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The Separation of Solids and Liquids with Hydrocyclone Based Technology for Water Treatment and Crude Processing

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ABSTRACT

Hydrocyclones have been used in a variety of process industries for over 100 years. They are a simple and effective device, but still widely misunderstood in the oil and gas industry. Hydrocyclones ideally lend themselves to numerous separation applications, overcoming conventional technical and economic operating constraints.

The objective of this paper is to "demystify" the basic operation of hydrocyclones and identify separation situations where hydrocyclones can offer significant advantages. These include a significant reduction in equipment size and weight which equates to significant costs savings on new projects, especially offshore. Hydrocyclones also provide the opportunity for additional processing capacity on existing facilities where little or no expansion space is available. Furthermore, hydrocyclones offer enhanced separation efficiencies when compared to conventional equipment. When coupled with complementary conventional process equipment the resultant hydrocyclone based water treatment system is smaller than an equivalent conventional system. This results in an increase in process efficiency per volume utilized.

INTRODUCTION

Solid-liquid separation, or more specifically, the separation of produced sand from crude and/or water will be defined as "desanding" and that hydrocyclone a "desander". Liquid-liquid separation as applied in the removal of residual oil from produced water will be defined as "deoiling" and that hydrocyclone a "deoiler". The dehydration, or liquid-liquid separation of water from crude, will be defined as "dewatering" and that hydrocyclone a "dewaterer". In all cases, the discussion will be based on static hydrocyclones.

Water is one of the most used and handled fluids in the oil and gas industry. Large volumes of water are used in injection operations, and even larger volumes are a major waste by-product associated with the production of oil and gas.

Hydrocarbon production data in the Asia Pacific region[1] allows forecasts to be made of the amounts of produced water. **Figure 1** shows total fluids production by country by producer. These production figures emphasis the large impact water has on oil and gas producers, and why it is an issue they need to increasingly address.

THEORY

Hydrocyclones operate under pressure. Fluid is directed tangentially into the hydrocyclone which causes it to spin. The spinning motion generates strong centrifugal forces which induces the solid and liquid, or the two immiscible liquids, to separate. The centrifugal force generated in a hydrocyclone varies over its length, and may reach a maximum of 2000g's.

The heavier phase is forced outward toward the wall of the hydrocyclone tube and this displaces the lighter phase which migrates toward the center where it forms a core. By controlling the pressure across the tube the core is forced to flow through the overflow and the heavier solids or liquid are directed to the underflow. The result is a process with typically a 2-3 second retention time. This process provides a simple but effective separator with no moving parts.

Because of the very high centrifugal forces inside the hydrocyclone separator vertical or horizontal installation orientation has no effect on separation performance.

Solid-Liquid

The separation of solids within a desander is predictable. The degree of separation can be calculated very accurately if sufficient parameters are known. The most important of these include:

- Flowrate and available pressure drop
- Liquid density and viscosity
- Particle density, size, and shape
- Solids concentration

The separation within a desander is defined by a collection of empirical relationships (correction factors, C_n), which work in combination to predict the cut sizes, D50 or D98. These cut or separation sizes are defined by the solids diameter, where 50% or 98% of that size is removed via the underflow.

The predicted cut size $D50_{actual}$ is the most common parameter used in predicting performance[2] and it is evaluated as follows:

$$D50_{actual} = D50_{base} \times C_1 \times C_2 \times C_3 \times \ldots C_n$$

The $D50_{base}$ value is determined at reference process conditions for a given desander diameter. Correction factors exist for the process variables listed above as well as for the following geometric variables:

- Cylinder length
- Cone angle
- Vortex finder diameter and length
- Inlet size and shape
- Apex size

The $D50_{base}$ relationship and the various geometric and operational correction factors indicate that:

1. A small desander diameter is more efficient than a larger diameter.
2. A long desander (achieved by either increasing the cylinder or cone length) is more efficient than a short desander.
3. Smaller inlet and vortex finders increase the efficiency of a desander, while apex size has a negligible effect on performance.
4. An increase in pressure drop, corresponding to an increase in flowrate, improves efficiency marginally.
5. Lower liquid densities and viscosity lead to higher solids removal efficiencies.
6. Higher particle densities and sizes are easier to separate, while the closer to a spherical shape a particle is, the easier the particle will be recovered.
7. Solids concentration does not effect desander performance at the low levels. However, increasing solids concentration reduces desander efficiency, and this can be important in high concentration applications such as sand jetting.

Liquid-Liquid

Stokes Law is the governing equation which helps predict the theoretical performance of a liquid-liquid separation process:

$$V_t = K\ G\ D^2\ (\rho_1-\rho_2)\ \mu^{-1}$$

where:

V_t = rising velocity of an oil droplet
G = Force (gravity for conventional separators)
D = droplet diameter
ρ_1 = specific gravity of continuous phase (water)
ρ_2 = specific gravity of dispersed phase (oil)
μ = viscosity of continuous phase (water)
k = constant

This equation can guide the engineer to an optimal liquid-liquid separation solution. The given constants, k and G, and the specific gravity of the liquids (P1 and P2) are uncontrollable. The droplet size (D) and sometimes the continuous phase viscosity (M) have the potential to be manipulated advantageously.

Separation efficiency is proportional to drop size, which should be enhanced or maintained at all times. A 40 micron drop may be sheared into 20 or 10 micron droplets in turbulent flow. Stokes Law indicates that it will take 4 times longer to separate a droplet if it is sheared to 20 microns and 16 times longer if sheared to 10 microns. Separation efficiency is inversely proportional to continuous phase viscosity which can be lowered by increasing the process temperature.

Liquid-liquid separation and the prediction of actual performance is much more difficult than solid-liquid separation due to the following:

1. The density differences between the two immiscible liquids is typically very small (i.e. specific gravity differences of 0.1 to 0.2). Furthermore, because the fluids are often emulsified, the "observed density differential" is smaller than the calculated differential would suggest.

2. The droplets of dispersed fluid (oil in deoilers, and water in dewaterers) tend to shear or coalesce (i.e. particle diameter size changes) readily. In addition, the actual evaluation of the droplet sizes is difficult to measure accurately, even when the required expensive measurement equipment is available. Thus, critical droplet size information is usually unknown, forcing performance predictions to be based on estimated droplet size distributions.

3. The dispersed fluid can undergo significant changes under the influence of either natural reservoir, or introduced oil field chemicals.

The result is an inlet stream with a droplet size distribution and specific gravity difference which is very difficult to measure, and may even change between sampling and analysis[3]. This unpredictability is the main reason hydrocyclone based liquid-liquid separation processes have only been accepted within the last 10 years. There has been a growing awareness within the oil and gas industry of the importance of effective fluids handling, and in particular the preservation of droplet size, by minimizing shearing forces within the process flow.

HYDROCYCLONE SEPARATOR

Hardware

All hydrocyclones are composed of four (4) main sections:

1. Inlet

The inlet section is comprised of a cylindrical feed chamber which serves to convert the incoming flow to a tangential flow with minimal turbulence. Critical design variables include the inlet area and inlet type. Smaller inlet sizes result in increased tangential velocity at the hydrocyclone inlet corresponding to efficiency increase and capacity decrease.

The inlet size chosen for a particular application will be based upon the efficiency and capacity requirements for that application. Desander, deoiler and dewaterer inlets are all similar in design.

2. Overflow

The overflow section may include a Vortex Finder or Core Stabilizing Shield (CSS) which accomplishes several tasks resulting in improved performance. The CSS is an annular cylindrical shield which totally encompasses the axially flowing fluid core. It provides the following advantages:

- By surrounding the core, the CSS "shields" it from potential turbulence in the inlet area. This turbulence can be associated with normal tangential flow patterns, gas entrainment, or upset conditions.
- The CSS decreases the available cross sectional area in the inlet region, thereby increasing the tangential velocity resulting in improved efficiency.
- The CSS reduces short-circuiting from the inlet to the overflow.

The less dense separated fraction exits the hydrocyclone at the overflow. This light fraction is made up of either water or crude in desanders, an oil/water mixture in deoilers, or predominately dehydrated crude in dewaterers.

The overflow orifice is sized to handle the expected load, as determined by the light fraction content in the feed, or by the flow split desired by the customer. Overflow orifices are typically of the plug or screw-in variety with a size dependent on the separation task at hand. A 75 mm hydrocyclone typically returns a desander with a 25 mm overflow size, a dewaterer with a 10 mm size, and a deoiler with a 3 mm size orifice.

3. Cone

Cone angles and geometries vary but all essentially accomplish the same objective. As the fluid is forced along the cone it accelerates in the narrowing cross-sectional area developing the high centrifugal forces required for separation. As the nominal hydrocyclone diameter decreases, efficiency improves and capacity decreases.

Desander cones generally include a cone section of 5 to 20 degree included angle. Deoilers can have a cone section between 2 to 10 degrees, a trumpet shaped cone, or something similar. Dewaterers are similar to desanders in shape except that the cone angle is more acute, generally between 10 to 45 degrees.

4. Tailpipe

The addition of a hydrocyclone tailpipe increases the residence time for separation. The size of the tailpipe is characterized by its diameter and length. Smaller tailpipe diameters create increased tangential velocities, higher G-forces and, therefore, improved efficiencies. After hydrocyclone diameter, the tailpipe diameter has the greatest impact on capacity.

Desanders normally have very short tailpipes. However, tailpipe length is essential for residence time in deoilers and dewaterers. No improvement is found with tailpipe lengths greater than 18 times the hydrocyclone inlet diameter.

Materials

Desanders are made from a variety of materials depending on the corrosive and erosive environment in which they operate. Materials available include various ceramics (alumina, silicon carbide, tungsten carbide, etc.) stainless steel, duplex stainless, stellite^{TM}, nickel, and titanium. Urethane, gum rubber, and nitrite materials may be appropriate in some applications, as these materials have good erosion resistance under certain chemical conditions at relatively low operating temperature. They are not appropriate at temperatures above 70 ^{o}C. This large variety of available materials reflects the long history and operation of solid-liquid hydrocyclones not only in the oil and gas industry, but in other industries such as mining, coal cleaning, and chemical processing.

The choice of deoiler materials has been largely determined by equipment vendors. As the number of vendors has increased, so has the choice. Stainless steel, duplex stainless, and stellite^{TM} have been the most popular. Coating the internal surfaces of the hydrocyclone using processes such as boride diffusion are increasingly popular as the resulting surfaces provide significantly better erosion resistance than with uncoated parts. A small number of urethane deoiling hydrocyclones are also in operation, but are inappropriate at higher temperatures.

Historically, the specification of highly erosive resistant materials for deoilers reflected the fact that a substantial amount of solids was expected, which in turn presented the potential problem of erosion of the liner. The installation of desanders upstream of deoilers eliminates this problem and deoiler material specifications can subsequently be relaxed.

Performance

Desanders are available in inlet cylindrical diameter sizes of 12mm to 750mm, separating 98% of particles from 3 to 108 microns, respectively. The capacities of the 12 to 750mm desanders range from 25 to 100,000 BWPD, and although desanders can be operated at higher pressure drops, they all operate efficiently at a modest pressure drop of 10 psi from inlet to overflow outlet. If a fine solids cut is required at high flowrates the required number of smaller hydrocyclones can be installed in a containing vessel. For oil field applications the removal of 98% of all particles above 50 micron solids eliminates the majority of produced sand build up as well as resultant erosion and/or corrosion problems.

Deoiler sizes are more difficult to define as not all suppliers use the inlet cylindrical diameter as the reference size. However it is possible to generically classify deoiler sizes as large, medium and small. Inlet cylindrical diameters in the 125mm range would be classified as large, 75mm diameter sizes medium, and 50mm diameters considered small. Capacities vary and depend on the pressure drop through the deoiler, which is significantly higher when compared to a desander at the same flowrate. For the comparisons described below an available inlet pressure to the deoiler of 80 psig has been assumed.

The first and largest commercial deoilers had an inlet diameter size of approximately 125mm and separated 98% of all droplets equal to or larger than 60 microns. The minimum operating pressure required for this hydrocyclone was approximately 80 psig corresponding to a capacity of 2,200 BWPD. This large deoiler is obsolete because of its lower than acceptable efficiency in most applications.

The most common deoilers are of medium size, in the 70 to 75mm range. These units typically separate 98% of all droplets equal to or larger than 30 microns. The minimum pressure required to operate these hydrocyclones is approximately 60 psig. At an available inlet pressure of 80 psig, capacities range from 900 to 1,300 BWPD. These units have acceptable efficiencies in most cases.

Small deoilers are selected to treat "tough" applications and return high operating efficiencies. These are approximately 50mm inlet diameter and typically separate 98% of all droplets equal to or larger than 15 microns. The minimum operating pressure required for these hydrocyclones is approximately 40 psig. At an available inlet pressure of 80 psig capacities range from 200 to 300 BWPD.

There is no "typical" dewaterer size as hydrocyclones are required to perform a number of different tasks. The potential water-in-oil combinations are infinite. However, applications can generally be classified within three main inlet water-in-oil (water-cut) cases. The typical single pass performance of dewaterers are shown in **Table 1**.

Hydraulic characteristics vary significantly and depend on water cut, fluid viscosity, and pressures. As a rule of thumb the capacity of a dewaterer is generally 30% higher than a deoiler of the same size and pressure drop. The main dewaterer applications include the processing of high water cut production wells which affect export oil quality, or the "de-bottlenecking" of pipelines operating at maximum capacity.

Packaging

The packaging of hydrocyclones have evolved and improved significantly over time. Large desanders were the standard in the early 1950's for recovery of coarse particle sizes (typically greater than 75 micron). Often the desired separation required only one desander. While that is still the case today multicone designs, used in many industries for over 30 years, are gaining favour. Many small diameter hydrocyclones packaged within a pressure vessel to treat large flowrates make up a multicone. Smaller diameter hydrocyclones provide better separation efficiency for the same pressure drop. Multicone desander systems recovery very fine solids using deck space and weights significantly less than filters with comparable performance[4].

Deoilers where first accepted in the oil and gas industry 10 years ago, and dewaterers 5 years ago. They both consisted of single hydrocyclones or "liners" in a pressure vessel. To treat the required capacity a number of individual vessels were piped together to provide a total system. These systems were large and bulky. The size and weight advantages over conventional equipment almost disappeared at large flowrates. Furthermore the large number of connecting flanges increased the hazards associated with potential leaks. See **Figure 2**.

The next development was the arrangement of a number of hydrocyclones in a pressure vessel. These vessels can contain from 2 or 3 to over 100 liners – **Figure 3**. These "multi" liner arrangements significantly reduced the size and weight of hydrocyclone systems, especially those with large flowrate requirements. These compact units are ideally suited for adding capacity in retrofit situations where available space is limited. A deoiler with 200,000 BPD capacity only requires approximately 4 square meters of deck space. The maximum number of liners in a vessel tends to have a limit based on the turndown required by the end user. This can be handled by installing blanks with the liners. As additional capacity is required more liners can be installed in place of blanks. However this change out requires production downtime.

In some instances producers require very high turndown due to significant fluctuations in flowrates over short time periods. Additionally they can not tolerate system downtime. For these applications some companies prefer the original deoiler packaging system; one hydrocyclone liner per pressure vessel, in spite of their bulk and safety issues. This system has now been made obsolete with the advent of Packaged Active Cyclone Systems, or "PACS". PACS is a new hydrocyclone packaging arrangement which has the advantages of both compact packaging and infinite turndown on-line. PACS delivers a multi-liner arrangement while providing the user with the ability to turn "on" or "off" liners without any downtime.

The PACS design offers the operational advantages of parallel vessels in a much smaller deck space. Where typical current vessel on-line turndown ratios are in the range of 3:1 to 7:1 the PACS design provides an order of magnitude higher with turndown ratios typically in the 15:1 to 50:1 range, which easily meets all requirements.

PROCESS DESIGN

Process engineers tend to focus on oil and/or gas issues to maximize total production. Only by equally addressing water and/or solids issues and appropriately handling these "by-products" will maximum crude and gas production be ensured.

Solids handling problems are caused by suspended solids, dissolved solids or a combination of both. These solids may originate either from the reservoir as sand, clay and silt, or they may be corrosion products or scale. Solids can cause erosion of valves, piping and other process equipment. They can build up in process vessels creating ideal conditions for bacterial growth, which in turn may lead to serious corrosion problems.

Residual hydrocarbon content in water is also an important parameter to control in order to ensure compliance with environmental regulations and optimize oil production. For high water cut production the processing of water becomes a major part of the operation.

Engineers designing or specifying water treatment facilities should have a fundamental knowledge of water chemistry before trying to solve a water treatment problem. These fundamentals about the nature of water emulsions include:

- Emulsions are defined as heterogeneous systems consisting of at least one immiscible liquid dispersed in another in the form of small droplets. These systems are either thermodynamically unstable (easy) or they can be persistent when stabilized by surface active components and solids (tough).
- Water dispersed in oil is often referred to as regular emulsion or oil external emulsion. Oil dispersed in water is a reverse emulsion or water external emulsion. Multiple emulsions are also possible such as an oil external emulsion in a water emulsion.
- Surface active or emulsifying agents (chemicals) can be introduced, or occur naturally, with great variety in the crude oil or gas reservoir system. The tough emulsion results from a reduction in interfacial tension, and/or a stability provided from electrostatic repulsion barriers between the immiscible liquids.
- The stability or toughness depends on temperature, Ph, salinity, viscosity, density of the bulk phase, volume fraction, size of the dispersed droplets, and the age of the emulsion.

Other oil field conditions affect the emulsion and provide additional problems for adequate separation. These conditions include the presence of scale, waxes, asphaltenes, and free and dissolved gases.

In dewatering applications a particularly tough duty is the separation of an equal (50/50) mixture of oil and water. It is not always clear which phase is continuous, or at what mixture the transition from continuous to dispersed phase occurs. When a transition does take place (which may occur within the hydrocyclone) large increases in viscosity can occur resulting in poor separation.

The challenge of adequately treating an emulsion becomes quite complex and the solution will be based largely on empirical data. While the discussion here has centred on treatment by hydrocyclones, thermal, electrical and chemical treatments are also important when used in conjunction with hydrocyclones as a total process solution.

PROCESS SELECTION

Details on hydrocyclone process design features have been adequately covered in other papers. A knowledge of the importance of differential pressures, reject ratios, pressure constants, turndown ratios, and fundamentals of control are all important concepts. Individual vendors will provide these details as applicable to their equipment. Provided below is a more global view of process solution possibilities.

Stand-Alone Desander

For removing solids and associated problems from a production system, desanders can be utilized either upstream or downstream of a production separator.

If there is incentive to locate a desander upstream of a separator, the desander must be sized to account for the fluid flow and the gas volume under the actual process conditions. The more conventional location for a desander is downstream of the production separator on the water outlet leg where the majority of the sand will accumulate. The water outlet line must be in the bottom center position to minimize sand build up in the separator.

Desander-Systems

For a more effective operation, a sand jetting system can be installed within the production separator. This involves a typical cycle time of 15 minutes where water is injected and then flushes the deposited sand and other solids on the separator bottom into the water line. **Figure 4** shows a simple process flow diagram of such a system.

Produced sand volumes of up to 30% can be handled with larger desander units (500mm and larger), while sand volumes up to 1% can be handled by smaller units (50mm and smaller). When a fine separation is required, a two stage desanding operation is often recommended. The first stage of large desanders would remove the larger sized solid particle. The second stage of smaller desanders would remove finer solids from the first stage overflow to achieve the desired total cut size.

Desanders are often installed with an accumulator tank which will hold and collect a predetermined amount of solids. The design size of the accumulator tank is dependent upon the solids loading and the length of purge cycle desired.

The desander and accumulator tanks are both open to the process fluid. When the accumulator tank is approximately one-half to three-quarter full, a purging process takes place[5]. This involves:

- normal operation; both desander and accumulator tank pressurized. Solids separate in the desander section and settle by gravity through the connection pipe into the accumulator tank.
- solids removal; isolate accumulator tank from the desander by closing valve, vent off pressure through fill-up line and open both drain lines.
- accumulator flushing; after initial draining fill up with water and drain.
- recommission accumulator tank; close drain valves and open isolating valves.

The desander continues to operate throughout this cycle. The separated sand is either directed overboard, reinjected downhole, or collected in drums, taken onshore, and disposed of in appropriate landfill locations.

Desanders are ideal for use in conjunction with water reinjection facilities which typically requires a specification of 98 % removal of greater than 2 micron size particles. Although at this specification, some type of filtration system may still be required, the installation of desanders upstream will ensure the removal of larger size particles. This will result in a significantly reduced loading on the filters, ensuring more efficient overall operation with reduced downtime.

Stand-Alone Deoiler

Deoiler applications are more complex than those of desanders.

The correct utilization of Deoilers is primarily dependent on their correct system location. A deoiler should be installed as far "upstream" as possible in the process system, where maximum pressure and temperature can be best utilized. The highest pressure location will return the highest potential capacity for the hydrocyclone along with the minimal potential for droplet shearing. While placement of the hydrocyclone as far upstream in the process as possible is desirable, some operators consider this a nuisance rather than a necessity. In part this attitude is a leftover from the location of conventional water treatment equipment, which is installed as far downstream in the treatment process as possible.

Conventional equipment is located (hopefully) where it works best, although the traditional downstream location can sometimes hinder even conventional equipment performance, especially in medium to high pressure systems. Significant pressure drops and the resultant tough emulsion formation occurs when the fluid is forced to "meet" the required operating conditions of the equipment rather than the other way around.

Oil droplet shearing should be avoided or minimized. Shearing takes place at several places along the process flow including downhole in the formation and perforations, the wellhead chokes, in high velocity flow lines, control valves, pumps, and other process equipment. To limit the breakup of oil droplets, velocity through pipework should be designed to be less than 3 m/sec. Additionally, the formation of small oil droplets can be prevented by limiting pressure drops between the water source and Deoiler. The effect of pressure drop on droplet size is significant and is illustrated in **Figure 5**.

Deoiler-Systems

The operation of a hydrocyclone and other water treatment equipment in series provides the potential for extremely efficient separation. There are numerous combinations possible, however only the most cost effective options will be discussed here.

Combination

The combination of desander and deoiler is one of the simplest and most effective[6]. The desander can be located upstream of the deoiler, or both upstream and downstream. The upstream or primary desander is designed to remove the majority of the larger sized particles. The downstream or secondary desander removes the remaining small size particles. **Figure 6** shows a process flow diagram for such an arrangement at an ARCO facility.

Heaters

The use of a heater system upstream of a hydrocyclone will improve separation efficiencies and may be feasible in situations where waste heat is available. Higher temperatures will reduce the water viscosity and, as shown by Stokes Law, enhance separation efficiencies. Furthermore, heating may also aid in the breakdown of some "tough" emulsions allowing for an easier separation. **Figure 7** shows the marked improvements in hydrocyclone efficiency at various temperatures. These results have been quite dramatic in the field. Heating can be provided by specific heater treating units, or with excess gas production to effect a simple heat exchanger system.

Coalescers

The use of a coalescer unit upstream of a hydrocyclone will improve separation efficiencies. The coalescer can increase the droplet size and, as shown by Stokes Law, enhance separation. Coalescers can also enhance the mixing of chemicals if "tough" emulsions require chemical mixing to break the emulsion.

The first operation of hydrocyclones in series with coalescers upstream occurred back in 1985 during field trials at Occidental's Claymore Platform. The vessel also allowed chemical reaction and oil skimming. Coalescing equipment include coalescing media, filter type elements and the principle of coalescing pipes[7].

Degassers

The provision of a correctly designed degasser tank downstream of a hydrocyclone will improve system separation performance as well as allowing for safe degassing of the produced water.

Some produced waters contain large amounts of dissolved gas which will come out of solution when the water is depressurized. The use of Dissolved Gas Flotation (DGF) units for water treatment is well known and documented. Gas bubbles come out of solution and attach themselves to the dispersed oil droplets pulling or separating them away from the water. This results in enhanced separation and is more effective than a process dependent on gravity and density differences alone.

Only a small amount of gas breaks out within a hydrocyclone because of the short fluid retention time inside. The small amount of gas that does break out migrates to the core because of its low density and separates with the oil. The bulk of the dissolved gas breaks out after the water has left the hydrocyclone, typically downstream of the clean water discharge control valve. For design purposes, the degasser tank downstream of a hydrocyclone should be sized for a water residence time of 1-2 minutes depending on fluid temperatures.

The operation of hydrocyclones in series with degassers occurred as far back as 1983 during field trials at Esso's Kingfish B platform, and subsequent testing on Snapper and Barracouta platforms. Even during initial testing the significant overall efficiency increases were apparent.

Pumps

If the available process pressure is below 40 psig it is recommended to boost the pressure by pumping the process fluid. Pump selection and operation are equally important.

A pump should be selected that will induce minimum shear. It has long been known that positive displacement pumps can provide low shear characteristics but typically require more maintenance than centrifugal pumps.

Centrifugal pumps are not normally thought of as low shear pumps, however due to their simplicity, reliability and relatively low costs, they are more appropriate for hydrocyclone systems. They can give low shear performance when properly sized and used correctly. A centrifugal pump with a closed impeller design should be selected and operated at a hydraulic efficiency above 70% and a maximum speed of 1800 rpm.

A single stage or multi-stage centrifugal pump can be used to raise the pressure of oily water mixtures. The choice is generally influenced by technical and commercial factors. A single stage centrifugal pump should be operated at a maximum differential pressure of 80 psig, this will generally cause minimal oil droplet breakup when the hydraulic characteristics of the pump and the total number of hydrocyclone liners is correctly matched.

Flowrate in a pumped hydrocyclone system should be controlled by a recycle loop or by variable speed control. Recycle operation is the simplest way of ensuring that the pump is not dead-headed and recommended over the more costly variable speed control mode of operation.

Stand-Alone Dewaterer

The use of dewaterers is dependent on their correct installation location. A dewaterer must be installed as far "upstream" as possible in the process system, where the greatest level of pressure and temperature can be best utilized. Useful separation is expected at oil viscosity's of less than 10 cSt.

Dewaterer applications are more complex than deoilers due primarily to the wide variability of water and oil ratios, typically 10-90%. This wide range of water and oil fractions yields many different types of emulsions. The feed to the dewaterer should also be substantially gas free, and the overflow and underflow stream typically require additional processing either by other hydrocyclones (deoiler/dewaterers) or other conventional separation equipment.

Dewaterer-Systems

Heaters

The provision of a heater system upstream of a dewaterer will improve separation efficiencies for the same reasons as those provided in the deoiler discussion.

Electrostatic Coalescer

A promising dewaterer process system is the series operation of a coalescing device upstream of a dewaterer. Preliminary testing has shown a pulsed-DC electrostatic coalescer and hydrocyclone combination reduced water cuts from 75% to 10% in a single pass[8].

FUTURE DEVELOPMENTS

The future development of hydrocyclones based systems will focus on:

- Fully realizing the potential of dewatering applications.
- More integrated process systems and packaging.
- The use of "mini" deoiling hydrocyclones.

Dewatering

While the first dewaterer application was sold commercially in 1988, it has not progressed as a widely accepted application. This is due more to the inaction of equipment vendors rather than lack of process potential. This situation is expected to change.

Integrated Process Packaging

PACS is the start of a series of integrated process packaging unique to hydrocyclone systems. The objective is further reductions in the size and weight of current systems, while increasing performance efficiencies. Conceptual design studies have addressed the future direction in packaging and includes:

- The integration of desanding at the well head location.
- The integration of separator and dehydration duties within one vessel.
- The integration of water treatment processes within the one vessel.

These systems can be further integrated within a combined package.

The most exciting of the integrated packaging ideas is the use of desanders at the wellhead. Several wellhead desanding studies are underway worldwide involving the cooperative efforts of universities, process system and technology companies, and over ten international oil companies. The goals of these studies are to determine the operating envelope of conventional desanding hydrocyclones under simulated wellhead conditions, with particular emphasis on the effect of large volumes of free gas on desander performance. It is anticipated that there is a maximum allowable gas concentration which a desander can tolerate, currently estimated at 30% actual gas volume. This information will provide a performance design specification for an upstream wellhead degassing device. Commercially available or custom designed degassing technology will be specified as part of the integrated package. Key components of the studies will include:

- Investigation of the relationship between influent gas concentration and solids removal efficiency and hydraulic characteristics of a conventional desander.

- Investigation of the relationship between influent gas concentration and potential oil-water emulsification within the desander.
- Development of a basic understanding of multiphase viscosity and phase inversion phenomena as applicable to multiphase flow to hydrocyclone systems.
- Development of a design specification for a degasser to be installed upstream of a conventional desander in wellhead operation.

Desanding hydrocyclones have already been used in a limited number of wellhead applications. For example, for the removal of proppant from wellstreams, without an upstream degassing facility. In these cases the desander has been successful in removing particles greater than 400 microns in size. However, it has been accepted that the efficient removal of much finer particles, in the region of 30-50 microns, is possible if the effects of free gas in the influent to the desander can be understood and controlled. The benefits provided by successfully developing wellhead desanders for finer particle removal are self-evident. Removal of produced sand before it enters the separation train will:

- Substantially reduce or completely avoid the need for sand-jetting primary separators.
- Substantially reduce the fall-off in process performance caused by sand build-up and reduced separator residence time. This will result in less water carry-over in oil streams and improved produced water quality.
- Substantially reduce erosion and corrosion problems throughout the separation system.

Mini Deoiling Hydrocyclones

Most of the initial deoiling development work throughout the 1980's on liquid-liquid hydrocyclones focused on the optimization of physical geometries. Although significant, that research has now reached a point of diminishing returns. All current commercial hydrocyclones, of similar size, achieve comparable performance.

To realize significant performance increases "mini" deoiling hydrocyclones have been developed. These "mini" 25mm deoilers will typically separate 98% of particles equal to or coarser than 10 micron at a minimum inlet pressure of 20 psig. At an available inlet pressure of 80 psig, capacities range from 150 to 250 BWPD.

For the majority of oil field applications the deoiler is required to discharge oil in water levels of less than 30 to 40 mg/l. A number of more stringent requirements are emerging[9] in some countries that include discharge requirements of less than 15 to 25 mg/l. These lower specification requirements are normally achieved by combining hydrocyclones in series with additional separation equipment. However, the new 25mm hydrocyclones can often meet the stricter requirements without additional separation equipment.

Another significant advantage of the mini deoiler is the space savings that is achieved by the creative vessel packaging that these mini units allow. These savings are possible because the mini deoilers have been designed to treat nearly the same amount of water as the small deoilers (150 to 250 BWPD for the mini versus 200 to 300 BWPD for the small), while occupying only 25% of the cross sectional area that the small deoiler occupies.

CONCLUSIONS

Desanders have been in use in the oil and gas industry for over 25 years, albeit in a relatively minor role. The introduction, and large acceptance of deoiler hydrocyclones in the early 1980's for produced water treatment was a revolutionary achievement for process equipment selection in a conservative industry. Ten years on a large amount of learning and information has resulted in the deoiler being a well proven technology. The surge in deoiler acceptance has resulted in the revisiting of the desander for more demanding applications. Furthermore the future potential of the dewaterer adds a new dimension to the ongoing objective of size and weight reduction of oil and gas process facilities.

As the complexity of the separation task increases, due to increasing environmental standards, so does the requirement of real commitment to development work. Furthermore a whole new approach is needed in the conceptual design of these systems. It is conceivable that a number of future production systems, especially minimum facility offshore structures, will include solely hydrocyclone based process equipment. The savings in size and weight and obviously cost of these systems will result in a second hydrocyclone lead revolution.

REFERENCES

1. International Petroleum Encyclopedia, 1992, 25th Anniversary Issue, pp. 272-306, PennWell Publication.

2. ARTERBURN R. A., "The Sizing of Hydrocyclones", pp. 9, Issued by Krebs Engineers, California, USA, October 1976.

3. GRAMME, PER EIVIND, "Sampling of produced water; traps and pitfalls", Norsk Hydro Research Centre Porsgrunn, Norway.

4. WINN B.B., "The Application of Centrifugal Type Sand Separators for Water Flood Programs", pp. 122, Issued by Krebs Engineers, California, USA.

5. LOHNE KJELL, "Separation of solids from produced water using hydrocyclone technology", pp. 11, 1993 Water Management Offshore Conference, October 6-7.

6. GUTHRIE, B.S., "Use Of Desanding Cyclones Upstream of Deoiling Hydrocyclones on Behalf of Krebs Engineers. Final Report"., Orkney Water Test Center, Orkney, UK., OWTC Document No. R114-02B, 27th Feb, 1992.

7. MEIJS F. H., and MITCHELL R. W., "Studies on the Improvement of Coalescence Conditions of Oilfield Emulsions", Journal of Petroleum Technology, vol. 563, May 1974.

8. "BP proves compact oil dewatering", The Chemical Engineer, pp. 31, 11 March 1993.

9. ROBINSON KEITH, and ALLEN ROGER M., "Produced Waters, Avoiding Environmental Problems in their Disposal", pp. 37, Asian Petroleum, January/February 1993.

TYPICAL DEWATERER PERFORMANCE

DEHYDRATION

Crude Oil S.G.	Process Temp (C)	Inlet Water Cut	Overflow % Flow	Overflow % Oil	Underflow % Flow	Underflow % Oil
0.7	70	10.0%	90.0%	98.5%	10.0%	13.5%
0.7	70	50.0%	50.0%	95.0%	50.0%	5.0%
0.7	70	90.0%	10.0%	85.0%	90.0%	1.7%
0.9	70	10.0%	90.0%	97.0%	10.0%	27.0%
0.9	70	50.0%	50.0%	90.0%	50.0%	10.0%
0.9	70	90.0%	10.0%	75.0%	90.0%	2.8%

FWKO

Crude Oil S.G.	Process Temp (C)	Inlet Water Cut	Overflow % Flow	Overflow % Oil	Underflow % Flow	Underflow % Oil
0.7	70	50.0%	60.0%	83.2%	40.0%	0.200%
0.7	70	90.0%	20.0%	49.5%	80.0%	0.125%
0.9	70	50.0%	65.0%	76.5%	35.0%	0.786%
0.9	70	90.0%	30.0%	32.5%	70.0%	0.357%

TABLE 1

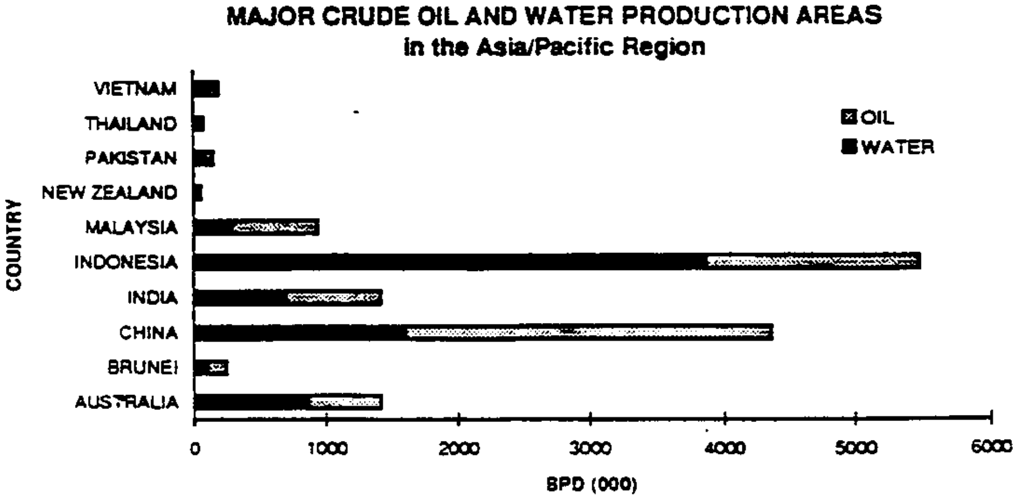


FIGURE 1

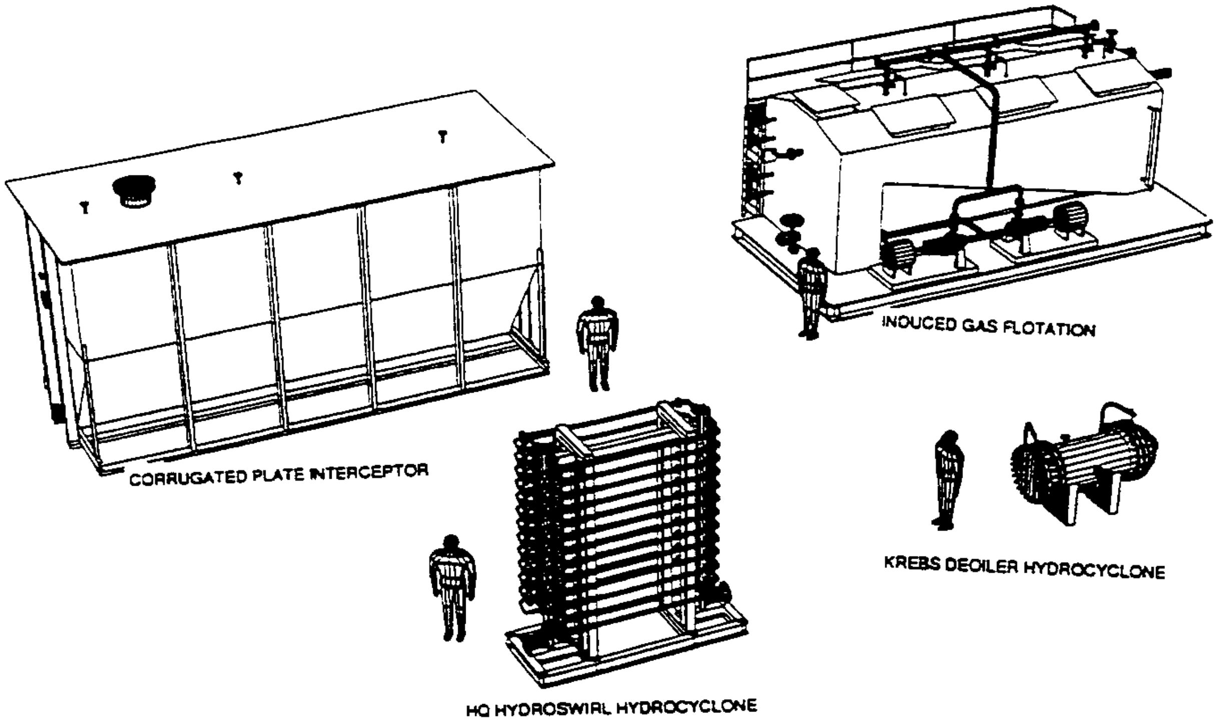


Figure 2

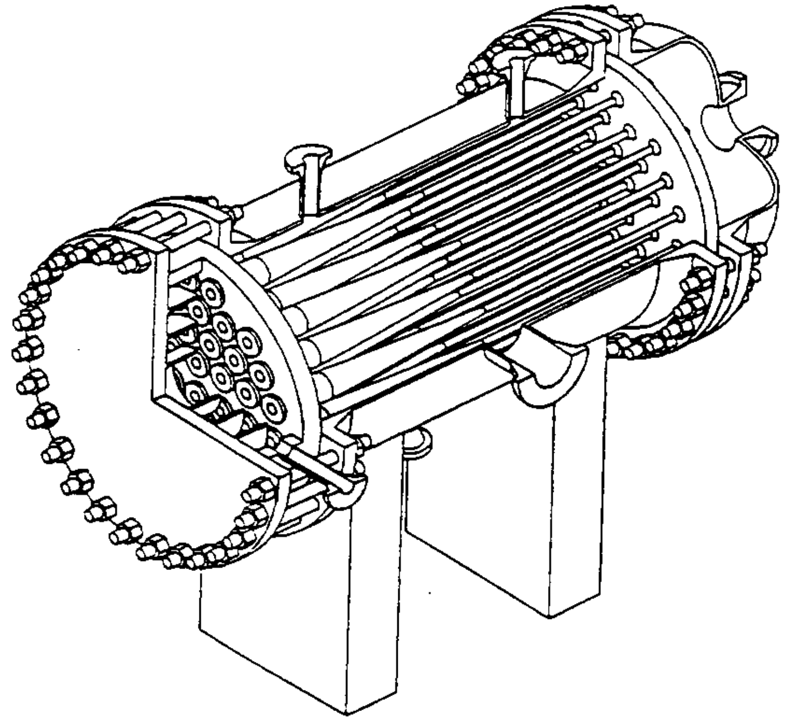
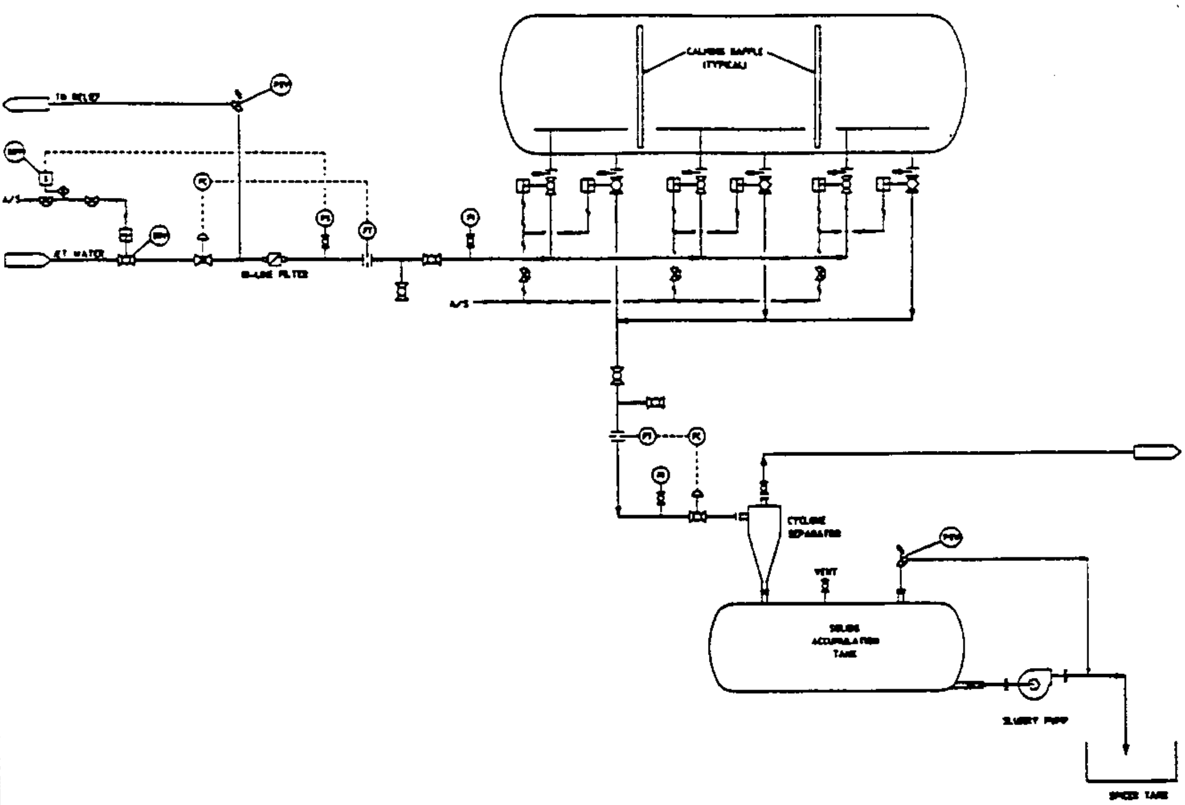


Figure 3



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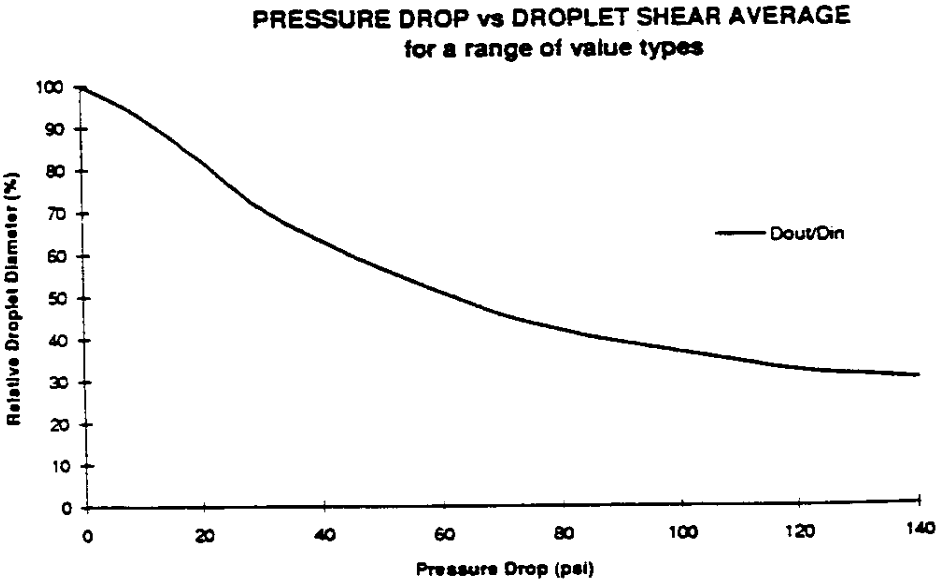
PRESSURE DROP vs DROPLET SHEAR AVERAGE
for a range of value types

Figure 5

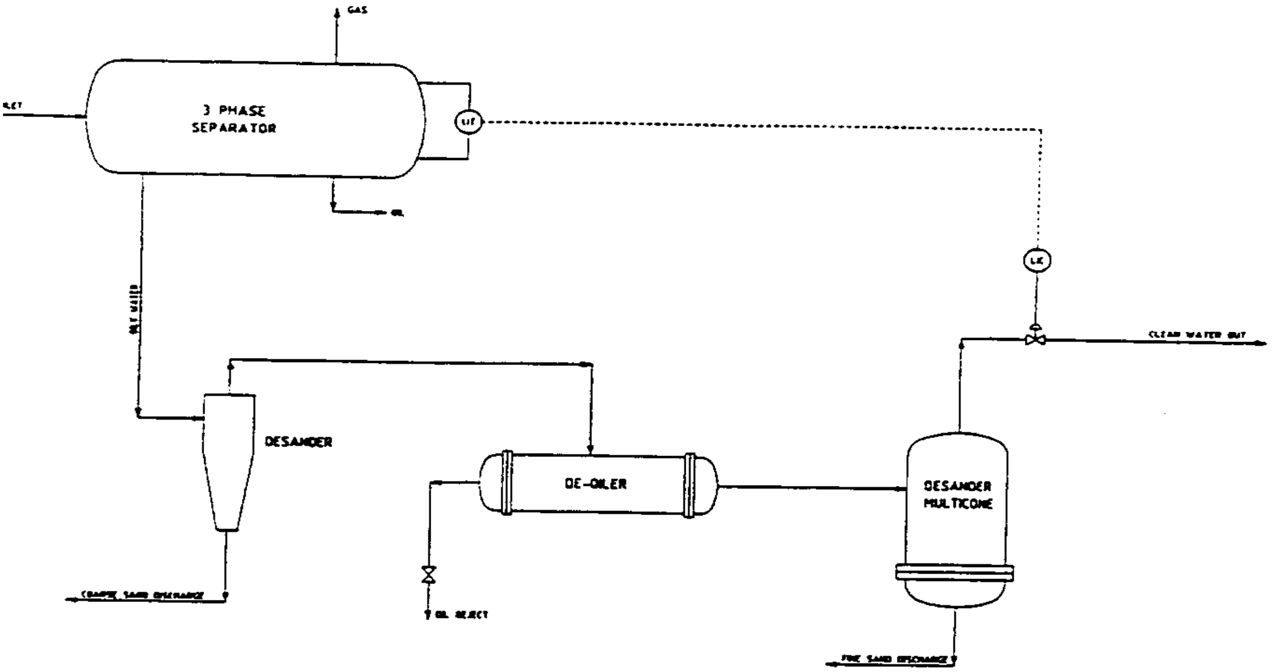

Figure 6

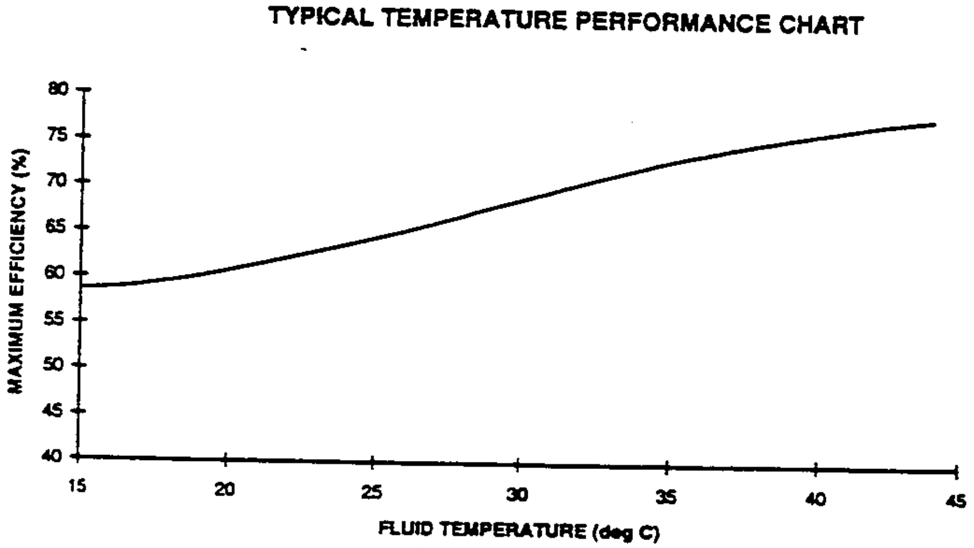

Figure 7