PROPER SEPARATION DESIGN CAN PREVENT COSTLY DOWNTIME

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ABSTRACT

Attention to proven design parameters, such as are used to design plant process equipment, can improve the operation of petroleum production systems. A review of the development of primary extraction devices is given, along with formulae for efficiency and allowable velocities. Vane type, wire mesh and centrifugal are examined. Staggered baffles and zig-zag or wave plates are discussed.

Design criteria for the application of these primary elements are compared, thus allowing the selection of the optimum type mist extractor for most desired services. The influence of liquid loading/entrainment on separator sizing is discussed. Vessel dimensions and liquid capacity are related for each type of primary element. It is shown how comparisons of advantages can help make an economic selection for any given problem.

INTRODUCTION

Carryover of liquid and solid particles can damage equipment, cause grave errors in gas measurement, reduce equipment capacity and foul treatment solutions. The problems and their consequences, once having occurred, are difficult and costly to correct. It is much easier to design systems initially with efficient, properly applied separation equipment. The purpose of this paper is to review separator development and give some overall parameters for selection of proper equipment. This will be particularly applicable to oil field production units, as price has often paid too great a part in the selection and design of oil and gas separators, dehydrators and sweeteners.

Many of the carryover problems can be traced to the primary mist or separation element. It would be valuable, then to review the development of such devices.

THEORY AND REVIEW

The first separation device was an empty vessel. The size of this vessel was determined by the use of Newton's Law, which is used to determine the free settling velocity for a given sized particle. The application of this relation to actual flowing conditions required some adaptation.

It became apparent that different constants had to be used in order to correct for varying Reynolds Numbers and the equation that best represents actual conditions is as follows:

$$u_t = 1.73[gD_p \ (d_\rho - d_g)/d_g]^{1/2} \qquad (1)$$

where: u_t=terminal settling to velocity (ft./sec.)
g =local acceleration due to gravity (ft/sec2)
D_p=Diameter of particle (ft.)
d_p=density of particle (#/ft)
d_g=density of gas (#/ft)

The above equation (1) will cover the range of Reynolds numbers from 1000 to 350,000 (calculated for velocity in the vessel). By correcting for Reynolds number the shape variations of liquid particles were roughly taken into account.

The use of the above formula produced very large pressure vessels that still did not rid the system of fine mists. Generally the particle size used to calculate the diameter was in the range of 50 to 75 microns, and large quantities of liquid were passed when fine particles were involved. This led to costly installations, and the problem of fine carryover was still present. It became apparent that a mist extractor should be employed which would reduce the vessel size and give greater efficiency on small particles.

PRIMARY ELEMENT REVIEW

Some of the first efforts employed staggered rows of inverted angle iron, with the flow either vertical or horizontal. This produced mixed results since the spacing, pitch and number of rows were found to be critical variables. As the gas velocity was increased, the drainage of the separated liquid was adversely affected and trailing edge re-entrainment increased. Different shapes (channels, air-foils [2]) other than angle iron were used and again the critical problem remained that of liquid drainage without re-entrainment. Parallel wave plates and zig-zag or chevron baffles have proved to have extraction efficiency, as have all of the above efforts, but increasing velocity caused drainage problems without some form of drainage pockets (3). The key to finding the most economical unit is to accomplish the highest efficiency at the highest break-through velocity. Most of the improvements in design have been made through empirical testing. One problem that has been encountered is the use of test models that are too small. There is a definite limit to the amount that a mist element can be scaled down since end effects can alter the results (3).

There is a tendency in the literature to classify staggered baffles, wave plates and all types of vanes in the same category. This is not absolutely correct and will be discussed in the next section.

VANE TYPE MIST EXTRACTORS

A number of patents have been issued in the past which have had merit. Much of what was done was based on theoretical calculations that sometimes worked and often left a lot to be desired. The first breakthrough occurred in 1935, when the inventor employed a novel approach; he used a zig-zag vane element to which he attached liquid drainage pockets. This produced a rather efficient mist extractor, and with some experimentation with spacing in relation to face velocity, a unit that could be incorporated into a pressure vessel resulted. This unit was a workable impingement/impaction mist element, and found quick commerical application. At the time of this development the size and throughput was determined from empirical data, but work done since that time has given us the ability to calculate size and efficiencies of vane type mist extractors with great accuracy.

Experimental work done on vanes with and without drainage pockets has shown that such channels are necessary to achieve acceptable efficiencies in separators that operate under pressure (6). Similar tests have shown that vanes are preferable to staggered rows of elements. If the liquid entrainment can be introduced into a drainage pocket (and eliminated) before reaching the end of the vane element then drag re-entrainment can be reduced to practically zero. This is difficult to do with only one drainage pocket as would be necessary with staggered baffles. This accounts for the considerably higher allowable gas velocities in vane units with continous plates versus that reported by Calvert (7) for staggered baffles.

Allowable mass velocity in a vane type separator can be estimated by the following equation (8) (For actual design purposes use sizing of the mist extractor manufacturer):

$$W = K/\sqrt{V_g} \tag{2}$$

Where: W = Mass Flow Velocity in Lbs/Hr-Sq.Ft
K = An Empirical Constant (=11,650 for most cases)
V_g = Specific Volume of gas in Lb/Cu.Ft. (actual cond.)
Note: $V = 1/\rho_g$

Efficiency of vanes on any given particle size can be calculated using the following equation (7):

$$\eta = 1\text{-exp}\ [u_{tc} nw\theta/57.3U_g b \tan\theta] \tag{3}$$

Where: η = Fractional Collection Efficiency
u_{tc} = Particle Terminal Centrifugal Vel. in Ft/sec.
n = no. of bends in flow path; w = width of vane Ft.
b = vane spacing Ft.; θ = angle of incination of bend
U_g = Superficial Gas velocity Ft/ Sec.

WIRE MESH MIST EXTRACTORS

The development of wire mesh as a primary extraction device followed the employment of vane or staggered baffles by several years. In columns or fractionators, mesh offered the advantage of having a thin vertical dimension and since the upward velocity in these vessels was carefully controlled (to prevent flooding or tray to tray entrainment) mesh units could be employed at large savings. The Souders and Brown equation was used to determine the allowable mass velocity of these columns, so it was natural to adapt it to calculate the area required for proper separation through a mesh pad. The formula is shown below (4):

$$U = K\,[(\rho_L - \rho_g)/\rho_g]^{1/2} \tag{4}$$

Where: U = Allowable Gas Velocity (Actual Cond.) Ft/Sec
K = An Empirical Constant (=.35 for clean services)
ρ_L = Liquid Density Lb/Cu.Ft.
ρ_g = Gas Density Lb/Cu.Ft.

Collection efficiency can be estimated for mesh by the following formula (2):

$$\eta = 1 - \exp\left[-2/3\,\pi\, a\, l\, \eta_t\right]$$

Where: η = Collection Efficiency for a given size particle
a = Specific Area of mesh Sq.Ft./Cu.Ft.
l = Depth of mesh pad in direction of flow Ft.
η_t = Target Collection Efficiency for single wire (2, Fig.20-105)

In the early uses of mesh elements, most of the applications were on clean fluids and for limited upward carryover (low liquid loadings or low velocities). As experience was gained in a variety of applications, it soon became apparent that care need be exercised where fouling fluids or high liquid loadings were present.

CENTRIFUGAL SEPARATION ELEMENTS

Almost from the first, work was started on units that employed centrifugal force as the force for separation. There is no question that this force can produce a strong driving effect for separation, but it is accompanied by two rather limiting problems; creep and excessive pressure drop. Centrifugal separators or cyclones (as they are generally called) have been employed to do many separations and have one advantage that impaction separators do not have (acting alone), this being that dry solid particles can be effectively eliminated. The work on cyclones has proceeded and many are effectively used, but all efforts to use this method without an accompanying high pressure drop have been less than spectacular. The main reason for this disappointing result is that the efficiency of a cyclone is inversely related to the radius of curvature of the cyclone path and is dependent on the velocity in the throat and the number of turns made by the gas.

Most efficiency determinations are made empirically due to the difficulty of trying to calculate the effect of eddy turbulence and liquid or dust creep (2,5). Allowable flows are also difficult to predict since they are totally dependent on the dimensions of the device. A generalized flow formula would have little meaning.

It is the author's opinion that multiple small cyclones are the most effective way to employ the principle in pressure vessel service, and that the efficiencies obtained are in the order of 97-98 per-cent. Lower efficiencies are likely to result when large radii of curvature are employed.

PRIMARY MIST EXTRACTOR SELECTION

In order to select a mist element for any given service, the advantages and disadvantages of each type should be compared. The following table is given to aid in such a selection:

Type	Advantages	Disadvantages
Vanes	Very High Liquid Capacity Strength Positive Liquid Drainage Non-Fouling Essentially 100% Turndown Smaller Vessel Housing High Corrosion Resistance Durability High Efficiency (99.9+) High Gas Capacity	Cost Large Vertical Dimension Can't Accept Vertical Flow Moderate Toleration of Vibration
Wire Mesh	Small Vertical Dimension Cost Can Accomplish Coalescing Low Pressure Drop Moderate Flow Capacity Best in Vertical Flow High Efficiency (99.9+)	Low Liquid Capacity Very Low Tolerance of Vibration Very Subject to Fouling Low Strength Low Corrosion Resistance Moderate Turndown
Cyclones	Separates Dry Solids Good in Vibrating Service Can be Used for Slurries Non-Fouling Must Have Separate Liquid Compartment Can Be Strong	High Pressure Drop Poor Turndown Medium to Low Efficiency Subject to High Erosion

The above table can now be used to select the best primary mist extractor for any given service. List the various process requirements for the service under consideration and match the unit that best suits those requirements. Let's take a look at several common operations and see how this would be done:

1. Oil and Gas Separation: This service usually requires some residence time for gas breakout; pressure drop is not normally a prime consideration; the fluids involved can be moderately to heavy fouling and flow of gas varies with the GOR.

Solution: Since residence time is required, the size of the separator is dependent on this fact and will generally be sized for liquid retention. This would require either a vane type mist extractor or wire mesh. If the liquid to be separated is moderately fouling the wire mesh would represent a less costly installation. If heavy fouling is anticipated, the vane unit is a necessity. Either of the two would give a moderate pressure drop, and widely varying gas flow conditions would best suit the vanes.

2. Outlet Mist Extractor - Glycol Absorber: The fluid is clean and liquid loading is light. Pressure drop is generally kept low and the absorber is determined from the Souders and Brown equation.

Solution: This is well suited to a wire mesh mist extractor and overall losses could be improved with the use of an agglomerating mesh pad.

3. Compressor Inlet Separator: This service requires a strong mist extractor, and very often one that will handle large quantities of liquid. High efficiency and capacity are necessary. Since the primary reason for this device is the protection of a very expensive compressor, cost is not a prime consideration.

Solution: Here, the vane unit is clearly dictated. Strength, High Liquid Capacity, and High Efficiency are some of the main advantages of vanes. It is important that this mist extractor stay in place and mechanical strength is important to resist the vibration that is very often present.

4. Amine Plant Outlet Separator: In order to prevent high losses of valuable amine solution, this service requires high efficiency on small particles. Any mist extractor employed will require coalescing of fine particles ahead of it.

Solution: Vanes or mesh can be used, behind filters. However, if the amine carry-over contains much Iron Sulfide the non-fouling aspects of a vane would give it superiority, as well as it's corrosion resistance.

5. Pipeline Dust Separator: This use very often presents a dry dust to be separated. Pressure drop is not highly desirable but becomes necessary in this service.

Solution: A job that can be accomplished with a cyclone type separator, provided that a very high efficiency is not required. If high dust retention is necessary a vane type Filter/Separator is required.

Any equipment that is used in the field should be analyzed as has been done above and the best suited mist extractor selected. One other factor that influences the sizing of a production separator is liquid retention time. It is a mistake to assume that all oil and water or three phase separations are alike. Most operators have experienced difficult problems in the separation of oil and water or hydrocarbons and glycol. Proper time for foam or emulsion breaking is hard to estimate. Two graphs (Figures 4 & 5) have been included for this purpose. These reflect some empirical data collected over a number of years, and are intended to be a guide rather than an absolute solution. (8)

With the knowledge of particulate engineering available there are few requirements in the handling of oil and gas that can not be properly made cost effective. Try listing your requirements and a proper application can save many dollars and much time.

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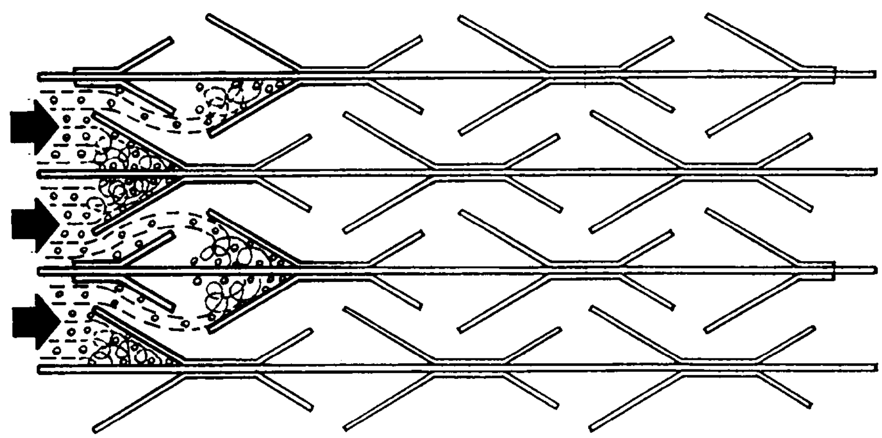

Figure 1—One example of a vane type bundle (top view) showing flow relations

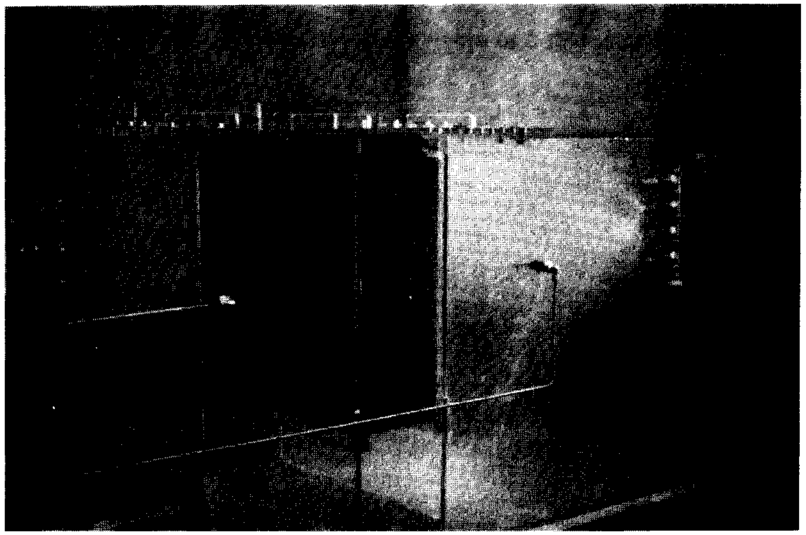

Figure 2—Vane type separator on test; note that continuous plates prevent trailing edge re-entrainment; the velocity through separator is 24 fps

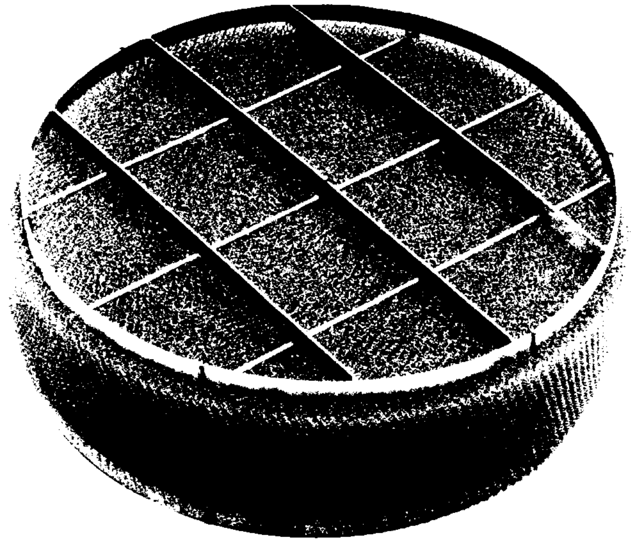

Figure 3—One example of a vertical flow wire mesh mist extractor; note hold downs to prevent mesh break-up

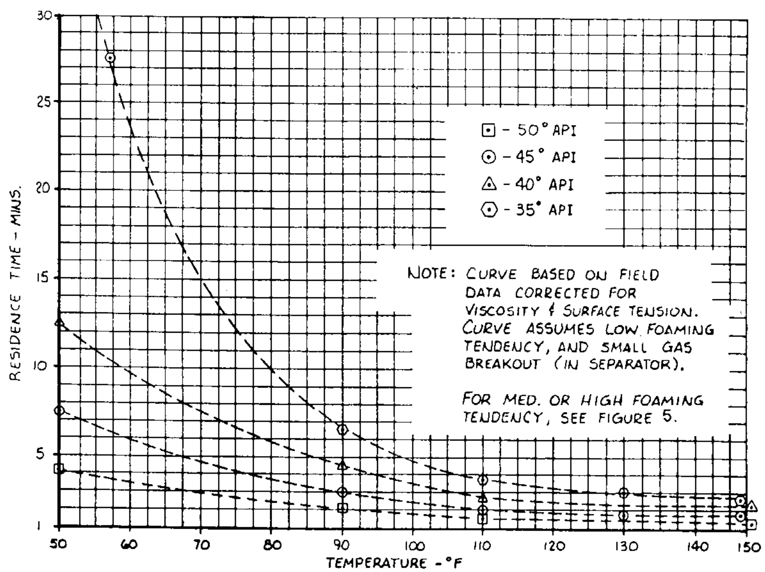

Figure 4—Suggested separator residence time for different temperatures and API gravities

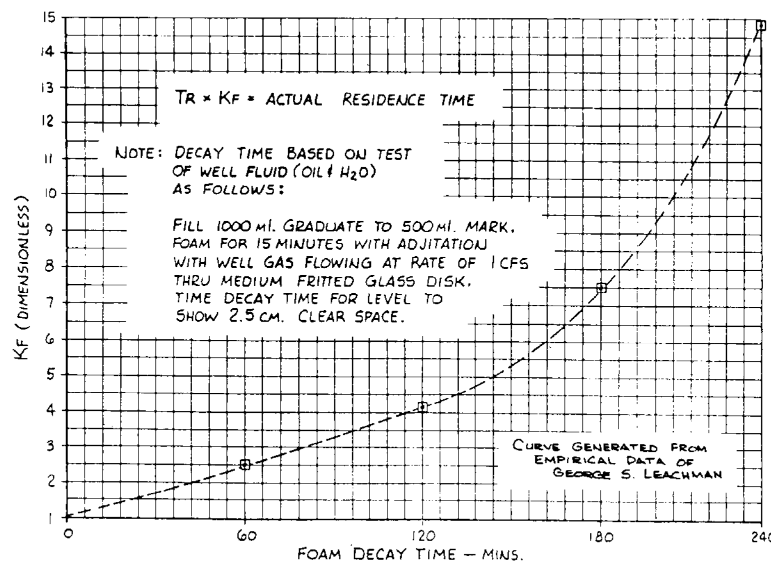

Figure 5—Correction to residence time for foaming tendency

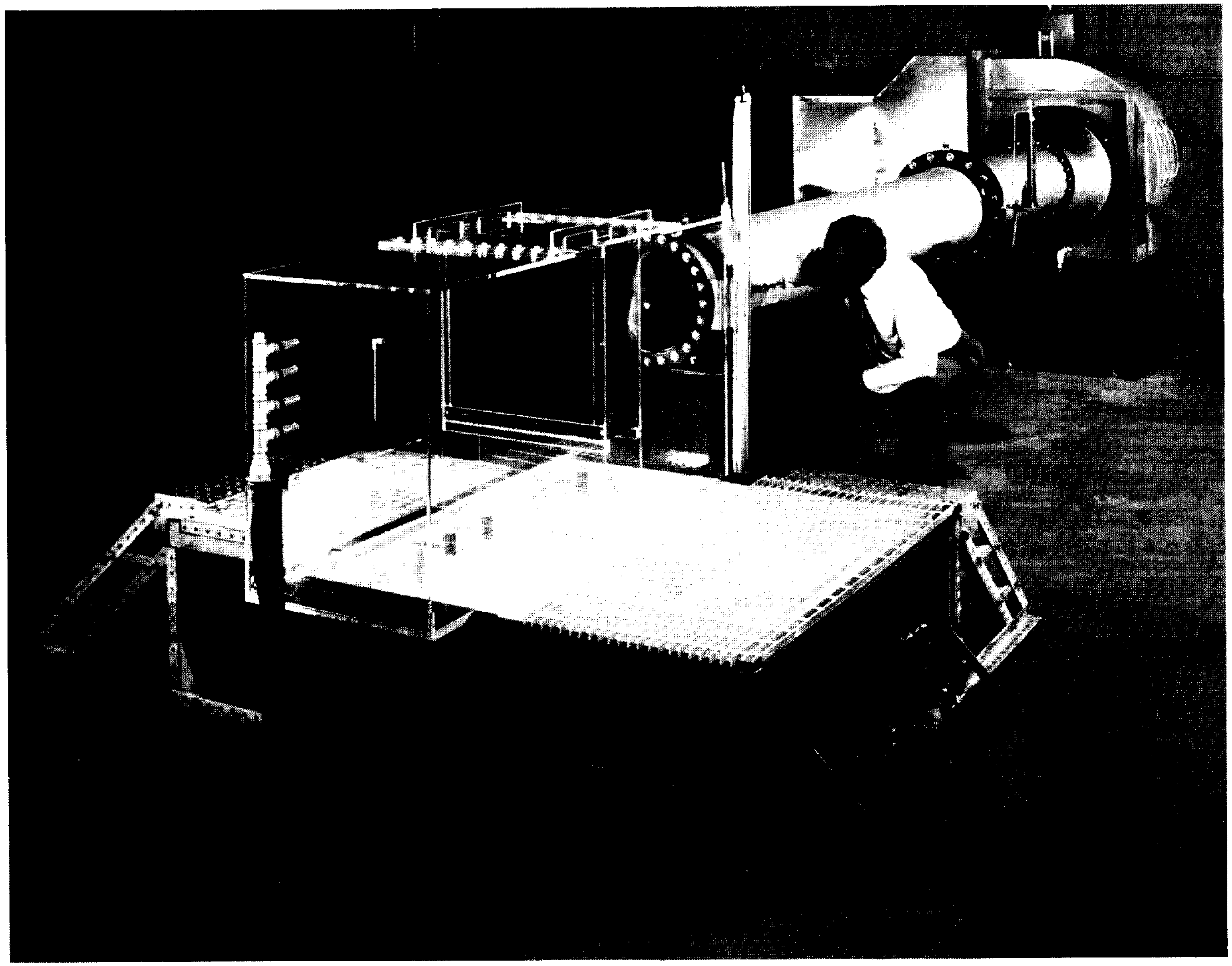

Figure 6—An example of a test facility for determination of breakthrough velocity, pressure drop, liquid capacity and efficiency of primary mist elements