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EFFECT OF DESIGN PARAMETERS ON THE SEPARATION EFFICIENCY OF VERTICAL GAS/LIQUID SEPARATOR IN OIL GAS PIPELINE

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Abstract

The main objective of this work is to size a vertical axis gas liquid separator to separate gas and liquid on a long distance in gas-liquid pipelines. This is necessary to ensure the safe operation of the compressors used along the pipelines.

The separator equipped with wave plate demister (vane pack) as the secondary separator.

The design is achieved through investigation of the parameters which has an effect on the separation efficiency of the separator. In this study, inlet pipe diameter, vessel bend spacing, vane pack bend angle, momentum breaker, vane pack plate spacing, and the number of bends in pack were used. From the results of this study overall separation efficiency of 99.99% has been achieved.

KEYWORDS: *phase separation, efficiency, vertical separator, vane pack.*

1. Introduction

Phase separators, particularly gas / liquid two-phase separators, are employed in a very wide range of industries. They can range from the small size application to large vessel employ on offshore oil production platforms or slug catchers at the shore terminals of undersea transmission pipelines.

Phase separator separates the well fluids into gas and liquid. A two-phase separator can be horizontal, vertical or spherical. The liquid (oil, emulsion) leaves the vessel at the bottom through a level-control or dump valve. The gas leaves the vessel at the top, passing through a mist extractor to remove the small liquid droplets in the gas. The mechanisms of phase separation employed include setting under the action of gravity or centrifugal forces and impaction onto solid surfaces.

1.1. Separator Type

There is primary (gravity) separator (vertical or horizontal) and secondary separator or demister employed for phase separation. The sizes of drop which can be removed from the gas phase can vary over a wide range in demister, depending on their form of source. According to their size, it can be classified as a rough approximation; those above 10 μ m are referred to as sprays, below these range droplets are regarded as mists or aerosols. Sprays and mists are not uniform but always consist of drops of a distribution of sizes.

The type of demister used will rely on the drop size distribution of the mist and the efficiency required. A combination of types will be employed in many cases. Gravity separator or cyclones are used if the mist with drops above 100 μm a unit capable of handling finer drops followed should be necessary. Therefore, for finer drops, whether the main part of the mist or the tail of a coarser mist, wave plate or mesh pad demisters or axial flow cyclones are suggested.

Wave plate demisters or separators (also known as vane pack demisters) are composed of series of wave plates laid side by side. The inability of drops to follow the gas through the plates can determine the effectiveness of wave plate. The drops tend to follow a straighter line, impinge on the wall and drain away. Additional features are employed in the form of recessed of protruding channels to assist drainage of the liquid, shown in Figure (1).

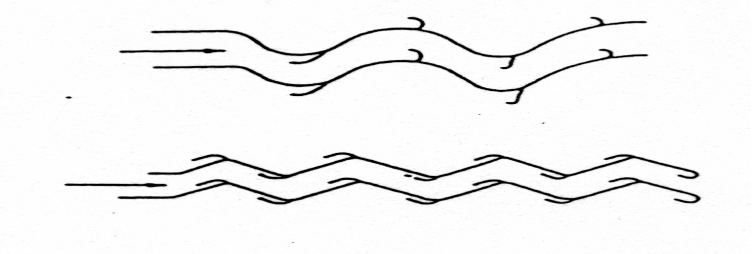

Figure (1) arrangement of typical wave plate

The wave plate units are operated with vertical flow or horizontal flow. In the case of vertical flow the collected liquid has drain counter-currently to the gas flow. Consequently, there is a limitation that is counter-current flow limitation or flooding when the gas begins to hold liquid up with it. But for horizontal gas flow, liquid drainage is obviously perpendicular to the gas flow. In both cases local re-entrainment and loss of efficiency can be cause by the accumulation of liquid.

The bend angle, the plate spacing and the approach velocity of the gas are the important parameters of the wave plate geometry. Excepting grade efficiency, pressure drop through the demister is also important parameter.

The main problem of drop removal is related to the fact that the effectiveness of many separators is decisively affected by the individual drop size. For a given configuration of demister, the fractional separation efficiency represents the probability of a drop with a given size being retained in the separator. The curve obtained by plotting the fractional separation efficiency as a function of particle size is called fractional separation curve. This can be combined with the particle size distribution to give the effectiveness of a specific separator with a particular laden gas flow. If a given contaminant is to be fully separated, the entire fractional separation curve must lie on the left of the oversize cumulative distribution curve. On the other hand, if the fractional separation curve lies on the right of the oversize cumulative distribution curve, no separation occurs at all, i.e. the separator is totally ineffective. Frequently the two curves overlap, and partial separation takes place Figure (2). The overall separation efficiency η_O is calculated from the fractional separation efficiency η_F :

$$\eta_O = \int_{d_{\min}}^{d_{\max}} \eta_F \, v(d)\, dd \qquad (1)$$

The integration is performed from the smallest to the largest particle diameter. However, for the practical purposes, it is sufficient if the particle size distribution and the fractional separation efficiency are available in graphical form. The approximate overall separation efficiency is then calculated from the following equation:

$$\eta_O = \sum \eta_F \, v_i \qquad (2)$$

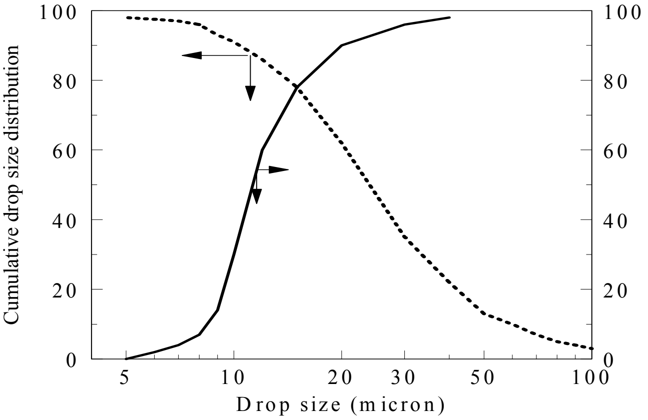

Figure (2) Particle size distribution curve and fractional separation efficiency curve

From the above it can be seen that sufficiently large drops are always completely separated while small drops can escape separation altogether. However, what the meaning of large and small is depends on the particular piece of equipment.

Typical grade efficiency curves for wave plates, measured by Azzopardi *et al.* (2000) are shown in Figure (3) where the effect of gas velocity can be seen. As well as data from plain wave plates, the figure also shows data from a unit with drainage channels or hooks. These results were taken on a carefully designed wind tunnel, which provided (nearly) saturated air to minimize evaporation of the drops. The drop flow was sampled before and after the demister and sorted into sizes. From this the grade efficiency could be determined.

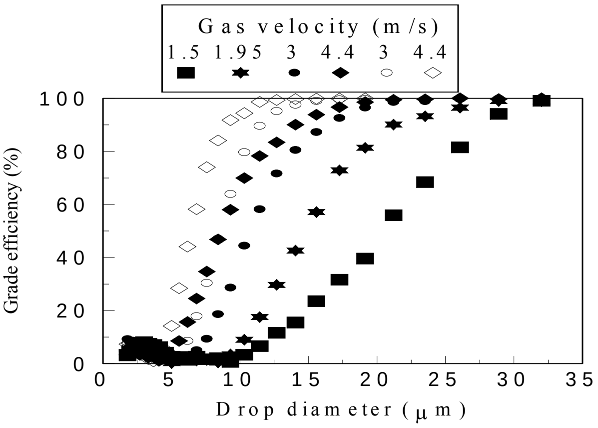

Figure (3) Effect of gas velocity and wave plate geometry on grade efficiency for wave plate demisters.

The occurrence of re-entrainment in wave plate demisters has been studied by Houghton and Radford (1939), Monat et al. (1986), Verlaan (1991) and Sanaullah and Azzopardi (1999). For vertical wave plates (gas up flow, downwards drainage of the liquid) the mechanism for the decrease in efficiency has been attributed to flooding of the draining film by the upward shear of the gas, Verlaan (1991). Flooding is the condition at which an upwards gas flow starts to prevent the down flow of liquid. From their experiments with air/water at ambient conditions, Monat *et al.* (1986) proposed that re-entrainment would occur when a critical value of dimensionless re-entrainment number ($U_g^4\rho_g^2/\rho_l g\sigma$) was exceeded. This group is the fourth power of the dimensionless velocity, usually called the Kutateladze number, a parameter much used in the analysis of flooding processes. For horizontal systems Sanaullah and Azzopardi (1999) propose that it is the centrifugal forces on the film as it goes around a corner that causes re-entrainment. They propose a simple model which successfully describes the limiting gas flow determined experimentally.

1.2. Pressure Drop

Pressure drop across the unit is another important design parameter. A correlation has been proposed by Wilkinson (1999) which predicts a large bank of data from plain wave plates to within +26/-37% with all data being encompassed by ~±53%. More interestingly, Burkholz (1989) has proposed that pressure drop correlates well with the drop diameter for which the collection efficiency is 50%. Figure (4) show that data from both plain wave plates and those with drainage channels both lie on one line when plotted in this way.

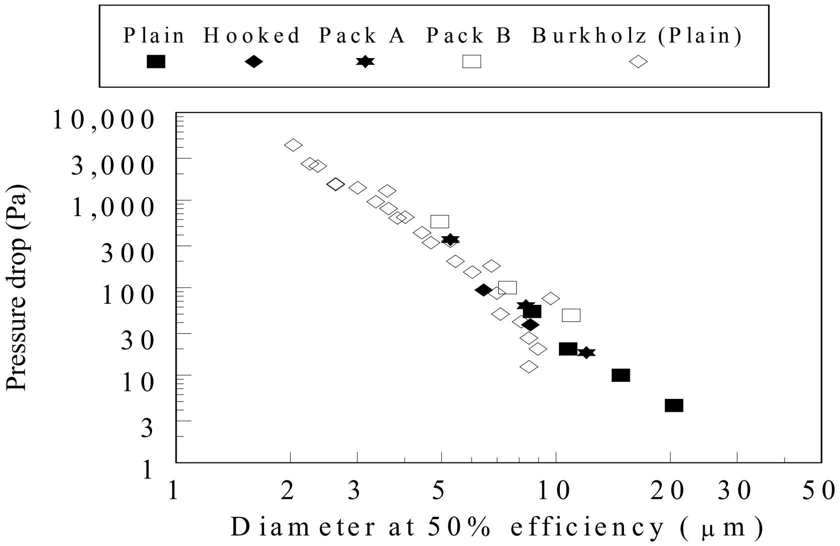

Figure (4) correlation of pressure drop with drop size whose collection efficiency is 50%.

1.3. Diameter and Height of Vessel:

Sinnott (1999) suggested that the settling velocity of the liquid droplets for the design of separation vessels can be estimated by the equation (3) given below:

$$Ut = k \cdot \left(\frac{\rho_l - \rho_g}{\rho_g} \right)^{0.5} \qquad (3)$$

Where U_t= settling velocity (m/s)
k = 0. 07
ρl = liquid density (kg/m^3)
ρg = gas density (kg/m^3)

The diameter of the vessel must be large enough to show the gas down to below the velocity at which the particles will settle out.

Therefore, the minimum allowable diameter can be calculated by the following equation:

$$D_v = \{4V_v/\pi\ U_t\}^{0.5} \qquad (4)$$

Where D_v= minimum vessel diameter, m
V_v=gas volumetric flow rate, m^3/s

The height of the vessel can be found from the optimum length to diameter ratio as a summarized in table (1):

Table(1) the range of optimum L/D ratio for vertical separator

Operating pressure range(barg)	Optimum L/
Atmospheric pressure to 17 barg	≤ 3
18 barg to 34 barg	≤ 4
Higher than 35 barg	≤ 5

2. Experimental Facility

A schematic of a vertical separator is shown in Figure (5) the inlet flow enters the vessel through the side. The inlet diverter does the initial gross separation. Liquid flows down to the liquid collection section of the vessel, then go down to the liquid outlet. When liquid reaches equilibrium, gas bubbles flow counter to the direction of liquid flow and eventually migrate to the vapor space. Then liquid leaves the vessel through the liquid dump valve, which is regulated by a level controller. The level controller senses changes in liquid level and controls the dump valve accordingly.

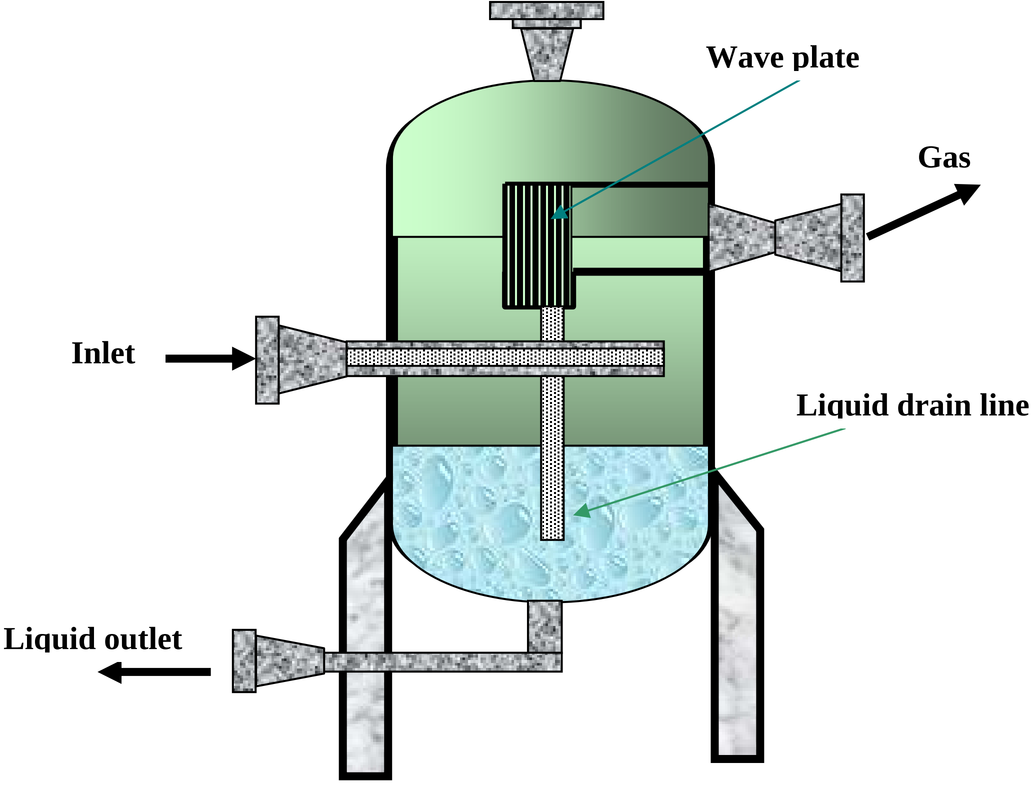

Figure (5) Vertical separator for gas/liquid separation

Gas flows over the inlet diverter and then up toward the gas outlet. In the gravity setting section, the liquid drops fall downward, counter to gas flow. Gas goes through the wave plate demisters before leaving the vessel. A controller opens and closes the pressure control valve at the gas outlet to maintain the desired vessel pressure.

3. Process Conditions:

For this study, the feed into the vertical separator is given in Table (2):

Table (2) process conditions

Gas flow ,Q (MMscf/D)	150
Gas to liquid ratio (bbl/scf)	30000
Liquid flow ,L(bbl/day)	4500000
Operating pressure ,P(bar)	20
Operating temperature ,T°	25

From the given conditions, the properties of gas and liquid as well as their mass flow rates are given in Table (3):

Table (3) properties of gas and liquid

Gas mass flow rate , Mv (t/h)	119.85
Liquid mass flow rate ,Ml(t/h)	16.77
Gas density, ρv(kg/m3)	13.52
Liquid density, ρl(kg/m3)	550.47
Gas viscosity, μv(kg/ms)	$1.161*10^{-5}$
Liquid viscosity, μv(kg/ms)	$1.668*10^{-4}$
Surface tension ,σ(N/m)	0.00994

4. Results and Discussion

4.1. Inlet pipe diameter

To obtain optimum the pipe diameter the inlet pipe diameter is changed according to the values of the standard pipe sizes.

The effects of the change in pipe diameter on the overall separator efficiency are shown in Figure (6). From figure, it can be seen that as the pipe diameter increases the overall efficiency decreases initially until a diameter of 0.2 m is reached. This can be explained by dispersion of larger droplets into smaller droplets due to increase in the vapour velocity .higher velocity tends to break large droplets into smaller droplets. At the same time, using larger pipe size would have an effect of producing larger droplets which should be relatively easier to coalesce [illegible] removed upon accumulation compare to finer droplets. As the pipe diameter increases beyond 0.2 m, the overall efficiency increases to a value of 99.99%. For the pipe diameter of 1.067m .from the figure, it is also observed that the overall efficiency only increases by small amount of 0.047 when the pipe diameter is increased from 0.813m to 1.067m, therefore the pipe diameter of 0.831 m is chosen as the optimum diameter.

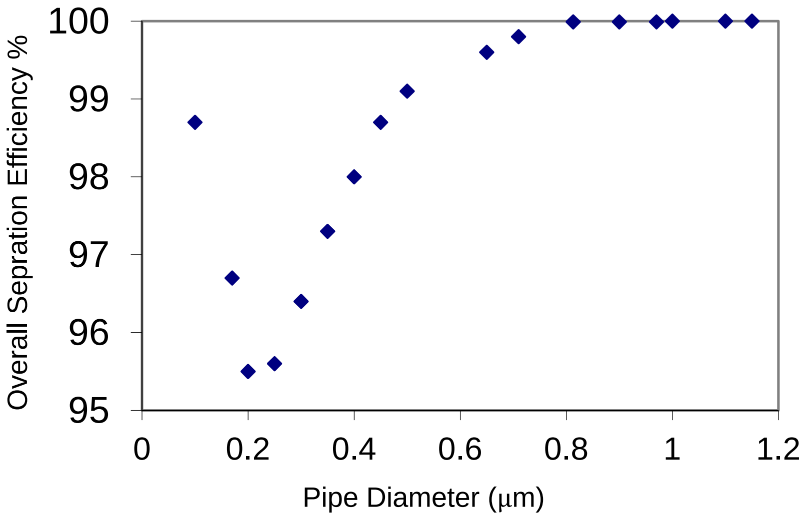

Figure (6) effect of varying inlet pipe diameter on the overall separator efficiency

4.2. Vessel Bend Spacing

With inlet pipe diameter fixed at 0.813 and other parameters, the vessel bend spacing is changed at values of 0.3, 0.4 and 0.5m. Figure (7) shows the effect of varying the spacing on the adjusted bend efficiency. From the figure, the efficiency achieved is almost the same for droplet sizes less than 20 μm and only at higher droplet sizes the efficiency greater at a spacing of 0.3m. Therefore the spacing of 0.3 m is chosen as the optimum spacing.

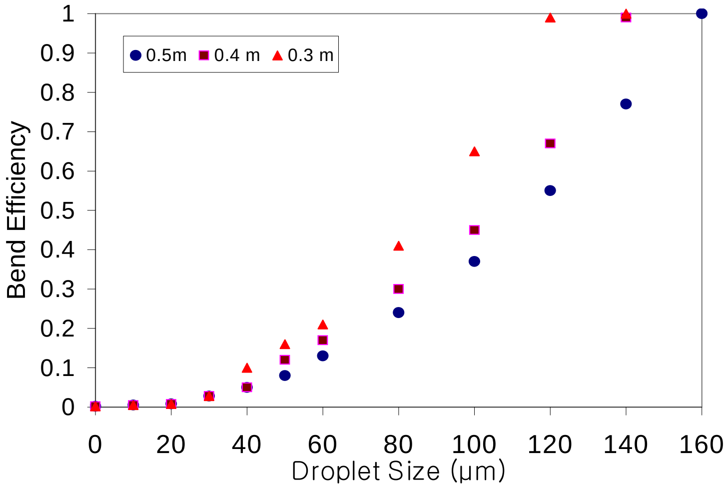

Figure (7) effects of varying vessel bend spacing on the adjusted bend efficiency.

4.3. Momentum Breaker Bend Angle

With fixing all parameters. The effect of the change in momentum breaker efficiency is investigated when angle is changed to 120°, 150° and 180°. The variation is shown in Figure (8). From the figure, as can be seen, the efficiency achieved is almost the same for droplet sizes less than 20 µm and then efficiency started to increase with increasing droplets diameter. In addition, it is clear from figure at higher droplet sizes the efficiency greater at angle 180° degree.

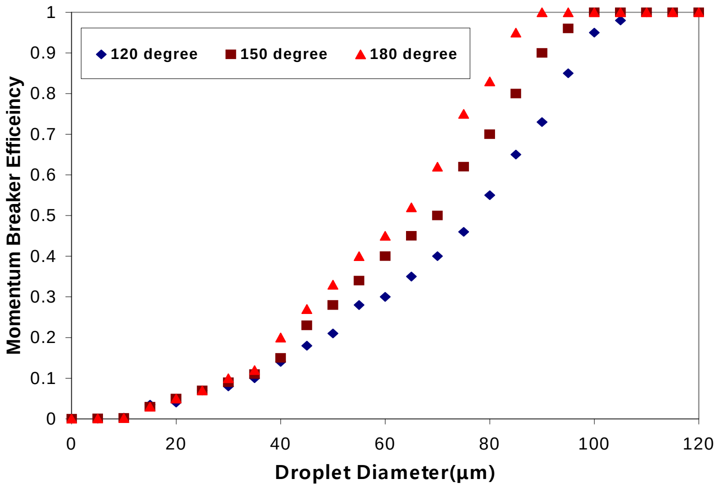

Figure (8) effect of varying momentum breaker bend angle on the adjusted bend efficiency

4.4. Vane Plate Spacing

From Figure (9), it is clear that the overall vane efficiency increases as the plate spacing is reduced. The figure also shows that changes in the vane plate spacing have more pronounced effect on the efficiency for droplet diameters less than 10 m compared to the parameters which were changed previously. In addition, reducing the vane plate spacing will lead to higher effectiveness in removing smaller droplets. Reducing the plate spacing will lead to droplets to collide at the bend wall at higher velocity and trap in the drainage channel. The pressure drops as estimated from the correlation shown in figure1 are negligible for all three spacing as they are all less than 5 pa. Therefore the plate spacing of 0.06m is chosen as the optimum plate spacing.

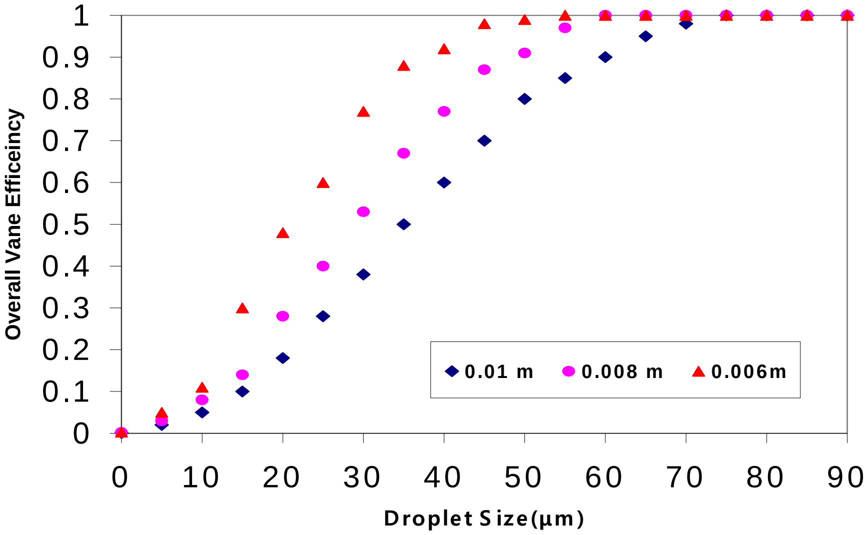

Figure (9) effect of varying the vane plate spacing on the overall vane efficiency

4.5. Number of Bends in Vane Pack

It was found from figure (10) that the separation efficiency increases as the number of bend in the vane increases. This is fairly obvious as the droplets have a higher chance of collide at the bend wall and coalesce to from droplets. From figure it is also observed that a certain vane has certain limitation on the size of droplets that it can separate, which does not vary with change in the number of bend in the vane .therefore increasing the bend number further will not help in achieving a better separation in terms of removal of more smaller droplets, but will help in more complete separation of larger droplets..

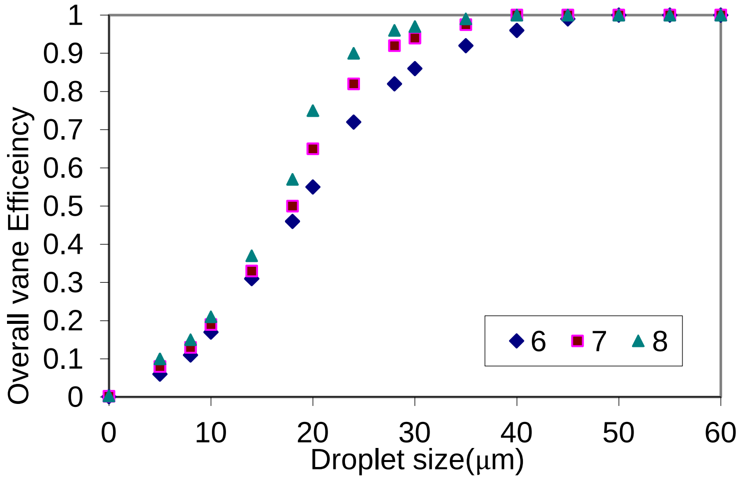

Figure (10) effect of varying the number of bends in vane pack on the overall vane efficiency

4.6. Vane Pack Bend Angle

From Figure (11), it is found that increasing the angle of vane pack bend will increase the overall vane efficiency as the gas and droplets have to bend through a greater angle. Therefore the number 80 degree is chosen as the optimum vane pack bend angle. The pressure drop for this case is around (10 pa) estimated from figure (4).

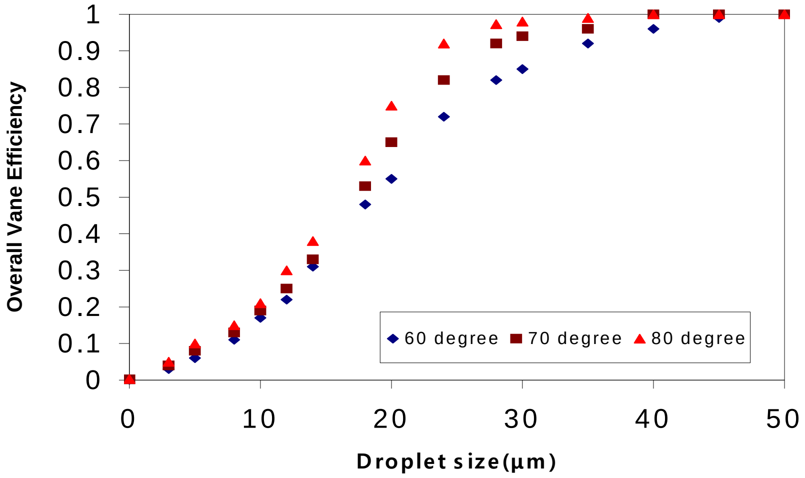

Figure (11) effect of varying the vane pack bend angle on the overall vane efficiency

4.7. Final Design

From the results of the investigations on the effects of changing various parameters on the separator efficiency, the following design as shown in table (4). An overall separation efficiency of 99.99% is achieved .The arrangement of the four vane packs in the separator is shown in Figure (12).

Table (4) final design parameters for the vertical phase separator

Overall design efficiency %	**99.99**
Vessel diameter (m)	2.7
Vessel height (m)	10.8
Pipe diameter (m)	0.813
Pipe bend radius(m)	1
Pipe bend angle	1.571
Vessel bend angle	1.571
Vessel bend spacing(m)	0.3
Momentum breaker bend radius(m)	1
Momentum breaker bend angle	3.142
Vane pack bend radius (m)	0.05
Vane pack bend angle	1.396
Vane pack bend spacing (m)	0.006
Number of packs	4
Pack depth(m)	1
Number of vanes per packs	200
Number of bends in packs	8

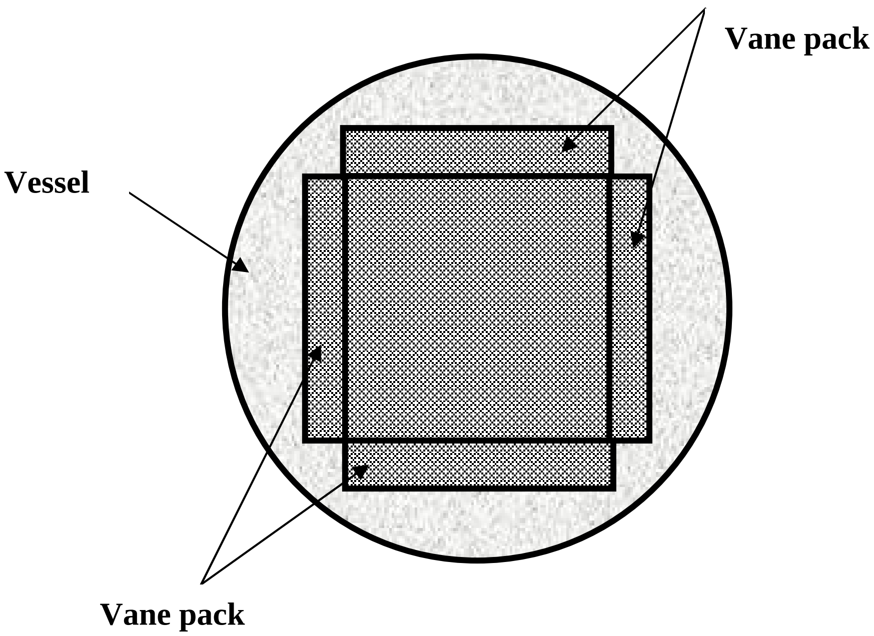

Figure (12) arrangement of vane pack from the top view of the vessel

5. Conclusion

An investigation has been undertaken to understand the effect of design parameter on vertical gas/liquid two-phase separator. From the data collected it can be concluded that:

- The efficiency increases with decrease in vane packs plate spacing.
- The efficiency of separator rises with an increasing in number of bends in the vane pack (up to 8).
- Increasing number of bends in pack increase the efficiency of separator.
- The efficiency of separator slightly increases with an increase in bend angle before separator, and the maximum efficiency of this case is 99.99%.

Abbreviations

η_O	Overall separation efficiency
η_F	Fractional separation efficiency
U_t	Settling velocity (m/s)
ρ	*L*iquid density (kg/m^3)
ρg	Gas density (kg/m^3)
D_v	Minimum vessel diameter, m
V_v	Gas volumetric flow rate, m^3/s
π	pi(3.14)
σ	Surface tension (N/m)
g	Gravity
U_g	Superficial velocity of gas (m/s)
L	Length of vessel, (m)
D	diameter of vessel, (m)
Mv	Gas mass flow rate , (t/h)
μv	Gas viscosity, (kg/ms)
P	Pressure, (bar)
T	Temperature, (C)

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کارتێکرنا دیزاینا پیڤانا پەستانا غازێ ل سەر شیانا ناڤبری ناۋ بەرا غاز/شل ل هێلا بوریێن غازێ

پوختە:

ئارمانجا سەرەکی یا ڤی کاری دە ست نیشانکرنا قەبارێ ناڤبرێ غازێ و شلێ بو ژێك جودا کرنا غازێ و شلێ ل سەر ماوەیەك درێژ ل هێلێن بوریێن غازێ. ئە ڤە کارەکێ فەرە بو کەرە رە نتیکرنا کارکرنا ئێمن بو پەستانێت ب کار اینایی لسەر هێلێن بوریا.

ناڤبرێ هاتی ئامادە کرنێ ب ژێکێشەرێ روی پێلەیی وەکی ناڤبرێ نەسەرەکی . دیزاین هاتییە ب دەستڤە اینان ب وردبینکرنێ دە ل پیڤەرێ غازێ ئەوا کارتێکرن هەیی لسەر ژێکجوداکرنا جوداکەری. دڤێ ڤێڤەکولینێدە دە, ستیراتیا بوریی یا ناڤخویی, ژێك دیربینا خواهربینا ئامانی, کوژیا خواهربینا پەرێ پانکێ, شلوڤەکەر, ژێك دیربینا پلیتێن پەرێ, ژمارا جەماندنان د کەرستێن هاتین ب کار اینان.

دڤێ ڤەکولینێدە ئەنجاما ٩٩,٩٩٪ ژ شیانا ناڤبرێ هاتیە ب دەستڤەئینان.

تأثير تصميم قياس ضغط الغاز على كفاءة الفاصل العمودي بين الغاز / السائل في خط أنابيب الغاز

الملخص:

الهدف الرئيسي من هذا العمل هو تحديد حجم المحور العمودي لفاصل الغاز و السائل لفصل الغاز والسائل على مسافة بعيدة في خطوط أنابيب النفط و الغاز. وهذا أمر ضروري لضمان التشغيل الآمن للضواغط المستخدمة على طول خطوط الأنابيب.

الفاصل المجهزة بساحب الرطوبة ذات السطح المتموج كفاصل ثانوي

تم تحقيق التصميم من خلال التدقيق في مقياس ضغط الغاز والتي لها تأثير على كفاءة فصل الفاصل. في هذه الدراسة، قطر الانبوب الداخلي، تباعد منحنى الوعاء، زاوية انحناء ريشة المروحة، المحلل, تباعد لوحات الريشة، وعدد الانحناءات في الحزمة. من خلال هذه الدراسة تم الوصول الى نتيجة ٩٩,٩٩٪ من كفاءة الفاصل..