Journal of Petroleum Science and Engineering 137 (2016) 240–249

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Upscaling modeling using dimensional analysis in gas–liquid annular and stratified flows

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ARTICLE INFO

Article history:
Received 1 October 2015
Received in revised form
23 November 2015
Accepted 26 November 2015
Available online 1 December 2015

Keywords:
High pressure conditions
Upscaling
Liquid holdup
Pressure gradient
Gas–liquid flow

ABSTRACT

Upscaling of models based on small diameter and low pressure experimental data to large diameter and high pressure conditions is very important in multiphase flow application and research studies. Studies with a large diameter facility and high pressure would significantly improve our understanding (and modeling) of flow characteristics in actual field conditions. Large diameter experiments can be found in literature to certain extent. However, experiments at high pressures are very limited because of the high cost of these experiments. A model based on dimensional analysis to scale up or down pressure drop and liquid holdup data is proposed in this paper. Annular and stratified flow regimes were considered in validating the proposed model. Therefore, our main objective of this paper is to investigate the effect of system pressures on the pressure drop and liquid holdup using dimensional analysis for annular and stratified flow regimes.

1. Introduction

Brill and Arirachakaran (1992) proposed ten challenges and unsolved multiphase flow problems. One of them still not fully investigated in literature is the prediction of multiphase flow pattern at elevated pressures. Hasan et al. (2007) mentioned an example of a wrong selection of flow pattern at high pressure, in which, annular flow is predicted when churn, slug and dispersed bubble flows are also possible. Incorrect prediction of the flow pattern at high pressure will result in erroneous prediction of pressure drop and liquid holdup. Currently, multiphase flow prediction tools available in literature lack method and technique validated at elevated pressure, and even lack systematic and usable data at high system pressure. Upscaling of models based on small diameter and low pressure experimental data to large diameter and high pressure conditions is very important in multiphase flow application and research studies.

Studies with a large diameter facility and high pressure would significantly improve our understanding (and modeling) of flow characteristics in actual field conditions. Large diameter experiments can be found in literature to a certain extent while experiments at high pressures are very limited because of the high cost of these experiments. Models and correlations are usually validated against low pressure and small pipe diameter data. However, two-phase flow behavior in large diameter pipes, under high pressure condition is different from those under typical laboratory conditions. It is important to validate the applicability of the models with experimental results obtained for conditions similar to those experienced in a real field. Thus, pressure drop and liquid holdup data at high system pressures are needed.

Abduvayt et al. (2003) conducted experiments at high pressure condition (2060 kPa) for nitrogen–water two-phase flow in a 0.1064-m ID pipe. It was observed that for the stratified flow, the flow pattern region on the flow pattern map extended to higher liquid flow rates than at low pressures. It was mentioned that the mechanistic model developed for low pressures has to be modified for high-pressure conditions to predict better the experimental data. It was claimed also that some correlations work better than others at high pressure.

Mantilla et al. (2012) investigated experimentally the liquid entrainment in gas at high system pressure. The experiments were conducted in a horizontal pipeline with inner diameter of 2-inch (0.0508-m). The gas–liquid fluids were oil–N_2 and water–N_2 at three different pressures, namely, 200, 500 and 1000 psig (1378 kPa, 3447 kPa, and 6894 kPa). The superficial gas velocity from 2 to 24 m/s and the superficial liquid velocity from 0.002 to 0.1-m/s were used. The flow pattern was stratified and annular flow regimes.

Tayebi et al. (2000) conducted experiments in oil–gas and water–gas flow at elevated pressure and high density (3.6, 5, and 6.9 bar absolute) in a 0.1-m ID pipe. The fluids used are Exxsol D80 or water and sulfur-hexa-fluorid, SF_6. Their experiments were

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http://dx.doi.org/10.1016/j.petrol.2015.11.028
0920-4105/

mainly for droplet entrainment, however, pressure drop and holdup data were reported. The variations in the gas densities were from 22 to 47 kg/m^3 and the superficial gas velocity from 3.5 to 7 m/s but the superficial liquid velocity was kept constant at about 0.25 m/s.

In this paper a new method and procedure of predicting pressure gradient and liquid holdup at elevated pressure in gas–liquid flow is presented and evaluated. The pressure drop data from Mantilla et al. (2012) and Tayebi et al. (1999) experiments will be used to validate the upscaling model proposed in this paper. In addition, recent data from Tulsa University Fluid Flow Project (TUFFP) 0.1557 m ID high-pressure facility will be used for validation. Moreover, data generated from OLGA simulator (version 7.2.3) will be used also for validation at higher pressure.

2. Experimental setup

The recent high pressure experiments are carried out at the Tulsa University Fluid Flow Projects (TUFFP) 0.1557 m ID high-pressure flow loop, whose schematic layout is given in Fig. 1 excluding the test section. The facility is a closed flow loop system consisting of separation and pumping stations for the gas (nitrogen) and liquid (Isopar L) phases and the test section. In the gas and oil distribution systems, a Sundyne turbine compressor and a Moyno progressive cavity pump boost the pressure of the single phases, which flow through the Micro Motion Coriolis flow meter system before they mix at the inlet of the flow loop. The compressor's nominal flow rate, discharge and suction pressures are 0.51 MMscm/d, 3.45 MPa and 2.78 MPa, respectively. The oil pump is able to deliver 45 m^3/h with the same discharge and suction pressures. After flowing through the test section, the fluid mixture is gathered and separated in the separator and the phases are returned to corresponding vessels. The facility operates at ambient temperature and is capable of conducting high pressure two-phase gas/oil experiments up to the maximum operational pressure of 3.5 MPa.

The details of the test section are given in Fig. 2. The length of its longest straight piping is 85 m with a facility width of 16.7 m. The stainless steel Schedule 40 test section has a length of 160 m and an internal pipe diameter (ID) of 0.155 m. The mass flow rates of each phase is measured with Micro Motion Coriolis mass flow meters CMF300 and CMF200 for nitrogen and mineral oil, respectively. In addition, basic instrumentations such as temperature transducers (Rosemount 3144 P with RTDs) and pressure transducers (Rosemount 3051-CD) are installed along the test section in order to calculate the superficial gas phase velocity.

The pressure gradients are measured by three differential pressure transducers. The liquid holdup are measured by wire-mesh sensor and Canty device combining with the quick closing valves. Additional details about the liquid holdup measurement by wire-mesh sensor and the measurement uncertainty are reported in Vuong et al. (2015).

3. Upscaling in single and multiphase flow by dimensional analysis

3.1. Similitude approach

The upscaling approach followed in this work is based on the similitude method which is well-known in single-phase flow. However, this approach has never been used in two-phase flow.

The basic requirement for dynamic similitude is that ratios of the forces acting on corresponding masses or surfaces at low and high pressure conditions must be the same (F_L/F_H=constant) throughout the entire flow field. Since the forces (type of forces: pressure, inertia gravity, viscosity, surface tension) acting on fluid elements will thus control the motion of these fluid elements, it follows that dynamics similarity will result in similarity of flow patterns. This leads to the fact that proper dimensionless numbers have to be equal. First the approach will be demonstrated and validated for recent measurement of single-phase flow pressure drop data at elevated system pressure then the two-phase flow model will be constructed and tested for pressure gradient and liquid holdup at high pressure conditions.

3.2. Pressure gradient in single phase gas flow at high-pressure condition

It is well known that the equality of Reynolds number is required to keep the similarity with respect to viscosity forces for the case of single phase flows of Newtonian fluids.

Then to scale up the pressure, for example, Reynolds number at low pressure (Re_L) must equal to Reynolds number at high pressure (Re_H), of course, at same mass flow rate of fluid. This will guarantee that the viscous forces will have the same ratio and as a result the Reynolds number will be equal. Thus Reynolds number based on the gas phase will be used for the similarity criterion. The subscript L, H and G are for the low pressure, high pressure and gas

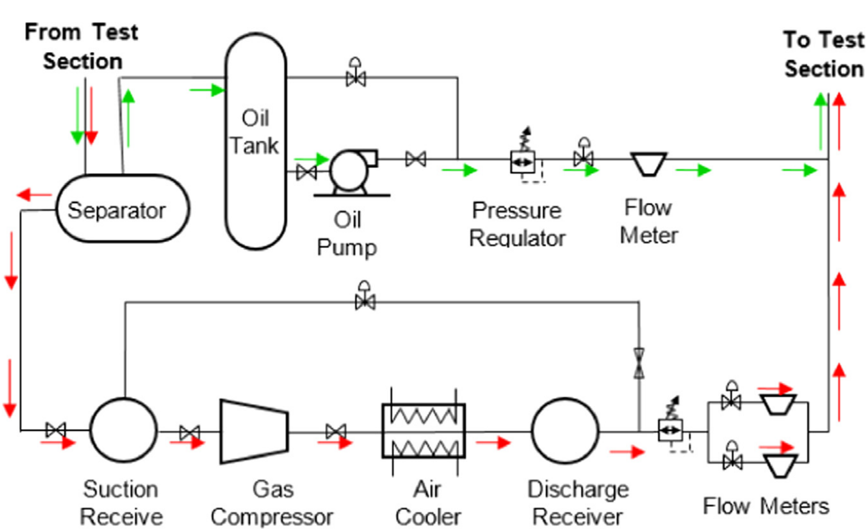

Fig. 1. Schematic layout of the 0.1557-m ID high-pressure flow loop facility area.