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THE APPLICATIONS AND PERFORMANCE OF A NOVEL COMPACT SEPARATOR IN THE OIL AND GAS INDUSTRY

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ABSTRACT

The oil and gas industry requires compact separators for a wide range of applications. Compact separators are desired because of a number of benefits they offer; examples being compactness, small footprint, having no moving parts, ability to design for high pressure wellhead applications. A compact separator named I-SEP has been developed by CALTEC in the U.K. This separator consists of a dual involute and generates high "g" forces to effect separation. It has a wider range of applications including gas-liquid separation, knock-out of liquid from wet gas, sand separation, well testing and clean-out, multiphase metering, partial oil-water separation, etc.

This paper describes the key features of I-SEP, its performance and the range of application. Its field application in underbalanced drilling is discussed and the main benefits of the system are highlighted.

Key words: *I-SEP, compact separator, cyclonic separator, sand separator, wellhead separator, Debottlenecking, in-line separator.*

1. INTRODUCTION

Compact separators are highly desired by the oil and gas industry for a variety of applications. Their compactness also enables them to be used where the bulky gravity separators cannot be installed.

CALTEC has developed a compact separator named I-SEP over the past five years and, following an extensive programme of testing including field trials, it is now available for a host of applications. This paper describes its key features, the performance and the range of applications

2. PRINCIPLE OF OPERATION, KEY FEATURES

I-SEP is a patented system and consists primarily of a compact dual involute and a specially designed separation chamber between the two involutes (see Fig. 1). The function of the first involute is to generate a spin and high “g” forces as the fluids enter the separator. The generated high “g” forces help the fluid droplets with different densities to coalesce and be separated. The denser phase is collected around the wall of the separation chamber and the lighter phase gathers within the centre core. The fluids maintain their spin and tangential velocities along their path, which helps to continue the separation of phases with different densities.

The tangential and axial velocities enable the fluids to pass through the separator and exit via the corresponding outlets. The collected dense phase is captured by the second involute.

A vortex finder helps to collect the lighter phases which accumulate within the centre core of the separation chamber. An axial outlet allows the collected light phases to exit the separator.

Generation of high “g” forces to separate fluids of different densities and to generate efficient separation is not new and dates back to the late 19th century, although the main part of the development work has been carried out since the 1950s.

Hydrocyclones, used in many industries for similar duties, work on the same principle. There is, however, a subtle difference between the conventional cyclones and separators such as I-SEP. Conventional hydrocyclones are also known as reverse flow cyclones. The reason is that after the generation of the spin at entry, the light phase moves upwards and exits via the top axial outlet. The denser phase, however, spins downwards and exits the bottom outlet, maintaining most of its tangential velocity. In contrast, separators such as I-SEP allow both the light and dense phases to spin and move uniaxially. For this reason these separators are also known as uniaxial flow cyclones. While both types perform similar duties, the said difference affects their performance in a number of areas including the sensitivity to flow fluctuations, the effect of back pressure on each outlet, and the efficiency of separation in many applications.

Key design features related to each type, which becomes part of the know-how and the confidential information held by the designers and suppliers of these units, contribute to the performance and efficiency of each unit in different applications. Both types have, therefore, applications unique to certain conditions and duty requirements. A significant amount of development work has been carried out to investigate the performance of such equipment and to improve their performance. The majority of work has, however, been carried out on reverse flow cyclones, particularly in applications where the flow fluctuations are minimal and the operating pressures are low (Refs. 1 and 2).

3. OPERATING CONDITIONS

The efficiency and performance of cyclonic separators is also dictated by the operating conditions and particularly the flow regime upstream of the separator.

The majority of cyclonic separators in use are for applications downstream of the process system where the flowrates and pressures are well controlled and are reasonably uniform. The industry has, however, a number of applications upstream of the process system or, for cases where there are significant variations in the pressure, the flow regime and the percentage of each phase. It is these arduous applications which have been the subject of the recent development work. I-SEP is a good example of cyclonic separators where the design efforts have been focussed on such difficult operating conditions.

4. PERFORMANCE – GAS/LIQUID SEPARATION

The performance of I-SEP has been extensively investigated, particularly in gas-liquid separation duties. Separating gas and liquid phases is a relatively easy task because of the significant difference between the density of the two phases. There is, however, a feature of gas-liquid mixtures known as flow regime, which poses problems and challenges for achieving efficient phase separation. The key features of multiphase flow regimes are the fluctuations in the instantaneous flowrates, pressure, fluid velocities and gas-liquid ratios. The severity of these changes depends primarily on the average gas-liquid ratios, superficial velocities of each phase and characteristics of the flow path. Flow regimes, such as the slug flow, stratified wavy and annular flow, are typical features of fluid flow through pipelines and process piping as shown in (Fig. 2). If flow through vertical pipes, such as risers or wellbore, are involved, additional regimes such as churn flow (Fig. 3) could also be involved. Any separator which receives flow under such conditions should be able to cope with such fluctuations. Conventional gravity separators are generally designed with the additional capacity to cope with such conditions. Selection of size and some of the internals also help to improve their performance, although there has been many cases where even bulky separators suffer from poor performance by generating excessive liquid carry-over in the separated gas phase, gas carry-under in the liquid phase, and poor oil-water separation efficiency. Such bulky separators have also limitations on their maximum operating pressure, because of the limitations in their wall thickness.

Compact separators do not have the spare capacity to handle major changes in the flowrate of each phase and, for this reason, a major part of the development work by CALTEC over the past years has been concentrated on improving the design of the compact separator (I-SEP) to cope with significant fluctuations in the flow.

The key factors which affect the separation efficiency are the detailed design, some features of the key components of the separator and the effect of back pressure on each outlet. The investigations have led to a design which optimises the performance and minimises the carry-over in each phase. Figs 4 and 5 show some typical examples of the performance of I-SEP under a range of gas-liquid mixture velocities and volumetric flow ratios. These show that the carry-over in each phase is relatively small despite the extreme level of flow fluctuations caused by the various flow regimes experienced upstream. Despite the optimisation of the system there is a small percentage of gas carried-under with the separated liquid phase, and a small percentage of the liquid in the separated gas phase. The percentage of carry-over or carry-under can, however, be reduced to almost nil, if required, by design and by the way the system is controlled. This high level of efficiency is, in general, achieved for one phase at the expense of the second phase. There are many applications where the efficiency of separation for one phase (gas or liquid) is of greater importance and therefore the excess carry-over in the second phase can be tolerated, as further downstream processing may take care of this carry-over.

A high level of efficiency in both phases can also be achieved by design and inclusion of additional features if required. An example of such a case is discussed in the following sections:

5. PRESSURE LOSS

The pressure loss across the unit is moderate. Its amount is dictated by the following main factors:

- Size of the unit
- Multiphase mixture velocity
- Multiphase mixture density
- Back pressure imposed on each outlet.

Typical pressure loss values are in the range of ½ bar to 1.5 bar for moderate gas-liquid mixture velocities, depending on the operating conditions as shown in (Fig. 6). Higher losses are expected in oil-water separation duties or when high mixture velocities in excess of 15 m/s are involved.

6. APPLICATIONS

The applications of I-SEP include the following main duties:

- Partial gas – liquid separation
- Full gas – liquid separation
- Knock-out liquid from wet gas
- Solid separation from gas or liquid phase
- Dust separation (from air or a gaseous phase)
- Partial oil-water separation.

I-SEP has been developed and designed in a number of configurations and sizes which make it suitable for a wide range of applications. These include: Onshore, Offshore, Subsea, Downhole and In confined spaces as part of a system such as vacuum cleaners.

As the unit is compact and can be machined out of solid blocks of metal, it can be rated to operate at high pressures of 5000 psi or more. A typical example of such an application is at wellhead where the unit can operate upstream of the wellhead chokes and can therefore be rated to the shut-in wellhead pressure. Typical pressure rating values are 5000 to 10,000 psig.

As a retrofit, it can assist the existing conventional separators which are overloaded because of the increase in the volume of gas, oil or water which they handle. Fig. 7 shows a typical example of an application upstream of a gravity separator where the bulk of the gas is removed and bypasses the main separator. The reduction in the flowrate of the gas entering the separator could reduce the velocity of the mixture entering the separator by a factor of 10 or more. This, in turn, not only improves the general performance and the capacity of the gravity separators but it also improves its oil-water separation efficiency, its capacity to handle high water cuts and its slug flow handling capacity.

Alternatively, the unit can be installed on the gas outlet line of the main separator to knock-out the excess liquid carry-over, as shown in Fig. 8.

7. SAND SEPARATION

In sand separation duties involving both gas and liquid phases, it is beneficial if the gas phase is removed in the first stage. This helps to reduce the mixture velocities of the remaining liquid-sand mixture and therefore minimises the erosion effect on the liquid-sand separator. This application is particularly beneficial in cases where the gas volume fraction of the mixture is high. In this way, by removing all or a major part of the produced gas first, the total mixture volume is reduced significantly, leading to a reduction in the total flow into the second stage, liquid- sand separator. The first stage gas-liquid separation also minimises the flow fluctuations in the second stage. Sand separation efficiency is thus improved, particularly for the finer particles in the range of 10 to 50 :m (microns).

The high velocities involved, particularly at high gas-liquid ratios, inevitably bring about erosion within parts of the separator. The amount of erosion varies and is mainly concentrated in specific sections subject to higher mixture velocities and a high concentration of sand. Erosion is proportional to the mixture velocity and the angle of the impingement of the solid particles. Tests carried out at CALTEC's laboratories on various samples of materials with different levels of hardness and material grain size and matrix, has demonstrated and confirmed that erosion is affected primarily by the following:

(a) Mixture velocity. Erosion increases significantly as the mixture velocity increases beyond a certain limit. Typical limits beyond which erosion could be severe are velocities beyond 15 to 20 m/s. There is a non-linear relationship between the velocity and the level of erosion. This means that (see Fig. 9) at high velocities severe erosion can take place during a short period of time, even at low angles of impingement (Ref. 3).
(b) The angle of impingement or flow against the surface of the metal. This affects the level of erosion and the service life, beyond which the extent of erosion becomes unacceptable
(c) Material hardness
(d) Material matrix and composition (micro hardness –vs- macro hardness)
(e) Grain size and angularity of solids
(f) Operating temperature.

The industry has experienced high levels of erosion in equipment such as choke valves where high velocities are generated. Good lessons have been learned and improvements have been made by selection of better materials and improvements to the design of the components. Nevertheless, this problem cannot be fully eliminated because of the inevitable harsh conditions which such units face. An acceptable solution is to provide liners or internals which are not only resistant to erosion but can also be removed and replaced relatively easily. Such features, which include improved details of the flow path and inclusion of liners such as ceramics, have been included in the design of I-SEP for sand handling applications.

8. WELLHEAD HIGH PRESSURE APPLICATIONS

There are a number of cases where the application of the compact separator at wellhead offers distinct advantages. The duties for wellhead separation include full or partial gas-liquid separation and solid separation. In most cases, the unit is to be designed and rated to shut-in wellhead pressures. Separation of gas and solids at high pressure has the benefit of reduced mixture velocity as the gas phase is at a higher pressure and its actual volumetric flowrate is significantly smaller. At high operating conditions the actual mass of the free gas phase is also smaller, thus enabling a compact separator to be used efficiently. Compact separators, such as I-SEP, can be designed for high pressure applications of 5000 psig or more because of their compactness and the fact that they are manufactured of machined parts, in contrast to gravity separators.

In order to provide an added safety in such an application, I-SEP compact separators can be housed inside a small containment vessel which is also rated to high pressure. In this case the vessel provides the added safety and barrier and allows the components of I-SEP to be made of discrete machined parts, bolted together. This feature eliminates the need for welding components with high plate thickness. It also enables easy replacement of the eroded parts at low cost, when sand production is involved, without the need to change the entire unit.

9. UNDERBALANCED DRILLING (UBD) APPLICATION

Underbalanced drilling offers a number of benefits which include: a high rate of drilling penetration, elimination of circulation loss, minimising formation damage, minimising or eliminating differentially stuck drill pipe incidents and generally a significant cost-saving.

UBD also involves partial production while drilling. The volume of gas produced during this operation for gas fields, or fields with high gas-oil ratios, could be significant. The entire flow, when reaching the wellhead, passes normally through a set of chokes and its pressure drops to a few hundred psi for processing. Bulky gravity separators are used for gas-liquid and solid separation. The separated gas at low pressure is usually flared as it is not economical to boost its pressure, using compressors, for transportation and utilisation. The high volume of gas also results in the need to design the gravity separators large enough to be capable of handling a large volume of gas at low pressure. The high velocities of the mixture also result in severe erosion through the chokes, the interconnection piping and the valves. Installing a compact separator, such as I-SEP, upstream of the chokes enables the bulk of the produced gas to be separated upstream and transported or utilised. The remaining fluids can then pass through the chokes and enter the downstream process system for further separation of gas-liquid and solid phases at low pressure. The I-SEP separator offers a number of benefits in this case:

(a) By removing the bulk of produced and injected gas, it increases the handling capacity of the total UBD system and the downstream separator.
(b) It prevents wastage of gas and flaring
(c) It reduces the mixture velocity of fluids passing through the main chokes and the downstream UBD process system, thus reducing erosion
(d) It enables the drilling operation and penetration rate to be speeded up, saving valuable time in completion of the drilling operation.

All these benefits offer significant cost savings which justify the investment costs for installing an upstream high pressure gas knock-out system. As such a unit operates upstream of the main chokes in open hole conditions, it has to be rated for the full shut-in wellhead pressure of 5000 psig or more.

A double I-SEP skid-mounted unit for such an application was designed and manufactured during the year 2000 for its first UBD application offshore North Sea. This compact skid had a footprint of 2.2 x 2.2 metres and an overall height of six metres which included a lower section for accommodating isolation valves (Fig. 10).

Following the successful onshore trials, the unit was moved offshore and was installed on Shell UK's Skiff platform for its maiden UBD operation (Ref. 4).

Such a compact unit was designed to handle total gas flowrates of up to 80 MMscfd and liquid flowrates (up to 15,000 bbl/d) with average gas volume fractions of 80% to 99% at the operating pressures of 800 to 1200 psig. The unit was designed for 5000 psig operation pressure, and tested at 10,000 psig.

The successful operation of the unit not only offered the said benefits but enabled a much faster drilling operation to be achieved. It is believed that the sheer reduction in drilling time and savings in the rig time during one operation recovered the capital invested for the manufacture of the unit. This unit was appropriately nicknamed “the Gas Buster” for this application. Figs. 10 and 11 show the Gas Buster skid and the I-SEP unit with an integral knock-out vessel.

The extreme high velocities of the mixture during its first operation and some control problems resulted in excessive erosion in a specific part of the separator subjected to the highest local velocities. The modularised form of the unit and the I-SEP package enabled these parts to be removed and replaced with an improvement in their design, inclusion of an erosion-resistant liner, and the introduction of a better control logic to cope with surge conditions, ready for the next drilling operation.

10. MULTIPHASE METERING

A further application of I-SEP is in multiphase metering. As this unit enables gas and liquid phases to be separated with an acceptable level of purity, conventional metering devices can be used for measurement of gas, oil and water phases. Fig. 12 shows the flow diagram for such a system. There are a variety of well proven gas or liquid flow meters which can be used in this case. Accuracies better than those generally offered by multiphase meters can be achieved. A typical value of ±5% is achievable in most cases.

11. OTHER APPLICATIONS

I-SEP has potential applications in a variety of cases which include:

- Downhole, in gas-liquid separation duties upstream of lift pumps to improve their performance
- Subsea, for gas-liquid separation duties where the liquid phase is boosted using a single-phase pump. The separated liquid phase can be further treated to separate oil and water phases. The water phase, in this case, can be pumped back into the reservoir via water injection wells
- Separation of solids from a gaseous or liquid phase (also non oil and gas applications)
- Removal of dust from air or gaseous media. I-SEP has been used successfully in Hoover’s new “vortex” bagless vacuum cleaners currently available in the market
- Bulk oil-water separation
- Liquid recirculation for multiphase pumps
- Well testing, well clean-out.

12. SIZE, OVERALL DIMENSIONS

I-SEP can be supplied in a variety of sizes depending on the operating pressures and the volumetric flowrates of gas and liquid phases. Typical range is identified by the size of the inlet pipe which is 2” to 9” nominal. The footprint of the unit within this range is 350 x 350 mm to 950 x 950 mm, with the height typically 1.25 times the width or diameter. In applications where full purity of the separated gas is required, the integral patented knock-out vessel has a nominal size of 6” to 14” diameter with a height of 2.5 to 3 metres. In this range, gas flowrates of up to 135 x 10^6 scfd average, and 66,000 B/D of the liquid phase, at 1000 psig operating pressure can be handled.

Other operating conditions, such as presence of solids, gas volume fraction of the mixture, flow fluctuations, the flow regime and erosion considerations also play a part in selecting an acceptable range of flowrates for each size.

I-SEP and the integral knock-out vessel and valves can be supplied as a compact skid-mounted unit for ease of transport, handling and installation where space is limited. In applications where high flowrates are involved, several identical units may be used in parallel.

I-SEP has a good turn-down capacity, typically, a turn-down of 1 to 4 is acceptable for each unit.

13. BENEFITS

Compact separators, such as I-SEP, offer the following benefits

- Compactness with a small footprint
- No active level control is required
- No moving parts
- Can be rated to high pressures
- Very low fluid inventory with increased safety
- Not sensitive to the motion of floating platforms or vessels
- Tolerant to flow fluctuations and turn-down
- Could help the existing gravity separators to improve their performance
- A wide range of applications
- Key components can be easily replaced if required
- In applications such as underbalanced drilling, considerable cost-saving and benefits are achieved.

14. CONCLUSIONS

Compact separators, such as I-SEP, have a wide range of applications and numerous benefits. Their applications extend to existing platforms where conventional gravity separators are used, and their utilisation in conjunction with the existing process equipment could enhance the performance and capacity of the process systems.

The ability to design I-SEPs for high pressure applications extends its use to cases where conventional gravity separators cannot be used. Examples being at wellhead for sand removal, multiphase metering, underbalanced drilling and well clean-out and testing.

There are relatively easy ways to overcome the problem of liquid carry-over in the separated gas phase or gas carry-under in the liquid phase when flow regimes are severe. While the industry is used to conventional separators because of their long track-record, new challenges and demands for low-cost, compact process systems and the need to reduce both the operation and capital cost of fields have brought about opportunities for using these novel separators.

15. REFERENCES

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16. ACKNOWLEDGEMENT

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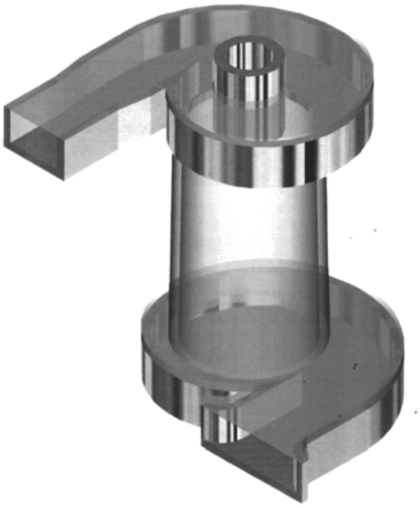

FIG 1. CALTEC'S COMPACT SEPARATOR I-SEP

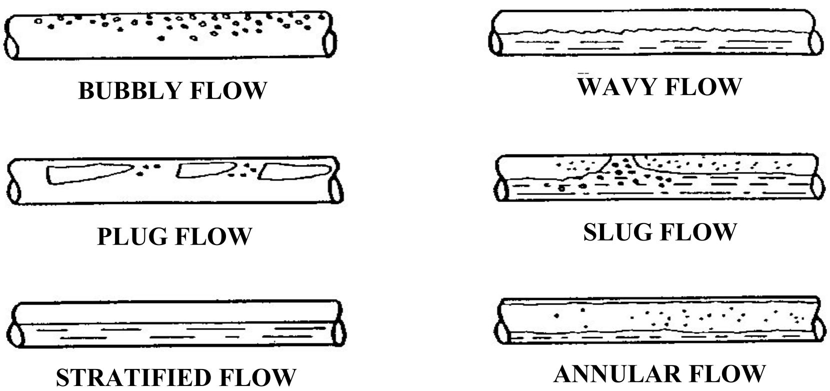

FIG 2. GAS -LIQUID FLOW REGIMES IN HORIZONTAL FLOW

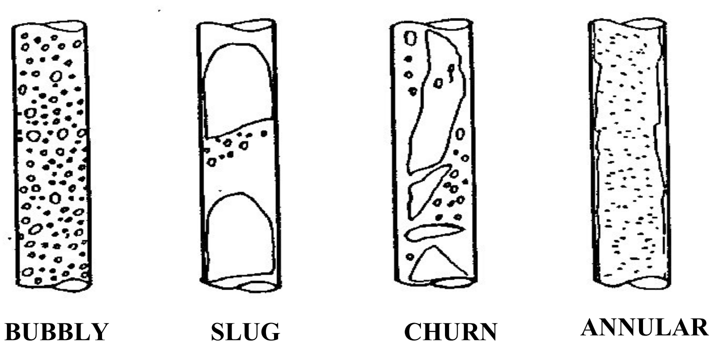

FIG 3. GAS -LIQUID FLOW REGIMES IN VERTICAL FLOW

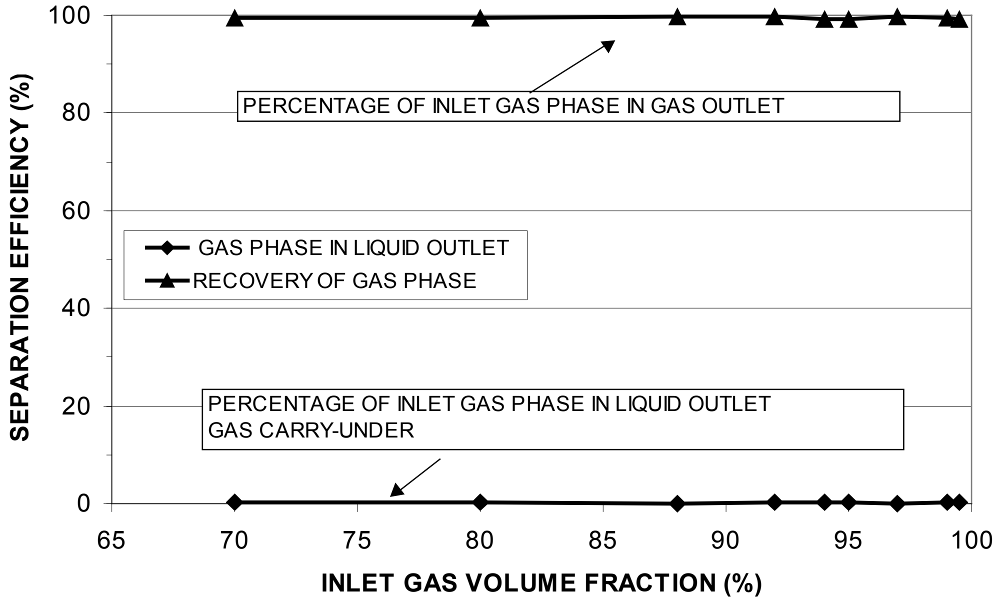

FIG 4. GAS -LIQUID SEPARATION EFFICIENCY OF I-SEP WITH A LIQUID KNOCK-OUT VESSEL AT 20 m/s MIXTURE VELOCITY

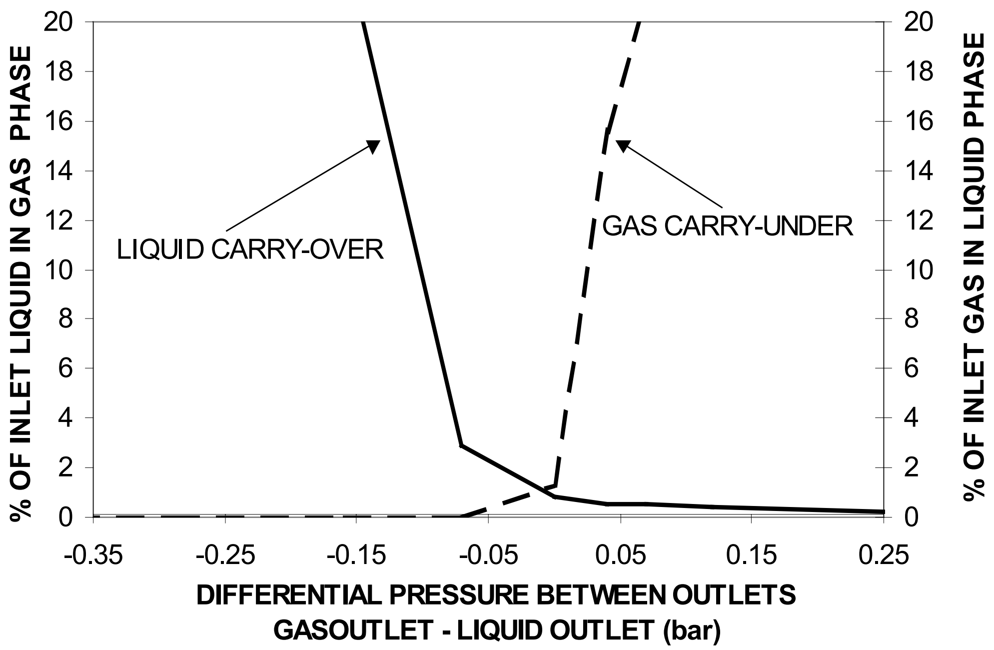

FIG 5. EFFECT OF DIFFERENTIAL PRESSURE BETWEEN OUTLETS SHOWING INFLUENCE ON PHASE SEPARATION EFFICIENCY

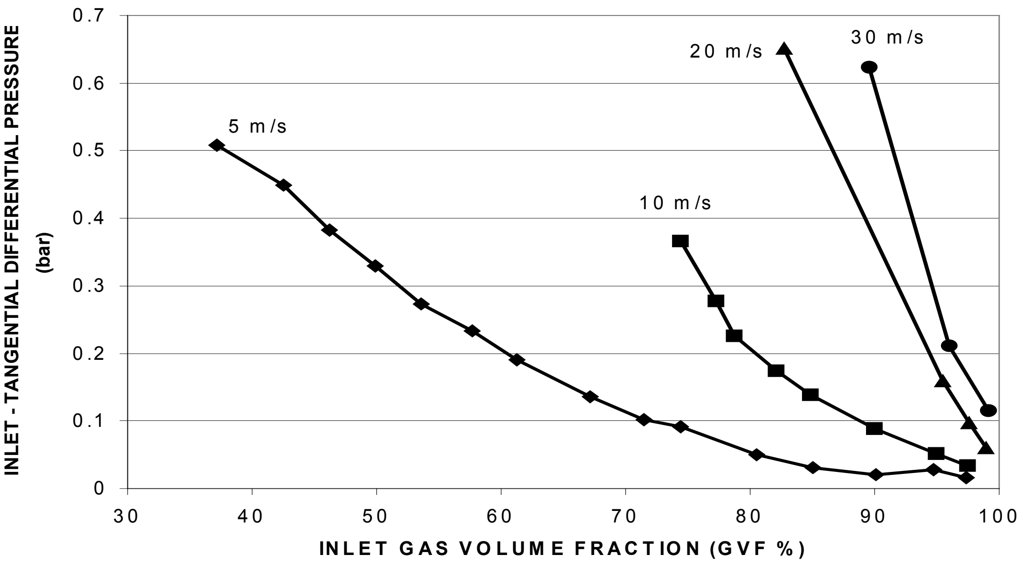

FIG 6. A TYPICAL PRESSURE DROP ACROSS I-SEP SEPARATOR FOR A RANGE OF FLOW CONDITIONS

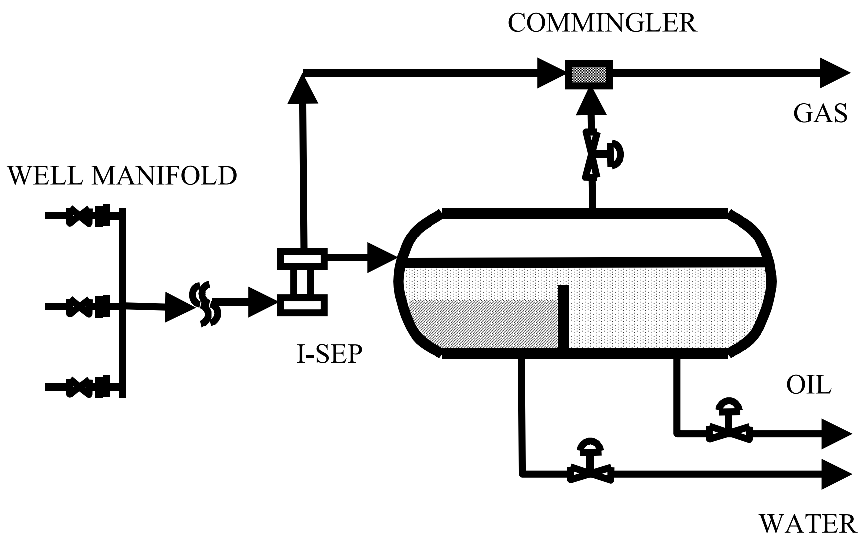

FIG 7. I-SEP FOR DEBOTTLE NECKING OF GRAVITY SEPARATORS

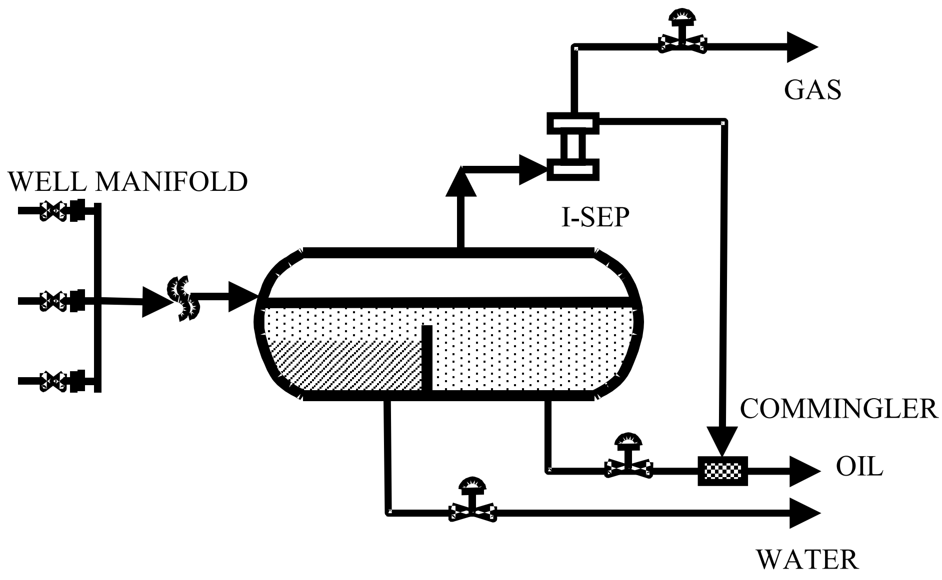

FIG 8. I-SEP FOR KNOCKING-OUT EXCESS LIQUID IN GAS PHASE

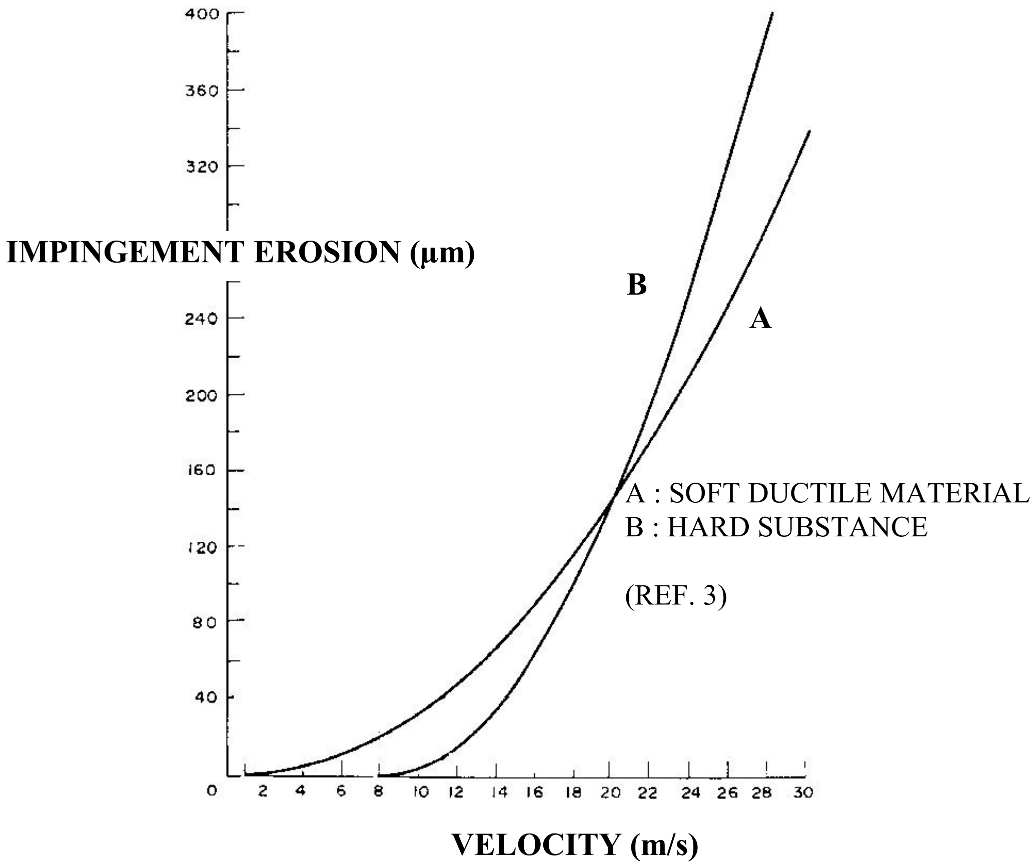

FIG 9. EFFECT OF FLOW VELOCITY ON MATERIAL EROSION

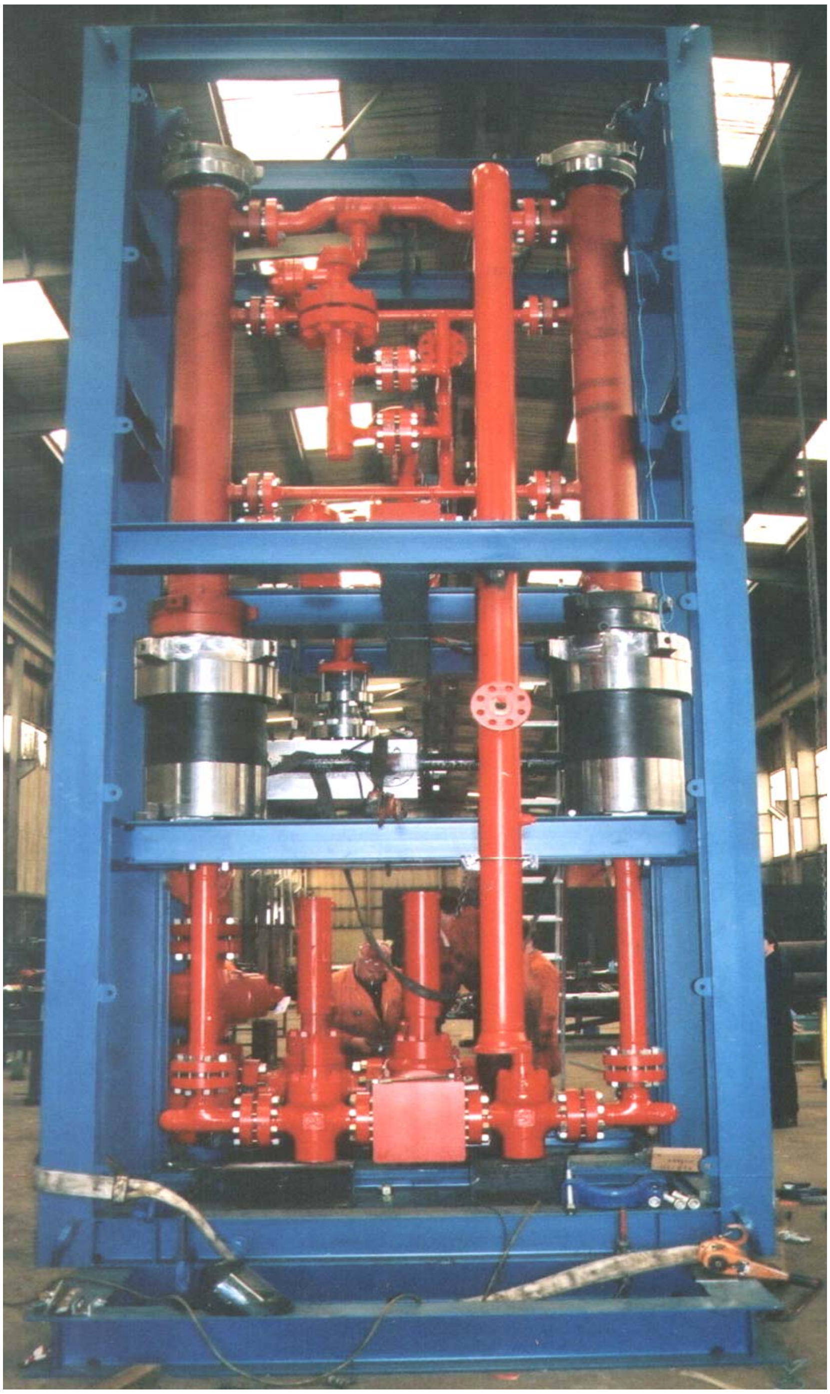

FIG 10. THE "GAS BUSTER" SKID CONTAINING TWO I-SEP UNITS

FIG 11. CALTEC'S COMPACT SEPARATOR I-SEP WITH INTEGRAL LIQUID KNOCK-OUT VESSEL (I-SEP)

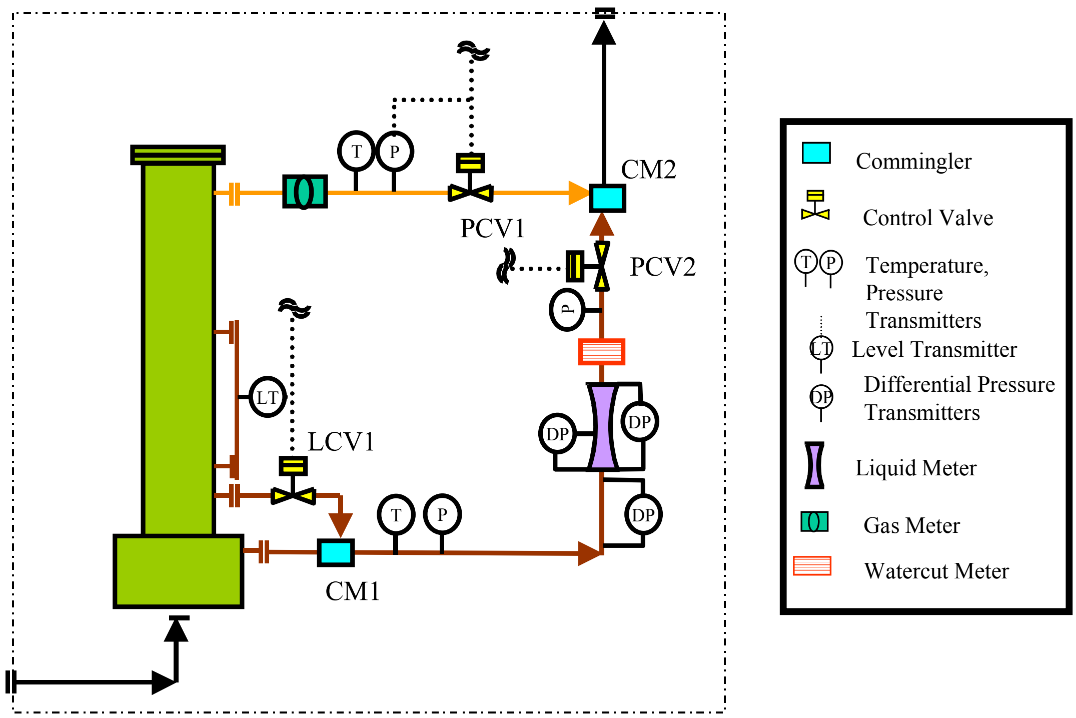

FIG 12 : SIMPLIFIED P&ID FOR MULTIPHASE METERING WITH I-SEP COMPACT SEPARATOR