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# TWO PHASE FLOW EXPERIMENTAL DETECTION METHOD AND CFD MODELS – A REVIEW

***Hilal Mohammed Mousa[1]** **Sadiq Salman Muhsun [2]** **Zainab Talib Al-Sharify[3,4]**

1. Department of environmental engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
2. Department of Water Resources, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
3. Department of Environmental Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq
4. School of Chemical Engineering, University of Birmingham, Edgbaston B15 2TT, Birmingham, United Kingdom.

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**Abstract:** Liquid-liquid two-phase flow has been studied widely by many authors. Two phase flow exist in petroleum industries, nuclear power generation and chemical plants. In the present study a review on two phase flow such as oil/water was discussed, also the patterns of the flow and types of measurement are presented. Also a review on the new trends using the computational fluid dynamic (CFD) to predict the liquid-liquid two phase are viewed.

**Keywords**: *Two-phase flow, flow measurement, CFD, flow pattern, modelling.*

## 1. Introduction

Two-Phase flow considered as significant phenomena that appear in various applications such as petroleum industries, nuclear power generation and chemical plants. Still, the complexity of predicting the behavior of this phenomenon makes it difficult for understanding. In single phase flow the design parameters like (pressure drop, flow regimes, and hold up) in pipes make it easy to be modeled. However, in case liquid-liquid two phase flow the presence of liquid such as water affects in increasing the complication in hydrodynamics and it will be a challenge to model the system . It is important to understand the hydrodynamics of the two-phase flow such as (liquid-liquid) for the designing process of (mixture-settlers, extractor, downstream separators, transportation pipeline, pipeline networks, emulsifier, etc.)[1-8]. During the last years, Computational Fluid Dynamics (CFD) became an important tool system for engineers to investigate the field characteristics such as (fluid flow, performance determination, design, and analysis of flow). The fast improvement in using CFD is a result of (easy accessibility, the massive growth in computer speed, and memory size) this led to the cost reduction of simulation instead of using the traditional experimental method. [9]

Water lubrication technique is the most preferable way which is used to reduce the pressure drop in case of the transportation of

**Corresponding Author*: hilalmo101@gmail.com

high viscous oil in pipeline network. The use of water lubrication is to reduce wall friction during the transport of oil in the pipeline. In this case, the phases (oil and water) will arrange themselves in various flow patterns that will lead to the minimization of their total energy. This flow pattern can significantly influence the (mass transfer characteristics, hold-up characteristics, pressure drop, heat transfer, and kinetics energy between the two immiscible phases oil/water). The flow patterns can be categorized to (core annular flow, mixed stratified, wavy stratified, and smooth stratified. annular flow is most desirable in the case of pressure drop reduction. For other cases dispersion of two phase (water dispersed in oil and oil dispersed in water) are essential for the case of heat transfer, mass transfer, and kinetic energy. Thus, the information about the transition boundaries for different flow patterns will help in getting accurate designing for the difference processes and unit operations. [10]

## 2. Two phase liquid-liquid flow patterns

The two immiscible liquids flow can found usually in the petroleum industry, in which crude oil and water extracted from wells, transported by using network pipelines, and then separated in process operations in the facilities. For that it is important to have complete understanding for the behavior of liquid-liquid flow regimes. it is obvious that prediction of the flow patterns, transition boundaries of flow patterns, and mainly the flow characteristics for instance (phase distribution, pressure gradient and velocity distribution) are important for the accurate designing of such systems [11-13].

The interest for studying various flow patterns of two phase liquid-liquid systems is due the fact that a unique hydrodynamic characteristics off low is obtained in each flow pattern. It is difficult to have certain rule for the flow pattern, mixture properties, transition boundaries because of the differences obtained in the experimental tests that used the liquid-liquid phase flow [14-18]

The flow pattern types allocated into four regimes of flow patterns and the mainly used classifications are described below:

- Annular flow: can be defined is the flow obtain when any of the phases create an annular film near the pipe wall, and other fluid flows centralized in pipe. This flow pattern arises particularly when there is two liquids that have corresponding densities, such as (water and heavy oil), or when large velocity obtained in the flow phase.

- Stratified flow: obtained when there are two immiscible liquids that flow in the same time in separated layers due to their difference in the density. A common way to know if it is a stratified or not is by observing the flow if it has two continuous phases. The continuous phases happen to be partially or fully dispersed.

- Dispersed flow: occurred when there is a formation of droplets of one of the fluids phases dispersed in other continuous phase of the other liquid. The dispersed flow may found homogenous across the whole pipe section area as there is a formation of drops that uniformly distributed, or may be found a formation of drops localized in the lower or upper part of the pipe.

- Plug/bubble: this type of flow occurred when there bubbles or plugs of one of the liquid phases flow continuously one after the other in the pipe and may be located at the top of the pipe in the case of oil flowing in water .[19-21]

In fig (1) An experimental map for detection flow pattern from previous case study.

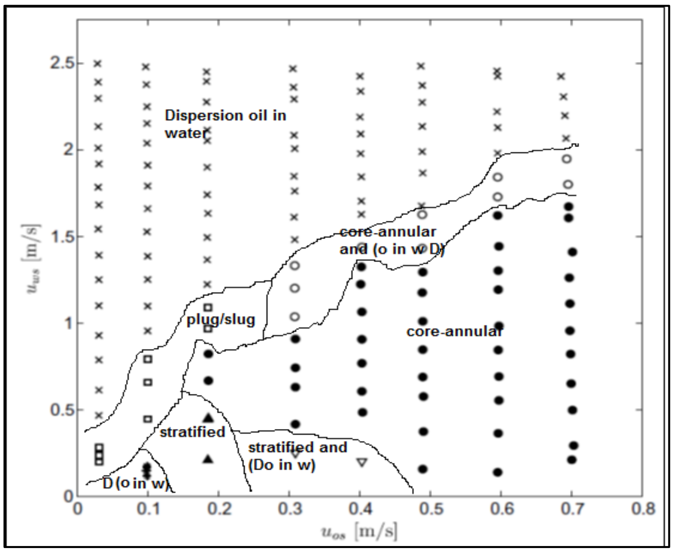


**Figure 1.** Experimental flow-pattern map . Uws, Uos: water and oil superficial velocities. ▲ = stratified flow; x = dispersion of oil in water; ● = core-annular flow; □ = plug/slug flow;∇ = stratified flow and dispersion of oil in water (D o in w); °= core-annular flow and oil in water (o in w D); *= oil film at the wall and inner dispersion of oil in water (D o in w) [19]

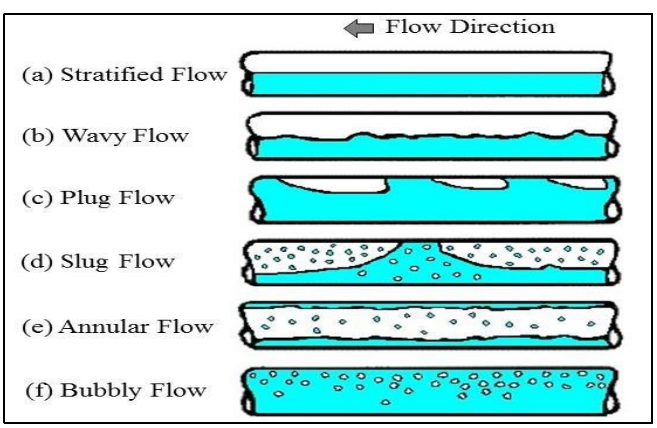


**Figure 2**. Show most used types of flow patterns in previous case studies.

Several methods have been used in two phase flow by using types of equipment to predict the flow such as oil in produced water. Example of these methods is the using of (high speed camera, UV visible spectrophotometer (UV–vis), Particle image velocimetry (PIV), planar laser-induced fluorescence (PLIF), gamma ray densitometry). The problem of using these methods that they have limitation that effect the accuracy of the results. (Trallero, 1995)[22], studied stratified flow and mixing interface for desperation of (water in oil, oil in water, oil in water and water, and desperation of water in oil and water in oil) in horizontal pipes, by using visual observation and using photographic conductance to prove the results. The pressure gradient also were studied. While (Angeli, 1996)[23], investigated the phase distribution of (stratified, stratified wavy with an oil droplets, stratified mixture with oil, also stratified mixture with water)in horizontal pipes , high speed camera with visual observation and high frequency impedance have been used to prove the results, pressure gradient also calculated. (Nadler and Mewes, 1997)[24], used visual observation to study stratified flow, stratified with mixture, desperation of water in oil and oil in water, another combination of water and oil used. Also (Soleimani, 1999)[25], investigated by using visual observation, gamma densitometer and high frequency impedance, to predict pressure gradient and phase distribution of different flow patterns (stratified, stratified wavy and stratified with mixture). (Rodriguez and Oliemans (2006)[26], investigated oil/water two-phase flow experiments by using high speed camera for detection of flow pattern and Gamma ray densitometry. The experimental work concluded using steel pipe of 15 m and 8.28 cm in diameter and in different inclination degrees, two liquids used differentiates in densities. The phase flow pattern, pressure gradient, hold) was calculated in each degree used. The flow pattern characterization and identification obtained from the observation, from recorded videos and from the homogeneous behavior analysis. The interface identified as stratified wavy and no mixing at interface. Also, Visual observations of transporting in horizontal pipes in combination with other devices have used include (photographic, video cameras, and high speed cameras), to investigate the flow patterns are presented in Early studies, such as (Russell *et al.*, 1959; Charles *et al.* 1961; Arirachakaran, 1989) [27-29]. Light fraction is one of the big problem for these techniques, that lead to have weakness of the using it and should have a certain environment to have good results. Other investigation by (Esam and Zahra'a, 2015)[30], investigated into liquid-liquid two phase annular flow, using gasoil-water that flow across horizontal circular transparent pipe with (32mm diameter and 6m in length). the experimental data have chained in atmospheric condition of laboratory. Different velocities and water cuts or artificial velocities have been used to classify flow patterns. The superficial water average velocity ranged (1.69m/s-3.38m/s) while oil superficial average velocity (0.39m/s-1.58m/s). The influence of superficial oil velocity and superficial water velocity on annular flow lengths has been studied. The experimental work included using video camera "high speed camera" method and the image processing procedure by using MATLAB to predict the hold up. A CFD study using FLUENT programing model, an improved turbulent diffusion model is employed for the purpose. The results achieved good agreements comparing with previous works. Another investigation by (Costa et al., 2013)[31], investigated in the application of oil/water Nano emulsion as to determination the oil content in oily water, the experimental work measurement included using (UV visible spectrophotometer (UV–vis)), and (total organic carbon (TOC) analyzer). Results of distribution size and optical micrographs curves showed that when using a small amount of Nano emulsion it will be capable of converting the oily water to a colloidal dispersion thus it will be able to have a read in the (UV–vis) and (TOC-VCHS)techniques. The results of oil content oil showed great accuracy measurement, for both (UV–vis) and (TOC-VCHS). Another method used by (Kumara et al., 2010)[32],characterized the flow structures in oil/water flow by employing particle image velocimetry (PIV) experimentally using a (56 mm) in diameter and 15 m in length stainless steel pipe. The data chained from fluids were not compatible, due to the light that refracted when it pass through the interface of the two liquids thus enabling to chain accurate for only one of phases. Also the experimental procedure showed two steps: the first that the flow illuminated in the top directed to the bottom by the laser sheet to predict the information of oil phase; the second, the laser sheet introduced obesity from the bottom directed to the top of the pipe to predict the information of water phase. This method proved to be a worthy effort in terms of chaining statistical information for two liquid phases. (PLIF) used by (Ibbara et al, 2017) (33), investigated tow phase oil/water (stratified and stratified-wavy) in horizontal pipes by using the planar laser-induced fluorescence (PLIF) in combination with image tracking velocimetry, this approach allowed to study the (density, viscosity, and surface tension) terms, the study covered different Reynolds number ranged from laminar/transitional to transitional/turbulent, the results showed well prediction in the variation comparing with other results from previous case studies.

**3. Modeling of two phase flow**

Experimental relativity indicates relationships between the variables and it is widely used for the prediction of flow parameters. The experimental correlations in many cases termed as empirical models. The Computational Fluid Dynamics CFD is now becoming an essential way of the designing process for many fields. CFD can facilitate the evaluation of (velocity, temperature, pressure, and the species concentration of multiple fluids flow through a solution, thus, allowing to design and get the optimization before the prototype phase. (Hui et al, 2003)[34], presented stratified-turbulent oil/water two-phase flow simulation through horizontal pipe statistically using the volume of the fluid(VOF) model, by employing (RNG k–ε) base model in combination with a Reynolds number turbulence model with near-wall low for each phase, selected continuum surface force approach to calculate the surface tension of the phase. A simulation relied on time dependent condition was presented and examined the final solution which matches with the steady-state parameter for the phase. Results of (the axial velocity in the profile, as well as pressure loss, local phase fraction profile, and slip ratio) were confirmed by the trialed data in the text. Also (Awal et al, 2005)[35], presented CFD simulation apparatus to analyze inline oil/water separation features supporting by the down hole conditions. They studied the startling sensitivity of the well inclination in the range of (80-100) degrees. A Eulerian-Eulerian model was chosen to achieve that, in which it is computationally most general, nevertheless it is better fitted for multiphase systems prediction within the case of dispersed phase that goes beyond 10% of two volumes. The case model for the CFD simulation based on horizontal wells. A 3D CFD simulation used to express the problem and the standard model of k-ε turbulence were used. They simulation used to predict an oil using viscosity and densities values as mentioned in the study and the water flows in (6.3 in) well. Another investigation by (Carlos F, 2006)[36], presented a 2D model for completely developed stratified flow of turbulent two phase oil/water. The model is set to predict the numerical solution for the basic dominant differential equations by using a (finite-volume approach) in a bipolar coordinate condition for the scheme, by employing the simple mixing-length model for turbulence. Also, modified turbulent diffusion model have been presented. The multi-fluid model have been tested and compared with the assimilated CFD code of FLUENT, for the oil/water dispersed flow measurements chained. (Kumara et al, 2008])[37], used FLUENT 6.3 CFD package to inspect the oil-water tow phase flow in horizontal tubes, The (RNG k-ε) model with standard wall treatment were used to find the influence of the turbulence flow. An experiment were made to measure the (oil-water pressure drop, velocity, and density) at different case studies, the simulation of FLUENT were based on volume of fluid (VOF), the results data from the CFD model compared with experimental successes in predicting stratified oil-water flow in pipes. While (Li-yang et al, 2008)[38], investigated the oil/ water two-phase flow, the simulation based on the flow inside T-junctions and was numerically simulated by using a 3D two phase model, and employed the turbulence model (k-$\varepsilon$) for the prediction of turbulent in the mixture. A number of experiments have been presented in the laboratory for oil/water in the case of flowing inside a single T-junction. As a result the influence of the performance of the T-junction is depends mainly on the (flow pattern and inlet volumetric fraction). An agreement is achieved between the numerical simulation predicted and the experimental work done for both the separation efficiency and oil fraction distribution. The main conclusions for this work are as follow: the two-phase model, incorporated with turbulence model of the mixture, can be efficiently used for the numerical simulation of the oil/water two-phase flow inside the T-junction. Also it showed that the two phase split ratio and the distribution ratio predicted well and a good agreement achieved with the experimental data chained. Other investigation by (Rashmi et al, 2009)[39], investigated numerically the three dimensional dispersed of two phase (immiscible liquids) stratified turbulent flow in horizontal pipes, and also CFD simulation of FLUENT 6.2 in term of k−ε model used, the distribution of VOF and pressure drop were found in this simulation and compared with experimental data from a previous case studies, the results were good in agreement in high velocity otherwise discrepancy observed at low velocities. Also Al-Yaari and Abu-Sharkh (2011)[40], used CFD calculations of ANSYS FLUENT 6.2 to predict the oil-water tow phase stratified turbulent flow. a numerical simulation presented to predict the flow pattern, smoothness and type of interface used. VOF with RNG k-ε model were employed to predict the interface, the stratified flow were experimentally investigated and the oil layer predicted well, while the water layer not predicted well. (Anand B. Desamala et al, 2013)[41], presented a study on tow phase oil-water in different flow patterns in horizontal pipes, CFD ANSYS FLUENT and GAMBIT have been used for this purpose, the conditions assumed (unsteady flow, constant liquid properties, immiscible liquids, co-axial flow , and T-junction entry), the VOF of and surface tension were employed to predict the flow pattern, the results were compared with experimental work and showed agreement in transition boundary pattern. Meanwhile (Desamala et al, 2014)[42], extended studies of oil-water tow phase flow by using ANSYS FLUENT 6.2, the methodology used predict the influence of (volume fraction profile (VOF), velocity profile, pressure across the cross section) under different pattern of flow (stratified mixed, stratified wavy, slug, and annular flow), assuming (immiscible liquid pair, unsteady flow, co-axial flow, and constant liquid properties), and ignored the dispersion of the two liquids, the simulation also compared with experimental work, the results showed different actions according to the flow pattern and discussed in the study and good agreement were observed.(Lawrence and Panagiota, 2014)[43], deliberate the interface pattern according to experimental data chained from the observations of the interface for the stratified two phase liquid–liquid flow. The experimental data made for flowing through horizontal (14 mm) in diameter of acrylic pipe, the assessment carried on for oil/water with artificial velocity ranged from (0.02 m/s-0.51 m/s), and from (0.05 m/s-0.62 m/s). The use conductance probes helped to obtain the average interface heights in two located places first in the pipe center and the other located close to the pipe wall, in which showed a concave shape for the interface for all circumstances studied. The correlation developed between the levels was used in the prediction for two-phase model. Likewise, from the chaining of time sequence of the probe sign located at the pipe midpoint, helped to the calculation of median wave amplitude and an equivalent roughness were used for the model of interfacial shear stress. In the last years (Ravinder Singh Gulia et al, 2017)[44], modeled a stratified two-phase oil-water flow with density ratio 0.9 by using CFD models, a 2D simulation of ANSYS FLUENT 14.5 have been used for this purpose, the influence of (velocity profile, temperature profile for non-isothermal, Pressure drop, and interface profile, wall shear stress, mass balance) have been studied by using this simulation under different (viscosity, density, specific heat, thermal conductivity), the result observed that a reduction in pressure drop were needed to pump a certain mass flow when comparing the result from multi-phase flow with single phase[26]

## 4. Conclusion

The presented review showed that there is many authors investigated the two phase flow in different flow patterns and the measurement tools were discussed and showed, although there is types of measurement is not available in our country but still the using of high speed camera to predict the flow pattern is mostly used and preferred under certain conditions. The use of CFD to predict two phase flow is the most common way due cost economics but need high efficiency for operation also much of time and efforts are needed due to the complexity of using the present CFD simulation programs. Most of the authors used ANSYS FLUENT to simulate the two phase flow by using different packages but still studies are needed in this field. As far as we know in the current time no data have been reported for using Comsol, CFD programming simulation, this interested us to study this field in our thesis.

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**Conflict of interest**

There is no conflict

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