Experimental Facility

Both static and dynamic facility were used for continuous flow plunger lift experiments. Fall experiments were mainly conducted in static facility and upstroke experiments were conducted in dynamic facility. The following provides the details of both static and dynamic facilities.

Static Facility

An indoor facility made up of 2-in ID acrylic pipe with 8 ft and 11-in. length. This facility named as static facility, and it is used for fall tests against static liquid column with and without gas injection. Balls, sleeves and bypass plunger have been tested for their fall velocity in this facility. Schematic of static facility including instrumentation location can be seen in **Figure 1**. High speed is camera used for visual observation purposes to identify the mechanics involved while plungers fall. Proximity sensors are used to detect plunger's location with time, which is further used to determine plunger fall velocity between two proximity sensors. Air is injected into the facility to test two-phase effect on plunger fall velocity. Sparger (bubbler) is used to create bubbles and distribute the injected gas homogeneously (**Figure 2)**. Static facility can also be deviated up to 30 degrees to investigate the deviation effects (**Figure 3**).

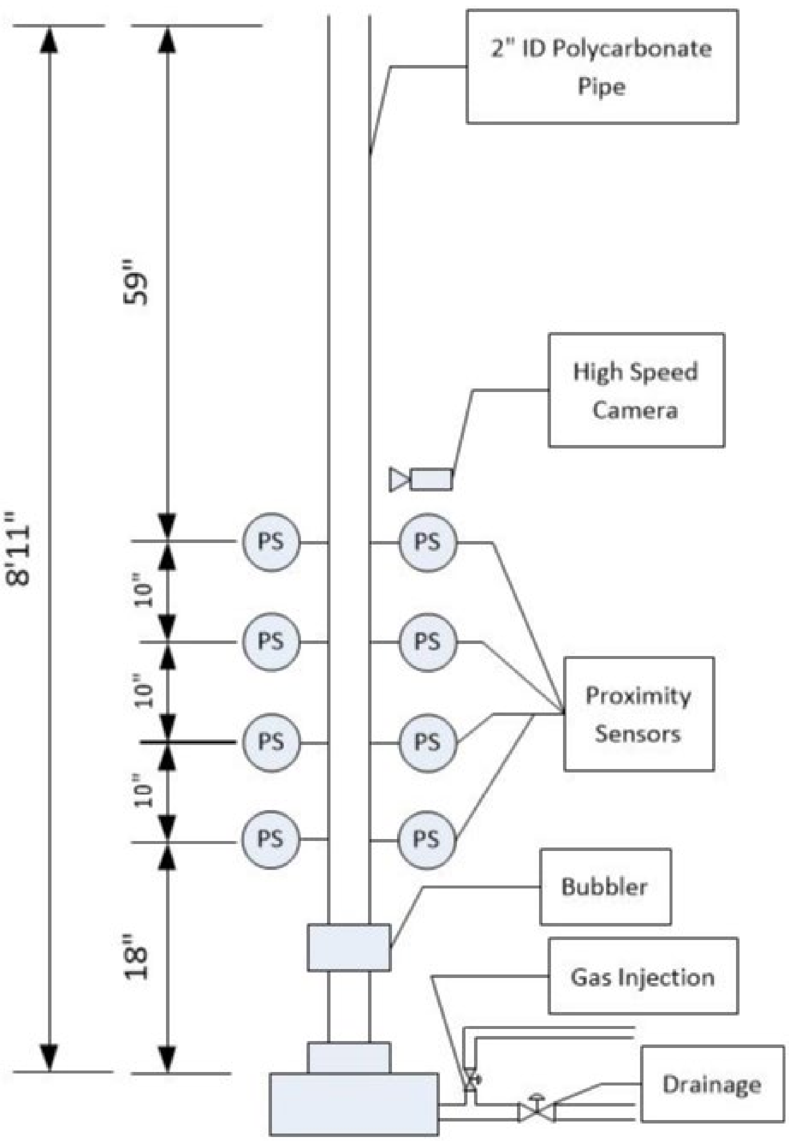


Figure 1: Static facility schematic.

Figure 2: Sparger used to create smaller bubbles from injected gas.

Figure 3: Inclined static facility.

Experimental Test Matrix, Test Plungers and Test Fluids

Static Facility Experiments

Fall experiments were conducted in both static and dynamic facilities. In static facility, bypass plunger and four different sleeves with 1.88-in and 1.9-in OD with 6-in and 9-in height were used along with cobalt, stainless steel and tungsten balls. Air, water, ISOPAR-L, low viscosity oil and medium viscosity oil were used as different fluids. With the air injection, bubble and churn flow patterns were observed with varying liquid holdup rates of 0.75 to 1. More than 1500 experiments were carried out considering at least 7 repetitions in static facility. **Tables 1** and **2** summarize the experimental matrix, sleeve and ball properties.

Table 1: Test matrix for fall velocity in static facility.

Flow Pattern	Liquid Holdup	Plunger Parts		Fluid
		Balls	Sleeves	
Static Bubble Slug/Churn	1 0.95 0.9 0.85 0.8 0.75	Cobalt Tungsten Stainless Steel	6" and 9" Sleeves of 1.88" OD 6" and 9" Sleeves of 1.9" OD	Water (0.94 cP at 73°F) ISOPAR-L (1.7 cP at 73°F) Low Viscosity Oil (17.4 cP at 73°F)
		Bypass Plunger		Medium Viscosity Oil (35.4 cP at 73°F)

Table 2: Plunger specifications and fluid properties.

Plunger Parts						Fluid Density	
Balls (lb)		Sleeves (lb)		ID(in)	OD(in)	Medium	Density(lb/ft^3)
Cobalt	0.428	6" Sleeve 1.88" OD	2.49	1.112	1.88	Water	60.93
Tungsten	0.7005	6" Sleeve 1.9" OD	2.5755	1.112	1.9	ISOPAR-L	47.63
Steel	0.3755	9" Sleeve 1.88" OD	3.7325	1.113	1.88	Low Viscosity Oil	52.71
Ball Diameter	1.374-in	9" Sleeve 1.9" OD	3.8615	1.118	1.9	Medium Viscosity Oil	53.69

3.2.3 Test Fluids

Static facility experiments were conducted in a climate controlled indoor environment at ambient temperature of 73 ºF. Water, ISOPAR-L, low viscosity oil and medium viscosity oil were used. In the dynamic facility, ISOPAR-L was used as liquid phase and compressed air was used as gas phase. Ambient temperature was varied between 70 ºF to 90 ºF. Properties of the test fluids are listed in **Tables 3** to **6**.

Table 3: Water.

Density (ρ)	997.6 kg/m^3 @ 73 ºF
Viscosity (μ)	0.94 cSt @ 73 ºF

Table 4: ISOPAR-L.

Density (ρ)	760 kg/m^3
Viscosity (μ)	1.64 cSt @ 25 ºC 1.3 cSt @ 40 ºC
Surface tension (σ)	0.024 N/m

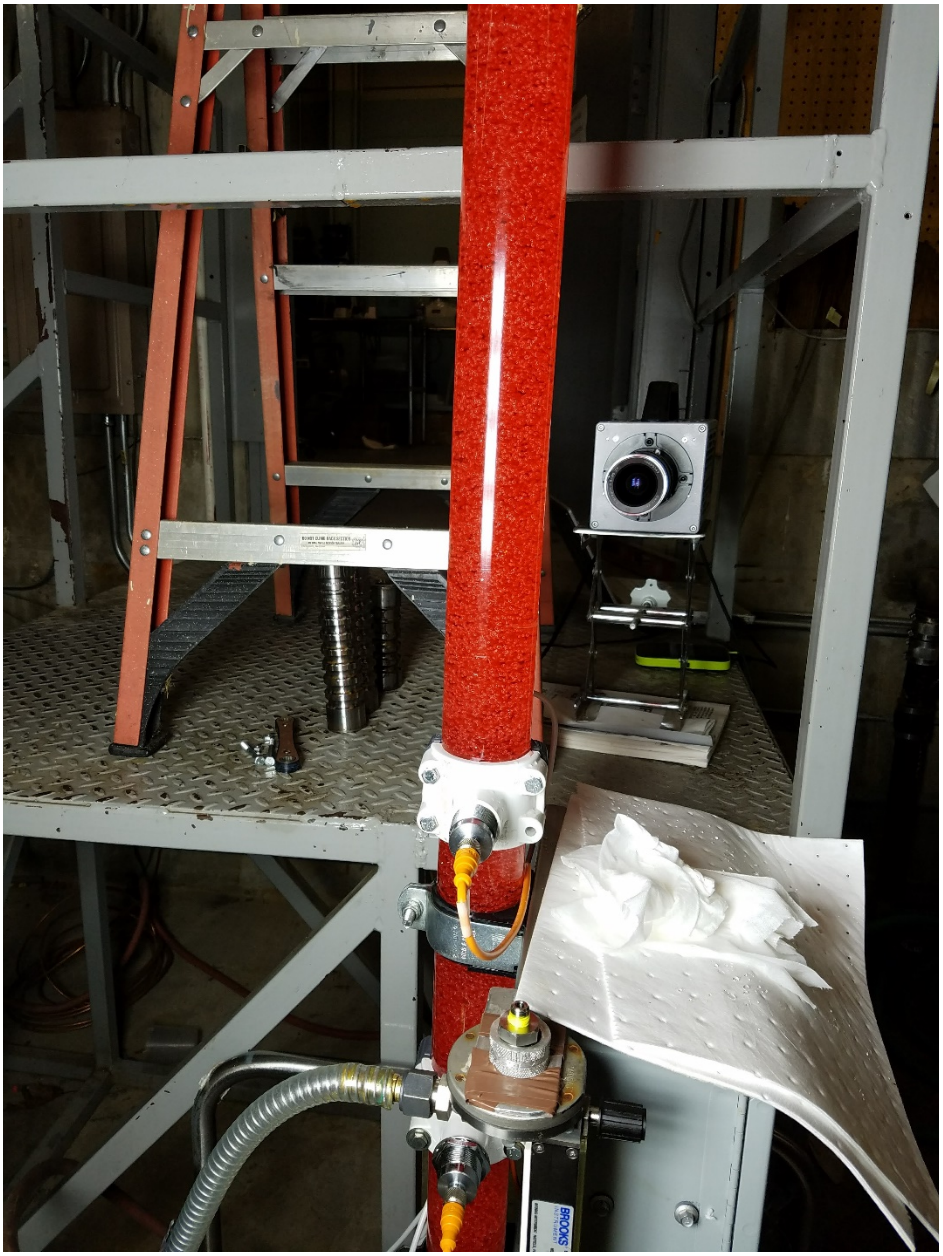
Table 5: Low viscosity oil.

Density (ρ)	844.3 kg/m^3
Viscosity (μ)	9.3 cSt @ 40 ºC 2.4 cSt @ 100 ºC

Table 6: Medium viscosity oil.

Density (ρ)	860.2 kg/m^3
Viscosity (μ)	17.3 cSt @ 40 ºC 3.72 cSt @ 100 ºC

Extra Photos: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