# ADVANCEMENTS IN LIQUID HYDROCYCLONE SEPARATION SYSTEMS

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## ABSTRACT

Since introduction in 1983, the Vortoil® Hydrocyclone has become widely accepted in the oil and gas industry, with treating capacity of over 7 MM barrels of water per day. This success is largely due to the ability of this technology to meet environmental discharge standards while offering significant installed weight and space savings and reduced operating costs.

Further research has enhanced the separation efficiency of this technology in anticipation of more stringent environmental standards as well as adapting the hydrocyclone for primary separation of produced oil and water.

The applications of the hydrocyclone technology to be discussed in this paper are:

1) Hydrocyclone system design,

2) Hydrocyclone designs for enhanced separation,

3) Low pressure operation,

4) Hydrocyclone systems for primary production separation.

Test results have shown significant improvement in oil removal efficiency for deoiling hydrocyclones, enabling lower oil content levels for produced water discharge. The improved designs enhance separation at greatly reduced pressures. Where insufficient feed pressure exists, systems using correctly designed and operated centrifugal pumps result in a cost effective, low shear solution.

Several field tests have been conducted to evaluate the ability of the hydrocyclone to make bulk oil/water separations. Results have shown that in high water cut production, hydrocyclones effectively remove bulk water, leaving less than 1000 ppm oil in the water stream and return a relatively dry oil stream. Conversely, in systems with a relatively low water content, the Dehydration Hydrocyclone has been able to meet BS&W specifications.

References and figures at end of paper.

## INTRODUCTION

The deoiling hydrocyclone provides a cost effective method to handle increasing water production, alleviating bottlenecks in many production systems. The ability to de-bottleneck water treating systems has in many instances allowed operators the flexibility to increase water floods and production rates, thus increasing oil production and extending reservoir life. In order to further expand the applicability of this technology, a two year research program was undertaken to improve efficiency and low pressure operation of the technology.

By improving separation efficiency, operators have an economic solution to new environmental standards. Efficiency improvements come not only from enhanced hydrocyclone separation but also from better system design and complimentary separation equipment.

The ability to operate hydrocyclones at lower pressures, coupled with the associated space and weight savings, offers greater application of the technology for older production with the potential of extending field life. Using correctly designed centrifugal pumps to elevate feed pressure is a cost effective option when system pressure is inadequate.

The application of hydrocyclones in primary separation has now been tested in an attempt to further increase production processing capacities over conventional equipment and potentially increase oil reserves. Typically, expanding process capacity of production platforms is cost prohibitive due to limitations on platform space. Hydrocyclones for bulk oil water separations can be used to dramatically increase process capacity with minimal topsides modification.

## HYDROCYCLONE PRINCIPLE OF OPERATION

The Vortoil hydrocyclone is a liquid/liquid separator developed specifically for separating crude oil or gas condensate from produced water. The technology has been designed to generate high centrifugal separation forces (over one thousand times the force of gravity) without creating significant droplet shear.

As shown in FIGURE 1, process fluids enter the hydrocyclone tangentially under pressure through the inlet chamber. The fluid is directed into a helical flow along the cyclone's axis. As the fluid is forced down the liner, the unique two taper design accelerates the fluids in the narrowing cross-sectional area in the first section, thus developing the high centrifugal forces required to separate the oil and water. This rapid acceleration is then maintained in the fine taper section, designed to offset centrifugal and frictional losses.

Centrifugal forces acting on the heavier water phase cause it to spin to the wall of the taper section. This in turn displaces the lighter oil phase to form a low pressure central core. The outer water annulus passes into the tail section and exits via the water outlet.

By applying back pressure to the downstream outlet, the low pressure oil core can be made to reverse direction and flow counter-current to the water stream. The oil core can then be removed separately through an overflow outlet centrally located in the back wall of the inlet section.

## HYDROCYCLONE SYSTEM DESIGN

Before discussing improvements in hydrocyclone design, it is important to understand the proper application of the technology and system design in order to maximize separation efficiency.

Previous work has shown that pressure drops typically encountered in production process equipment such as control valves can significantly reduce the droplet size of the process fluids.(1) This in turn results in lower separation efficiency. Hydrocyclones are unique in their ability to treat produced water at high pressures. This enables the device to separate oil droplets prior to reducing system pressure where significant droplet shear occurs, and thus attain higher separation efficiency.

This is contrary to most conventional treating methods which operate at low pressure, downstream of significant pressure drops that can shear oil droplets. This creates a more difficult separation, typically requiring the use of chemicals to repair damage done by reducing system pressure.

The other aspect of the hydrocyclone is its ability to coalesce. In most cases, the very small oil droplets that are not effectively removed in the hydrocyclone, tend to be coalesced. This effect can be utilized by installing a low retention time, skim tank at the discharge of the hydrocyclone. A process diagram showing a typical installation is shown in FIGURE 2.

With the reduced pressure downstream of the hydrocyclone, dissolved gas is liberated from the produced water. The gas bubbles then attach to the coalesced oil droplets and float out the residual oil. In many instances, this process can provide an additional 50% oil removal.

## ENHANCED HYDROCYCLONE PERFORMANCE

The Vortoil liquid hydrocyclone geometry is based on research work conducted at Southampton University in England in the late 1970's under the direction of Martin Thew. During the past several years, Conoco has undertaken an extensive research program to examine the operational parameters and major geometric components in order to optimize the hydrocyclone system. The test program included the following parameters:

| System Conditions | Geometric Parameters |
|---|---|
| Droplet Size | Inlet Area |
| Temperature | Nominal Diameter |
| Fluid Density | Length |
| Pressure | Geometric shapes |
| | Diameter Ratios |

Due to the amount of data collected, details of the research work will not be presented here. Instead, the resulting geometry chosen from this work will be compared to a conventional 35 mm design.

The results of the test work has enabled Vortoil Separation Systems to introduce an optimized geometry which has a model designation of "K" liner. Upon selecting the appropriate geometric configuration, a direct comparison was made between the K liner and a conventional 35 mm design. The units were compared operating side by side while varying pressure, concentration and droplet size. A schematic of the test facility is shown in FIGURE 3.

Comparative results shown in FIGURE 4 indicate the percent increase in efficiency of the K Liner over the 35 mm units. In this particular test the two units were operated using a feed droplet size of 9 and 15 microns. The results show that over the operating pressure range tested, the K liner shows a 10% to 25% increase in efficiency at the 15 micron drop size. At the smaller 9 micron drop size which represents a more difficult separation, the K Liner is 22% to 55% more efficient.

This is more significant at the low differential pressures (below 20 psig) where the K liner efficiency is dramatically higher. It should be noted that these tests were conducted at the specific conditions listed and indicate only relative efficiency between the units under those conditions.

TABLE 1 lists several field tests conducted using the K liner. The table also lists comparative data with a 35 mm unit where available. The results show in all cases a significant reduction in the outlet oil content when compared to conventional designs and an average overboard quality of less than 20 ppm. The table also includes information on the use of a downstream skimmer in combination with the hydrocyclone. The results show the significant oil reduction that can be achieved using a low retention time, oil skimming device.

Recent field testing at the Petrobras Vale do Paraiba Refinery with the "K" Liner has given very good results. The unit was tested for its capability to de-oil the water effluent from a desalter . The water from the desalter had an oil content ranging from 1,000 to 760,000 ppm. The higher concentrations were artificially created by lowering the oil water interface level in the desalter in order to simulate upset conditions. For inlet concentrations of 1,000 to 5,000 ppm, oil separation efficiency was above 97% and for inlet concentration above 30,000 ppm, the efficiency was above 99.9%.

## LOW PRESSURE OPERATION

Low Pressure operation of hydrocyclones can be addressed in two ways, 1) by improving the separation efficiency of the hydrocyclone or 2) elevating the system pressure to provide adequate hydrocyclone performance and operational flexibility.

### Hydrocyclone Operation

The test results described above show that the K liner is efficient at ssures as low as 15 psig. Generally the absolute efficiency at the pressure will be determined by the temperature and droplet size of produced fluids. It should also be considered that, if under certain conditions the hydrocyclone outlet does not meet the discharge standard, the combined system efficiency using a downstream skimmer usually will.

### Pumped Systems

Extensive testing has been conducted to determine methods to pump produced fluids without creating significant droplet shearing. As mentioned before, any significant droplet shear will affect the separation of the fluids. Previous work conducted on low shear pumps reported that the use of progressive cavity pumps offered a low shear method of creating system pressure.(2) Although this has proven a good technical solution, the cost and operational problems of progressive cavity pumps has led to further investigation for a simple, low cost alternative.

The most cost effective method was deemed to be centrifugal pumps which are widely used in the industry. A cooperative test program was established with a major pump manufacturer to determine the optimal design of centrifugal pump for low shear operation.

It was found that by limiting the pump head and correctly selecting the volute type, diameter and RPM, low shear pumping could be obtained. The pump was tested by measuring the droplet distribution at the inlet and outlet of the pump using crude oil under controlled concentration and droplet conditions. The pump was tested at various speeds and pressures to find the optimum operating conditions.

FIGURE 5 shows typical results where the change in droplet size across the pump is measured at various flowrates. This depicts the change in volumetric concentration of droplets at or below the ranges indicated as measured at the inlet and outlet of the pump. A ratio of 1 would indicate no change in droplet size while a ratio of .9 indicates a 10% reduction in droplet size at the outlet.

The results show that although there is a reduction in droplet size for the 25 micron range, there is only a small change in 5 micron droplets. The smaller droplets are most difficult to separate and would therefor be an indication of the hydrocyclone performance. It can be concluded that the minimal shear that takes place would have only a small impact on the hydrocyclone efficiency.

Further evidence that properly designed centrifugal pump systems can produce low shear has been seen in field installations. Most recently, a 240,000 bpd onshore produced water system was commissioned using centrifugal pumps followed by Vortoil hydrocyclones. The hydrocyclone system is currently handling inlet concentrations averaging 300 to 500 ppm with the hydrocyclone outlet averaging less than 20 ppm. The low outlet concentration is a clear indication that minimal shear is taking place in the pumps.

### Process Control

In production process systems where flowrates vary constantly, it is necessary to provide a wide range of flow control. This has led to a process design for pumped systems as shown in FIGURE 6. The test results showed the centrifugal pump is best operated at a constant flow to minimize droplet shearing resulting from process back pressure.

In the system shown, the pump and hydrocyclone are designed to operate at the maximum system flowrate. Level control of the upstream separator operates normally while a flow bypass is provided from the outlet of the hydrocyclone which recycles part of the flow upstream of the pump. A pressure control valve regulates the fluid bypass as the level control closes to maintain the pump pressure and prevent throttling.

The added advantage of this system is that the recycled fluid will repeatedly pass through the hydrocyclone where further separation can take place. This improves the overall separation efficiency of the system.

## PRIMARY SEPARATION USING HYDROCYCLONES

The compact, modular design of the deoiling hydrocyclone allows economic upgrades in water treating capacity. This additional capacity alleviates limitations in the water treating system, allowing greater process capacity. This moves the process bottleneck upstream to the primary separation equipment.

The most recent advancement made in the Vortoil hydrocyclone technology is its adaptation into primary oil water separation. The use of hydrocyclones in primary oil water separation can further alleviate process bottlenecks and can accommodate increased production rates from satellite fields or other reservoir management programs such as water floods. Processing higher fluid volumes can potentially increase field life and recoverable reserves.

The application of hydrocyclones in bulk oil water separation can be separated into two functions: Preseparation and Dehydration.

### Preseparation

In Preseparation, the hydrocyclone removes bulk water in high water cut production, typically above 50% water, leaving a relatively dry oil stream that can be dehydrated in a conventional separator. The water stream from the Preseparation hydrocyclone contains a relatively low concentration of oil, typically less than 1000 ppm, which can be treated using conventional deoiling technology.

Figure 7 illustrates a conventional three phase process where the original design capacity has been exceeded due to an increased water flow rate. Over time the oil production has dropped from 50,000 bopd to 40,000 bopd. At the same time, water rates have increased from 50,000 bwpd to 100,000 bwpd. This represents an increase in production fluids of approximately 70%.

One solution to this increase in production fluid using a Preseparation hydrocyclone is shown in Figure 8. In this process, the primary separator is converted to two phase operation. The fluids are degassed and then processed in the Preseparation hydrocyclone where the majority of bulk water is removed. The separated water is then processed in a conventional deoiling system.

The oil stream from the Preseparation system may contain up to 20% water and can then be sent to the second stage separator for further dehydration. The second stage separator can effectively dehydrate the crude oil as it is now operating within its original design conditions.

### Dehydration

The Dehydration hydrocyclone has been adapted to remove residual water (typically less than 50%) from the crude oil or condensate. The unit will provide an oil stream that is less than 1% BS&W specifications. The water stream will contain some residual oil which can then be recirculated to the upstream separator or sent to a second stage separator.

Figure 9 shows a three phase separation process in which production rates are forecast to increase from 90,000 bpd to over 130,000 bpd. Based on existing separator designs, it is expected that pipeline BS&W will increase up to 10%. In order to maintain pipeline specifications of 1% BS&W, a Dehydration hydrocyclone is installed on the discharge of the mainline oil pumps as shown in Figure 10.

The Dehydration system provides an economical solution where the excess water is recycled to the primary separator where it is effectively removed. The dry oil stream is fed directly to the export pipeline.

## CONCLUSIONS

As the oil industry strives to meet increasingly more stringent regulations and improve economic performance in uncertain times, the Vortoil hydrocyclone technology continues to provide cost effective solutions.

The hydrocyclone offers a compact, economic oil/water separation system capable of handling increased production rates while simultaneously improving environmental performance. Through cost effective process expansion, production systems are able to produce beyond their original design life. The hydrocyclone equipment costs are more than offset by the higher revenues from increased oil reserves.

## REFERENCES


1. Flanigan, D.A., Stolhand, J.E., Scribner, M.E., Shimoda, E.; "Droplet Size Analysis: A New Tool for Improving Oilfield Separations"; paper 18204, 63rd Annual SPE Conference, Houston, TX, October 2-5, 1988.

2. Flanigan, D.A., Skilbeck F., Stolhand J.E., Shimoda E.; "Use of Low Shear Pumps in Conjunction With Hydrocyclones for Improved Performance in the Cleanup of Low-Pressure Produced Water"; paper 19743, 64th Annual SPE Conference, San Antonio, TX, October 8-11, 1989.


*Table 1, K Liner Field Test Results*

| LOCATION | INLET (ppm) | 35 mm OUTLET (ppm) | K LINER OUTLET (ppm) | DEV (ppm) | EFFICIENCY | DESCRIPTION |
|---|---|---|---|---|---|---|
| TULLOS, LA. | 520 | | 39 | 20 | 96.2% | PUMPED, REINJECTION |
| EAST CAMERON, LA. | 82 | | 10 | | 87.8% | 40 API, OFFSHORE GOM |
| WEST DELTA, LA. | 91 | 25 | 11 | | 87.9% | 37 API, OFFSHORE |
| RANGELY, COLORADO | 124 | 27 | 17 | | 86.3% | CO2/WATERFLOOD |
| NORTH SEA | 280 | | 39 | 19 | 93.2% | NO CHEMICAL INJECTION |
| NORTH SEA | 880 | 73 | 22 | | 97.5% | W/ WATER CLARIFIER |
| SHIP SHOAL, LA. | 560 | 180 | 35 | | 93.8% | LOW TEMP 80 F |

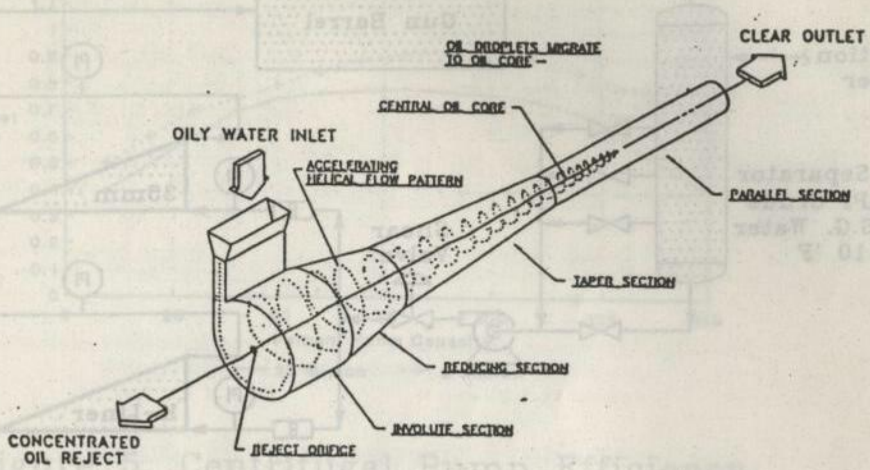



Figure 1, Liquid - Liquid Hydrocyclone Principle of Operation

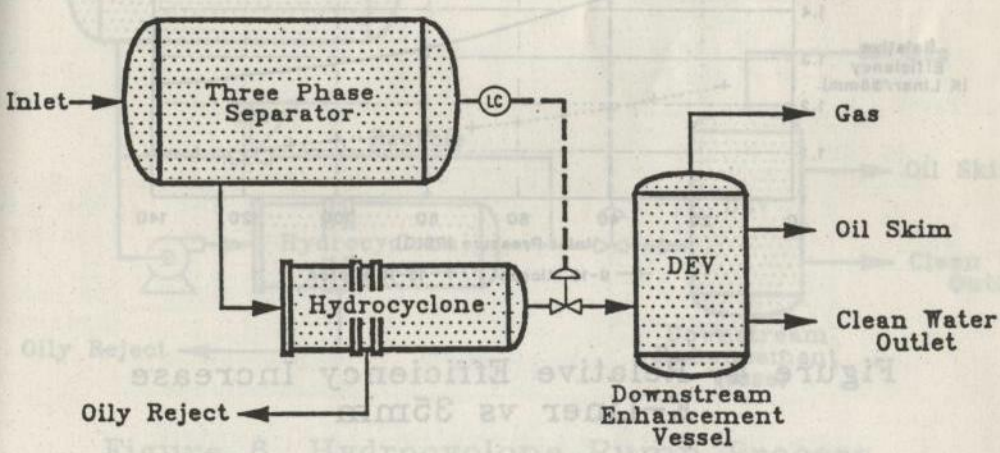



Figure 2, Hydrocyclone DEV Process

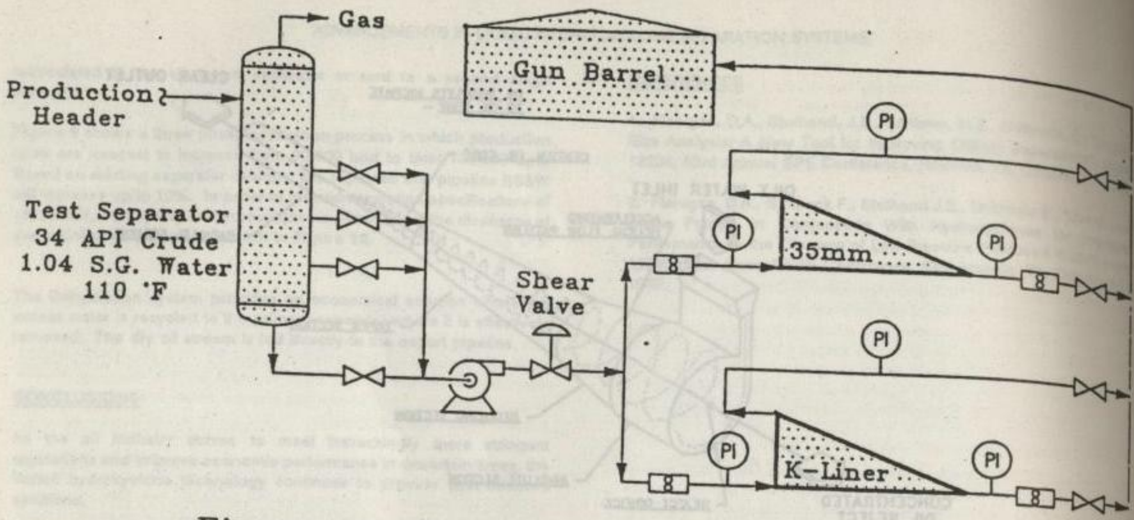



Figure 3, Hydrocyclone Test Facility

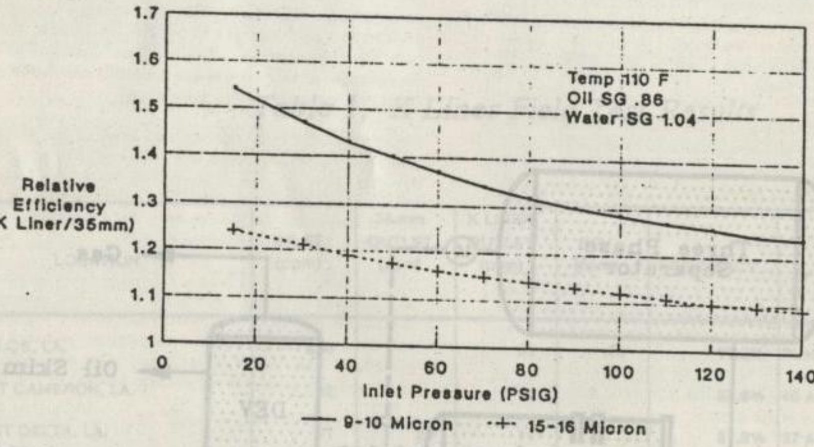



Figure 4, Relative Efficiency Increase K-Liner vs 35mm

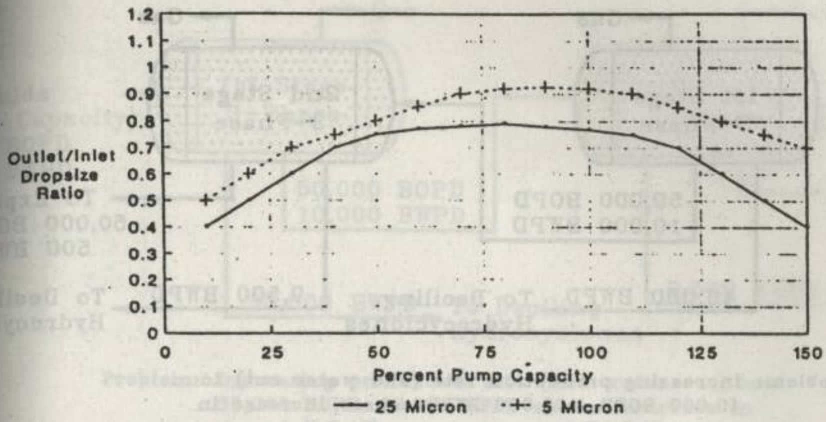



Figure 5, Centrifugal Pump Efficiency
Droplet Size vs Flowrate

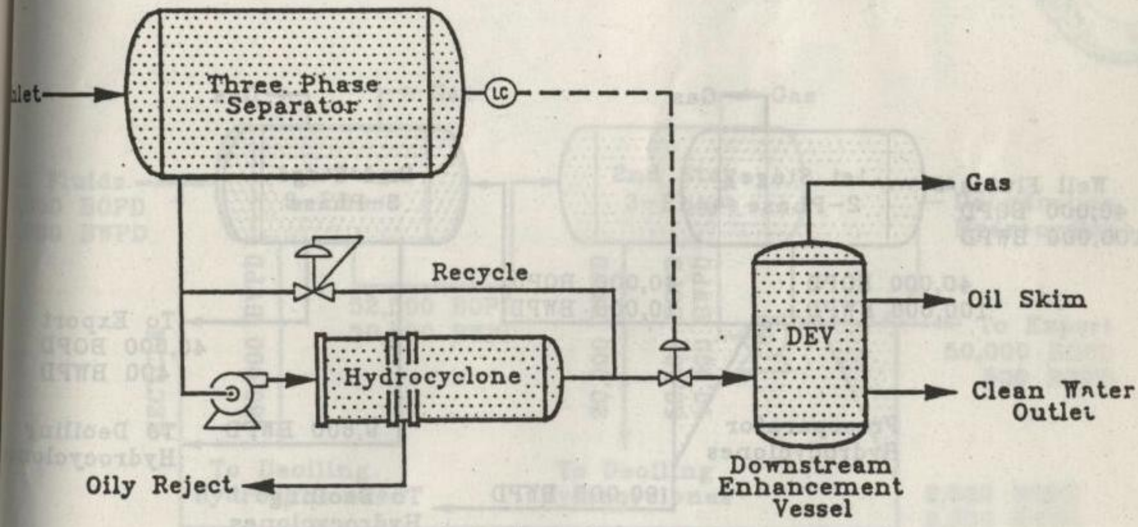



Figure 6, Hydrocyclone Pump Process

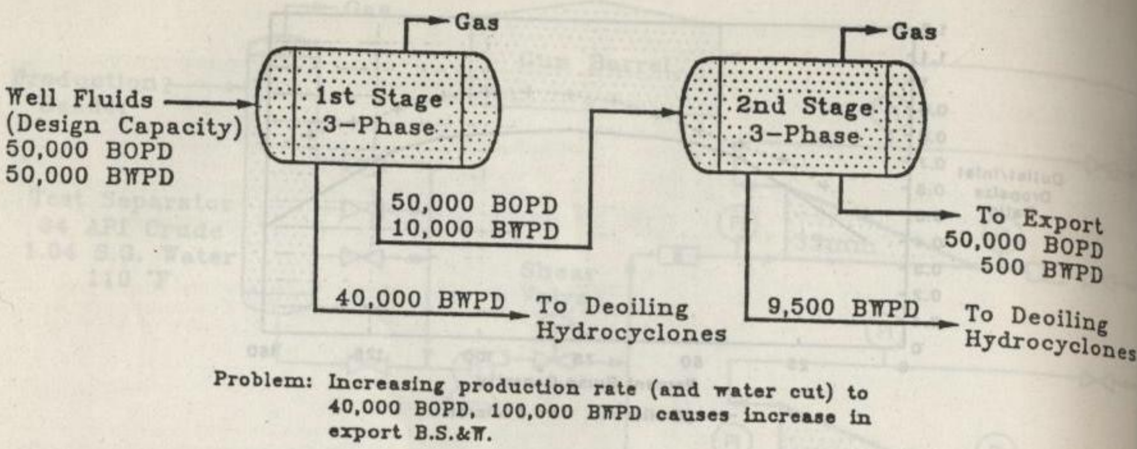



Figure 7, 3-Phase Conventional Separation Train

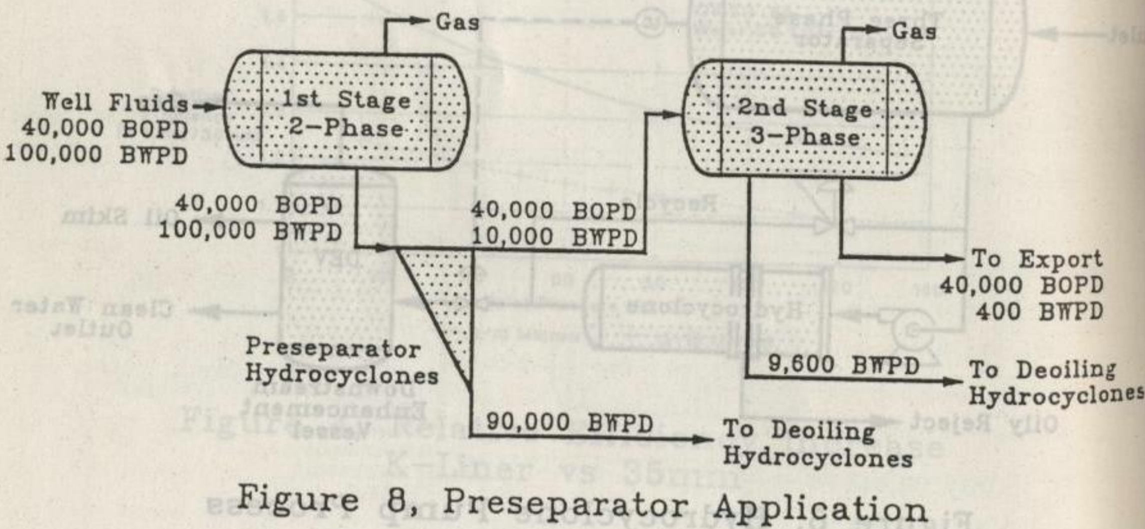
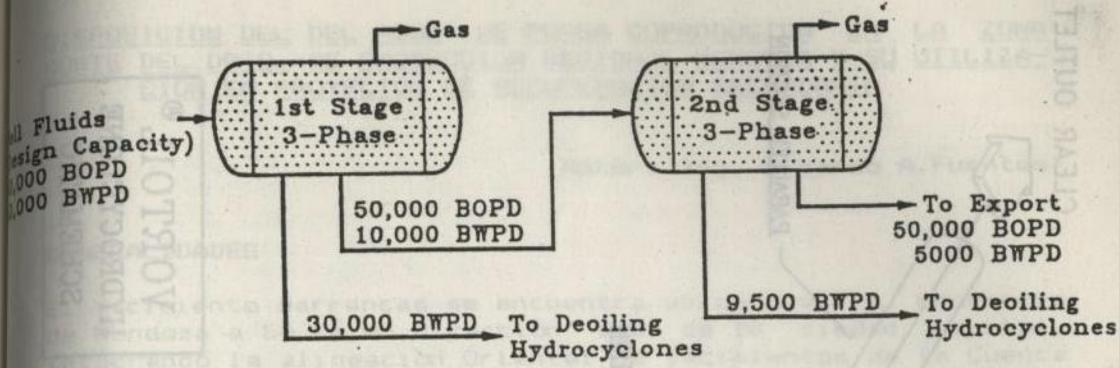



Figure 8, Preseparator Application




**Problem: Increasing production rate (and water cut) to 50,000 BOPD, 80,000 BWPD causes increase in export B.S.&W.**

Figure 9, 3-Phase Conventional Separation Train



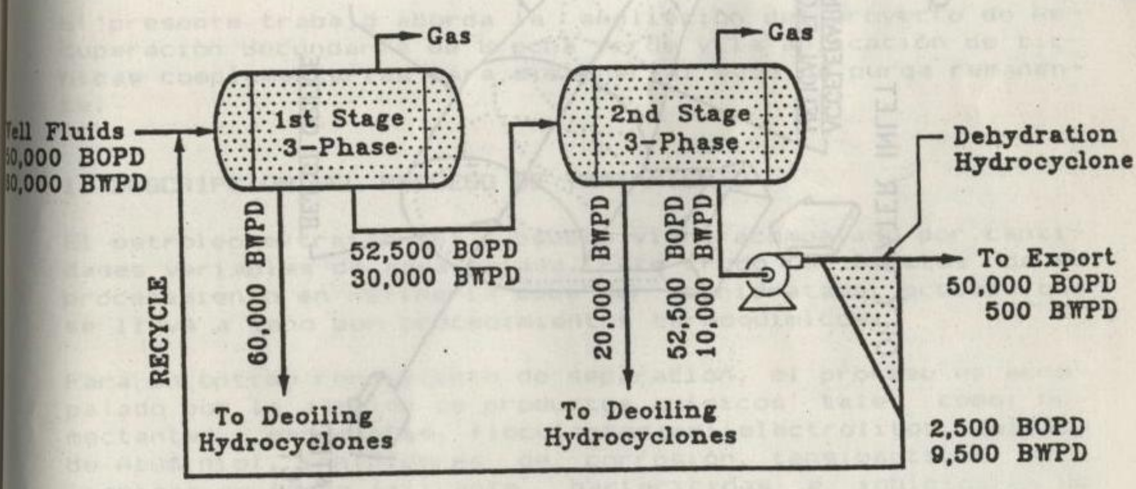
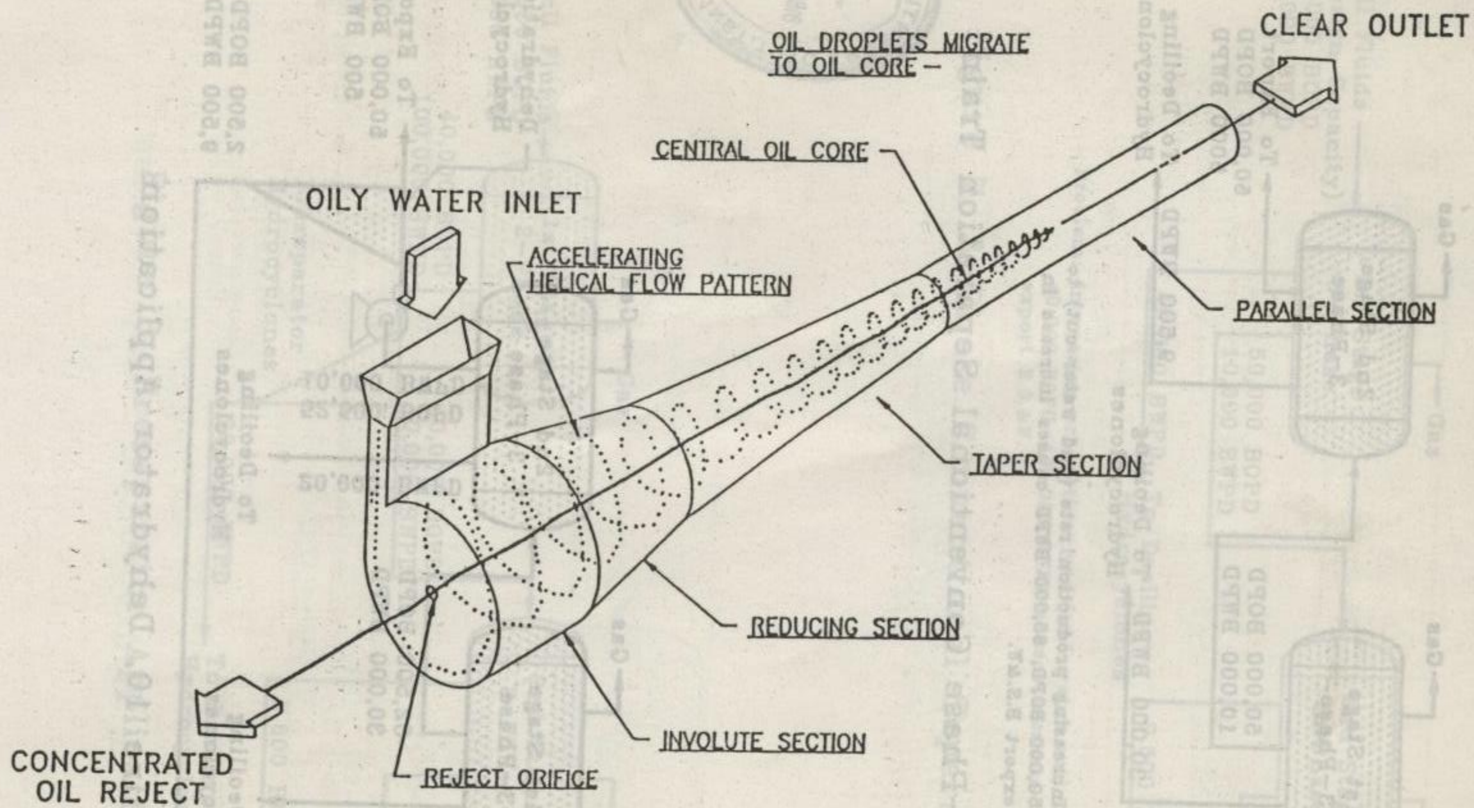



Figure 10, Dehydrator Application

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