Research Article

Appropriate Separator Sizing: A Modified Stewart and Arnold Method

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Oil and gas separators were one of the first pieces of production equipment to be used in the petroleum industry. The different stages of separation are completed using the following three principles: gravity, centrifugal force, and impingement. The sizes of the oil droplets, in the production water, are based mainly on the choke valve pressure drop. The choke valve pressure drop creates a shearing effect; this reduces the ability of the droplets to combine. One of the goals of oil separation is to reduce the shearing effect of the choke. Separators are conventionally designed based on initial flow rates; as a result, the separator is no longer able to accommodate totality of produced fluids. Changing fluid flow rates as well as emulsion viscosity effect separator design. The reduction in vessel performance results in recorded measurements that do not match actual production levels inducing doubt into any history matching process and distorting reservoir management programs. In this paper, the new model takes into account flow rates and emulsion viscosity. The generated vessel length, vessel diameter, and slenderness ratio monographs are used to select appropriate separator size based on required retention time. Model results are compared to API 12J standards.

1. Introduction

With the advent of computers and commercial simulators, it is comparatively easier to obtain the production forecast of a producing well, without having to rely on preset analytical models which may or may not follow the exact field conditions. Unfortunately, this advantage has not been utilized in the design of separators. The basic separator sizing is still being done on the basis of API 12J specifications and the different flow rates that may arise during the production lifetime are also not taken into account.

An obvious thought is to just use the production data obtained through the simulator and use it in the simple API 12J calculations, but the flow rates are not enough. One of the major problems in designing two- or three-phase separators relate to the problem of emulsion. This can be taken into account using the correlations developed by Choi [1] to augment separator design as specified by Choi [1]. According

to Arnold and Stewart [2], a preferred diameter of water droplet ($500\ \mu\text{m}$) to be separated from oil and a diameter of liquid (water and oil) of $200\ \mu\text{m}$ to be separated from gas are preferred in the analysis. Furthermore, retention times of oil and water are taken to be between 3 and 30 minutes, respectively [1]. Viscosity of oil is obtained by using the Chew and Connolly correlation [3] of gas saturated viscosity (μ_{ob}) with respect to dead oil viscosity (μ_{od}).

2. Oil-Water Separation Theory

According to Stewart et al. [4], the oil-water separation is governed by Stoke's law for terminal velocity of spheres in a liquid medium. The terminal velocity of the continuous phase is defined by

$$V_t = \frac{G}{18\mu} (\rho_w - \rho_o) D^2. \quad (1)$$

TABLE 1: Emulsion type resulting from phase dispersion coefficient.

Phase dispersion coefficient, θ	Result
<0.3	Light phase always dispersed
0.3–0.5	Light phase probably dispersed
0.5–2.0	Phase inversion possible
2.0–3.3	Heavy phase probably dispersed
>3.3	Heavy phase always dispersed

FIGURE 1: Separator sizing methodology.

As illustrated above, the terminal velocity is a function of an emulsion (oil-water) viscosity that takes into account an oil-rich or a water-rich system. The viscosity of an emulsion as given by Taylor is

$$\mu_{em} = \mu_c \left[1 + 2.5\phi \left(\frac{p + 2/5}{p + 1} \right) \right], \quad (2)$$

where $p = \mu_{\text{inner phase}}/\mu_{\text{outer phase}}$.

As production goes on, inversion from oil-dominant to water-dominant emulsion takes place. This can be estimated by

$$\theta = \left(\frac{Q_L}{Q_H} \right) \left(\frac{\rho_L \mu_H}{\rho_H \mu_L} \right)^{0.3}. \quad (3)$$

Table 1 summarizes types of emulsion based on the phase dispersion coefficient, θ .

For all practical purposes, we use θ of 0.5 as an inversion point.

The emulsion viscosity obtained from the above procedure can only be used to calculate the minimum capacity of the separator; therefore, there is no limit on the size of the separator as viscosity does not directly influence the capacity of a separator. For this purpose, we use a new retention time that is calculated using the following formula to yield a more direct correlation to the size:

$$T_{r(\text{future})} = \frac{\mu_{\text{future}}}{\mu_{\text{base}}} T_{r(\text{base})}. \quad (4)$$

Figure 1 illustrates the new methodology of sizing separators.

3. Example Field Sizing

For illustration purposes, an example was selected. The well produces from a fractured carbonate reservoir, with most of the fractures connecting to an aquifer. Eclipse 100 reservoir simulator was used to model the reservoir and the following

FIGURE 2: Simulated production forecast.

FIGURE 3: Emulsion viscosity evolution over time.

oil, water, and gas production forecast for the well were produced.

It is clear from the 22-year simulated forecast, shown in Figure 2, that the separator will not be able to accommodate produced fluids if it is sized using a conventional design based on only initial flow rates.

Taking into account emulsion viscosity and using a correlation developed by Viles [3], emulsion viscosity as a function of simulation time plots as follows.

In Figure 3, we can see that the emulsion viscosity peaks at 9.1 cp, whereas the calculated oil viscosity which is conventionally used in separator sizing is just 3.43 cp.

The new retention time calculated using (4) for base retention times of 3, 5, 10, 15, and 20 minutes are 8, 13, 26, 39, and 53 minutes, respectively.

As per the new proposed methodology these peak emulsion viscosities and the peak flow rates were used to size the separators.

The sizes were calculated based on the following.

(1) Conventional method:

- API 12J minimum sizing requirements (initial flow rates only);
- Arnold-Stewart's method (initial flow rates only).

FIGURE 4: Sizing - API 12J.

FIGURE 6: Modified Arnold-Stewart's method for peak flow rates.

FIGURE 5: Arnold Stewart Method.

FIGURE 7: Modified Arnold-Stewart's method using peak emulsion viscosity.

(2) New method (modified Arnold-Stewart's method):

- based on flow rates;
- based on emulsion viscosity.

Figures 4, 5, 6, and 7 offer a unique opportunity to select separators based on the appropriate retention time. The charts offer envelopes enclosing vessel diameter, vessel length, and vessel slenderness ratio for calculated retention times. Any combination within a selected envelope is capable of handling a required capacity.

Now, as per the modified methodology, we have to compare the sizes obtained from the modified method using peak flow rates and peak emulsion viscosity, this is illustrated below in Figure 8 using a *Pareto chart* (tr is retention time, MASem is modified Arnold-Stewart's method based on emulsion viscosity).

The above pareto chart is based on bulk volumes of various sizes. Actual volumes have been purposefully not

considered as they may yield wrong sizing. The chart compares different design methods and compares differences in design, indicating that the modified Arnold-Stewart method for emulsion viscosity yields the largest vessels; automatically, taking care of increased total liquid flow rates that could be encountered later in the life of any production well.

4. Conclusions

- The new model resulted in an oversized separator that yielded an optimum performance throughout the life of the produced well.
- The current design is based on 50% full capacity; however, separators maybe able to accommodate up to 60~70% capacity while operating under optimal performance, in such a case, the separator may

FIGURE 8: Pareto chart of sizes obtained from different methods.

be downsized (based on the maximum required diameter).

- (3) The generated vessel length, vessel diameter, and slenderness ratio monographs make can be used to select appropriate separator size, based on the required retention time.
- (4) Despite the fact that computational fluid dynamics offer a much more comprehensive design, developed methodology, on the other hand, is intended to address the already existing stocks of separators.
- (5) Emulsion rheology model is based on Newtonian flow model. This holds true when Newtonian fluids are very dilute (this study well); however, it may sometime not be the case and a non-Newtonian flow model needs then to be incorporated.
- (6) Foam constraints have not been considered in the design due to lack of proved foam rheology correlations.

Nomenclature

API: American Petroleum Institute
 μm : Micrometer
 μ_{ob} : Viscosity of gas saturated oil (cp)
 μ_{od} : Viscosity of dead oil (cp)
 μ : Viscosity (cp)
 V_t : Terminal velocity (ft/sec)
 G : Acceleration due to gravity (9.81 m/s^2 or 32 ft/sec^2)
 ρ_w : Water density (lb/cuft)
 ρ_o : Oil density (lb/cuft)

D : Diameter of the separator (in)
 μ_{em} : Emulsion viscosity (cp)
 μ_c : Continuous phase viscosity (cp)
 Φ : Volumetric ratio of inner phase to outer phase
 θ : Phase dispersion coefficient
 Q_L : Flow rate of light phase (stb/d)
 Q_H : Flow rate of heavy phase (stb/d)
 T_r : Retention time (min)
 ρ_L : Light phase density (lb/cuft)
 ρ_H : Heavy phase density (lb/cuft)
 μ_L : Light phase viscosity (cp)
 μ_H : Heavy phase viscosity (cp)
 Q_o : Oil flow rate (stb/d)
 Q_w : Water flow rate (stb/d)
 Q_g : Gas flow rate (MMscf/d)
LCC: Liquid capacity constraint
SR: Slenderness ratio.

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