Mohr Separations Research, Inc.

UPGRADING A REFINERY "ONCE-THROUGH" COOLING WATER SYSTEM FOR POLLUTION PREVENTION

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ABSTRACT

Many refineries utilize "once-through" cooling systems using river or lake water as the fluid for cooling process streams. This is an efficient means of cooling but can be a water contamination source if any of the heat exchangers leak. A "once-through" system at a refinery was studied to explore the possibility of upgrading equipment to ensure the capture of any oil in the refinery effluent in the event of a leak in a heat exchanger.

A refinery has many products that could leak into the cooling water and the magnitude of potential leaks varies widely. The water temperature varies also with weather conditions.

A design utilizing more efficient internals (multiple angle coalescing plates) for the pits would be expected to reduce the impact of releases, and further improve effluent water quality. Wide variations in possible water oil content, temperature, and oil specific gravity made design of an efficient system difficult. For this reason, a statistical approach was taken in the design.

This paper provides information on a current refinery situation, variations in the flow, oil content, etc., as well as the methods used to estimate the probabilities of meeting effluent requirements under spill conditions with various quantities of coalescing plate media.

INTRODUCTION

Some refineries utilize "once-through" cooling systems using river or lake water as the fluid for cooling process streams. This is an effective means of cooling, but can be a water contamination source if any of the heat exchangers or other equipment items leak and the existing facilities are incapable of managing the release. In any refinery, it is always advisable to consider the possibility of equipment failure, and in some cases, it is wise to consider the possibility of catastrophic failure.

A "once-through" system at a refinery was studied to determine the possibility of upgrading equipment to ensure the capture of any oil in the refinery effluent, in the event of a leak in a heat exchanger.

EXISTING SYSTEM AND COMPLICATING FACTORS AT THE SITE

The Once-Through Cooling Water (OTCW) system analyzed had a gravity separator with eight existing pits, arranged in two trains of four pits in series. These pits contained rudimentary baffle systems to prevent the escape of large quantities of oil if a breakthrough occurred. Adjustable oil skimmers and outlet weirs were also installed. Because the pits were designed before the advent of the API separator design, they were not initially sized to meet the API’s 150 mg/L effluent criteria in the event of a leak (American Petroleum Institute). The arrangement of the existing pits is shown below in Figure 1.

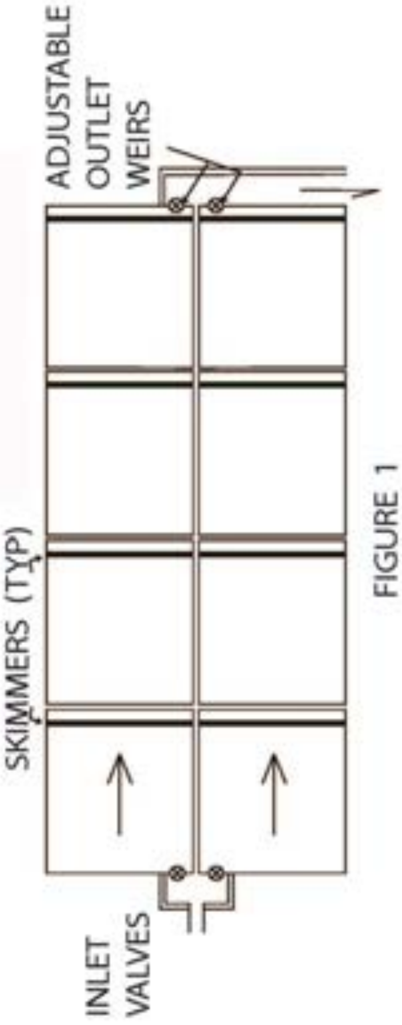

FIGURE 1
EXISTING PIT CONFIGURATION

A refinery has many products that could leak into the separator feed sewer system and the magnitude of potential leaks varies widely. The OTCW API's process only cooling water as rainwater runoff water and various process waters are segregated into an Oily Water Sewer (OWS) sewer system with multiple treatment steps. The water temperature varies with weather conditions, but the waste heat keeps it from becoming extremely cold or freezing.

An analysis of five years of process and lab data, including a rudimentary statistical analysis, yielded the following representative process conditions, as shown below in Table 1.

Table 1: Process Design Conditions

Property	**Range of Conditions**
Flow, US gpm	10,000 – 25,000
Temperature, °F.	60 – 90
Influent oil concentration mg/L	0 – 1,000
Oil Specific Gravity	0.82-0.92

HYDROCARBONS IN WATER

The hydrocarbons present in refinery wastewater can exist in one or more of several conditions. These are shown below, arranged in general order of difficulty of removal (Cheremisinoff):

1) Free oil - large droplets or sheets that rise freely to the surface. This oil is easily removed in simple gravity separators.

2) Mechanically dispersed oil - fine droplets ranging in size from a few microns up to a few millimeters. The oil found in droplets is usually the result of some mechanical mixing of oil and water, such as is found in pumping or in turbulent flow through a pipe. The oil droplets can be found in a "bell curve" of droplet sizes with some small, some large and a predominance of average size droplets. The average size will vary dependent on the amount of mixing that the two liquids have undergone, as well as the presence or absence of emulsion causing surfactant chemicals. These dispersions may be removed by the use of an enhanced gravity system.

3) Chemically stabilized emulsions - droplet dispersions similar to mechanically dispersed oil, but with droplets stabilized by surface-active agents (surfactants). More surfactants or more mixing will cause a smaller average droplet size. The average droplet size is important because many separation devices are designed to capture droplets by gravity or enhanced gravity separation, and if the average droplet size is smaller, the separator will have to be larger and consequently more expensive.

4) Oil adhering to solid particles. These can be removed by filtration or by enhanced gravity separation if the combined specific gravity is different from the water.

5) Dissolved oil - either truly dissolved oil or finely dispersed droplets, so small (less than 5 microns) that removal by normal physical means is impossible. Dissolved oil must be removed by biological treatment, absorbents, distillation, or other non-gravity

means.

In a refinery wastewater stream, the majority of the oil will be present as either free oil or mechanical dispersions of oil (American Petroleum Institute). These may be treated readily by enhanced gravity systems for removal of the hydrocarbons. Most hydrocarbon removal systems depend on gravity or enhanced gravity separation, taking advantage of the buoyancy of the droplets.

The rising of hydrocarbon droplets in a separator is governed by Stokes's Law (Perry). This function, simply stated, is shown in the following equation:

$$Vp=\frac{G}{(18x\mu)}x(d_p-d_c)x\,D^2$$

Where:

V_p = droplet settling velocity, cm/sec
G = gravitational constant, 980 cm/sec^2
μ = absolute viscosity of continuous fluid (water), poise
d_p = density of particle (droplet), gm/cm^3
d_c = density of continuous fluid, gm/cm^3
D = diameter of particle, cm

From the above equation, it may be seen that the important variables are the viscosity of the water, the difference in specific gravity of the water and hydrocarbons, and the hydrocarbon droplet size. After these are known, the droplet rise velocity, and therefore, the size of separator that is required, may be calculated. Stokes's Law is only valid for spherical particles or droplets and only in a laminar flow range.

PROPOSED NEW DESIGN

The system pits were each 28 feet wide, with about eight and a half feet of water depth. A design including the addition of more efficient internals (multiple angle coalescing plates) for the pits was proposed as a method of avoiding release in the event of heat exchanger leaks or other major hydrocarbon releases to the sewer system. Figure 2 below shows the proposed plate installation and Figure 3 shows a detail of one of the three modules required per separation train.

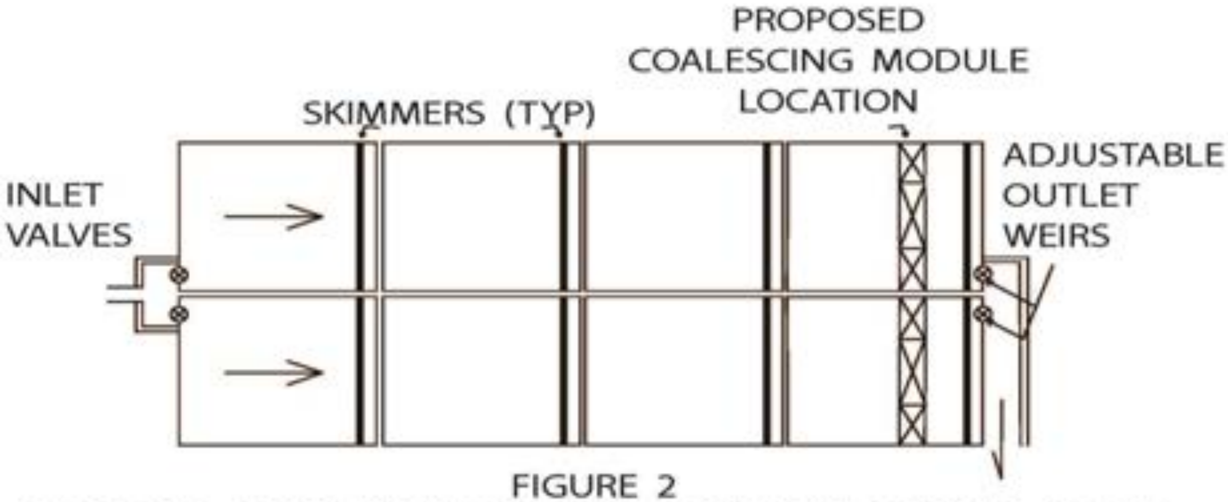

FIGURE 2
PROPOSED CONFIGURATION WITH COALESCING PLATES ADDED

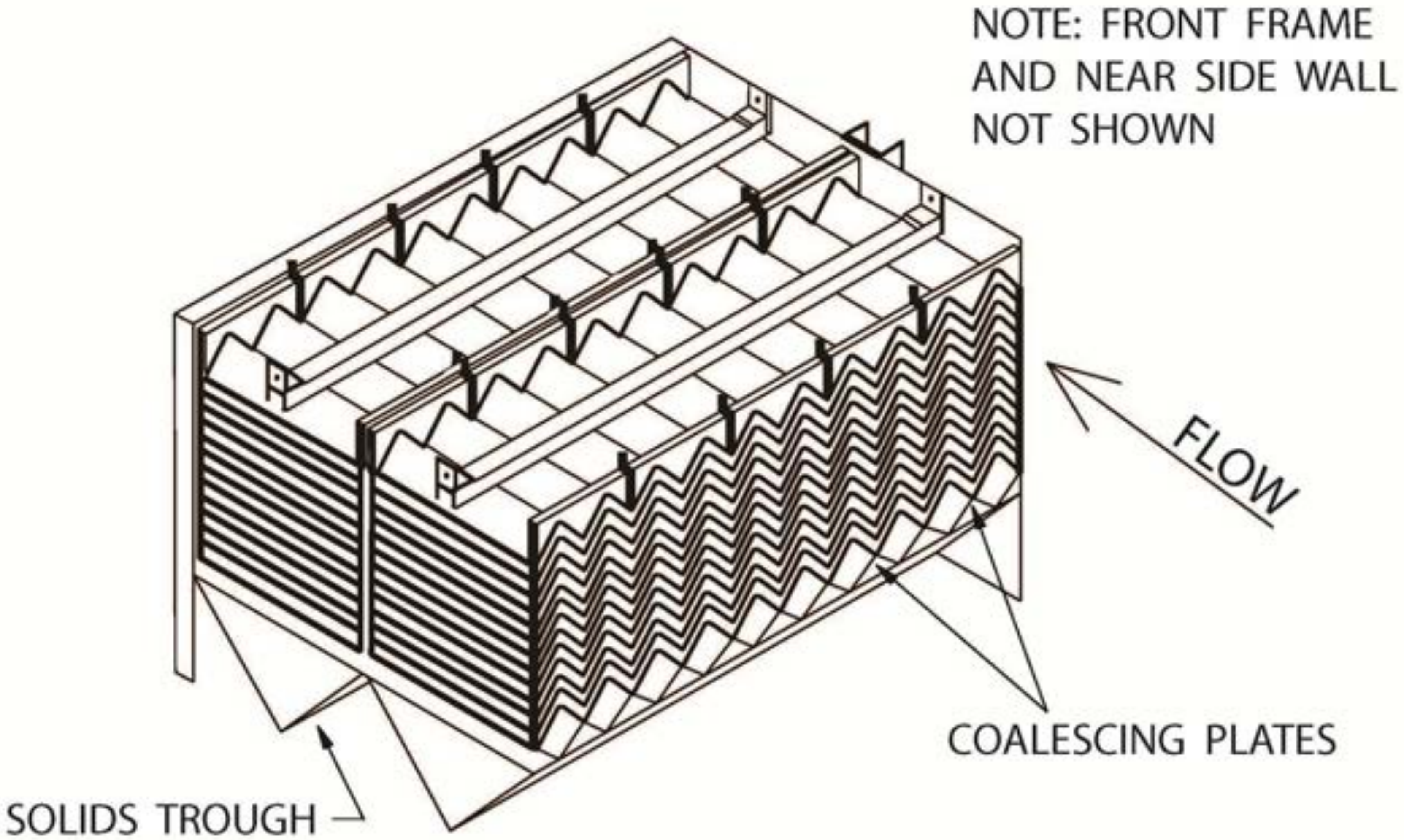

FIGURE 3
PROPOSED INSTALLATION
COALESCING PACK MODULE

This type of design would be expected to forestall releases, but the wide variation in possible water oil content, temperature, and oil specific gravity made design of an efficient system difficult. For this reason, a statistical approach was taken in the design.

The goal of the design was to convert the existing pits into a separation system suitable for removing oil down to less than 15 mg/L, utilizing only minimum modifications. The 15 mg/L goal was set to ensure that no sheen appears on the surface of the separator effluent water (Horenstein).

DESIGN CASES CONSIDERED

Calculations were done to investigate the effect of installing one, two, three, four and five rows of separator plates, as shown below in Table 2. Incoming wastewater parameters were chosen to simulate three standard deviations, in each direction from the average refinery conditions, in order to capture the expected range of operation.

Table 2: Incoming Wastewater Parameters

Property	**-3σ**	**-1σ**	**Mean**	**+1σ**	**+3σ**
Temp. °F	90	80	75	70	60
Influent Oil Concentration mg/L	100	400	550	700	1000
Oil S.G.	0.82	0.852	0.87	0.887	0.92
Oil droplet size (microns)	125	160	175	180	190

Notes:

1) ***The lower limit of the inlet oil concentration was selected as 100 mg/L because 0 mg/L influent would yield meaningless numbers.***

2) ***The mean micron sizes were chosen based on experience in oil-water separator design. In general, the mean micron size is dependent on the hydrocarbon concentration and inlet conditions.***

3) ***The assumption of three standard deviations in each direction indicates that the extreme values shown will be about 99% of the numerical distance to the true extreme. The one standard deviation value was then calculated by dividing the difference in the values by three. For example, the difference between the mean concentration of 550 mg/L and the low concentration of 100 mg/L is 450 mg/L, so one standard deviation is 450/3 or 150 mg/L. The plus one standard deviation is therefore 700 mg/L and the minus one standard deviation is 400 mg/L.***

Increasing the number of rows of coalescing packs is expected to yield lower effluent oil concentrations, but would increase the cost. An economic balance is therefore necessary to make the best choice of equipment.

METHODS USED TO ESTIMATE PROBABILITIES OF MEETING ENVIRONMENTAL REQUIREMENTS

Based on the properties shown in Table 2, performance simulation calculations were performed varying the number of coalescing packs using a proprietary computer program, and the effluent oil concentration plotted on the attached Figures (4-7), shown below.

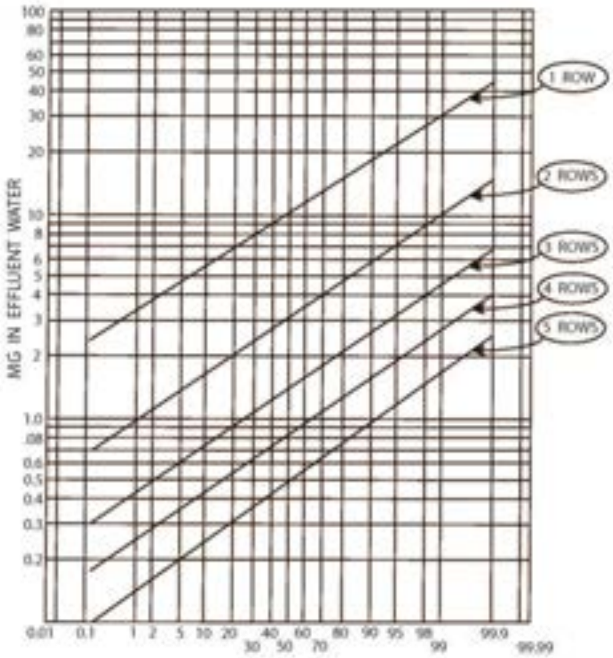

FIGURE 4
PROBABILITY OF EFFLUENT BEING LESS THAN
INDICATED AT 10,000 US GPM TOTAL FLOW

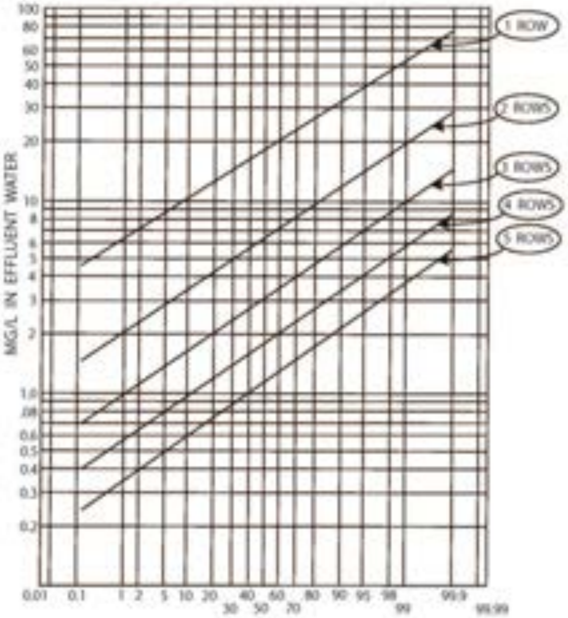

FIGURE 5
PROBABILITY OF EFFLUENT BEING LESS THAN
INDICATED AT 15,000 US GPM TOTAL FLOW

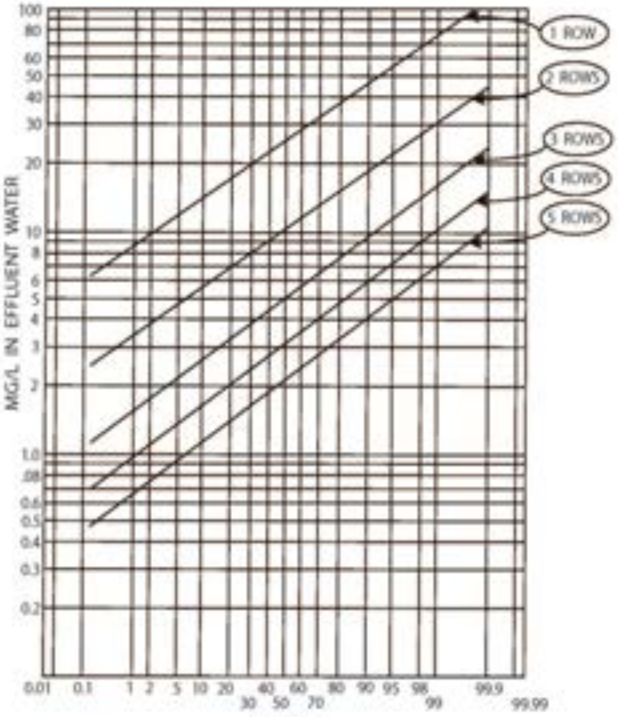

FIGURE 6
PROBABILITY OF EFFLUENT BEING LESS THAN
INDICATED AT 20,000 US GPM TOTAL FLOW

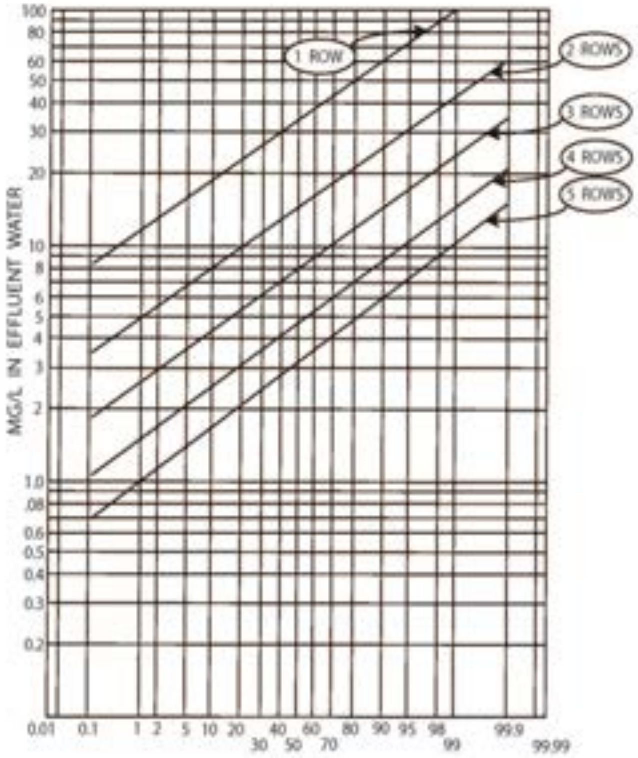

FIGURE 7
PROBABILITY OF EFFLUENT BEING LESS THAN
INDICATED AT 25,000 US GPM TOTAL FLOW

The program used determines the effluent oil concentration by dividing the droplet size distribution into several segments, determining the average rise rate of the droplets in these segments, and (based on Stokes's Law rise rates and the residence time with the media) determines the amount of droplets captured by the media. The effluent oil concentration is therefore the inlet amount of oil less than the oil captured by the media. The oil droplets captured by the media are coalesced into larger drops on the surface of the media and subsequently released to the surface of the separator for recovery by the skimmers.

A system of this type would often be designed using worst case process conditions to ensure that the effluent requirements would be met under all conditions, but the high flow rate and extreme variations (other conditions in this situation) made a "worst case" design very expensive. A statistical approach was therefore adopted to avoid undue cost, while still giving reasonable assurance that the effluent goal would be met.

Figure 8, shown below, is a summary of the data from the previous four Figures and shows the statistical probabilities of meeting the required effluent oil concentration of 15 mg/L.

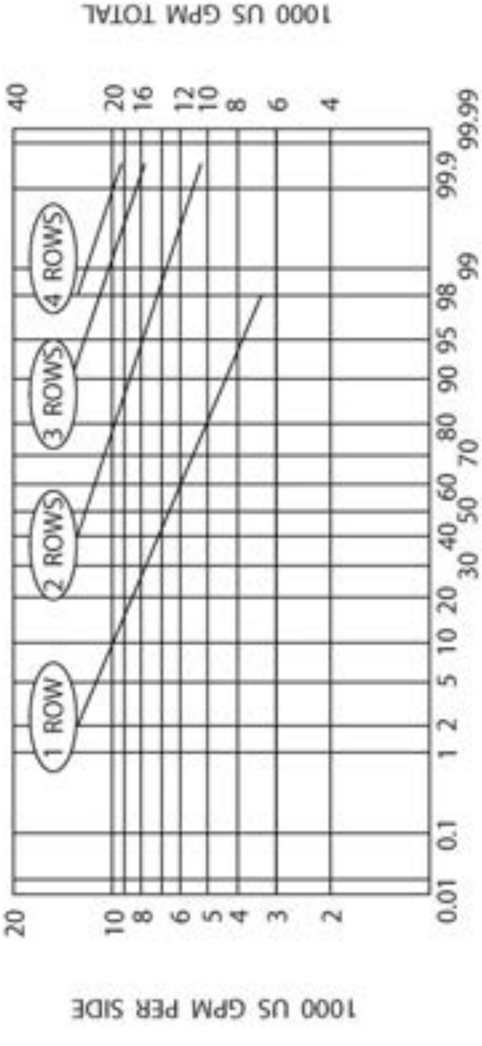

FIGURE 8
PROBABILITY OF EFFLUENT MEETING 15 MG/L OR LESS OIL
CONTENT AT DIFFERING FLOWS AND NUMBERS OF ROWS OF PLATES
(CROSS PLOT OF FIGURES 4-7)

The initial four figures may also be used to estimate the probabilities of meeting other effluent concentrations, and, if necessary, figures similar to Figure 8 could be constructed for other effluent concentrations.

All of the calculations assume even distribution of flows between the pits.
In addition to the calculations noted above, "worst case" calculations were prepared at 15000 US GPM total flow and with 1-5 rows of media packs at the lowest temperature and other plus 3σ conditions. The results of these calculations are shown below in Table 3.

Table 3: "Worst Case" Calculations

Number of Rows of Coalescing Packs	Effluent Oil Concentration, mg/L
1	89
2	35
3	19
4	12
5	8

SUMMARY AND CONCLUSIONS

The calculations indicate that the existing pits can be retrofitted with multiple-angle coalescing packs to meet the effluent requirement of 15 mg/L or less (as read from Figure 8). It is possible to install two, three, four or five rows of coalescing packs as required to meet effluent target of less than 15 mg/L as shown in Table 4.

Table 4: Probability of Meeting Effluent Oil Concentration Less than 15 mg/L

Number of rows of coalescing plates	10000 US GPM Flow	15000 US GPM Flow	20000 US GPM Flow	25000 US GPM Flow
1	80%	32%	10%	3%
2	99.9%	95.5%	76%	55%
3		99.9%	98.4%	92%
4				99%

It is recommended (based on a 90% probability of meeting the requirements) that three rows of coalescing plates be installed if flow rates to 25000 US GPM are envisioned in the near future and two rows installed if flows less than 17000 US GPM are expected. The study indicates that if effluent oil concentration, substantially less than 15 mg/L is required, more coalescing plates may be required.

Installation of the packs could be made in either the third or fourth chamber of the four chamber systems. Because the pits cannot be shut down for installation of the plates, it will be necessary to provide the plates pre-installed in three interlocking steel frame modules. The choice of three modules instead of only one is suggested because the pits have an overhanging lip on the sides which would preclude lowering a single module into the pit. The outside modules can be lowered into the pit and moved to the sides of the pit beneath the lip, and the center module lowered into the pit between the outside modules. Based on the solids loading expected and the maintenance intervals desired, it will probably be necessary to provide solids accumulation and removal troughs integral to the modules.

The accumulation of sludge is a possible problem with the system. Further information on the type and amount of solids expected should be gathered so that more accurate estimates of solids removal can be made and a final recommended solids handling system can be designed.

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