Journal of Petroleum Science and Engineering 146 (2016) 409–417

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Experimental study on drag reduction of aqueous foam on heavy oil flow boundary layer in an upward vertical pipe

Jie Sun [a], Jiaqiang Jing [a,b,*], Peiyu Jing [a], Nian Duan [a], Cheng Wu [a], Jiatong Tan [a]

[a] School of Oil & Natural Gas Engineering, Southwest Petroleum University, Chengdu 610500, China
[b] Oil & Gas Fire Protection Key Laboratory of Sichuan Province, Chengdu 611731, China

ARTICLE INFO

Article history:
Received 11 January 2016
Received in revised form
1 June 2016
Accepted 7 June 2016
Available online 8 June 2016

Keywords:
Heavy oil
Aqueous foam
Foam annulus
Flow pattern
Pressure gradient
Drag reduction

ABSTRACT

Flow patterns and pressure gradients of viscous oil flowing through a 25 mm ID vertical tempered borosilicate glass test pipe under the action of aqueous foam were investigated using 201 methyl silicone oil and AFS–2 aqueous foam. Measurements were made for flow rates of the oil at 8.33, 11.67, and 15.00 l/min, and the corresponding flow rates of the foam were 0.36–8.41 l/min, 0.58–11.86 l/min, and 0.32–15.44 l/min respectively. A model was established to predict pressure gradients of the oil–foam flow. The results indicate that flow patterns of the oil–foam upflow in vertical pipe mainly include thread–like flow, uniform and wavy annulus–like flow, non–uniform and wavy annulus–like flow and thick, non–uniform and wavy annulus–like flow. Injection of foam can lead to a stable foam annulus, which can isolate and lubricate the oil and inner pipe wall, and then reduce the flow resistances of heavy oil. All the drag reduction efficiencies exceed 50% when the flow ratios of foam to oil reach the critical values of 0.18, 0.20 and 0.24 respectively. Meanwhile the recommended ranges of foam injection under the experimental condition are 0.18–0.65, 0.20–0.60 and 0.55–0.87 separately. When a stable foam layer formed, the predicted pressure gradients are in good agreement with the measured ones, and the relative errors are basically kept within $\pm 20\%$.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

In recent years, global demands of energy have been increased due to industrial growth while the worldwide production of conventional crude oil has almost reached to its peak (Mohsenzadeh et al., 2015). Heavy crudes account for a large fraction of the world's potentially recoverable oil reserves (Langevin et al., 2004), and heavy oil production will play an important role in the future of the ever–growing world's energy consumption (Mohsenzadeh et al., 2012). However, high viscosity makes heavy oil easily creep around the inner wall of the wellbore in production, which greatly reduces the efficiency of the lift system and heavy oil production. At present, the main methods for viscosity and drag reduction of heavy oil in wellbore include steam and multi–thermal fluid injection (Gu et al., 2015; Dong et al., 2014), hot water injection (Zhao and Gates, 2015; Bera and Babadagli, 2015), electrical heating (Rangel–German et al., 2004; Bientinesi et al., 2013), chemical injection (Liu et al., 2007; Kianinejad et al., 2013), and injection of light oil diluent (Yu and Li, 2013; Denney, 2015). These methods have been widely applied in different heavy oil production areas of the world, but while they are generally used to wholly treat the oil, and have their respective adaptability and limitation. For instance, for deep or low thickness heavy oil reservoirs, steam injection, multi–thermal fluid injection and hot water injection methods can be economically unfeasible due to extreme heat losses in stratum and wellbore (Wu et al., 2012). Large equipment investments and power consumption in electrical heating method often leads to high development cost. Surfactants used in chemical injection cause formation pollution, which later needs high treatment fees. Injection of light oil diluent changes the quality of the produced crude oil and the viscosity reduction efficiency by this approach are not satisfactory in high water–content producing well. Therefore, to find out an efficient, economic and low–consumption method for heavy oil transport in wellbore is currently still a hotspot issue in heavy oil production both at home and abroad (Escobar–Remolina et al., 2012).

Since Isaacs and Speeds (1904) first mentioned the possibility to pipelining viscous fluids through water lubrication, many researches related to core–annular flow (CAF) were then carried out. Prada and Bannwart (2001) studied the CAF flow characteristic of heavy oil–water in a 25 mm vertical flow loop and verified a significant drag reduction of water annulus. Silva et al. (2006) found that in heavy oil–water core–annular flow the hydrophilic property

* Corresponding author at: Southwest Petroleum University, Chengdu 610500, China.
E-mail addresses: sunj101@163.com (J. Sun), jjq@swpu.edu.cn (J. Jing).

http://dx.doi.org/10.1016/j.petrol.2016.06.011
0920-4105/© 2016 Elsevier B.V. All rights reserved.

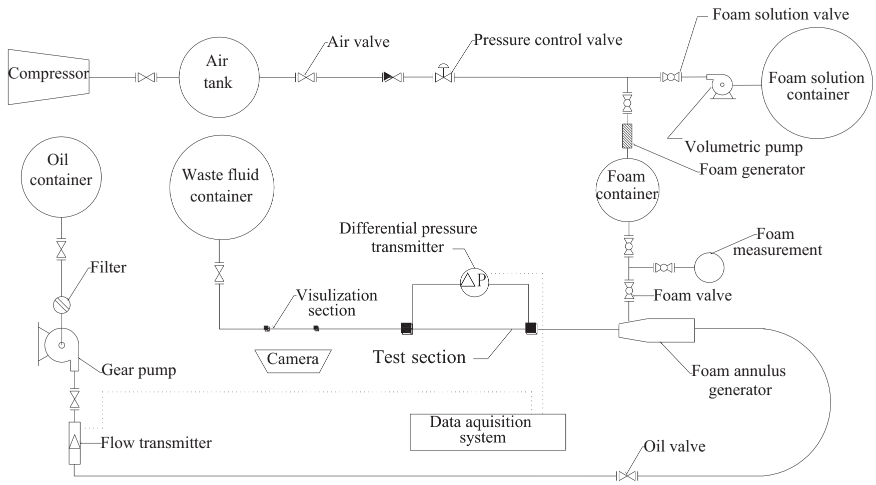

Fig. 1. Installation of heavy oil–aqueous foam flow simulation.

of the inner pipe wall could be improved by oxidating its surface or increasing its roughness to reduce the adherence of heavy oil, but both of the two methods are difficult to implement. Varadaraj and Thomas (2007) employed a family of demulsifier additives (Sodium salts of polynuclear aromatic sulfonic acids) to enhance the shear stability of a high–viscosity fluid–water core annular flow system. Nevertheless, instability of water annulus, emulsification of oil and water and high water consumption in water–annulus technology have not been effectively solved yet, which makes this technology have not reached the level of popularization and application by far.

Mccormick and Bhattacharyya (1973) conducted the pioneering experiment of a fully submerged body of revolution covered with hydrogen bubbles produced by electrolysis on the microbubble drag reduction. Kodama et al. (2000) investigated the skin friction reduction by microbubbles using skin friction sensors in a circulating water tunnel, and found that the skin friction reduction was greater at larger air injection rate and lower speed. Ortiz–Villafuerte and Hassan (2006) measured the velocity fields of both continuous phase and dispersed microbubble phase in a turbulent boundary layer of a channel flow by particle tracking velocimetry, and discovered that a combination of concentration and distribution of microbubbles in the boundary layer can achieve drag reductions up to 40% when the accumulation of microbubbles took place in a critical zone within the buffer layer. However, is this method also effective for drag reduction on heavy oil flow bound layer?

Inspired by water lubrication technique and microbubble drag reduction mechanism, Jing et al. (2013a) proposed a new idea for drag reduction on heavy oil flow bound layer using aqueous foam, i.e. aqueous foams are injected into the space between the oil and pipe wall to form foam annulus, and the isolation and lubrication action of the annulus contributes to heavy oil flow drag reduction. Compared with the aforementioned common techniques, this method has lower energy consumption, less pollution to environment and no whole treatment, then compared with the water–annulus technique, less water will be consumed. In our previous work, an aqueous foam liquid system with high foaming ability and stability has been screened out (Jing et al., 2013b), and drag reduction effects of aqueous foam on heavy oil flow bound layer in horizontal and inclined pipe have also been investigated (Jing et al., 2014, 2015), which demonstrates a remarkable drag reduction effect.

In this paper, the experimental program was conducted using a model oil (201 methyl silicone oil) and an aqueous foam prepared independently. Flow patterns and drag characteristics of heavy oil flowing through vertical pipe under the action of aqueous foam were explored, hoping to verify the possible validity of drag reduction for heavy oil flowing in production well.

2. Materials and methods

2.1. Materials

Black color and high viscosity brings about great difficulty to flow pattern detection of the heavy oil–foam flow. In this experiment, the transparent 201 methyl silicone oil was selected as a model oil, which is helpful for the observation of oil–foam flow patterns.

Based on the synergistic effect of different foaming agents and foam stabilizers, a highly stable aqueous foam system (AFS–2) was screened out by Waring Blender method. The corresponding ingredients are 1 g/l sodium dodecyl sulfate, 1 g/l agent 3#, 3 g/l polyacrylamide, 3 g/l SF–1 suspending agent and 3 g/l dodecanol, and the evaluation of foam performance was investigated in detail by Jing et al. (2014).

2.2. Experimental apparatus

Flow patterns and pressure gradients during simultaneous vertical upflow of oil and foam were observed and measured using the flow facility shown schematically in Fig. 1. It consists of foam generator and container, foam–annulus generator, air supply unit, data acquisition system and other power equipments, tempered borosilicate glass test tube and fittings.

The foam generator with a foam solution and air inlet on the top and a foam outlet on the bottom is an airtight cylindrical vessel filled with wire mesh (Fig. 2); the foam container ($H=0.572$ m, $D=20$ cm) is a specially–made cylindrical vessel with a built–in piston; the foam–annulus generator consists of inner cylinder (oil flow channel) and outer annular cylinder (foam flow channel) (Fig. 3). The test section ($L=1.5$ m, $D=25$ mm) is made of tempered borosilicate glass pipe with rough inner wall, which is convenient to simulate the drag characteristics of heavy oil flowing through steel pipe and observe the flow patterns. In addition, the test pipe can be rotated in the ranges of $-90°$ to $90°$.

2.3. Experimental procedure

The aqueous foam was prepared by the following procedure: first, inject the prepared foam solution into the foam generator;

Download English Version:

https://daneshyari.com/en/article/1754520

Download Persian Version:

https://daneshyari.com/article/1754520

Daneshyari.com