1
Introduction

1.1
Motivation and purpose

In the petroleum production industry, oil extraction is an operation that normally lies around the structure of an oil well (Figure 1.1). When an oil formation is detected (by exploratory techniques), exploratory wells are drilled into it. Depending on the amount of estimated reserves and the economic viability of production, additional wells are drilled in the production interval, which is the zone that intersects with the oil layer in the reservoir.

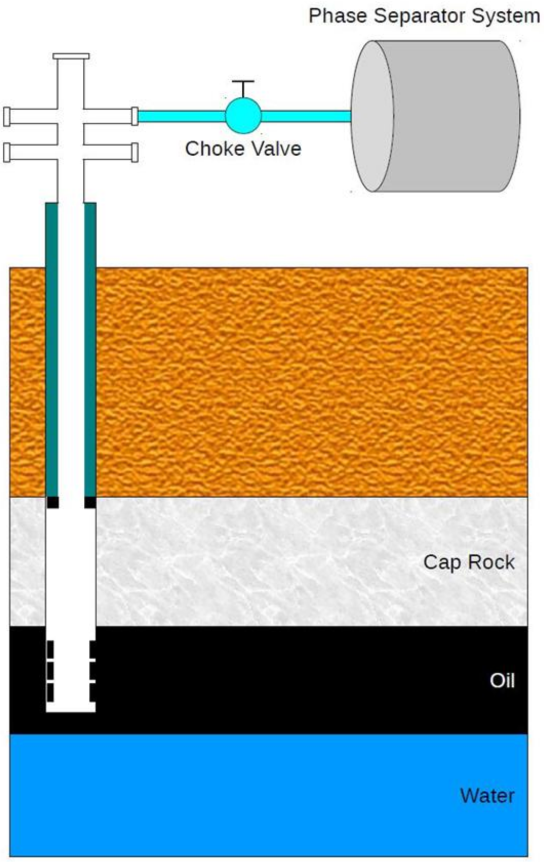

Figure 1. 1 Diagram of a typical oil production system.

In the well, the produced fluids (gas, oil and water) are transported from the reservoir to the surface through the casing and tubing. The casing is used to protect the wellbore from collapse of the surrounding rock and to prevent fluids from leaking off to other underground layers. Inside the casing, regular production takes place through the tubing.

At the surface, the casing and the tubing are connected to the wellhead, where various types of valves are located. Those valves allow to shut off the well, to perform work-over and maintenance operations and to regulate the flow in the production system (choke valve). Downstream of the wellhead (or of the manifold if the production occurs through several wells), oil, gas and water are properly separated by means of flash, expansion or knockout vessels (liquid/gas separation); and API, skimmers tanks, thermal separators or electrostatic separators (oil/water separation).

When the well starts to operate, only oil is produced, but with increasing lifetime, production of water starts to take place. In the beginning, when small amounts of water are produced, water is dispersed as droplets in the oil. With increasing water-cut, the number of water droplets increases, until at certain water content, it becomes the continuous phase. Consequently, oil droplets are formed, and phases are inverted. Various mechanisms are responsible for the increment of water-cut. Among them, the presence of an active water layer (aquifer) and water flooding are the most common mechanisms. In the first case, water is produced because the aquifer reaches the production interval of the well. In the water flooding case, due to the large mobility of the water compared to that of the oil, the injected water bypasses the oil and reaches the production well.

The real problem of oil production at high water-cuts is that not all oil (dispersed in the water) can be separated from the water. The limited residence time in the first stage separation vessels (based in the density difference of the fluids) causes that small oil droplets (generated through entire production system, from reservoir to choke valve) do not reach the oil layer, remaining in the oil-water interface. For that reason, the oil water mixture needs to be separated in a second stage separator, such as a hydrocyclone (Young et al., 1994) or a centrifuge (Plat, 1994). Even in these centrifugal units, the separation efficiency is low for droplets smaller than a certain critical size that depends on the flow rate and the design and geometry of the separator. Although there are other techniques with higher separation efficiencies, like membrane filtration, their principal disadvantage is that they are not able to treat the larger volumes of water encountered in these high water-cut production systems. In addition, the concentration of oil that can not be separated from water phase will generate serious problems for treatment and final disposal of the wastewater.

To optimize the phase separation and due to the environmental impact generated by disposal of large amounts of oil (dispersed in millions of cubic meters of water), the best alternative to reduce harmful effects is to study where, when and how oil droplets break in the road they travel during production, and try to control the equipment and/or mechanisms responsible for high fragmentation rates.

Research efforts aimed to solve this problem started when Davies, Nilsen and Gramme (1996) recognized that identifying the flow zones where small droplets are formed in the production system is vital to optimize the phase separation process.

Then, Janssen and Harris (1998) investigated the size of the droplets flowing out of the reservoir into the bottom of the well. They conclude that droplets are typically of the size of the pore neck or larger (tens of micrometers up to millimeters). Previously, Sarbar and Wingrove (1997) showed that for some field cases, droplets smaller than 5 µm are encountered downstream of the choke valve.

Muntinga (1998) studied the effect of the geometry of the choke in the breakup process. He showed that breakage in the choke is not a stationary process, and droplets need a specific time to reduce their size to the maximum stable drop diameter.

Van der Zande et al. (1999) considered that flow through a circular orifice in a pipe exhibits the same characteristics as flow through a choke valve. They studied the turbulent breakup of a diluted O/W emulsion in the orifice and concluded that the breakup mechanism described previously by Percy and Sleicher (1983) was not the dominant mechanism (acceleration at the entrance of the restriction). They showed that drop breakup in a restriction is caused by the turbulent velocity fluctuations in the high velocity zone downstream of the restriction, and that the maximum stable drop diameter was (aside from the fluid properties) a function of the average energy dissipation rate per unit mass.

Galinat et al. (2005) carried out an experimental analysis of drop breakup in turbulent pipe flow downstream of a restriction using a high-speed trajectography technique. They first performed a global analysis of the fragmentation process for a dilute dispersion, observing that the mean drop diameter downstream of the restriction linearly increases as a function of the inverse of the square root of the pressure drop, results that are in agreement with the previous experiences of Percy and Sleicher (1983). In addition, experiments based on the observation of single drop breakup downstream of the orifice have allowed the identification of different breakup mechanisms, and the determination of statistical quantities such as the breakup probability, the mean number of fragments and the daughter drop distribution.

Galinat et al. (2007) reported experimental and numerical results of the breakup probability of a drop travelling through inhomogeneous turbulent flow generated in a pipe downstream of a restriction, where various Reynolds numbers, damping coefficients and drop volume fractions were tested. Their simulations predicted well the main features observed in the experiments. In addition, the model was used to compute the breakup probability in concentrated dispersed two-phase flows when the oscillation frequency and the damping rate were provided.

Recently, Maniero et al. (2012) numerically modeled the drop breakup at the same turbulent conditions as described by Galinat et al. (2007) by coupling Direct Numerical Simulation (DNS) of the continuous phase, Lagrangian droplet tracking, a dynamic model of drop deformation and a breakup criterion based on a maximal deformation. The dynamical model is adapted from the Kolmogorov–Hinze theory of turbulent breakup to the Rayleigh–Lamb theory of drop oscillations. Compared to PIV measurements, DNS results have demonstrated to provide a reliable prediction of the turbulent flow field and its statistics at the drop size scale; also, experimental breakup locations have been correctly predicted by adjusting only the critical deformation for breakup.

1.2
Scope of the dissertation

In this dissertation, the drop breakup mechanisms in turbulent flow of single droplets and diluted O/W emulsions were investigated for two specific cases: flow in a rotor – stator mixer and flow through an orifice in a pipe. The aim of the work was to analyze the breakup mechanisms for both flow cases by visualization of the process using a high-speed camera. In addition, the relative influence of geometry (for the case of breakup through the orifice), interfacial tension and dispersed phase viscosity were analyzed. Finally, a mechanistic model was obtained to predict the droplet size downstream of the orifice as a function of the properties of the fluids and the flow conditions.

To provide a clear synopsis of the work that has been carried out, this dissertation is divided into 5 chapters. In this first chapter, a brief introduction to the problem of oil production under high water-cut conditions has been given. In chapter 2, the published literature associated to the theoretical and experimental studies on turbulent drop breakup of diluted O/W emulsions is reviewed. Moreover, emulsions basics, fundamentals of turbulence theory, drop breakup phenomenon and hydrodynamics in the two turbulent flows considered in this dissertation: flow in a rotor – stator mixer and flow through an orifice are presented. Chapter 3 presents the materials and experimental conditions used in the development of this investigation. The results and their discussion are showed in chapter 4; and finally, in chapter 5, the conclusions of this dissertation and some suggestions for future work are summarized.