PRODUCED WATER TREATMENT WITH VORTOIL® HYDROCYCLONES IN HIGH PRESSURE GAS PRODUCTION

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INTRODUCTION

With the imminent tightening of produced water discharge limitations, oil and gas companies have focussed a great deal of attention on oil-water separators. With hundreds of process systems in place and plans of many more to be constructed in the near future, designers are searching for an effective way to up grade and/or improve traditional processes in order to meet the requirements imposed. Meeting the oil content specifications in discharge water is the goal, but the methods of obtaining this goal in the most cost effective manner will ultimately determine the project's success.

Vortoil Separation Systems (VSS, a division of Conoco Specialty Products Inc.) has designed, manufactured and sold Vortoil® hydrocyclone separators since 1989. There are over 7 million bpd of installed VSS process capacity world wide. Vortoil separators (standard, high efficiency, low pressure, etc.) provide a superior separation and operating performance to other types of separators used for produced water treatment. The significant knowledge we have gained over the past years allows VSS to offer expertise in optimizing process systems through the use of hydrocyclones.

While VSS aims to make the most efficient separators available, the approach to solving separation problems is not purely to build a more efficient separator. By taking advantage of the process design options offered by Vortoil separators, system designers have solved produced water disposal problems while reducing system costs and increasing operating efficiency.

CONVENTIONAL PROCESS DESIGN

The produced water stream for a typical oil & gas production process is illustrated in Figure 1 (pressures will vary and one or more of the pressure stages may not be required). Produced water from the various stages of separation flows to a common, low pressure header. This oily water stream is normally routed to a low pressure gravity separator (CPI or Skimmer) for surge dampening, degassing and free oil removal. The water out of this vessel is at relatively consistent flow and oil concentration, and is suitable for treatment by a number of "water polishing" technologies. These technologies include, but are not limited to, Induced Gas Flotation (IGF), centrifuges, filters and liquid/liquid hydrocyclones.

Figure 2 illustrates use of an IGF unit in a typical treatment process. This has become the conventional approach to water treatment in the Gulf of Mexico and other oil and gas production regions. Partially because this design approach is well accepted, process designers planning upgrade water treatment consider replacing the IGF unit with a pump fed hydrocyclone system.

Figure 3 illustrates such an installation. This approach has been successfully used to meet discharge specifications, but does not provide a system with the full benefits and performance available from hydrocyclone systems. The weight, space, cost, and operating requirements of such a system may offer only marginal improvements over the IGF which was replaced.

SEPARATION PERFORMANCE VS. DROPLET SIZE

Before a separation system can be designed, all the variables that effect the performance of the system must be considered. With liquid/liquid separation the most important variables are described in Stokes Law.

$$v = F \times \frac{(d^2 \times (\varphi_w - \varphi_o)}{\mu}$$

Where v is the settling velocity, which ultimately dictates separation efficiency, F is force (gravity), d is the droplet diameter, φ_w is the density of water, φ_o is the density of oil and μ is the water viscosity. All gravity separators are governed by this equation. In the majority of the cases, fluid properties are fixed. Temperature, which affects the viscosity is manipulated quite easily with Heater Treaters. Force is either supplied (earth's pull) or applied, as is the case of the hydrocyclone. This leaves droplet size as an important variable in determining separation performance.

The separation performance of a 35mm Vortoil hydrocyclone versus inlet droplet size for a given set of feed stream conditions is indicated in Figure 4. The graph indicates that having a volumetric mean droplet size of approximately 25 microns, the unit will provide 90% oil removal. (VSS emphasizes that this data is presented only to illustrate that a centrifugal or gravity separator's performance will vary with oil droplet distribution. Note that actual performance will vary with field conditions.)

For this illustration, it is useful to assume the performance of the hypothetical IGF and hydrocyclone units are equal. In most cases, unaided by chemicals, a Vortoil hydrocyclone will remove a higher percentage of small droplets than an IGF unit. Therefore, the assumption of equal separation performance favors the IGF unit. If this assumption were true, selection of IGF or hydrocyclone would be purely based on comparison of installed and operating costs.

The failure of this approach to equipment selection is that it ignores other features of the equipment being considered. These features may offer process advantages if recognized and used.

EFFECTS OF PRESSURE DROP ON SEPARATION PERFORMANCE

The effect on oil droplet size distribution, by pressure drops across control valves, has been reported by others [1]. Figure 5 shows the decrease in mean droplet size, as an oil-water mixture flows through a globe valve at various pressure drops. Note that as little as a 40 psi pressure drop can result in a 50% reduction in mean droplet size.

Separation efficiency of the hypothetical treatment units would decrease, from 90% with a 25 micron mean, to 70% with a 14 micron mean[1]. The result is that disposal water oil concentration would increase to the point that presumably, neither unit would meet specification under these conditions.

POTENTIAL ENERGY

Returning to the typical production process, Figure 6 traces the negative effect of pressure drops on the oil droplet distribution in the produced water stream. The water outlet of each 3 phase separators is presumed to contain 400 ppm oil with a mean droplet size of 20 micron. (This is based on a variety of field measurements.)

At the common header, it is projected that the mean droplet size will have decreased by at least 50%, to 10 micron (concentration does not change). Due to the very large pressure drop from the 1000 psig and 400 psig separators, the actual mean droplet size could easily be smaller.

Some degree of coalescence is likely in the piping and the skimmer will remove approximately 50% of the oil from the water stream. Unfortunately, the skimmer removes only the largest droplets and the skimmer outlet, while lower in concentration, also exhibits a lower droplet mean.

At this point, the hypothetical treatment devices must remove 76% of the oil to reach the current outlet quality requirement of 48 ppm. However, separation efficiency of the devices is greatly reduced with an 8 micron mean. To attain the desired performance, larger droplets or additional downstream equipment is required. Droplet growth can be achieved through chemical treatment or mechanical coalescers, or a combination of the two. Any of these approaches adds cost, size and complexity to the system.

A simpler, more cost effective method of attaining improved separation performance is to place the water treatment device at a point in the process where droplets are naturally larger. The largest droplet size available is at the 3 phase separator outlets, upstream of the Level Control Valves. To take advantage of this option, the hypothetical treatment device must have certain design features other than the previously assumed separation performance.

By placing a separation device immediately downstream of the 3 phase separation vessels, upstream of the control valve, the detrimental effects of droplet shearing have been eliminated. There is also an abundance of system pressure available to assist in the separation process. Simply put, use the potential energy available (system pressure) to separate the oil from the water, not to mix it.

KEY DESIGN FEATURES

Hydrocyclone principles of operation have been thoroughly described elsewhere and are not repeated here. It is sufficient to say that the Vortoil hydrocyclone is a centrifugal separator that has no moving parts. The separator uses pressure energy to generate very strong centrifugal forces for instantaneous separation of immiscible liquids, e.g., oil and water. There are several well known features of Vortoil hydrocyclones, such as high efficiency, compact size, light weight, insensitivity to motion, etc. These features can provide significant benefits, but are only indirectly related to the process advantages offered by Vortoil separators.

The key design features of Vortoil hydrocyclones, which enable them to be used in process applications where other separators can not, include:

1. High turn-down ratio. Vortoil separators are designed to provide peak efficiency over a wide range of pressures and flow rates. Turn-down ratios exceeding 7:1 can be achieved. This flowrate flexibility allows the unit to be used in series with other separators without the need for intermediate surge dampening. (Figure 7)

2. High tolerance for variations in inlet concentration. Within reasonable limits, the outlet concentration is only slightly affected by inlet concentration. Again, no intermediate oil removal vessels are required for peak performance. (Figure 8)

3. Ability to operate at high pressure. Vortoil hydrocyclones are contained within pressure vessels, which are offered in pressure ratings from ANSI class 150 (operating pressure of 250 psig @ 100° C) to ANSI class 900 (operating pressure of 2,000 psig @ 100° C). This feature allows the separator to be used upstream of pressure reducing devices such as level control valves.

4. Ability to operate at high temperature. The materials of construction and ability to operate at pressure allow separation at high temperature, even well above the boiling point of water.

The features listed above differentiate Vortoil separators from the other hypothetical treatment devices. For example, Induced Gas Flotation units can not operate at high pressure, do not work well with surging flows, and must have consistent, low inlet oil concentration.

VORTOIL PROCESS DESIGN

The VSS preferred process design is to install a Vortoil unit at each source of produced water, using process pressure to drive the units (Figure 9). This approach offers the following advantages:

1. Oil water separation is simplified due to the advantageous oil droplet size distribution.

   - Reduction or elimination of chemical treatment is often the result.

   - The recovered oil stream is coalesced, rather than emulsified, and can be easily reintroduced to the production process without creating upsets.

2. Additional equipment requirements are significantly reduced.

   - Controls consist of little more than the existing 3 phase separator water level controller and valve.

   - A downstream vessel, required for degassing, can also be used for additional oil recovery. Oil recovery is enhanced by the dissolved gas flotation effect that is created, with the result that a short residence time can often provide 50% removal of the oil remaining in the Vortoil water outlet stream. (Note: Use of a skimmer vessel downstream of liquid/liquid hydrocyclone to enhance oil recovery is a patented process of CSPI.)

3. Space requirements are minimal.

   The Vortoil unit for each separator is small enough to be integrated into the separator skid, or placed immediately alongside. Little or no deck or pad space is required.

CASE HISTORY

VSS has an excellent example of hydrocyclone performance in a high pressure separation gas process. When Conoco acquired the North Maurice field in southern Louisiana, the

Trahan No. 1 well produced 900 MCFD, 10 BCFD, and an estimated 2,000 BWPD. At the time, untreated water was dumped directly to a Salt Water Disposal (SWD) well from the high pressure (HP) separator, resulting in SWD injection problems, low production rates, and high operating costs.

In order to increase production rates, Conoco planned a major facility upgrade which was to include a produced water treatment and disposal system. The planned system included a skimmer tank to reduce the oil content of disposal water to below 50 ppm (50 mg/l). Due to the operating pressure of the skimmer, a surge tank and high volume SWD pumping system to inject the treated water into the SWD well were also specified.

VSS got involved in the design of the new facility during the fabrication phase of the specified equipment. A field test was conducted to confirm predicted performance claims. The test did in fact confirm the Vortoil system could provide excellent oil/water separation. The test also showed the disposal water contained much higher oil concentrations than estimated. Despite inlet oil concentrations up to 1,600 ppm in the HP separator dump, the Vortoil unit consistently reduced oil content to below 15 ppm (see Figure 8). Additionally, it was determined that the pressure of the water stream after treatment in the Vortoil unit was sufficient for direct injection, without the need for pumping.

A permanent installation was installed at the North Maurice Trahan No. 1 well. A vortoil hydrocyclone separator capable of peak rates of 6,300 BWPD was specified, as actual water production was 4,500 BPD. The hydrocyclone unit is installed in the water dump line of the HP separator, upstream of the Level Control Valve. The Vortoil unit's inlet pressure is approximately 920 psi and the pressure drop across the unit is less than 100 psi at peak dump rates. Downstream of the LCV, the treated water is piped directly to the SWD well.

Placed in operation in May 1990, the unit continues to deliver excellent performance. Continued monitoring shows inlet concentrations from 450 to 2,000 ppm are consistently reduced to less than 20 ppm by the Vortoil separator. Maintenance has been virtually non-existent since start-up.

By employing hydrocyclones in the oil/water separation, the need for a skimmer, surge tank, and high volume SWD pumping system (and the associated electrical power expenses) were eliminated.

While eliminating SWD well problems and reducing capital and operating costs, the Vortoil separator helped to increased gas production more than 160% and triple the volume of gas condensate production.

SUMMARY

Under the pressure of holding down costs or maintaining production, system designers may naturally want to simplify their decisions. Considering various hydrocyclones as interchangeable, retro-fit replacements for IGF devices is one such simplification. Without increasing demands for space or loading, hydrocyclones can compliment most existing processes.

However, the full potential of hydrocyclone technology, whether applied to produced water treatment or other applications such as primary separation, can only be achieved by designing the process to take advantage of the unique features of hydrocyclones. Vortoil hydrocyclones have been designed and packaged specifically with this point in mind. The result is a device which offers the compact size, low weight and low maintenance common to all hydrocyclone designs, but with greatly expanded options for successful application.

ACKNOWLEDGEMENTS

This paper is not intended as a technical treatise on hydrocyclone technology. Rather, the intent is to persuade the reader to consider a system design approach when comparing equipment alternatives. However, the examples used are based on exhaustive work performed by many people within Conoco Inc. and CSPI.

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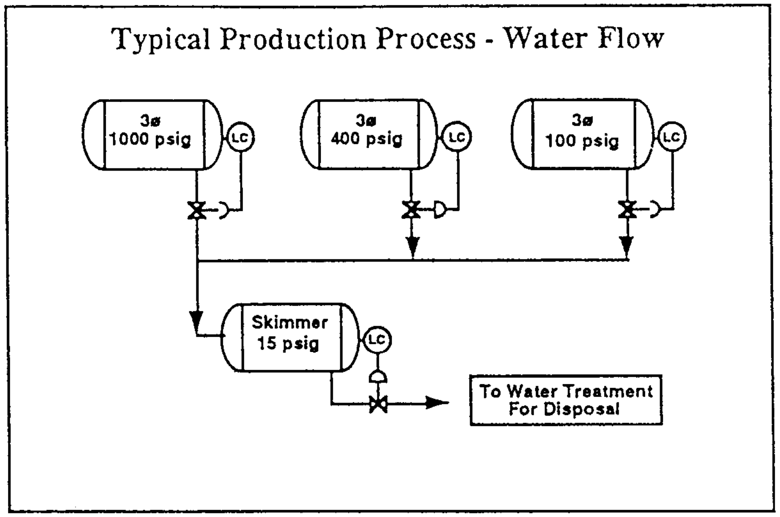
REFERENCES

1. D.A. Flanigan, J.E. Stolhand, M.E. Scribner, and E. Shimoda, Conoco Inc.: "Droplet Size Analysis: A New Tool for Improving Oilfield Separations", paper 18204 presented to the 63rd Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, TX, October 2-5, 1988.

2. D.A. Flanigan, Conoco Inc.; F. Skilbeck, Conoco U.K. Ltd.; J.E. Stolhand and E. Shimoda, Conoco Inc.: "Use of Low-Shear Pumps in Conjunction With Hydrocyclones for Improved Performance in the Cleanup of Low-Pressure Produced Water", paper 119743 presented to the 64th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, San Antonio, TX, October 8-11, 1989.

3. N. Meldrum, Conoco U.K. Ltd.: "Hydrocyclones: A Solution to Produced Water Treatment", paper 5594 presented to the 19th Annual OTC, Houston, TX, April 27-30, 1987.



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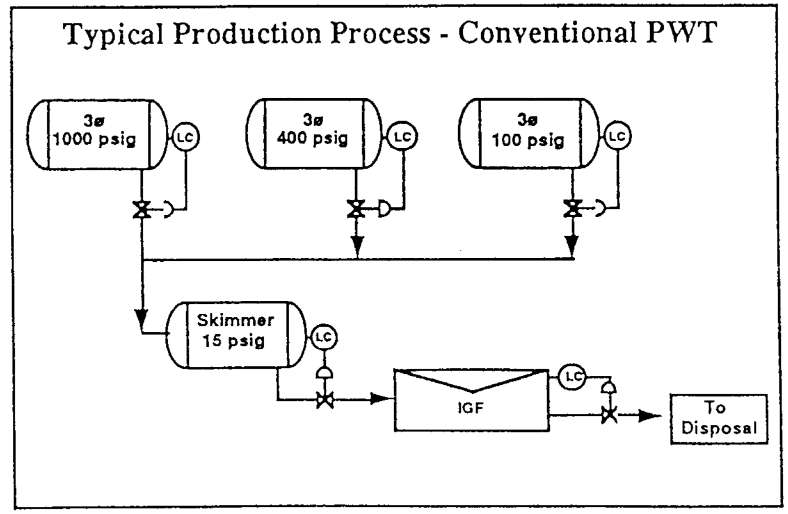

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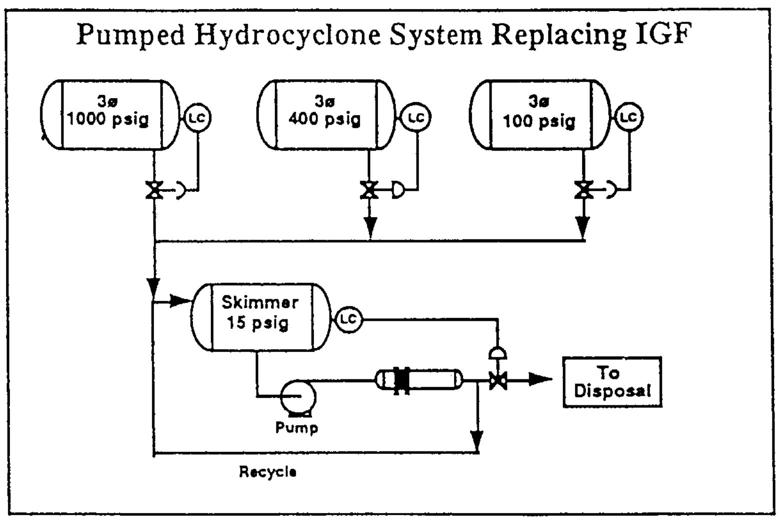

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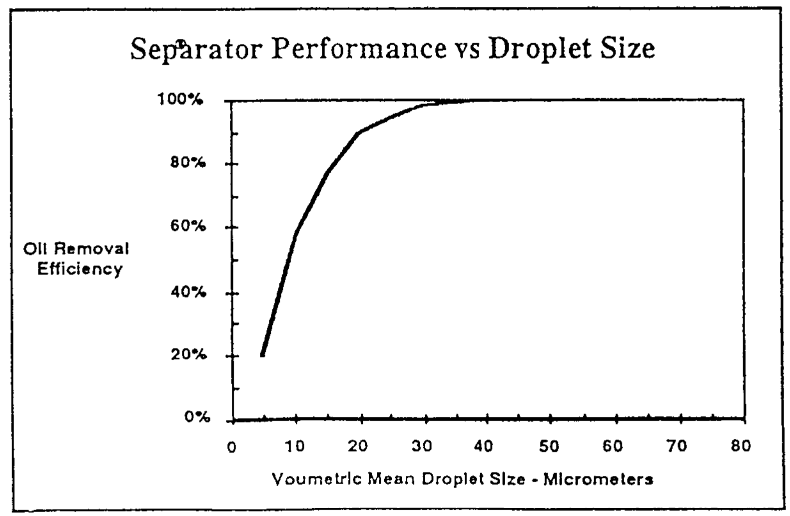

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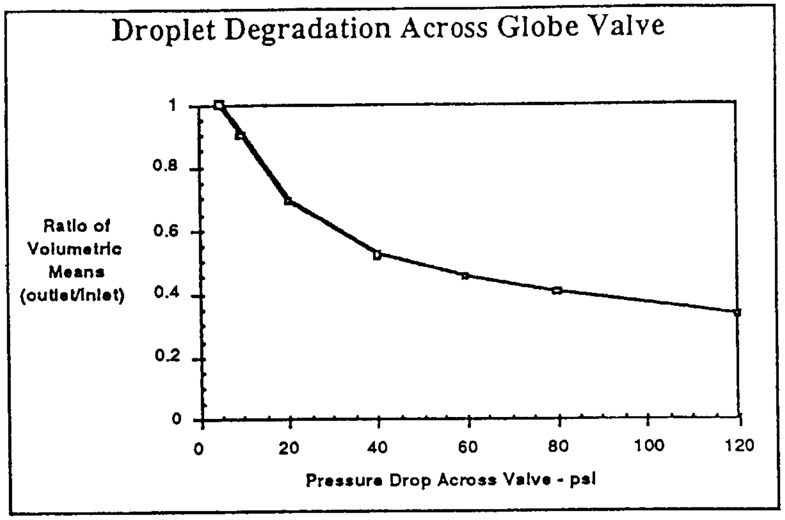

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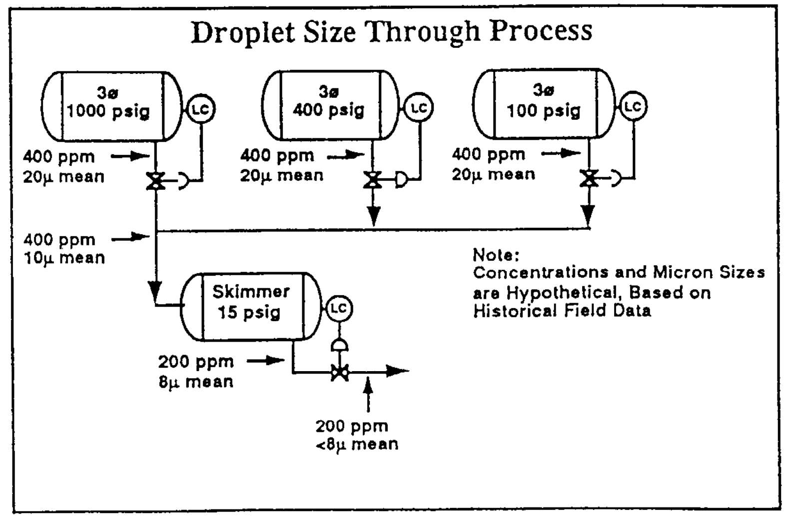

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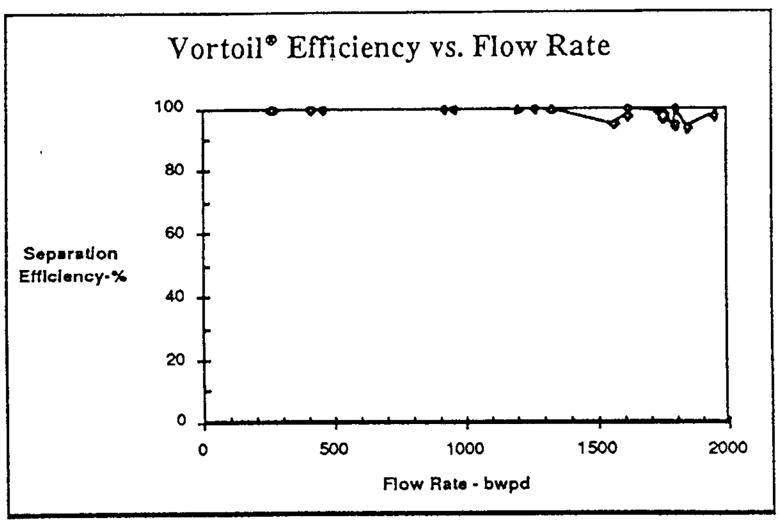

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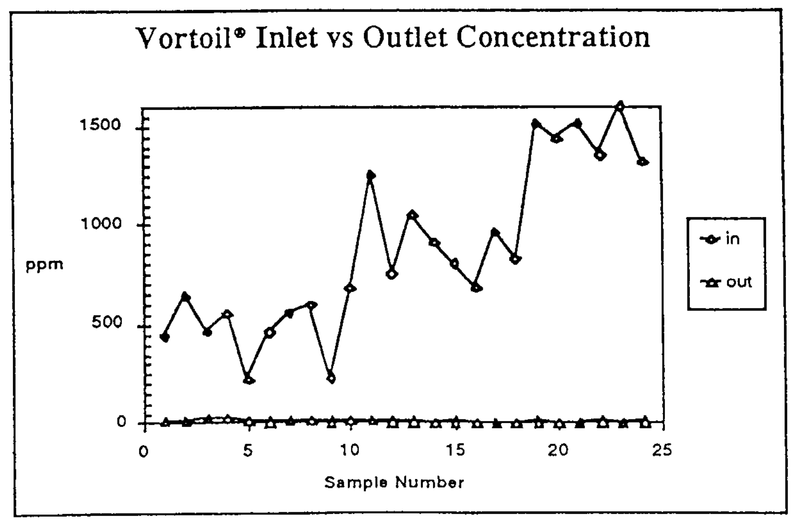

Figure 8

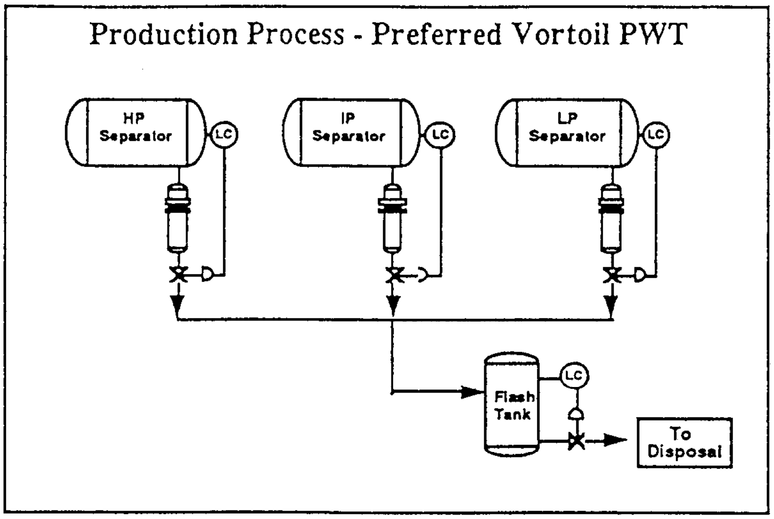

Figure 9

Process Advantages of Vortoil Hydrocyclones

Physical:

- Size, Weight (up to 90% savings)
- Insensitive to Motion
- High Pressure Capability, No Atmospheric Emmissions

Operating:

- No Moving Parts
- Tolerant of Upstream Variations
- Ease of Operation

Performance:

- Outstanding Process Performance

Cost:

- Installed Cost is Low
- Operating Cost is Low

Figure 10