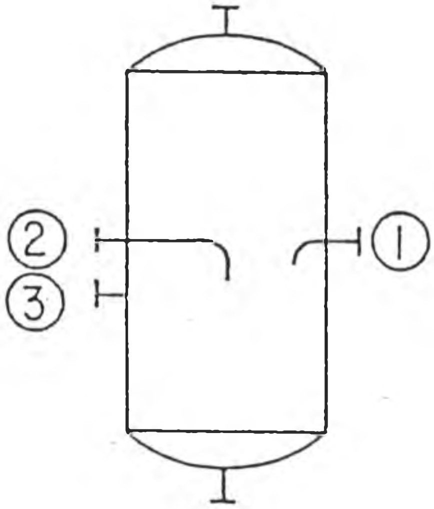


Fig.B20 Separator Inlets for Liquid-Vapour Service. (Earnest E.Ludwig ,1964)

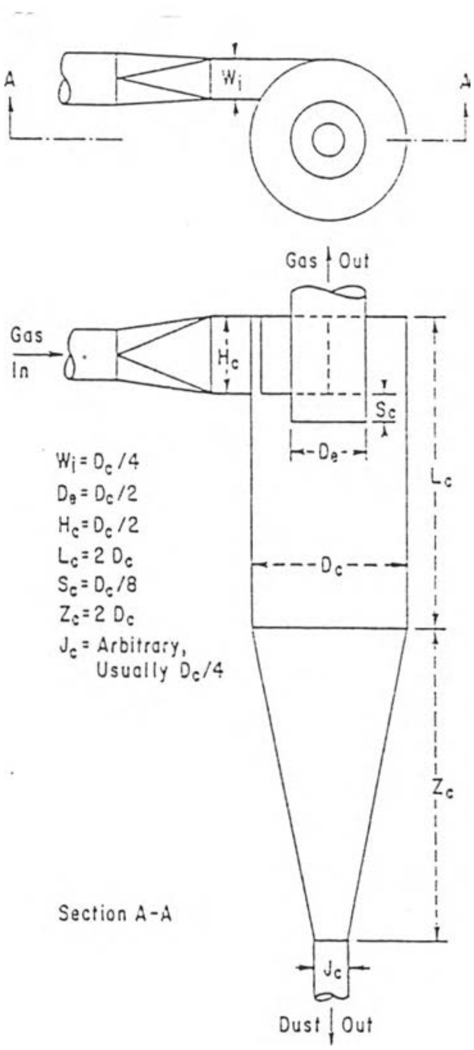


Fig.B21 Cyclone Separator Proportions-Dust Systems.

(Earnest E.Ludwig ,1964)

B3.4.2 Cyclone Separators

B3.4.2.1 Liquid Cyclone-Type Separator

The unit shown in Figure B18 has been used in many process applications with a variety of modifications. It is effective in liquid entrainment separation, but is not recommended for solid particles due to the arrangement of the bottom and outlet. The flat bottom plate serves as a protection to the developing liquid surface below. This prevents re-entrainment. In place of the plate a vortex breaker type using vertical cross plates of the plate a vortex breaker type using vertical cross plates of 4 inch to 12 inch depth also is used. The inlet gas connection is placed above the outlet dip pipe by maintaining dimension of only a few inches at point 4. In this type unit some liquid will creep up the walls as the inlet velocity increases.

In order to handle higher loads, the liquid baffle is placed at the top to collect liquid and cause it to drop back down through the gas body. If the baffle is omitted, the liquid will run down the outlet pipe and be swept into the outlet nozzle by the outgoing gas as shown in Figure B-19B. Figure B19 and B-20 show several alternate entrance and exit details. The unit with a tangential entry is 30-60 percent more efficient than one with only a turned down 90 elbow in the center.

If the design of Figure B21 is used for liquid-vapor separation at moderately high liquid loads, the liquid sliding down the walls in sheets and ripples has somewhat of a tendency to be torn off from the rotating liquid and become re-entrained in the upward gas movement.

Bibliography

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