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Modeling and operability analysis of water separation from crude oil in an industrial gravitational coalescer

M. Mohayeji, M. Farsi, M.R. Rahimpour*, A. Shariati

Department of Chemical Engineering, School of Chemical and Petroleum Engineering, Shiraz University, Shiraz, Iran

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ABSTRACT

The main aim of present study is to develop a mathematical model to analyze the performance of an industrial gravitational coalescer to separate water from crude oil. The considered process consists of a mixing valve and coalescer tank that connected in series. Gravitational coalescer is a huge two-phase separator that separates free water from crude oil based settling time. In this research, the water removal from crude oil is simulated based on a two-dimensional model at steady state condition. The population balance method is used to predict drop size distribution in mixing and coalescence stages considering breakage and coalescence terms. To prove accuracy of the considered model and considered assumptions, the outlet water cut, water removal efficiency and salt content from gravitational coalescer are compared to plant data. Then, effect of temperature, fresh water rate, and mixing pressure drop is studied on water and salt removal efficiencies. The simulation results show that there is an optimum condition to maximize water and salt removal efficiency in desalting process.

1. Introduction

Extracted crude oil from reservoir contains some impurities such as brine, sediment, heavy metals and crystalline salts. These impurities cause corrosion, plugging problem especially in distillation towers, fouling in furnace tubes and pipelines and poisoning of catalysts in down-stream units [1]. Thus, some technologies are developed to decrease salt, sediment and water content in the crude oil to achieve an acceptable value. Chemical, thermal, gravitational and electrical separations are common dehydration methods in industrial units [1, 2]. Through these methods, the fresh water is mixed with the crude oil in a mixing valve to dilute the base brine and reduce salt content in the emulsion. Then the prepared emulsion, that contains water drops dispersed in crude oil, is treated to separate brine from crude oil in a drum. According to thermodynamic viewpoint, water oil emulsion is not a stable state and stability of emulsion droplets are because of natural surfactants in crude oil [3]. Resin, asphaltene, paraffinic compounds, wax and clay are major surfactants agents in crude oil.

Many researchers have focused on separation of water droplets from crude oil as a multi-phase system. Mitre et al. modeled a mixing valve based population balance equation at steady state condition. They proposed a new breakage model for droplet dissipation in the 0.1–100 μm range and estimated the model parameters by the orthogonal distance regression method [4]. Håkansson et al. simulated crude oil in water emulsification in a high-pressure homogenizer considering fragmentation, emulsifier absorption and coalescence based on the population balance approach [5]. Comparison between simulation results and literature data demonstrated the accuracy of the developed model. Chen et al. studied water separation from crude oil in AC electrical field based molecular dynamic simulation. The simulation results showed that the created dipole moment between drops increases collision rate [6]. Abdul-Wahab et al. developed a simple model to predict salt and water removal efficiencies in an industrial desalting unit based computational intelligence techniques and design of experiments. They considered temperature, water cut rate, fresh water rate and pressure drop as input variables [7]. Bresciani et al. used concept of cellular automata to calculate water separation efficiency from crude oil in electrical field [8].The velocity of the water droplets was calculated by the balance of forces acting on a pair of droplets in a group, and cellular automata was used to simulate the whole group of droplets. The comparison between simulation results and experimental data proved the accuracy of the developed model. Mohammadi et al. simulated coalescence of two water droplets in oil by CFD technique. They studied effect of collision velocity, oil viscosity and water-oil interfacial tension on coalescence rate [9].The finite volume numerical method was applied to solve the Navier–Stokes equations in conjunction with the volume of fluid approach for interface tracking. The results revealed that decreasing oil viscosity or increasing water–oil interfacial tensions decrease

* Corresponding author. Tel.: +98 71 36133780; fax: +98 71 36287294.
E-mail address: rahimpor@shirazu.ac.ir (M.R. Rahimpour).

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Nomenclature

A	Hamaker constant
B	birth rate
b	breakage frequency
C_c	experimental constant
C_e	experimental constant
D	death rate
e	collision efficiency
f	number density function
g	gravitational acceleration
l	drop diameter
$P(l\|l_0)$	probability of birth drop with diameter l due break of drop with diameter l_0
S	source term
u	velocity
v	number of fragment due breakage
V_{ij}	velocity difference of emulsion drops
x	length element
y	depth element

Greek letters

α	collision frequency
β	coalescence frequency
ε	turbulent energy dissipated
μ	ratio of dispersed phase viscosity to continues phase viscosity
μ_c	continuous phase viscosity
υ	kinematic viscosity
ρ	density
σ	interfacial tension

Subscripts

c	continues phase
co	crude oil
d	disperse phase
k	drops contour

Superscripts

b	breakage
c	coalescence

coalescence time. Binner et al. studied effect of microwave heating on water separation from oil emulsion through gravitational separation. It was appeared that microwave heating decreases settling time of emulsion drops [10]. Alves et al. studied effect of salinity on surface property of water-oil emulsion system. It was concluded that increasing salinity in aqueous phase makes a strong rigid film on emulsion drops and decreases coalescence rate [11]. Aryafard et al. developed a mathematical model to predict water and salt removal efficiencies in an industrial two stages desalting process. Then, the effect of mixing pressure drop, fresh water rate and strength of electric field was studied on characteristics of treated crude oil. The simulation result showed that increasing rate of fresh water from 3% to 6% decreases salt content in the treated crude oil from 2.06 to 0.71 PTB [12].

The main aim of present study is to develop a detail mathematical model to predict water and salt separation efficiencies in an industrial gravitational coalescer. The considered process consists of mixing valve and gravitational coalescer drum that connected in series. In Section 2, the crude oil desalting and dehydration in an industrial process is explained. In Section 3, the developed mathematical model for the mixing valve and gravitational coalescer drum is presented at steady state condition. The population balance method is used to predict drop size distribution in mixing and coalescence stages considering breakage and coalescence terms based on a two-dimensional model. In Section 4, the simulation results and operability of the considered process are presented and compared to the base case. In this section, effect of temperature, fresh water rate, and mixing pressure drop on water and salt removal efficiencies is studied.

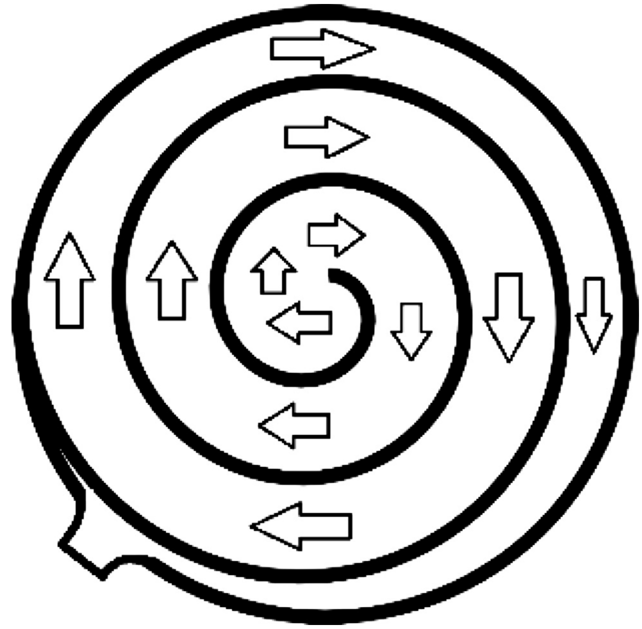

Fig. 1. Gravitational coalescer tank horizontal cross section.

2. Process description

In crude oil desalting unit, emulsion drops are separated from oil in several steps. Generally, desalting can divide in two main steps including separation of free water from crude oil in a big gravitational coalescer tank and separation of stable emulsion in a small electrostatic coalescer tank. At the entrance of desalting unit, demulsifier agent is mixed with crude oil to decrease interfacial tension of oil and water emulsion. Then, the fresh water is mixed with crude oil through a mixing element to dilute the brine to a level that the target salt content can be achieved by the dehydration process. Produced emulsion is entered to the gravitational coalescer tank and free water is separated. Geometry of gravitational coalescer tank is shown in Fig. 1.

Crude oil is fed to the gravitational coalescer tank and goes to spiral path that is prepared by baffles. In this path, free water is separated from crude oil and flows downward. The industrial design residence time in gravitational coalescer is about 24 h.

3. Population balance equation

Several mathematical theories are developed to predict droplets dispersion in a continuous phase such as Euler–Lagrange, Eulerian multi-fluid and population balance methods [13–19]. Population balance as an accurate and widely used mathematical tool in engineering develops a balance on the mean number density considering breakage and coalescence of droplets as death and birth terms. Number density function depends on the droplet properties, the physical space and residence time [20]. In this research, the mixing valve and gravitational coalescer tank are modeled based population balance equation at steady state condition. The considered assumptions in the developed model are as follows:

- Breakage of emulsions drops is neglected in gravitational coalescer.
- Plug flow regime is considered.
- Adiabatic condition.
- Curvature of spiral path does not effect on crude oil velocity.