APPLICATION OF OPTIMUM SIZED LOW Δ P CENTRIFUGAL DEVICES FOR HIGH EFFICIENCY SEPARATION OF LIQUIDS FROM NATURAL GAS

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This paper concerns itself with expansion of information concerning centrifugal separation equipment used in gas plants. The paper will also review basics of separation processes utilizing centrifugal force. Techniques will be described by which these and other forces combine to effect separation. It will also describe equipment proven after years of use and that has more recently been used after development efforts.

Characteristics of this equipment and evaluation of results will be presented.

General recommendations regarding application, use, and maintenance of equipment will be included in this report.

BASIC MECHANISMS OF SEPARATION

Worthwhile papers have been written concerning theory of separation. A bibliography is included for those desiring to pursue the theoretical aspects of this subject. This paper will not concern itself with the theory of drops, surface tension, coalescing, etc.

Centrifugal action is the primary mechanism used to separate droplets from gas in most of these centrifugal separators. However, other means are closely associated with this force.

Please refer to Fig. 1. It illustrates an ordinary oil/gas separator. In this illustration, gas flowing in the nozzle at the left is intercepted by the first in a series of baffles. These baffles obstruct the flow path bounded by the upper portion of the vessel and the controlled liquid level below. The baffles also change the direction of the gas containing liquid droplets. Two mechanisms are the means by which liquids are separated.

The first mechanism is impingement against the first baffle or diverter. The second mechanism is a change in direction which basically constitutes a centrifugal action. This is graphically illustrated in the lower inset. The heavier gravity liquids are thrown out of the lighter gravity gas. This takes place because of a specific gravity differential and adequate time available to traverse the necessary distance to escape by centrifugal force.

Although this separator is not thought of as a centrifugal separator, centrifugal action does take part in the separation process. As the liquid approaches the baffle opening at a velocity V (V being the vector representation), and as the liquid direction is changed to V_2, the droplets experience a centrifugal force (represented in direction by V). The same is true for the gas. The gravity difference is what causes the separation.

Fig. 2 is an example of a typical centrifugal separator. Gas enters at the inlet flange in the top view and proceeds through the nozzle neck. The nozzle neck directs the flow tangentially onto the wall and around the diameter of the vessel. The gas continues downward in a rotary motion and then changes direction to exit through the central nozzle in an upward direction. A liquid level is maintained in the lower part of the separator vessel by a level control.

Another type separator is illustrated in Fig. 3. It shows equipment utilizing the forces resulting from impingement and centrifugal action. Gas flow containing the liquid droplets is directed against a formed head. The separation process is by impingement removing the larger drops in the initial stage. With the louvers being placed as they are in the internal member, a rotary motion is imparted to the gas. The liquid is thrown to the outer wall by centrifugal action. The lighter gas is swept inward by the louvers to the center tube to exit at the right. The brim of the hat-shaped louver internal with its section of louvers does the same as the axial louvers. In addition, this brim is a barrier preventing liquid from being reentrained at the outer diameter. Liquid is removed at the drain on right.

Fig. 4 illustrates still another type of separator. It utilizes centrifugal action and change of direction in the early stage. Another separation mechanism, coalescing, is utilized in a later stage. Most of the liquid has been removed in the initial stage. Parallel plates, then controlling gas flow, direct a reversing motion. The liquid drops remaining in the gas are swept across the plate surface. At this point, both coalescing and centrifugal action cause and promote the growth of droplets. This liquid is entrapped in the containment troughs. The liquid accumulates and drains by gravity to a collection area at the base of the parallel plates. Liquid is drawn from the base of the parallel plates via a drain tube to the liquid reservoir below.

Coalescing, as it occurs on the parallel plates mentioned earlier, is the mechanism by which liquid, in minute drops which normally "float" through a separator will instead, collect at a surface. There, they join to form larger separable size droplets. One might imagine water blown on a table surface to visualize this effect. Surface tension contributes to holding the liquid on the surface.

Without going into detailed physics, we have reviewed several of the mechanisms by which liquids are separated from gas. In summary, these mechanisms are as follows:

1. Change of Direction
2. Centrifugal Force
3. Impingement
4. Coalescing
5. Gravity

These five mechanisms are the most commonly utilized and often combined forces in the separation process.

Centrifugal action is the primary force and is the dynamic force in almost all gas/liquid separators used in the field. This is true for types of separators discussed in this paper.

These separators have limits of high liquid volume and small micron size droplets. Any condition permitting large "slugs" of liquid to hit a separator sized for a <u>normal</u> volume will result in spillage. The separator is not sized to handle excess volume created unless specially equipped separator vessels are used. At the other end of the spectrum, small amounts of liquid in the form of micron size droplets will "float" through, riding the gas flow stream. This makes the separation ineffective for some uses. Means to extend these ranges will be described later in this paper. The limitation of efficient range of operation is a problem all separator designers confront.

In the course of explaining the basics of separation, some of the more conventional types of centrifugal separators have been described.

Fig. 5 considers the manner in which a unique separator is built to "enhance the chance" of collecting "mist" or "fog" micron size particles. The overall efficiency is increased by providing ample means for small droplets to coalesce on a vessel wall or on a mesh surface.

Now, let us examine the function of the mesh. Although the mesh provides the large surface area for liquids to condense or coalesce on, and although it does a good job where flow is maintained uniformly, a disadvantage occurs when large range of flow is required. Normally, as minute droplets occur on a surface they combine with other droplets increasing their weight. They gain weight resulting in a fall by gravity against or perpendicular to the flow of the gas. At this time, the droplets are heavy enough to fall out of the gas stream. However, flow ranges below the design condition allow droplets to "float" through the mesh doing no effective good. Flow ranges higher than the designed flow range will actually blow the coalesced drops thru the mesh. In either case, the efficiency of removal is very much reduced

Referring to Fig. 5, the effiency is better when the coalesced drops are allowed to stay on the vessel wall and be swept in the direction of the liquid reservoir. And, importantly, the liquid reservoirs (Fig. 5) are removed from any area of turbulence that might cause reentrainment. The ports shown on the exit tube even permit gas breaking out of the separated liquid to flow freely to the exit tube without causing counterflow.

Fig. 5 is a unique two-stage device. First, there is an impingement and a centrifugal stage. Second, there is a helical screw causing centrifugal action again with coalescing. All small droplets tend to migrate under centrifugal forces. This is due to relatively high velocity in the screw. Coalescence and agglomeration takes place on the ample wall available to the liquid. The enlarged droplets are separated as previously discussed in this paper.

The separator described in Fig. 5 functions best in a vertical position, unlike many other separators.

In the course of the development of this screw section, slots have been placed in the outer wall to permit moisture to escape outwardly. This results in excess recycling of gas, more pressure drop, and less than optimum efficiency. This is often due to problems of fabrications causing reentrainment.

The entire separator in Fig. 5 is generally designed to handle gas as limited by the inlet flange.

In separators of this type it has been shown by efficiency calculations that there is an ideal velocity through the screw. Maximum of small micron particles will be collected, coalesced, and (within this type of collector) removed at the ideal velocity. It can be shown by calculation and test that within a relatively small number of flights, virtually all of the separation can be accomplished. (A "flight" is 360° of rotation.)

One example is a tandem separator which includes a cone and two flights of screw section. A gas velocity of 125 ft./second should remove 99.9 percent of the entering liquid, nominally "mist" or "fog."

Conceivably, the containing tube of screws of this type and vessel walls of a more conventional type separator would operate more efficiently with a "wetted" surface. This will theoretically promote surface tension "snaring" of the minute liquid amounts if this is the design intent of the equipment. The desired removal efficiency must justify the cost.

Fig. 6 illustrates a device similar to that of Fig. 5 with minor modifications. The first stage is omitted in this device. Any given size screw would control operation within certain volume-efficient limits. The separator is sized "keying" on a nominal pipe size. This sizing includes the relatively narrow neck containing the screw. By utilizing three paths within that area and selecting any one, any two, or all three paths, the proper velocity for efficient liquid removal can be controlled over a larger range up to the maximumn range. However, this operation involves a modification of the equipment in the field. A plug (or plugs) is placed in the desired flow path for less than the maximum flow rate. In this form, (shown in Fig. 6) the device can accept less than major slugging from gas containing small amounts of liquid but yielding little in the way of moisture to the outlet.

APPLICATION OF SEPARATORS

This centrifugal equipment, as a general statement, when properly designed and sized can remove up to the 99 percent efficiency range. This is adaquate in many applications. Consider an inlet separator to an amine or glycol plant. Normally, an inlet separator will require extraction of a major amount of liquids but not demand service in the 99.9 percent efficiency range.

The type and distance to other facilities upstream of an inlet should be considered. An outlet separator from a plant, on the other hand, will require the higher efficiency range prior to the gas entering the sales line.

Remember, when applying this equipment to various plant services, liquid in a gas stream is not homogeneous in either size or shape. There are large and small drops in a typical untreated stream with a random distribution of drop size. Realistically 100 percent of a large droplet size may likely be removed or broken up in a given separator. A very small percentage of smaller size droplets may be collected. Statistically, the percent of the entering liquid removed is what we normally consider in final analysis. In order to get a larger percent of the liquid, it is necessary to remove a bigger percent of a smaller micron drop size, at which point a filter separator should be added in tandem. The same containing vessel may house separator and filters. Molecular sieves are another option to filters. Removal of drops by a screw separator has been represented by numerous calculations and statistical data and verfied by actual results. Equipment normally has to be sized and worked over a narrower spectrum to separate liquid and gas in tighter efficiency range. This is true unless certain characteristics are built into the equipment.

Questions that arise are: What are the "slugging" characteristics of the inlet stream? Can the resulting moisture content of the leaving stream be averaged out to meet line specification? Is it a continuous monitoring shutdown system in effect that controls the system? Can the normally escaping liquids be "averaged out" which would prove less critical for controlling the tight efficiency ranges?

What are the effects of pressure drops within the separator? Is the separator a plant between the wellhead and the sales line with ample or with a marginal difference of pressure? Is the application in a plant or in a transmission line where loss of pressure has to be made up by horsepower? Does the separator inherently have a large pressure drop?

Does the inlet flow fluctuate widely? Must liquid removal remain high during this fluctuation? Must liquid removal remain efficient at high pressure, low volume condition as well as low pressure, high volume condition? This is a difficult situation encountered in transmission lines.

What are the critical aspects of the equipment's operation? Can liquids escaping the separator cause damage to a compressor installed downstream? Is equipment sized on a normal or an upset condition basis? Is the operation of a facility on an attended or an unattended basis? Equipment should be sized on the basis of the upset condition, unless the excess liquid caused by a cleaning of a low spot in a line is of no consequence. Can large liquid knockouts be placed prior to and near enough to the separator? Some users actually permit these line upsets provided the receiving pipeline does not raise a "red" flag. The amount of excess liquid lost to a sales line may go unnoticed when the liquid is comingled with other's production. This is considered a risky practice.

Will maintenance of the equipment present any problems? What will be the consequences and the frequency of failures and will they be occuring suddenly?

Can fluid levels in liquid resevoirs be controlled satisfactorily or is the control effected by turbulence? What are the physical limitations of the separator? Some equipment is much smaller in diameter, an advantage particularly on offshore platforms. If unusually large volumes of liquid must be handled, the effective dumping of the liquid can require larger reservoir irrespective of the separator. Are there likely to be H_2S clogging problems such as is experienced in mesh materials? This often causes foaming problems.

The previous questions and comments refer to separators and their installations in general terms. Considerations which should be given to the types of separators described earlier in this paper are as follows.

Fabricated elements directing centrifugal flow will influence centrifugal action, consequently resulting separation and back pressure. The tangential entry is intended to cause agglomeration and coalescing of drops on internal walls. Fabrication irregularities will prevent normal flow and cause turbulance, a breakup of drops, and reentrainment. Progressive wall erosion will cause a fall in efficiency, increase in pressure drop, and even a dangerously thin wall.

The separator shown in Fig. 2 requires accurate tangential elements of construction for the entry of the inlet flow. It is occasionally intended to provide a less turbulent condition in the separators. This is accomplished by creating a transition piece which is round at the nozzle flange and thin rectangular in shape at the entry to the vessel, thus less turbulent. This transition piece is difficult and expensive to make, but very efficient. A casting is suitable for this application. Modification in the field, in either case, will likely result in a significant change in performance.

Separators of this configuration will require a vortex breaker. A fluid level elevated at the outer periphery in a turbulent area will result in reentrainment. An internally mounted float for level control, normally, is <u>less</u> desirable than an externally mounted one. This is because difficulty is encountered reading a true level in turbulent areas. An external float provides more stable control both in this and most other separators. The length of the separator should provide for separation of the turbulent gas and the liquid level.

Fig. 4 illustrates a style of separator with closely spaced parallel plates. It is a relatively efficient separator over large ranges. This type separator inherently has little pressure drop. Maintenance may be necessary if foreign matter is encountered in the separator. However, this is not an excessive maintenance problem. The plates should be short in height. The liquid collected in each entrainment flows from the top of the vane downward to the bottom encasement. There are two factors contributing to vane ineffeciency. The first is liquid overflowing the entrapment before reaching the collector at the bottom. The second is slugging.

A problem with vanes (as in Fig. 4) occurs when water and hydrocarbon liquids have to be separated from gas. There is a strong tendency for the hydrocarbon to coat the metal surface, thus allowing water to slip over the hydrocarbon and past the vanes, resulting in appreciable drop in efficiency.

The separator in Fig. 5 must be fabricated accurately to perform up to its capability. The turbobaffle of stage 1 must be shaped to induce separation and centrifugal flow without undue pressure drop. The flow sweep is intended to cause a film at high gas velocity, necessitating a clean wall. Irregularities will cause the typical problems of turbulance. A pipe end is intended to split and divide moisture laden gas from drier gas in the second stage of this equipment (the split after the centrifugal action of the screw). Poor axial allignment of internal elements and poorly formed edges are critical and will cause poor performance. Modification, or what is intended to be a simple field repair, although undertaken with the best of intentions can, in fact, result in poor performance.

Tubular elements are sized to result in specific and related flow areas. An alteration of a wall thickness can effect performance.

Illustration Fig. 5 shows separators are about half the diameter and significantly more efficient when compared to horizontal separators sized to handle the same capacity. This configuration with its special means of control, has been tested successfully in field use and is particularly advantageous if large slugs are a problem. A valve in the separator inlet line senses a predetermined high level point in the first stage liquid reservoir. The valve automatically restricts open flow until the upset condition slug is passed safely through the reservoir and liquid level returns to normal.

One application in a transmission line is typical of a problem encountered by a user. Nominal gas delivery is often at a maximum of 100 MMSCFD of gas at a reduced pressure of 100 PSI because of line "drawdown". The user specification was to handle the same 100 MMSCFD of gas at 1000 PSI. This requirement has been continuously handled in a 10 in. flanged, 24 in. diameter separator maintaining 10 lbs/MMSCFD of gas (7 grain/100 SCF), over the entire range.

Equipment in Fig. 5 capitalizes on a change of direction in both stages to separate liquid and gas. This is true of most other separators with the difference that the reservoirs are removed from the turbulance of the gas flow. The reservoir is sized to accomodate an internal float. An internal float is acceptable in this separator in both reservoirs because turbulence will not effect control.

In both stages of separation, the liquids are swept away from the flow of gas. These liquids are swept sway as a film on a wall beyond the area of gas reversal. This permits an equal efficiency in separating, liquid hydrocarbons, water, or both.

Separators in Fig. 6 are used most often in gas transmission lines. They are added in tandem to equipment previously installed by others to "clean up" spillage. On occasion, they have been mounted within the vessel walls of other inadequate separators.

Horizontal separators are utilized to separate rich amine or glycol between stages of contactors as illustrated in Fig. 7. The lean amine or glycol injection is made at the entry of the contactor. Complete mixture is accomplished in the first (enlarged) section. The following screw section and its liquid collector will extract a very large amount of liquids. A high efficiency is not required for this application because additional lean fluids are injected in a second stage. This equipment is built with two or even three stages utilizing a more efficient vertical separator after the final stage.

Liquid removal in quantity is the primary concern in this application. An adequately large liquid reservoir is needed for each stage of separation.

RECOMMENDATIONS

The following considerations are recommended prior to purchasing a centrifugal separator:

1) Review the specifications for the gas to be delivered.

2) Select equipment most suitable for specific needs. Equipment should be supported by information indicating the necessary performance level will be achieved throughout anticipated range of operation and in the manner it will be used.

3) Consider maintenance problems which might be encountered.

4) Consider the physical installation of the equipment.

5) Equip and instrument the separator adequately to permit it's proper use.

6) Determine if improved operational value is justified by the additional cost of equipment and its installation.

Equipment that is understood, selected, and used properly will provide long satisfactory service.

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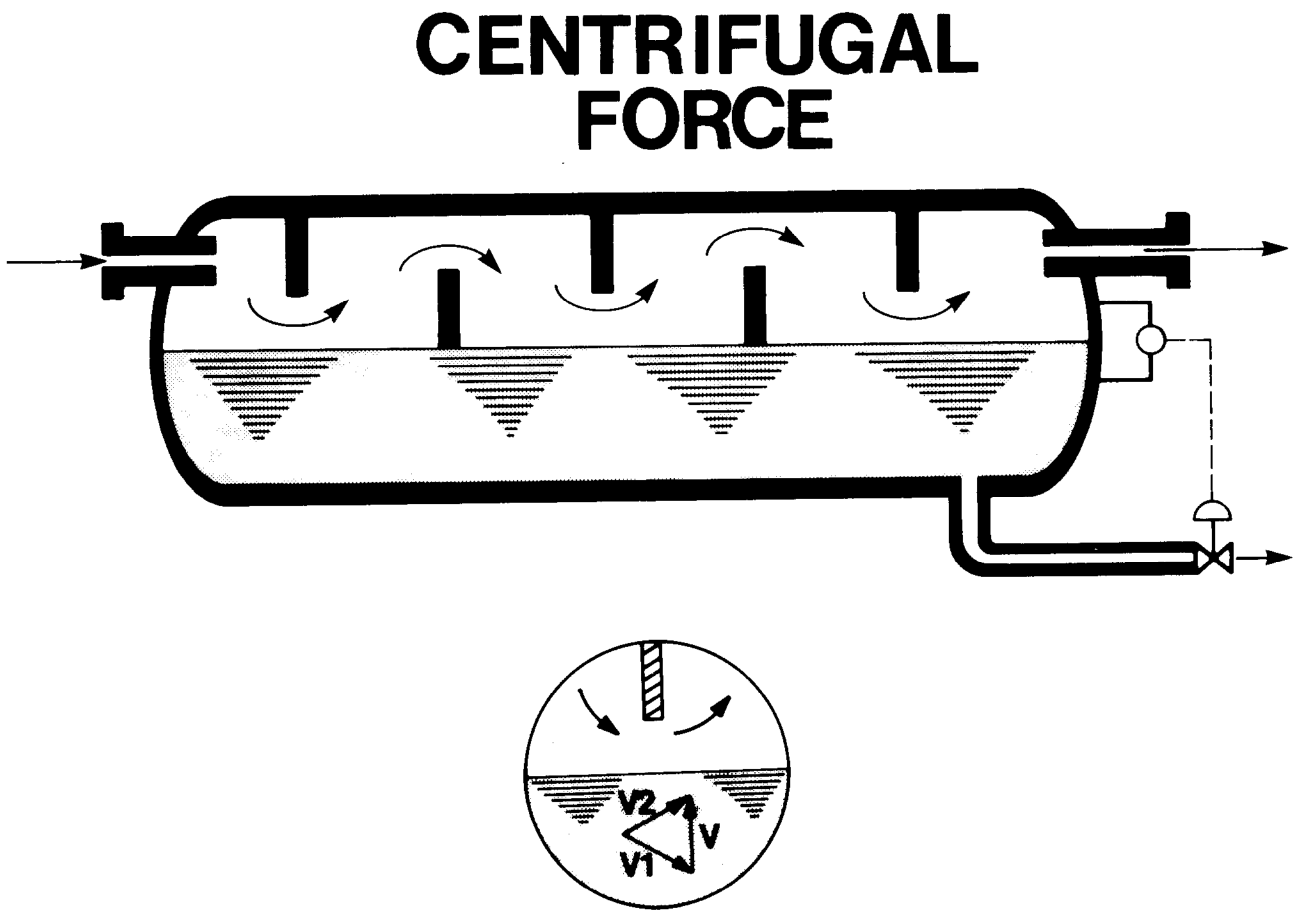

FIGURE 1

SEPARATOR

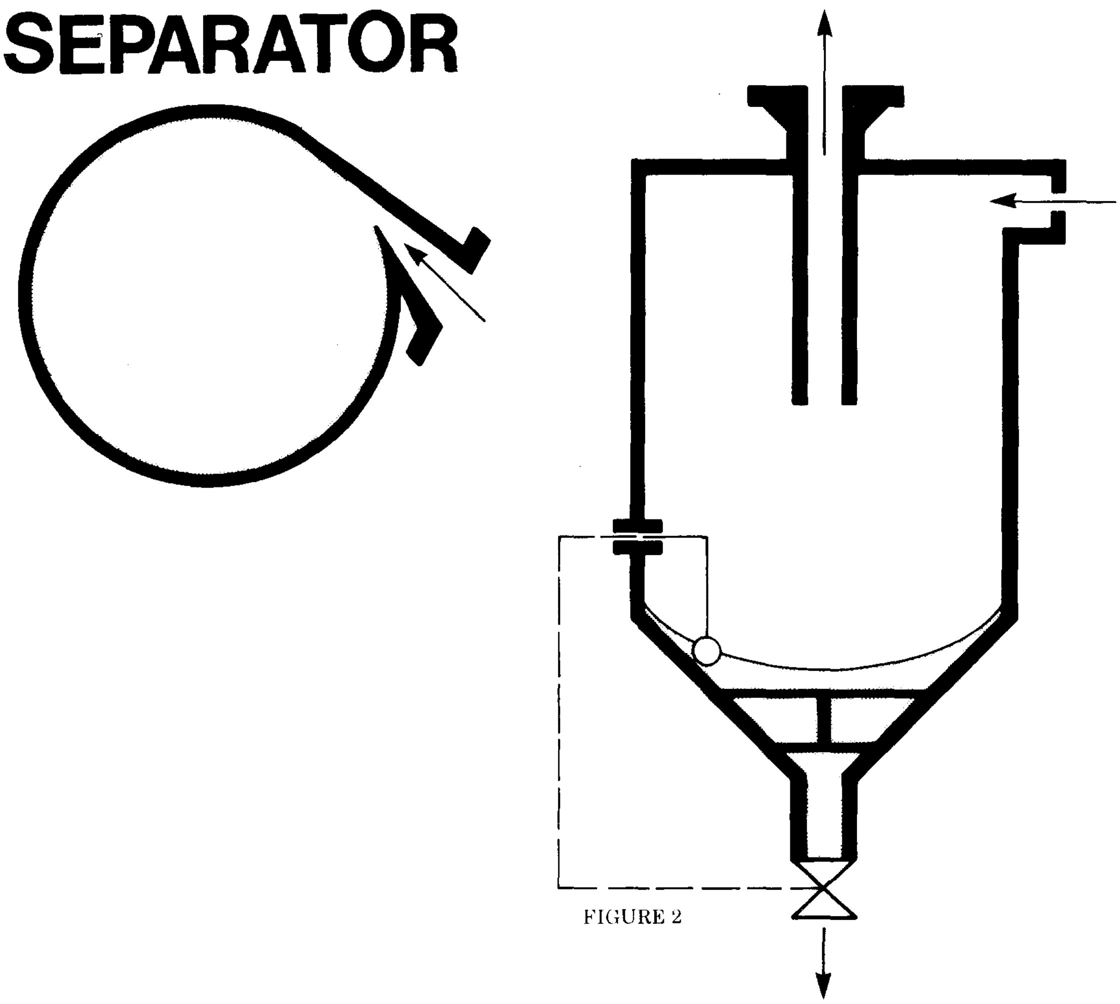

FIGURE 2

SEPARATOR

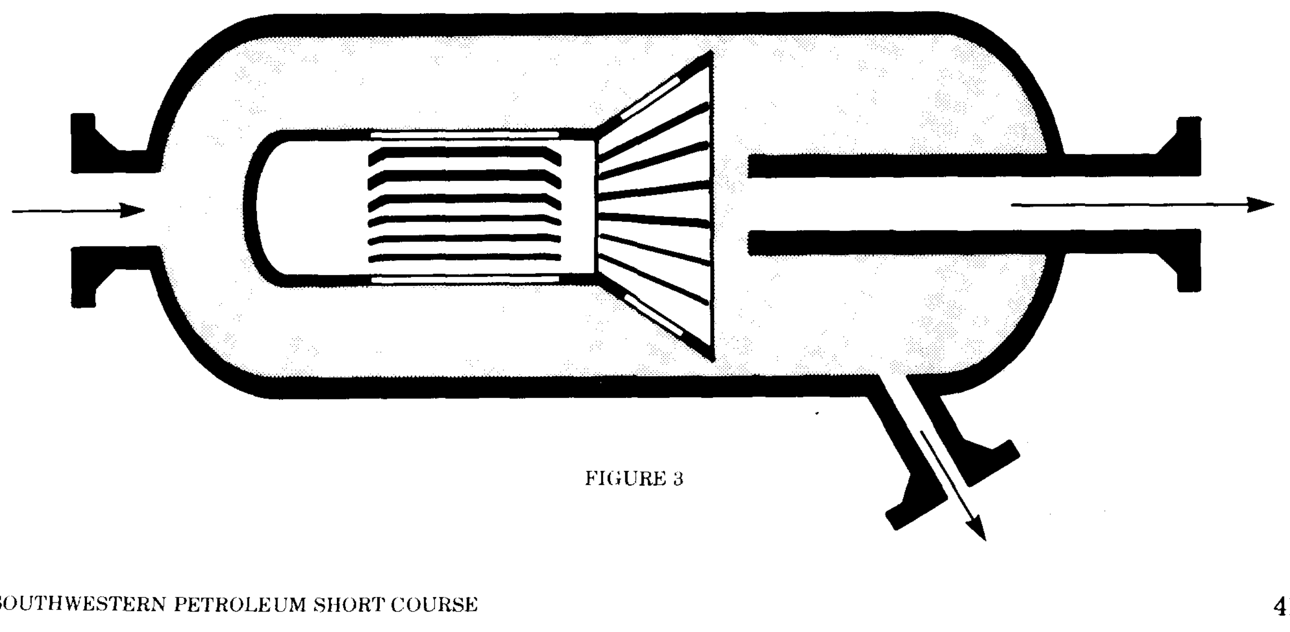

FIGURE 3

VERTICAL GAS SEPARATOR

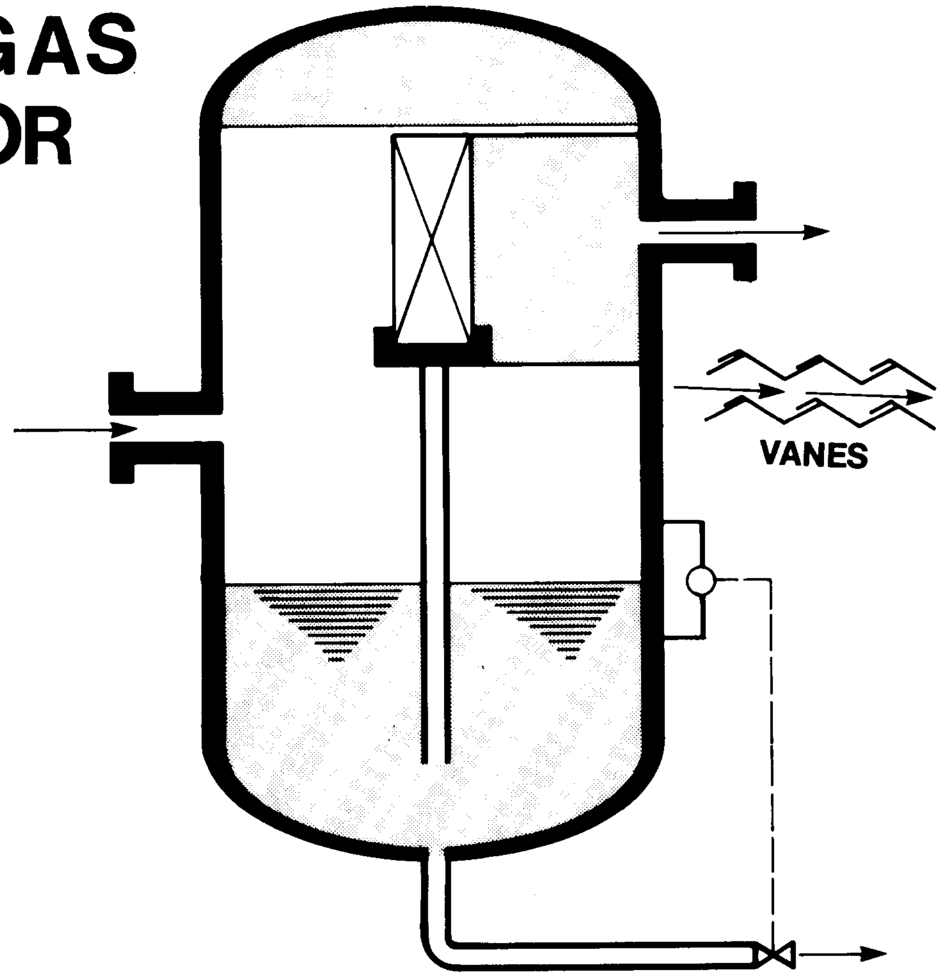

FIGURE 4

TANDEM SEPARATOR

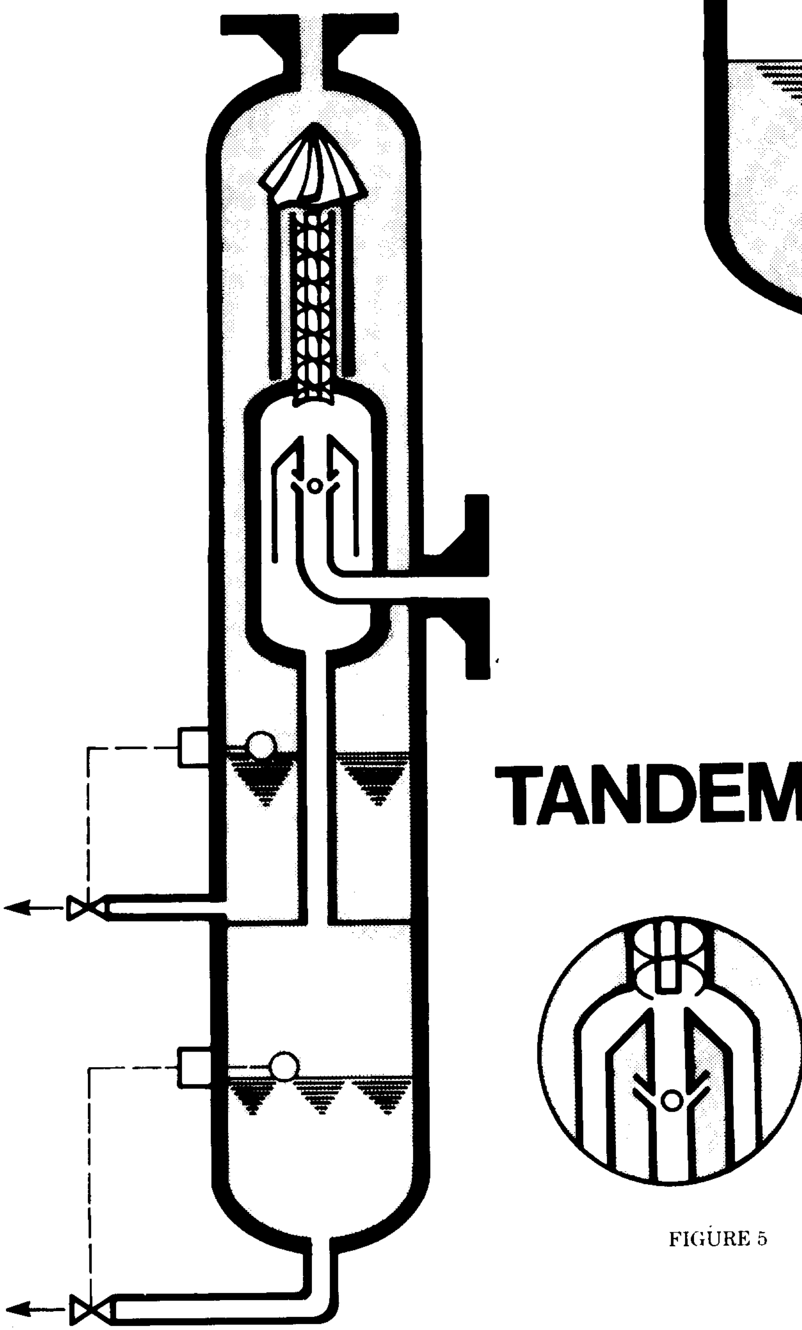

FIGURE 5

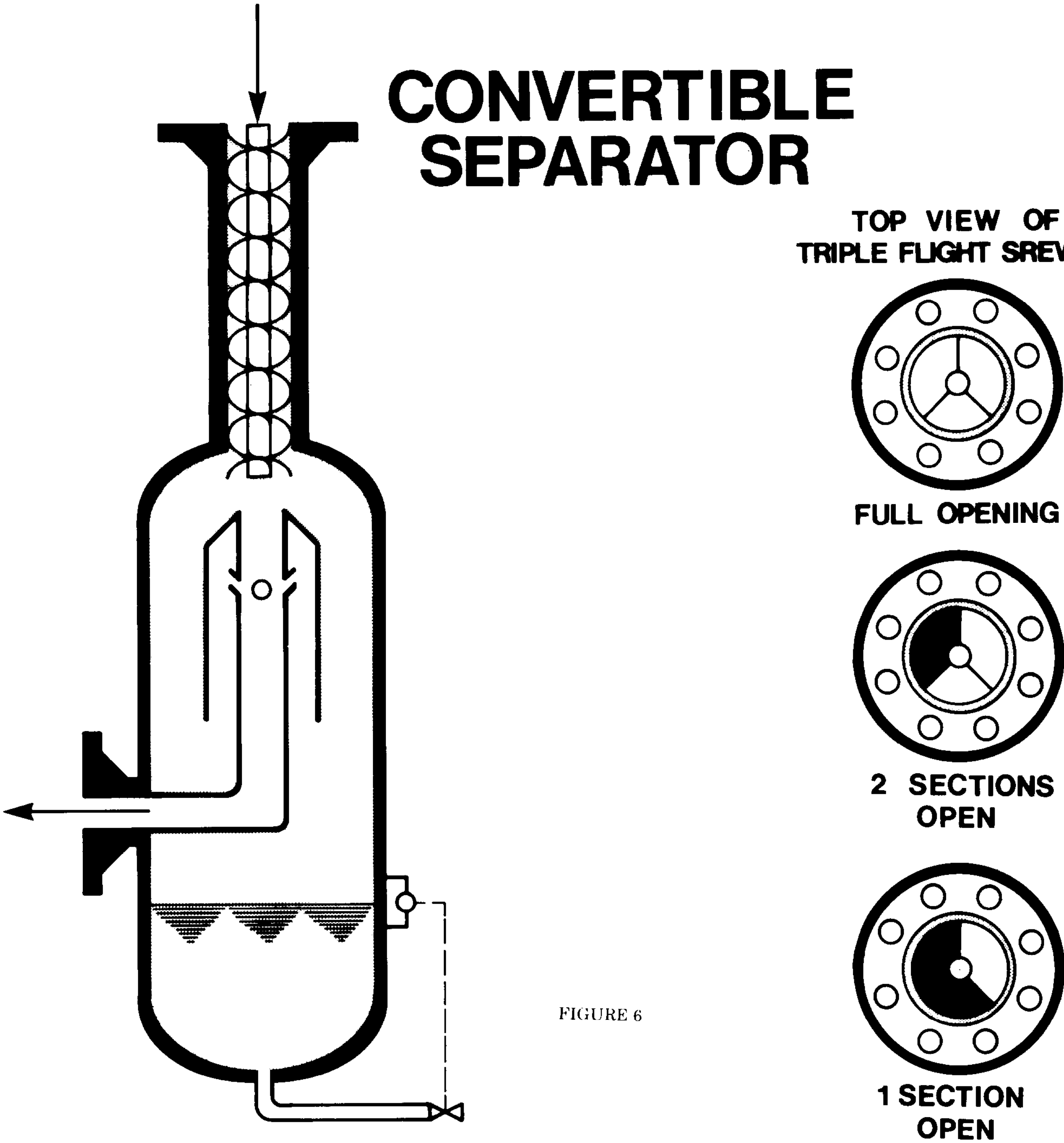

FIGURE 6

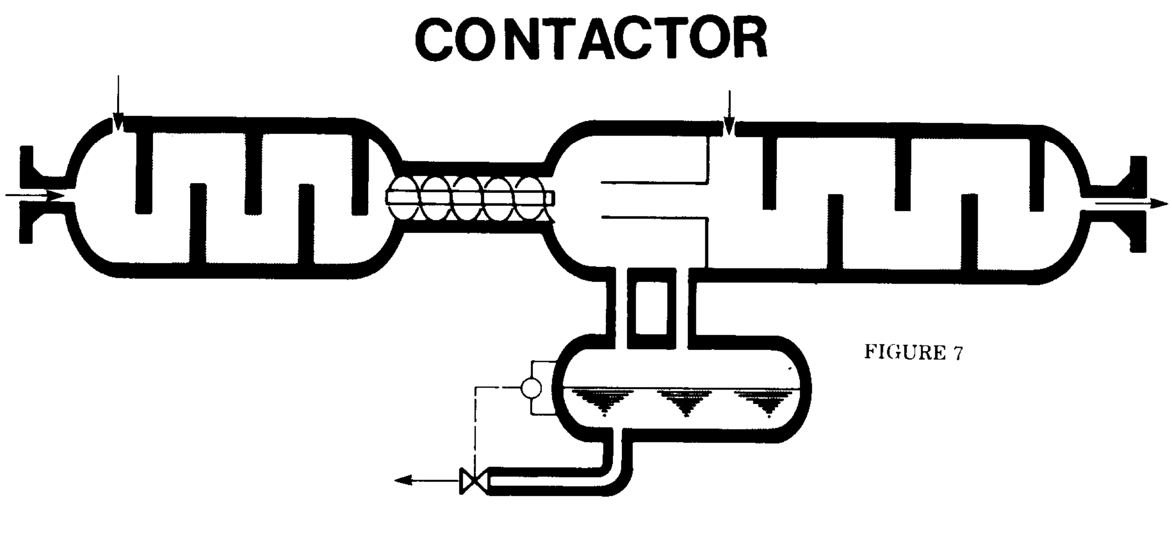

FIGURE 7