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Modeling and simulation of crude oil desalting in an industrial plant considering mixing valve and electrostatic drum

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ABSTRACT

The aim of present study is development of a mathematical model to predict water and salt removal efficiencies in an industrial crude oil desalting plant at steady state condition. The considered desalting process consists of the mixing valve and AC electrostatic desalting drum that were connected in series. The mixing valve and desalting drum are modeled based on population balance method considering water droplet breakage and coalescence to predict the droplet size distribution. The class method as a common mathematical technique is selected to solve population balance equation. The accuracy of the developed mathematical model and considered assumptions are evaluated via industrial data from a desalting plant. Then, the effect of pressure drop in the mixing valve, flow rate of fresh water and strength of electric field on the desalting and dehydration efficiencies are assessed. The results show that electric field has a significant effect on the process efficiency, so increasing electric field strength from 1.0 kV/cm to 2.0 kV/cm improves water separation efficiency from 93.92% to 97.85%.

1. Introduction

Produced crude oil from reservoirs contains some impurities such as sand, asphaltene, clay, brine and so on. Brine causes pressure drop in pipelines, deactivation of catalysts, fouling and corrosion in equipment, increasing heat consumption and decreasing the crude oil value. Thus, desalting methods are developed to decrease salt, sediment and water content in the crude oil to achieve an acceptable value. There are some desalting methods to separate brine from crude oil such as gravitational coalescing, thermal coalescing, chemical coalescing, mechanical coalescing, and electrical coalescing. Electrostatic desalting is a common method to separate brine from crude oil that used electric field to enhance drop collision [1]. In this process, the fresh water is mixed with the crude oil in a mixing valve to dilute the base brine and reduce salt content [2]. Then the prepared emulsion, that contains water drops dispersed in crude oil, is treated applying a high-voltage electric field to separate diluted brine from oil in an electrostatic drum. Electric field can be generated by direct and alternating currents.

Many researchers have focused on water separation from crude oil as an attractive topic in crude oil processing. Eow and Ghadiri studied effect of pulsed direct current on water drops separation from crude oil, experimentally [3]. Pruneda et al. developed an economical mathematical model to calculate the optimum temperature in crude oil desalting process [4]. The results showed that the maximum profit is attainable at 135 °C for Maya Crude Oil. Frising et al. modeled the drops coalescence considering three stages involve collision, dehydration and rupture of the interfacial film and formation of a larger droplet [5]. Chiesa et al. studied the effect of continuous phase viscosity on the coalescing of water in oil emulsion in presence of an electric field, experimentally [6]. Mahdi et al. studied effect of emulsifier concentration, temperature, flow rate of wash water, settling time and mixing time on dehydration efficiency in a desalting plant [7]. The results showed that salt removal efficiency approaches to 93.28% at the optimal condition. Bresciani et al. simulated water separation from crude oil in an electrostatic desalting system based on cellular automata method [8]. Comparison between the simulation results and plant data proved the accuracy of the developed model. Vafajoo et al. studied effect of temperature, chemical injection rate and crude oil pH on salt removal in an electrostatic desalting process [9]. The experimental results showed that maximum salt removal is attainable at 50–100 ppm demulsifier and pH 9–12. Meidanshahi et al. modeled a pilot plant electrostatic desalting drum based on

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Nomenclature

B_i	Bond number
Ca	Capillary number
d	Droplet diameter
E_0	Electric field strength
e_{ij}	Collision efficiency
f	Daughter drop size distribution function
g	Gravity
$g(\nu)$	Breakage frequency
H	Particles production rate
K	A constant
k_B	Boltzman's constant
m	Number of fragments formed per breakage of a droplet
$n(\nu,z)$	Continuous number density
N_{brown}	Number of collisions due to Brownian motion
$N_i(z)$	Discrete number density
$N_{turbulent}$	Number of collisions due to turbulent motion
P	Pressure
PTB	Pounds of salt per thousand barrels of crude oil
T	Temperature
u	Velocity
u_c	Continuous phase velocity
v	Volume
$V_{ij}^{(0)}$	Relative velocity
w	Volume
We	Webber number
z	Length

Greek letters

$\beta(v,w)$	Coalescence frequency
δ	Ratio of the radius of the small drop to that of the large drop
ε	Oil permittivity
λ	Kolmogorov length scale
μ	Viscosity
ν	Kinematic viscosity
ξ	Rate of turbulent dissipation
ρ	Density
σ	Interfacial tension

the population balance at steady state condition. They calculated the droplet size distribution at outlet of the drum considering an arbitrary inlet size distribution for water droplet [10]. Mohammadi et al. investigated coalescence of binary water droplets, falling in stagnant oil exposed to an electric field, experimentally. They studied the effect of applied voltage amplitude, initial distance of the drop pair, and skew angle of the electric field. The experimental results proved that the stronger electric field and skew angle of the electric field can decelerate the electro-coalescence [11]. Håkansson et al. simulated oil in water emulsification in a high-pressure homogenizer considering fragmentation, emulsifier absorption and coalescence based on the population balance approach [12]. Comparison between simulation results and literature data demonstrated the accuracy of the developed model. Raikar et al. modeled the water droplet breakage based on the population balance model [13]. Mitre et al. experienced and modeled the water and crude oil mixing in a valve-like element to predict the droplet size distribution. The simulation results proved the accuracy of the considered model [14].

The main aim of present study is to develop a mathematical model for the predicting of water and salt separation efficiencies in an industrial one-stage crude oil desalting process. The considered desalting process includes the mixing valve and AC electrostatic desalting drum that connected in series. In Section 2, the crude oil desalting and dehydration in an industrial electrostatic process is explained. In section 3, the developed mathematical model for the mixing valve and electrostatic drum is presented at steady state condition. In section 4, the simulation results and operability of the considered process are presented and compared with the base case.

2. Process description

In the single stage desalting process, at the entrance of unit, demulsifier is added to the crude oil for the decreasing interfacial tension of oil and water [15,16]. Then, the fresh water is mixed with crude oil through a mixing device to dilute the brine to a level where the target salt content can be achieved by the dehydration process. Produced emulsion is entered to bottom of the electrostatic desalting drum. Emulsion flows along the horizontal drum in upward direction and is entered to the AC electric field section. In this section, an electric field is applied on the emulsion, which increases the dipolar attraction force between droplets and accelerates the water drop coalescence. The AC field treating is effective for the emulsion that contains high water cut and the water droplets are spaced nearly. Smaller droplets move up with the continuous phase and the larger drops move down because of the dominant downward gravitational force compared to upward drag force. Fig. 1 illustrates the schematic diagram of a single stage

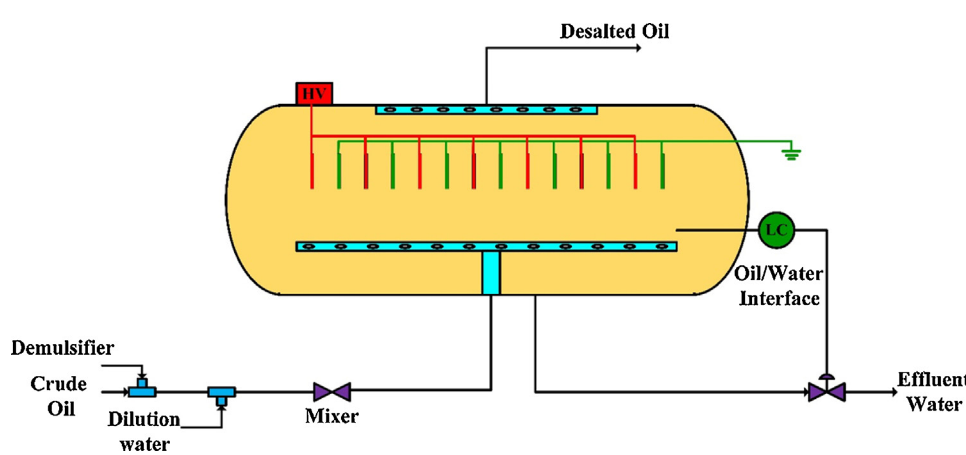

Fig. 1. Schematic of single stage desalination process.