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Application of evolutionary computational approach in design of horizontal three-phase gravity separators

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ABSTRACT

We introduce in this work an evolutionary computational algorithm with sophisticated procedures for optimization of three-phase gravity separators. A model horizontal gas/oil/water separator, considered as target design, having well-defined length, diameter, effective length, baffle height, and water channel length, is hereby presented that features optimal design corresponding to minimum volume. The developed computer code is executed to monitor and update evolution in the volume of model separator towards target design. In this way, the implemented evolutionary algorithm manipulates volume genotype to create new alternatives by recombination and mutation of previous generations. This ended in near-to-optimal solutions irrespective of the properties of the first generation adapted to the model separator. The outputs from this theoretical investigation provide a broader image on the level of separation in gravity separators that can be utilized for actual design.

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1. Introduction

Identification of phase separation in multi-component systems was the subject of different investigations in the past, so that the industry and academia were alike keen on developing new techniques to achieve an optimal separation level under specified conditions. In this regard, varieties of strategies have ever examined to gain desired extent of separation in different processes. A major part of such investigations is aimed to separate oil from water or other aqueous fluids (Auflem et al., 2001; Jaworski and Meng, 2009; Kang et al., 2012).

The gravity separators are obviously the most important type among this family, which are widely served to sever immiscible phases with different densities. The literature provides multifarious reports on the application of gravity separators (Zeevalkink and Brunsmann, 1983; Fossen et al., 2006; Oh et al., 2012; Bazin et al., 2012). In this way, the kinetics of separation of model oil-in-water emulsions under enhanced gravity is considered as a key enabling interface evaluation (Krebs et al., 2012). In a gravity separator, the dispersed droplets of the dense component move downward through the continuous light phase to join the heavy continuous stream, while an inverse situation is the case for the light phase (API Spec. 12J, 1989; Ludwig, 1994; Datta, 2008).

Despite the fact that separation mechanism in a gravity separator seems quite simple, in reality the design of such apparatus confronts one with obvious difficulties. The complexity of the design procedure arises from the fact that there are varieties of parameters, which affect the performance of separator, namely the separator length and its diameter, the baffle position, baffle height, residence times, surge times, and finally the extent of the separation (Walas, 1998; Smith, 2005). Thus, proposing a proper design via conventional methods needs a great deal of experience and barely leads to a unique response. The efficiency of gas cyclone separators has been intensively considered through modeling and optimizing by using different mathematical approaches such as genetic and neural network algorithms (Rosa et al., 2001; Elsayed and Lacor, 2012, 2010). In addition, there exist a number of papers on dealing with optimization and characterization of gravity separators in terms of flow characteristics (Auflem et al., 2001; Zhang et al., 2007; Plasencia et al., 2013).

Normally, one can design a gravity separator as horizontal or vertical vessel depending on the platform requirements and practical limitations. Horizontal separators provide larger liquid surface areas compared to vertical types leading to better settling and gas breakout. Besides, the longer distance from the input to outputs of the vessel in horizontal arrangement improves the efficiency of separation (Skeie and Halstensen, 2010). From a

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Nomenclature

L_e	separator effective length (m)
L_t	separator total length (m)
L_w	water channel length (m)
D_{esp}	seperator diameter (m)
$\beta = L_w/L_e$	baffle position (dimensionless)
V_f	dispersed phase droplet velocity (m/s)
D_p	droplet diameter of dispersed phase (mm)
ρ_h	heavy phase density (kg/m^3)
ρ_l	light phase density (kg/m^3)
ρ_c	continuous phase density (kg/m^3)
ρ_g	gas phase density (kg/m^3)
g	acceleration rate (m/s^2)
μ_c	continuous phase viscosity (mPa s)
Re	Reynolds number (dimensionless)
$t_{res,w}$	residence time for water(min)
$t_{surge,w}$	surge time for water (min)
$t_{res,o}$	residence time for oil (min)
$t_{surge,o}$	surge time for oil (min)
t_r	required time (min)
t_a	available time (min)
HHLL	high high liquid level (min)
HLL	high liquid level (min)
NLL	normal liquid level (min)
LLL	low liquid level (min)
LLLL	low low liquid level (min)
HILL	high high interface level (min)
HIL	high interface level (min)
NIL	normal interface level (min)
LIL	low interface level (min)
LLIL	low low interface level (min)
Top	top of the vessel (min)
Btm	bottom of the vessel (min)
V_{sep}	separator volume (m^3)

practical standpoint, oil removal efficiency is strongly dependent on the configuration of internal devices and the layout. The minimum required volume of the flowing gravity separators is mostly governed by the residence time (Lopez-Vazquez and Fall, 2004). The design of such vessels with minimum volume is always associated with a trial and error process and strongly dependent to the skill of designer. Accordingly, the lack of information would necessitate optimizing the size of gravity separators varying their configurational parameters. In this regard, genetic algorithm might be a potential tool to get started in estimating the variation interval for changing parameters to meet a near-to-optimal solution. This beneficial method takes genotype variables, instead of variables themselves, by seeking the population of solutions based on probabilistic principles. Interestingly, the global optimum is achievable whether the optimization problem is discrete or non-linear (Michalewicz, 1996). However, there are a few reports, to our knowledge, on the application and implementation of computational methodologies in design of gravity separators.

The present work aims to introduce an optimal design based on evolutionary computational strategy that ultimately approaches a unique solution. In this way, the efficiency of a model horizontal gas/oil/water separator is investigated by altering the design criteria. To make a better sense of separation level, an optimal design corresponding to the case that the volume of separator takes the minimum value is reported. In this regard, a computer code is created that takes an initial design criteria as the first generation of separator design procedure and propose a situation in which next generation is sampled from previous genotypes by recombination and mutation with respect to the population of previous generations. The evolutionary approach implemented in this work allows searching in a broad database of solutions leading to a unique solution that is applicable to an industrial plant. This algorithm is flexible in application with regard to the target design, by which a separator giving minimum weight or design cost.

2. Problem description

Fig. 1 depicts an image of a typical horizontal three-phase gravity separator. In this illustration, the inlet flow, specified as mixture, comprises oil, water and gas phases.

When the mixture stream passes through the separator length, it splits into three separate phases. One can see through the figure that the heaviest phase departs the vessel from the water outlet, while gas phase, as the lightest phase, leaves the vessel from top gas outlet. The oil phase departs the vessel through oil outlet gate. The corresponding parameters of different parts of a typical separator are listed in Table 1.

To put the suggested design procedure into practice and define a clear objective, the target is set to calculate the optimal size of a three-phase separator, which is installed in the downstream of a presumed wellhead. The typical flow condition and properties are chosen as summarized in Table 2 (API Spec. 12J, 1989).

In reality, the plant and equipment requirements impose some considerations on design procedure toward favored separation, which are recognized as design criteria. The limitation to the length of a separator and maximum allowable hydrocarbon content in downstream of a flare are examples of drawbacks, which must be considered due to the plant and equipment, respectively. To meet a proper design, all of the criteria must be taken into account. In the current work, to achieve a well-defined design, a

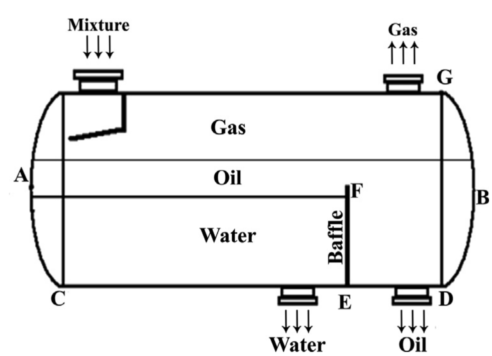

Fig. 1. The longitudinal section of a typical three-phase gravity separator.

Table 1
Parameters devoted to the longitudinal section of the separator.

Line	Definition	Parameter
AB	Separator length	L_t
CD	Separator effective length	L_e
EF	Baffle height	h_b
DG	Separator diameter	D_{sep}
CE	Water channel length	L_w