Designing parallel-plates separators

Here is a way to design parallel-plates interceptors to separate oil globules from water. According to the author, in addition to being smaller, these interceptors are in many ways superior to widely used separators for this type of service.

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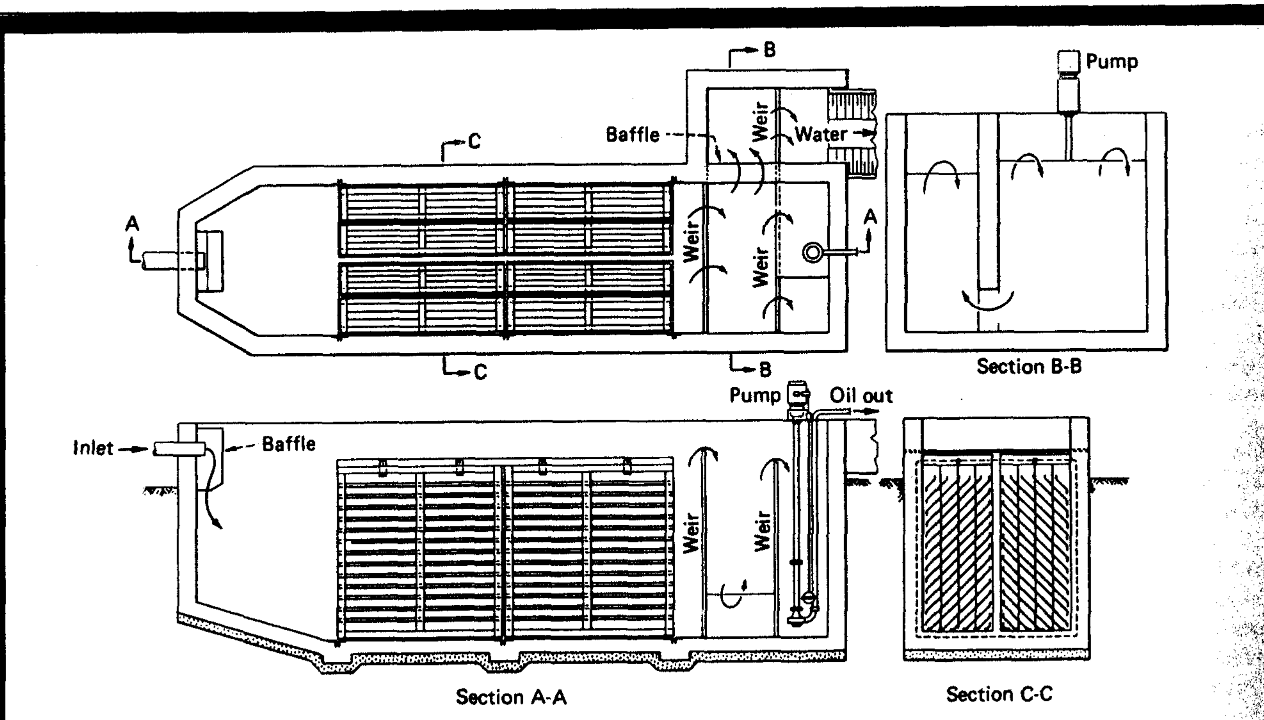
☐ Traditionally, oil-water separation in effluents from petroleum refineries has been achieved by means of the American Petroleum Institute (API) type separators as the first separation step. Even though a properly designed API separator is very efficient and easy to operate, it has disadvantages that in some cases are very difficult to overcome. Typical problems are: construction cost, space requirements, evaporation losses, fire hazard, high steam-consumption to avoid freezing of heavier products, etc.

An API separator has been designed to allow oil globules 0.015 cm dia. and larger to rise from the separator bottom (at the entrance of the unit) to the liquid surface, just before the outlet of the separator. In other words, the globules have to cross the entire separator depth to rise to the surface.



A PPI separator allows oil recovery with only one pump and with two weirs of different heights — Fig. 1

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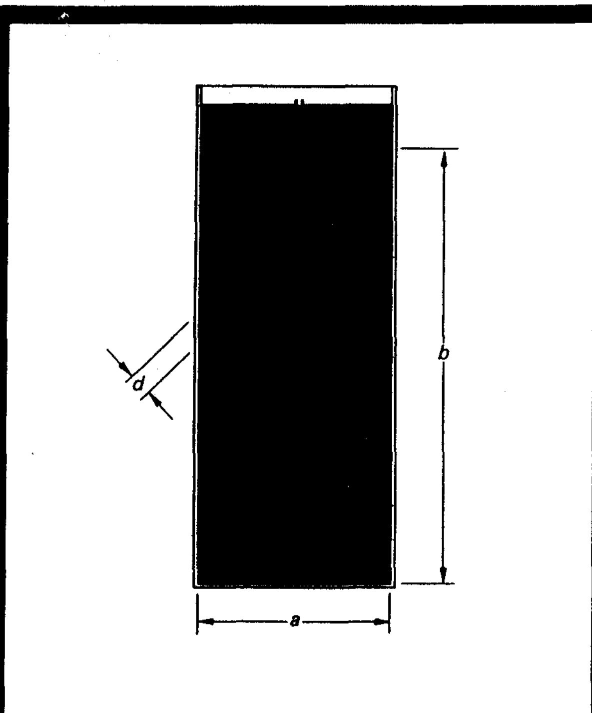


Package of plates of a PPI separator Fig. 2

Parallel-plates-separator operation

The difficulties mentioned above have been minimized by the parallel-plates interceptor (PPI), a different type of separator first introduced by Shell Oil Co. in 1950, and whose use has received wide acceptance during the last years.

By means of a PPI, the oil path has been reduced to a slight distance by a set of parallel plates inclined at 45 deg. Oil coagulates at the undersurface of each plate and slides upward to the liquid surface where it can be skimmed off. Furthermore, solid particles collect on top of each plate and slide down to the bottom. These properties make a PPI much smaller than its equivalent API separator, which allows automatic oil recovery without skimmers, with only one pump (see Fig. 1), and by means of two weirs of different heights [*1*].

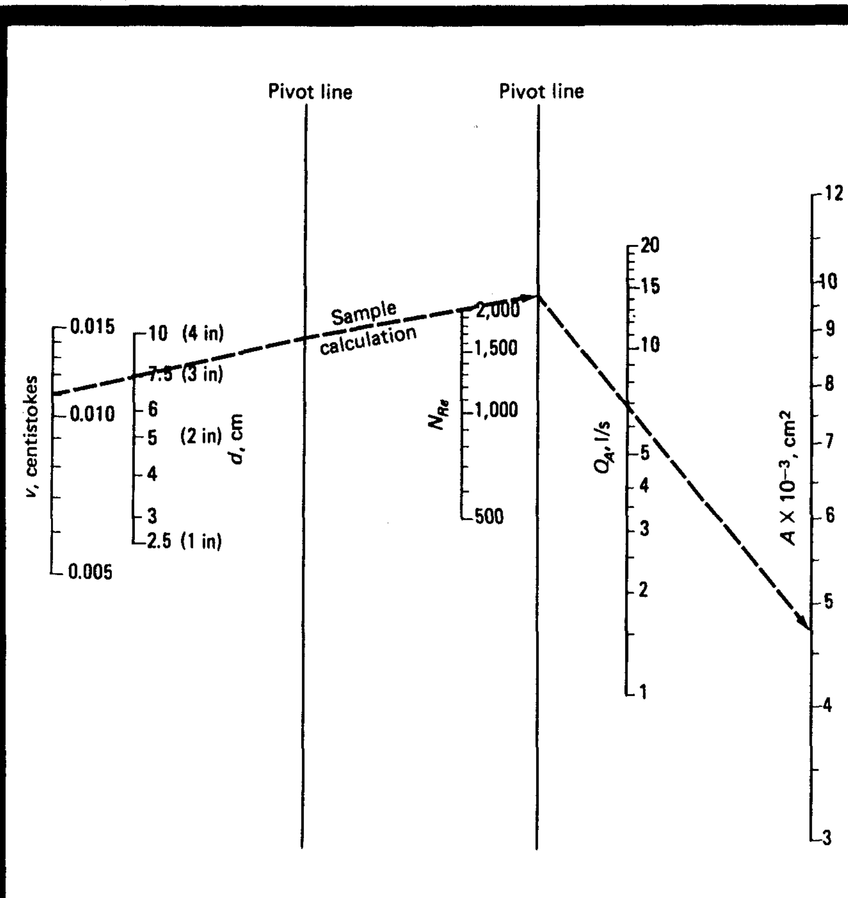
Although the PPI has been increasing in popularity, very little has been written about criteria to get a sound design of this separator. This article deals with a theoretical design approach that agrees fairly well with at least one existing PPI [*2*]. The development of this approach will be based on one package of plates such as the one shown in Fig. 2.

Retention time

The retention time (t_r) is provided by two equations:

$$t_r = d\sqrt{2}/V_t \qquad (1)$$

$$t_r = AL/Q_A \qquad (2)$$



Area requirements to ensure laminar flow Fig. 3

where V_t = rising velocity of the bubbles, cm/s; d = distance between plates, cm; A = transversal area, cm², (a) (b) in Fig. 2; L = separator length, cm; and Q_A = flow through A, cm³/s (Fig. 1).

If a and b are much greater than the distance between plates "d", then $R_H = d/2$. Hence, the Reynolds number (N_{Re}) is given by:

$$N_{Re} = 2dQ_A\rho/Au \qquad (3)$$

where ρ = fluid density (usually the same as water); and u = fluid viscosity (usually the same as water). Therefore:

$$A = 2dQ_A\rho/uN_{Re} \qquad (4)$$

Combining Eq. (1), (2) and (4):

$$L = uN_{Re}\sqrt{2}/2\rho V_t \qquad (5)$$

But since $u/\rho = v$, where v = kinematic viscosity, finally:

$$A = 2dQ_A/vN_{Re} \qquad (6)$$

$$L = vN_{Re}\sqrt{2}/2V_t \qquad (7)$$

Eq. (6) and (7) are design equations; the terms Q_A, ρ and u are known for each case, and V_t is a function of the minimum globe diameter to be separated. Then, by Stokes' Law:

$$V_t = (g/18u)(\rho_w - \rho_o)D^2 \qquad (8)$$

where g = acceleration due to gravity; u = absolute viscosity of water; ρ_w = density of the water; ρ_o = density of the oil; and D = diameter of the oil particle. (All of the above equations must be used with consistent units.)

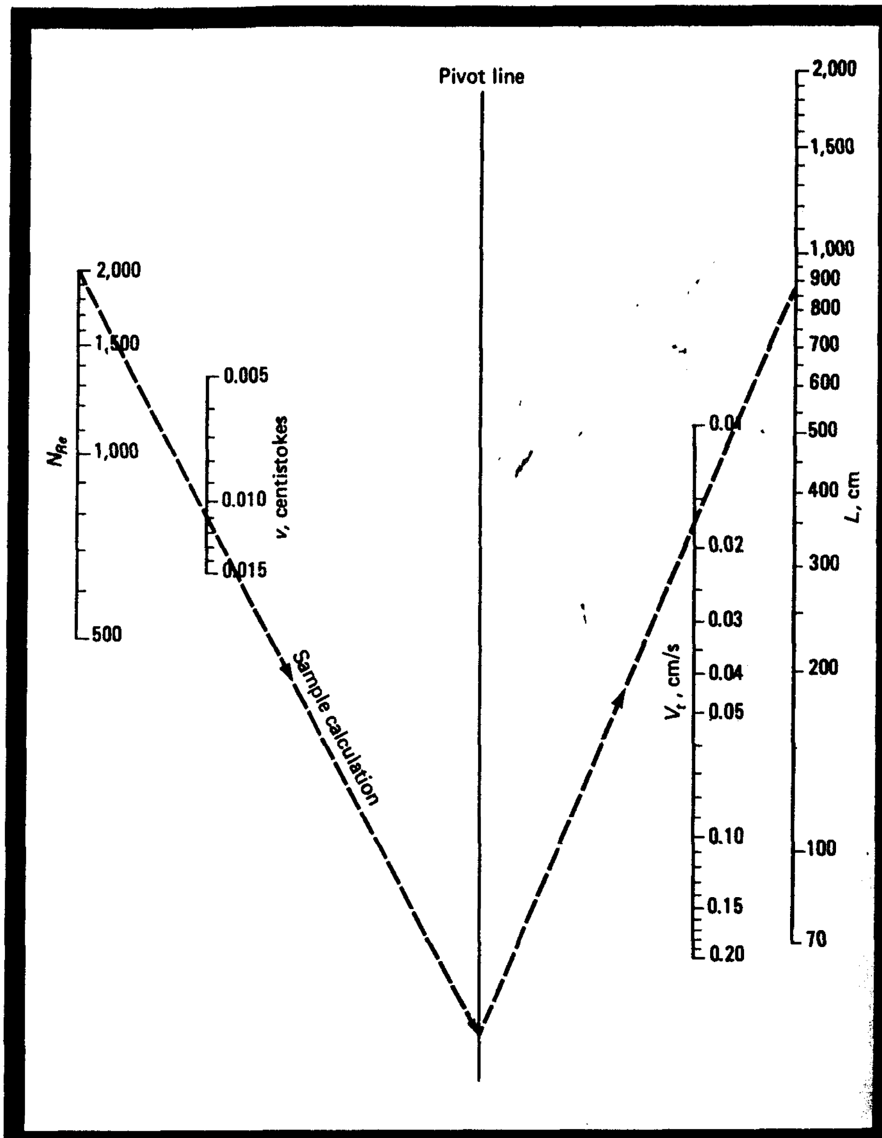
Since there are two equations—(6) and (7)—and four unknown variables—A, L, d and N_{Re}—two variables must be arbitrarily fixed, and unless space restrictions are critical, it is convenient to assign values to d and N_{Re}.

Because PPI dimensions are much smaller than the equivalent API separator, it is possible to design with laminar flow—i.e., a Reynolds number equal to or less than 2,000. In addition, the smaller the distance between plates (d), the smaller the transversal area required for a given flowrate and a given Reynolds number; therefore, the greater the efficiency [3]. On the other hand, a small distance could mean clogging and diminished flow area by floating debris and materials not retained by inlet trash racks. This would increase maintenance costs.

Taking the above into consideration, it seems convenient to design in the following ranges:

$500 \leqslant N_{Re} \leqslant 2{,}000$ and
1 in $\leqslant d \leqslant$ 4 in

Eq. (6) and (7) may be represented graphically to cover these ranges, as shown by the nomographs in Fig. 3 and 4.



Separator length to remove oil globules Fig. 4

Sample calculation

It is desired to treat an oily flow with the following characteristics: total flow = 27.8 l/s; kinematic viscosity = 0.011 centistokes*; rising velocity = 0.018 cm/s; distance between plates = 7.5 cm; Reynolds number = 2,000. The separator is to have two channels, each one with two packages of plates, i.e., Q_A = 27.8/4 = 6.95 l/s. What should be the total area and the length of the separator?

From Fig. 3, A = 4,740 cm^2 (total area = $4A$ = 18,960 cm^2), and from Fig. 4, L = 865 cm.

For a given type of oil (an assigned ρ_o value) at a fixed temperature, V_t depends only on globule diameter. Therefore, if the globule-diameter distribution of the oily flow is available, it may be superimposed on the rising velocity in Fig. 4. The nomograph will then provide the separator length to achieve a desired percentage of oil removal.

*1 stoke = (g)/[(s)(cm)(ρ)]; 1 centistoke = 0.01 stoke.

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