

**THE EFFECT OF DRAG REDUCING AGENTS ON CORROSION  
IN MULTIPHASE FLOW**

**CHEOLHO KANG, WILLIAM. P. JEPSON AND MADAN GOPAL**

**NSF, I/UCRC CORROSION IN MULTIPHASE SYSTEMS CENTER  
DEPARTMENT OF CHEMICAL ENGINEERING  
OHIO UNIVERSITY  
ATHENS, OHIO  
USA**

**ABSTRACT**

The effect of drag reducing agents (DRA) on corrosion and flow regime has been studied in a 10 cm diameter, 18 m long plexiglass flow loop in 50% oil/water mixtures with carbon dioxide gas. Superficial liquid velocities between 0.1 and 1 m/s and gas velocities between 1 and 10 m/s respectively were studied. The corrosion rate was measured for stratified, slug and annular flow. The height of liquid film, slug velocity, and slug frequency were obtained from the video image using a super-VHS camera. The DRA effectiveness was examined for DRA concentrations between 0 and 75 ppm.

Flow regimes maps were determined with 25 and 75 ppm DRA. These results were compared to the flow regime map with no DRA. The results indicate that the transition from stratified to slug flow is obtained at a higher superficial liquid velocities. This resulted in much lower corrosion rates due to the elimination of the highly turbulent slugs.

The corrosion rate for stratified and annular flow did not generally reduce with adding DRA concentrations.

For slug flow, the slug frequency decreased with the addition of 50 ppm DRA. This led to decrease of corrosion rate by almost 50%.

**Keywords: DRA, multiphase flow, flow regime map, slug flow, slug characteristics, shear, large diameter pipeline, temperature**

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## INTRODUCTION

The flow of multiphase mixtures is frequently encountered and internal corrosion of carbon steel pipelines is a common problem in the petroleum industry. It is usually not practical to separate the multiphase mixture at the well site since many oil wells are located in remote sites, e.g. subsea and Alaska. Therefore, the multiphase mixture is transported through a large single pipeline to a central gathering station. The distances that the multiphase mixture is transported are often many miles and the pressure drop in these pipelines can be significant. Also, corrosion is a major concern.

DRA can be used to reduce frictional losses in pipeline, which leads to a decrease in the pressure gradient for a given flow rate. Lester (1985)<sup>1</sup>, Nijs (1995)<sup>2</sup> and Virk and Baher (1970)<sup>3</sup> have shown that drag reducing agents can be beneficial to reduce pressure drop in turbulent flow, but not in laminar flow. Lester (1985)<sup>1</sup> has indicated that DRA degrades by shear when centrifugal pumps are used. Chang, David and Darby (1983)<sup>4</sup> also examined shear degradation effects in 0.46 cm diameter tubes. They have indicated that DRA degrade by age, losing effectiveness after a few days, and shear.

The effect of DRA in single and two phase flow in 2.54 cm diameter horizontal pipes has been studied by Rosehart, Scott and Rhodes (1972)<sup>5</sup>. They found that drag reduction in two-phase flow is greater than in single-phase flow at the same superficial liquid velocities. These results were restricted to the slug flow regime.

The benefits of DRA added to an existing systems are increased flow rate, reduction of operation costs, and reduction of pressure gradient.

Lee, Sun and Jepson (1993)<sup>6</sup> have shown flow regime maps and flow patterns for oil-water-carbon dioxide gas in a 10 cm diameter pipeline. They have indicated that the flow regime transitions in oil-water-gas three phase flow differ from those in both gas-liquid and oil-water flow systems. Jepson and Taylor (1989)<sup>7</sup> have shown that the transitions from stratified to slug flow occurs at higher liquid velocities in larger diameter pipelines. They also noted that the results from small pipe diameter could not be easily extrapolated to larger pipes.

Vuppu and Jepson (1994)<sup>8</sup> have indicated that the corrosion products in oil-water flow depend upon the temperature, pressure and flow velocity. Kanwar and Jepson (1994)<sup>9</sup> have proven that the corrosion rate increases with an increase of flow velocity or an increase of carbon dioxide partial pressure.

Kang, Wilkens and Jepson (1996)<sup>10</sup> and Jepson, Stitzel, Kang, and Gopal (1997)<sup>11</sup> have shown that reducing the slug frequency leads to a reduction in the corrosion rate.

This study outlines on the effect of DRA on flow regime and slug characteristics such as the height of liquid film, slug frequency and slug velocity, and hence corrosion rates.

## EXPERIMENTAL SETUP

The experimental layout of the flow loop is shown in Figure 1. The specified amount of oil-water mixture is stored within a 1.2 m<sup>3</sup> stainless steel mixing tank (A). The tank is equipped with heating and cooling coils to maintain a constant temperature. The oil-water mixture from the storage is

then pumped into a 10 cm ID PVC pipeline using a 76 HP stainless steel, low shear progressive cavity pump (B). The liquid flow rate is controlled by the variable speed pump.

Carbon dioxide gas from a 20,000 kg receiver is introduced into the system at an inlet pressure of 0.27 MPa. The gas flow rate is metered with a variable area flow meter. The gas is then mixed with the liquid at a tee junction (F). The multiphase mixture then flows through 3.1 m long flexible hose (10 cm ID), allowing the inclination to be set at any angle. The oil-water-gas mixture then flows into a 18 m long plexiglass pipeline (10 cm ID) where flow pattern, slug characteristics and corrosion rate are determined. The multiphase mixture then returns to the mixing tank and gas is vented to the atmosphere.

In the test section the corrosion measurement is determined using two flush mounted electrical resistance (ER) probes. The sampling tube is used to measure the concentration of oxygen, the presence of iron and the distribution of the phases.

A super-VHS camera is used to record images of moving slugs. Slug characteristics such as the height of the liquid film, slug translational velocity and slug frequency are obtained using this camera. The Froude number is calculated from the height of the liquid film and the slug translational velocity.

Superficial liquid velocities between 0.1 m/s and 2 m/s and superficial gas velocities between 1 m/s and 10 m/s respectively were studied. Oil with a density of 800 kg/m<sup>3</sup> and viscosity of 2 cp was used in this study. The gas used was carbon dioxide. A water cut of 50% was used throughout the experiments. These experiments are performed at 40° C. The effectiveness of DRA was examined for four concentrations; 10, 25, 50, and 75 ppm.

Initially, the experiments were carried out with no DRA present. These results were compared to those with DRA concentrations. The DRA concentration is calculated on a total volume basis as follows:

$$V_{DRA} = \frac{C_{DRA} \times V_{total}}{1 \times 10^6}$$

where,  
 $V_{DRA}$  = Volume of the DRA to be added  
 $C_{DRA}$  = Desired DRA concentration (ppm)  
 $V_{total}$  = Total liquid volume of the system, m<sup>3</sup>

Experiments were performed for stratified, slug and annular flow in horizontal pipes. Flow regime map, corrosion rate and slug characteristics such as slug frequency, slug velocity and the height of the liquid film have been studied.

## RESULTS

Figure 2 shows a plot of flow regime map in 50% oil-50% water-carbon dioxide gas in horizontal pipes without DRA. Comparing Figures 2, 3, and 4, it is noted that the transition from stratified to slug flow is obtained at higher superficial liquid velocities when DRA is present. It is seen from figure 2 that the transition from stratified to slug flow has been identified at a superficial liquid velocity of approximately 0.22 m/s. The transition to the slug flow regime shifts to higher superficial liquid velocities with adding 25 ppm DRA. Figure 3 shows that slug flow occurs at superficial liquid

velocities above 0.34 m/s. When 75 ppm DRA is added, the transition to slug flow shifts further to superficial liquid velocities of 0.5 m/s. It can be seen from these Figures that the transitions to plug and pseudo-slug flow regime also shifts to higher superficial liquid velocities. The presence of DRA does not affect the values of superficial gas velocity of the flow regime transitions.

Table 1 and Figure 5 show the effect of DRA on corrosion rate in 50% oil-50% water-gas. All corrosion experiments were carried out for at least six hours and the pump used did not produce sufficient shear to degrade the DRA for that time frame. The corrosion rates were measured at superficial liquid and gas velocities of 0.2 to 1 m/s and 2 to 10 m/s respectively. It is seen from Figure 2 that these flow rates covered stratified, slug and annular flow regimes.

The corrosion rate for stratified, slug, and annular flow is presented in Table 1. It can be seen that the corrosion rate for slug flow is much higher than that in stratified and annular flow. For stratified flow, the corrosion rate at a superficial liquid velocity of 0.2 m/s and gas velocity of 2 m/s does not reduce with adding the DRA concentrations. The corrosion rate has the same value of 0.6 mm/year up to 50 ppm DRA. The DRA does not affect the flow characteristics substantially under these conditions.

Slug characteristics such as slug velocity, slug frequency and the height of the liquid film have been measured at each DRA concentration. The result shows that slug velocity does not change with DRA concentrations in all cases. However, the height of the liquid film decreases with DRA concentrations. Table 2 shows the effect of DRA on slug frequency. It is seen from this table that the slug frequency does not change much at a superficial liquid velocity of 0.5 m/s. At higher superficial liquid velocity of 1 m/s, the slug frequency decreases from 39 to 32 slugs/minute and from 24 to 15 slugs/minutes at superficial gas velocities of 2 and 4 m/s as 50 ppm DRA was added, which leads to an decrease of corrosion rate. Kang, Wilkens and Jepson (1996)<sup>10</sup> have shown that reducing the slug frequency leads to a reduction in the corrosion rate.

It is seen from Table 1 that corrosion rates at superficial liquid velocity of 0.5 m/s and superficial gas velocities of 2 and 4 m/s, decrease from 0.9 to 0.6 mm/year and from 1.0 to 0.7 mm/year when 10 ppm DRA is added. A further increase in DRA concentration to 50 ppm did not decrease the corrosion rate.

It is seen from Figure 5 that the corrosion rates at superficial liquid velocity of 1 m/s and gas velocities of 2 and 4 m/s are 1.0 and 1.2 mm/year with 0 ppm DRA. When 10 ppm DRA is added, there is a little decrease in corrosion rate. However, the corrosion rate is reduced by almost 50 % with 50 ppm DRA. The corrosion rates decreased from 1.0 to 0.4 mm/year and from 1.2 to 0.6 mm/year respectively.

Annular flow occurs at the high gas velocities of 8 and 10 m/s. It is seen from Table 1 that the DRA has no effect on corrosion rate substantially at a superficial liquid velocity of 0.2 m/s. At higher liquid velocity of 1 m/s, it is seen from Figure 5 that the corrosion rate decreases from 0.7 to 0.4 mm/year when 50 ppm DRA is added.

## CONCLUSIONS

Experiments have been carried out to test the use of a DRA in multiphase applications.

It is observed that the transition to slug flow regime with the presence of DRA occurs at higher superficial liquid velocities. The transition to plug and pseudo-slug flow regimes also shifts to higher superficial liquid velocities

In stratified and annular flow, the corrosion rate did not generally reduce with DRA concentrations.

The DRA did not affect the slug velocity. However, the height of the liquid film decreases with DRA concentrations. At a superficial liquid velocity of 1 m/s and gas velocity of 4 m/s, the slug frequency decreases from 24 to 15 slugs/minute with 50 ppm DRA.

In slug flow, the corrosion rate at a superficial liquid velocity of 1 m/s and gas velocities of 2 and 4 m/s decreases approximately 50 % from 1.0 to 0.4 mm/year and from 1.2 to 0.6 mm/year respectively with 50 ppm DRA concentration.

The DRA did not degrade over a 6-hour time frame using the low shear pump.

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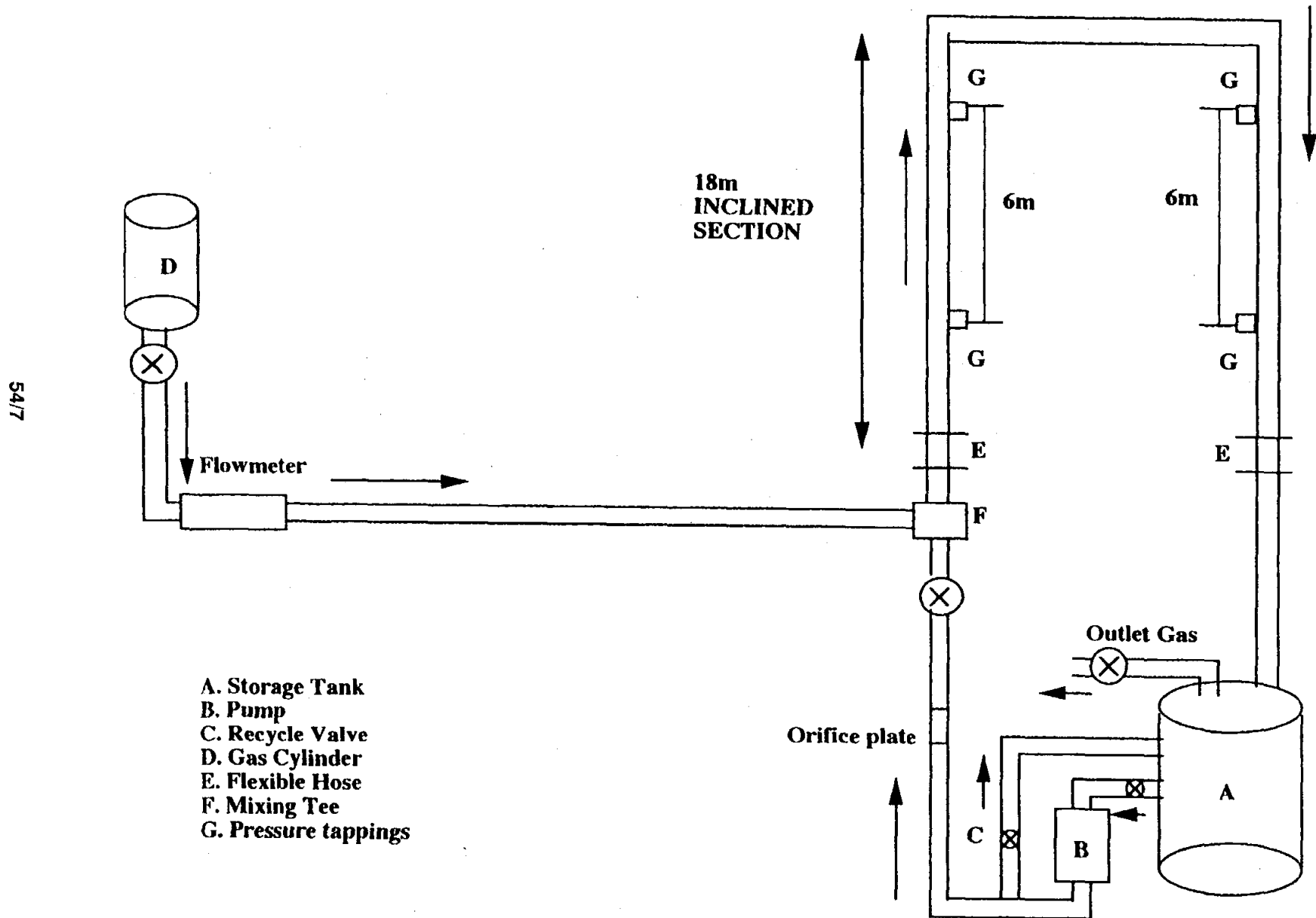
**Table 1. Effect of DRA on Corrosion in 50% Oil-50% Water-Gas in Horizontal Pipes**

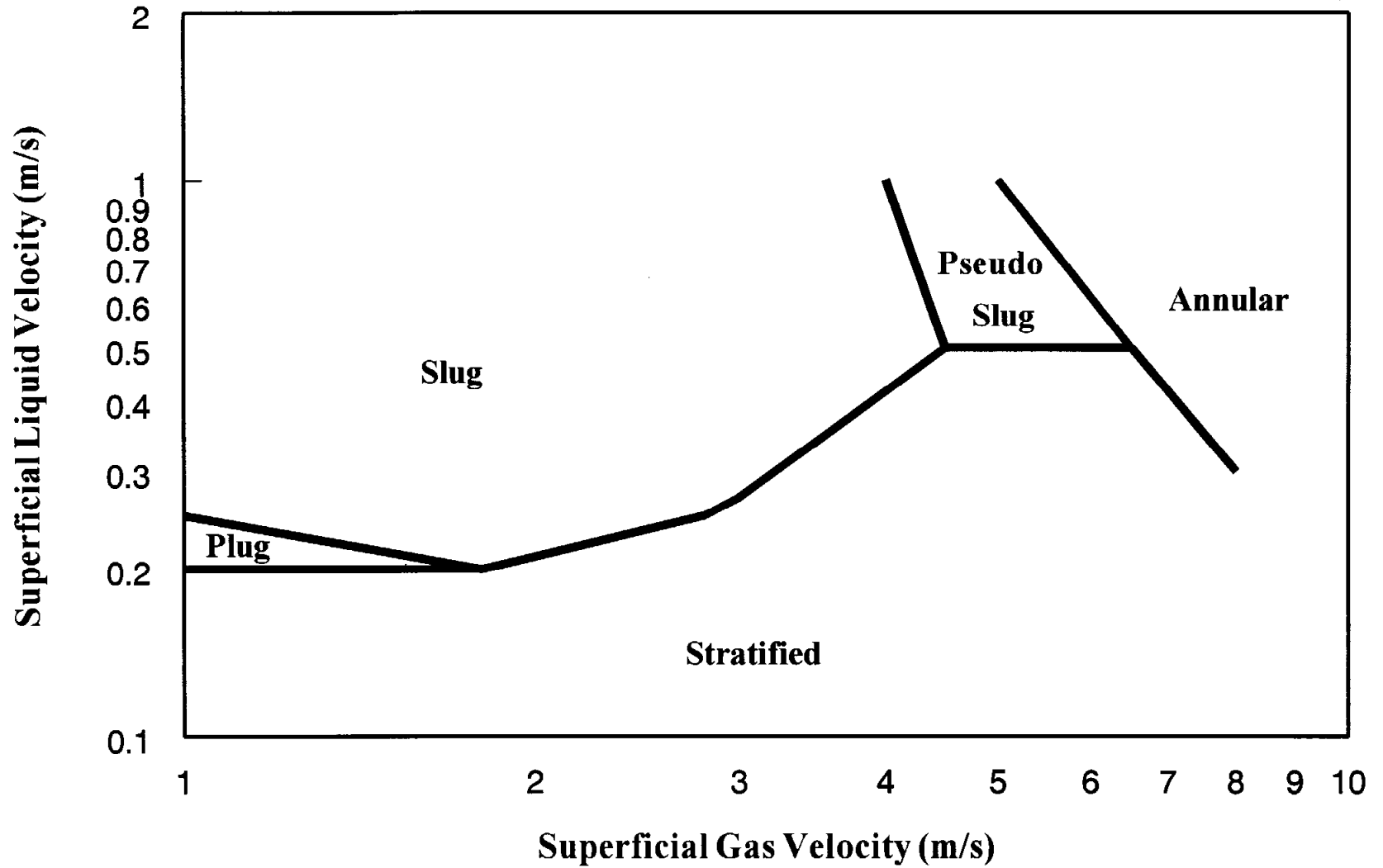
Superficial Liquid Velocity, m/s	Superficial Gas Velocity, m/s	Flow Regime	Corrosion rate, mm/year		
			0 ppm DRA	10 ppm DRA	50 ppm DRA
0.2	2	Stratified	0.6	0.6	0.6
0.2	8	Annular	0.4	0.4	0.4
0.2	10	Annular	0.5	0.4	0.4
0.5	2	Slug	0.9	0.6	0.6
0.5	4	Slug	1.0	0.7	0.6

**Table 2. Effect of DRA on Slug Frequency in 50% Water-50% Oil-Gas in Horizontal Pipes**

Superficial Liquid Velocity, m/s	Superficial Gas Velocity, m/s	Flow Regime	Slug frequency, slugs/minutes		
			0 ppm DRA	10 ppm DRA	50 ppm DRA
0.5	2	Slug	9	8	10
0.5	4	Slug	7	6	10
1	2	Slug	39	42	32
1	4	Slug	24	15	15

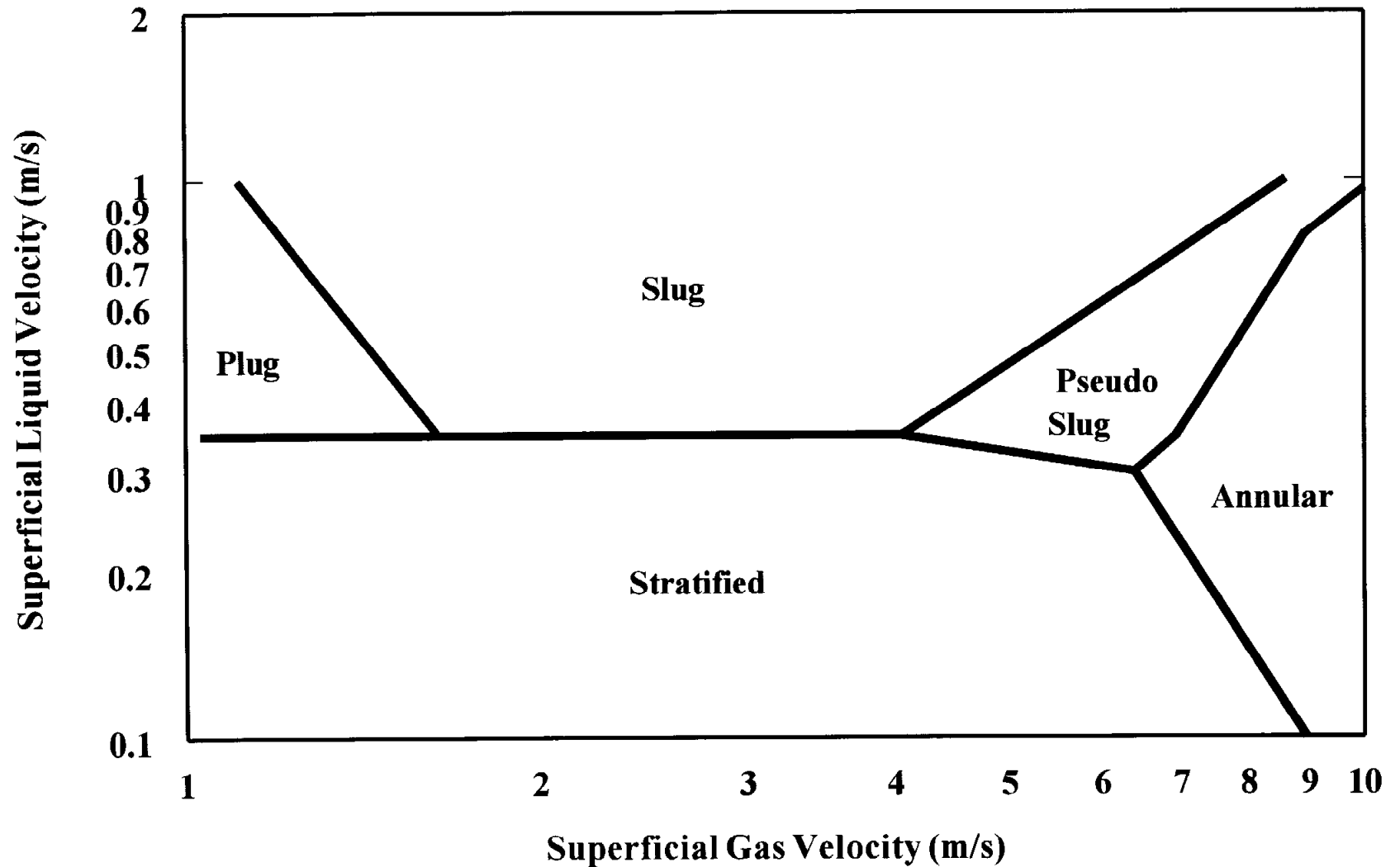
**Figure 1. Experimental layout of the flow loop**



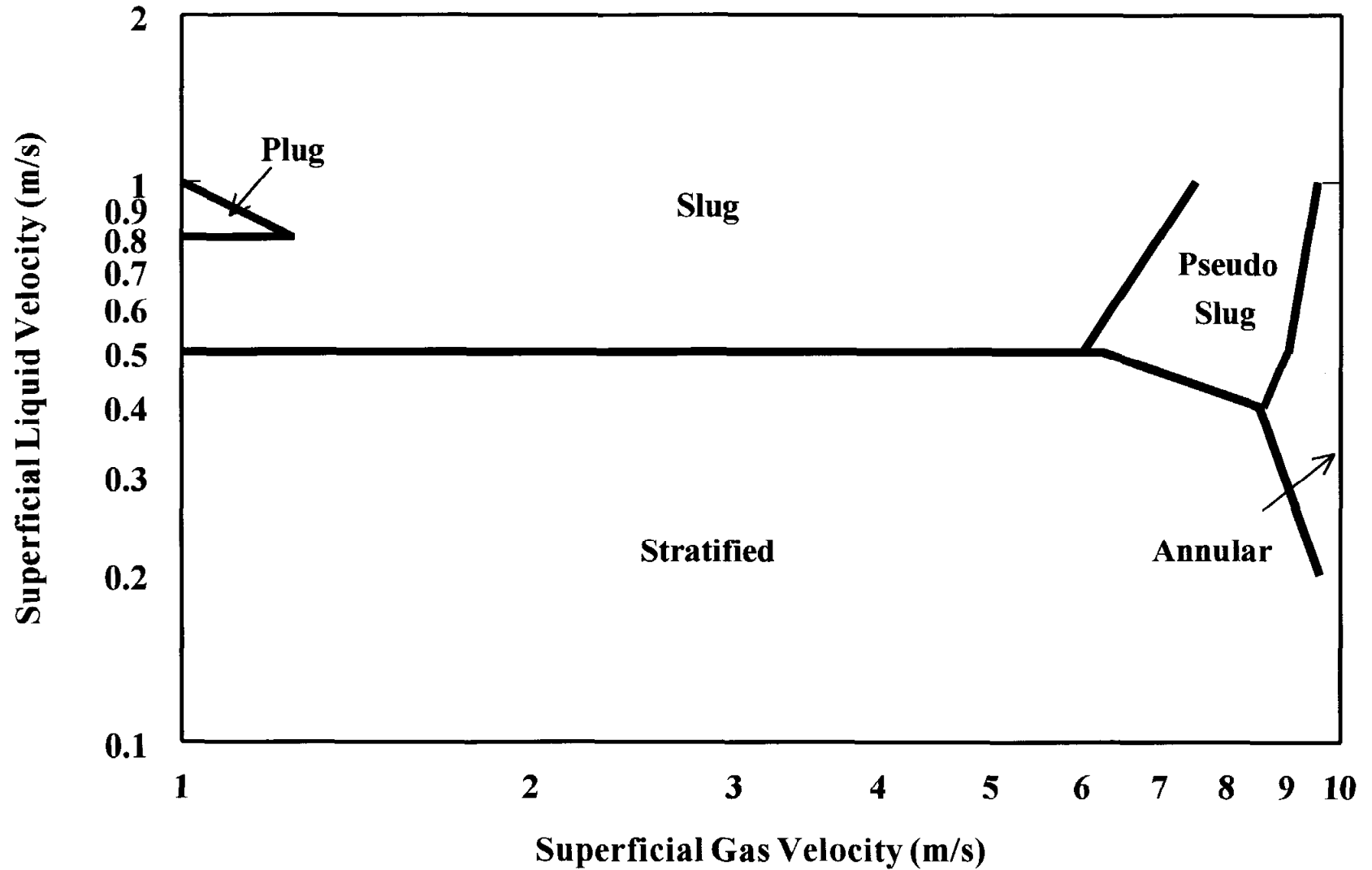


**Figure 2. Flow Regime Map for 50% Oil-50% Water-Gas  
0 ppm DRA, Horizontal Pipes**



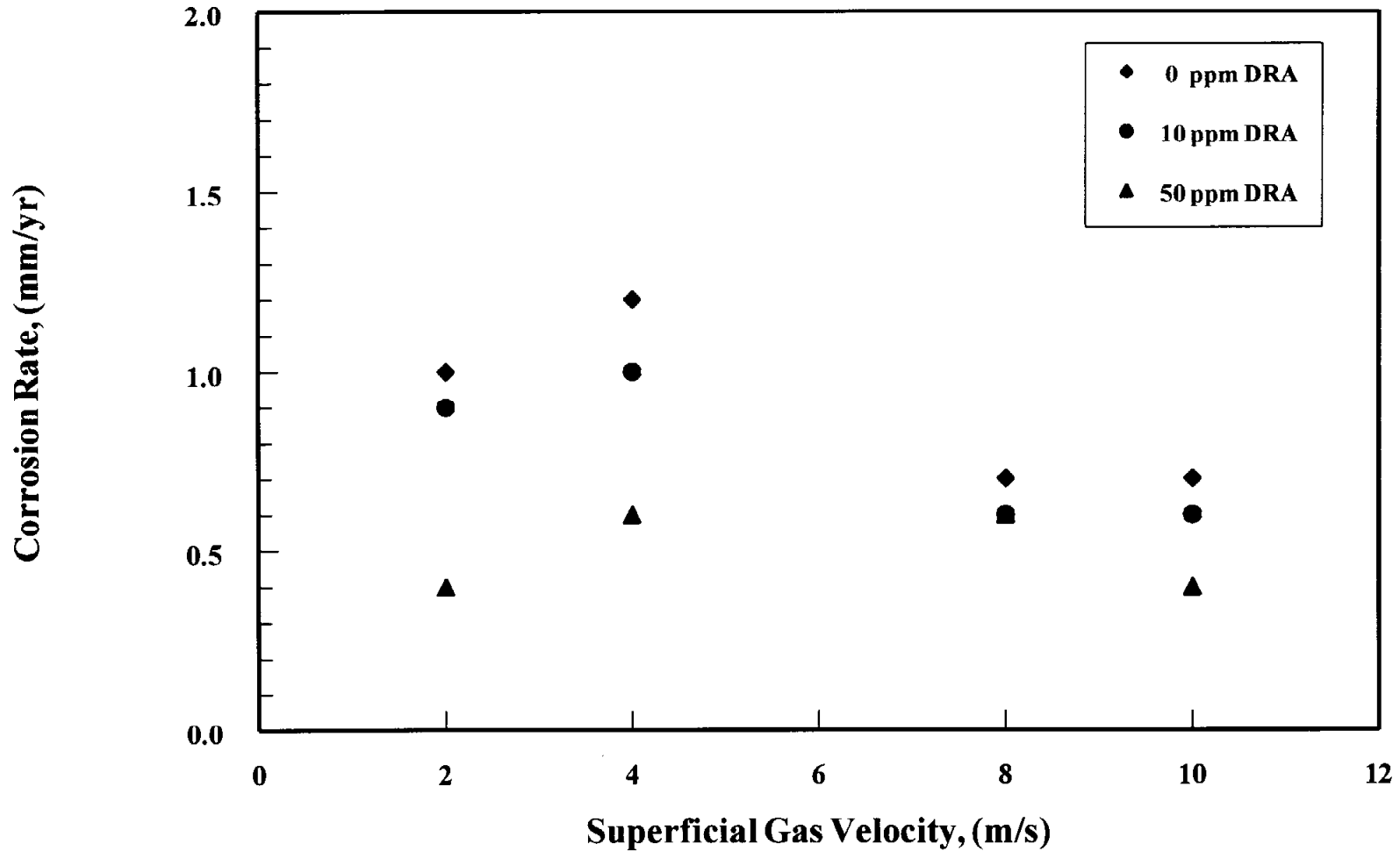


**Figure 3. Flow Regime Map for 50% Oil-50% Water-Gas  
25 ppm DRA, Horizontal Pipes**



**Figure 4. Flow Regime Map for 50% Oil-50% Water-Gas**

**75 ppm DRA, Horizontal Pipes**



**Figure 5. The Effect of DRA on Corrosion Rates in Horizontal Pipes  
50% Oil-50% Water-Carbon Dioxide Gas,  $V_{sl} = 1.0$  m/s**