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Advances in hydrate equipment

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Abstract

Gas hydrate blockage in pipelines during offshore production is a major problem with increasing water depth. In deep water environment, low temperature and high-pressure conditions are favourable for formation of gas hydrate in the presence of water and gas molecules. It is a serious flow assurance issue that can lead to plugging of production facilities. To safely implement hydrate management strategies, it is important to study and understand mechanisms and behaviours connected to hydrate formation in different multiphase systems involving gas, oil and water. Several laboratory flow loops have been fabricated to conduct and study hydrate formation, agglomeration and dissociation. Various stages of hydrate formation have been measured and observed under continuous mixing, as a factor of different variables (temperature, pressure, presence of kinetic, thermodynamic inhibitors and anti-agglomerants). This article reviews the recent development of hydrate flow loops for industrial and academic study. Data obtained from experimental hydrate studies in literature can be used to develop predictive models applicable for oil and gas transportation in deep water operations.

Keywords: Hydrate Formation; Temperature; Pressure; Gas; Thermodynamic Inhibitors

1. Introduction

Gas hydrates are ice-like solid compounds in which gas molecules are sheathed in cages and are formed by hydrogen-bonded water (H_2O) molecules and stabilized by Van der Waals forces. Usually, at high pressure and low-temperature conditions, these non-stoichiometric compounds are developed. Methane (CH4), carbon dioxide (CO_2), ethane (C_2H_6), propane (C_3H_8), hydrogen sulphide (H_2S), and butane (i-C_4H_{10}) are among the typical hydrate formers frequently encountered in deep-sea situations. Throughout the extraction of oil and gas, water is often present together with an abundance of hydrocarbons in proximity. Thus, clathrate hydrates are formed within the oil, gas and multiphase flow lines mostly under thermodynamically favourable conditions (low temperature and high pressure) such as the deep-sea conditions.

One of the significant problems in flow assurance is the formation of gas hydrates. Gas hydrate formation leads to the blockage in pipelines, therefore becoming the reason for the loss in hydrocarbon production, transportation and processing facilities. Flow assurance challenges become more significant as oil and gas explorations field development has progressed into deeper water (> 500 m), where longer pipelines in hostile operating environments are prone to gas hydrate formation. Multiphase flow through pipelines contends with many engineering applications besides installations. In petroleum production and processing, chemical processing, problems associated with the concurrent flow of multiple phases through flowlines has been a long-time interest. This interest has risen substantially in recent years due to solicitations to new developments in petroleum production and refining. By transporting multiple phases like gas, oil, and water together from wells in satellite fields to existing processing facilities, it would be more economical for expanding production. The hydrate formation in transmission pipelines, which leads to blockage, is always the main

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issue affecting transmission safety. During production, processing, and gas transmission, there is a high possibility for the plugging of pipelines due to hydrate formation, which poses the major flow assurance challenge.

Many conventional hydrate mitigation methods are adapted over the years. However, many of them are either incompetent or required an enormous amount of chemical solvents occasioning in high operational cost along with the severe environmental impact on operating gas and oil facilities. Besides, the existing inhibitors are still not able to provide an economical solution particularly at high pressure and rapid subcooling conditions. Also, there is no detailed research regarding multiphase systems, which are mostly operating conditions during natural gas production. Likewise, none of the previous investigations dealt with the hydrate phase behaviour modelling of the multiphase mixed gases system. Laboratory flow loops are required to investigate hydrate phase behaviour and optimize hydrate management strategy.

2. Flow loop experiments

Currently, there are several laboratory flow loops fabricated to conduct experiments on hydrate formation and control in gas pipelines. This article reviews the recent development of hydrate flow loops for industrial and academic study. Yongchao et al (2018) conducted a series of experiments about hydrate formation process and pressure drop properties in a spiral flow loop. The spiral flow loop is constructed by Jiangsu Key Laboratory of Oil/gas Storage and Transportation Technology. The loop is 97m long and the internal diameter is 25mm. The design pressure is 8MPa and the design temperature ranges from −5 to 30^{0}C. The gas and liquid can be injected into the loop by a plunger compressor and a magnetic centrifugal pump respectively. Flow parameters, such as pressure, temperature, flow rate, and pressure drop, can be collected by the sensors that are equipped on the loop. The hydrate formation unit is the core component of the hydrate spiral flow loop, and the sensors equipped are the core component of hydrate formation unit. The Schematic diagram of the loop is shown in Figure 1. There were six observation points, which were defined as VA1, VA2, VA3, VA4, VA5, and VA6, respectively. The six observation points and the data collection points in a spiral flow loop are distributed in unequal intervals. The origin of the pipeline is taken as the coordinate origin, and the coordinates of the various observation points are recorded in the data collection system.

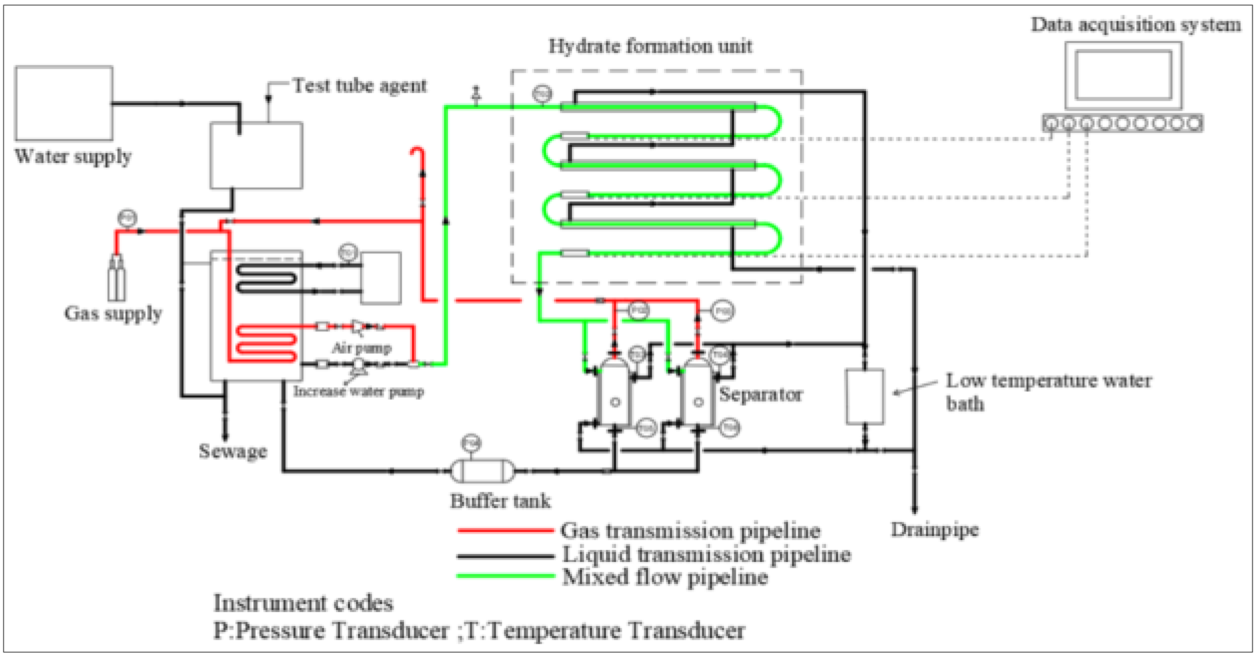

Figure 1 Schematic diagram of the hydrate spiral flow loop (Yongchao et al 2018)

Mauricio et al (2012) investigated hydrate behaviour in gas pipelines using the Hytra loop, a one-inch flow loop operating in a gas dominated flow regime at high pressure and low temperature conditions. In these experiments, gas from the city network was circulated at high velocity through the test section of the loop and deionised water was injected at constant flow rate to simulate steady-state production of natural gas with low water content. Temperatures and pressures in the loop were varied in a range of 6 to 18°C and 6895KPa to 10342KPa respectively, to produce a wide range of subcoolings. In this flow loop the gas volume fraction is higher than 90% and the gas and liquid phases are circulated independently using a high-pressure pump for the liquid phase and a reciprocating compressor for the gas phase. It is a single-pass flow loop of a small size, one inch (0.025m) outer diameter, 40m long, which allows for high superficial gas velocities with a relatively small capacity compressor. A simplified layout of the rig is presented in Figure 2.

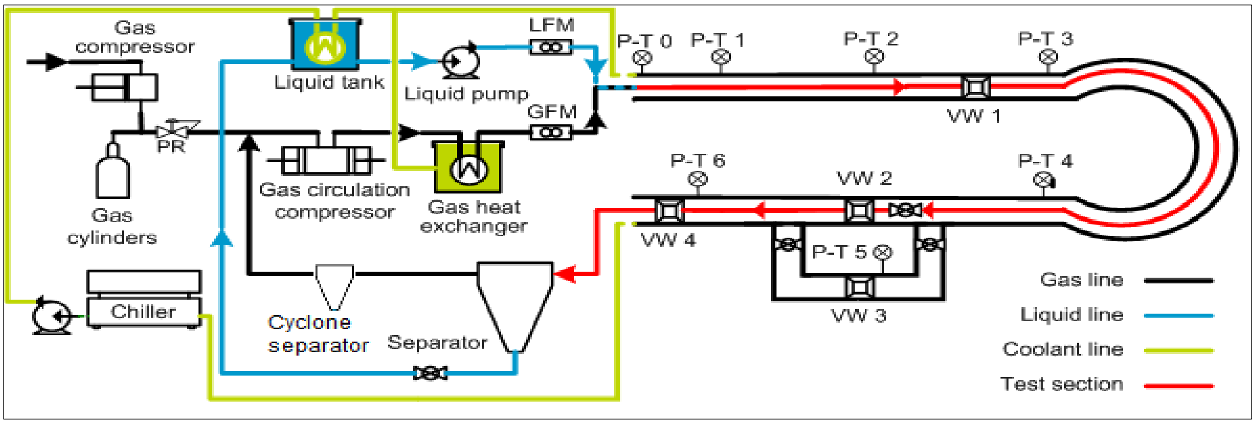

Figure 2 Simplified layout of the Hytra Loop (Mauricio et al 2012)

Shunsuke et al (2020) conducted experiments in a flow loop to obtain data for hydrate formation rate, an interfacial area between gas and water, and the viscosity of hydrate slurry. The flow loop is about 16.7m long with 10mm diameter and consists of circulation pump, flow meter, temperature and pressure gauges, differential pressure (dP) gauges, an in-line camera and ports for gas or water injection. Figure 3 illustrates a schematic of the flow loop. The in-line video camera can shoot a multiphase flow of gas, water and hydrate in the flow loop.

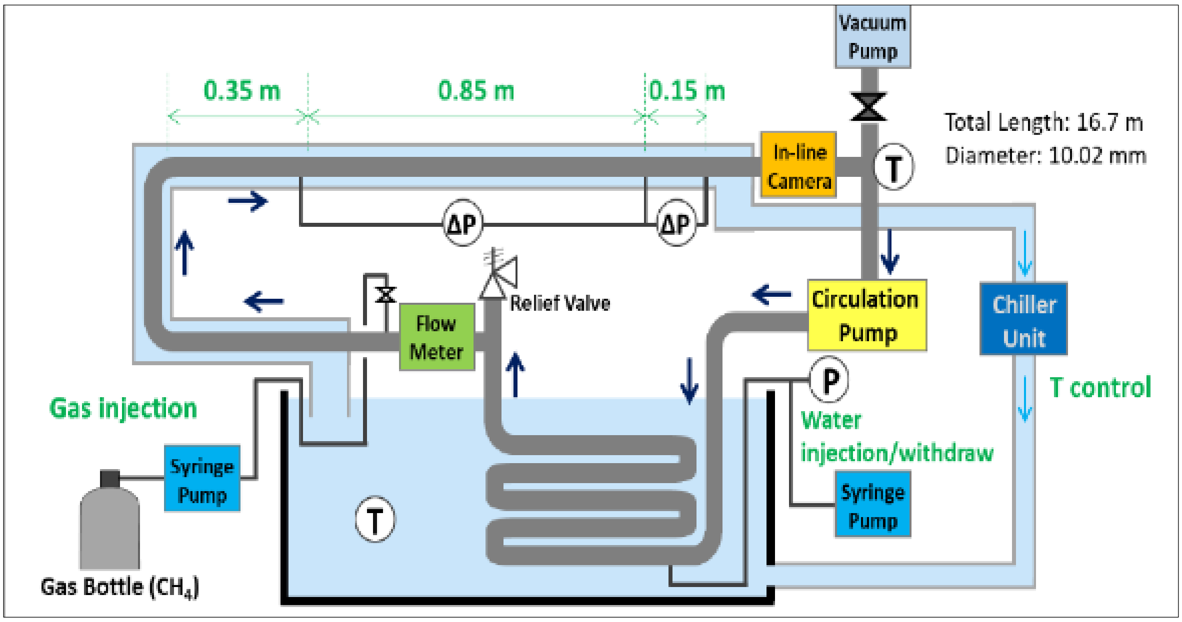

Figure 3 Schematic of the flow loop (Shunsuke et al 2020)

Jai et al (2020) investigated the phase behaviour of gas hydrate formation in gas dominant multiphase pipelines containing mixed gas with high CO_2 crude oil, and deionized water. The experimental conditions are in the pressure range of 3-7MPa with water cut as 20% of the volume. Figure 4 represents the schematic diagram of the experimental setup used in this work. The apparatus engaged for determining the phase behaviour of gas hydrates in pure and multiphase systems work is equipped with a high-pressure reactor made from stainless-steel with a capacity of 650 ml. The reactor can be operated in the temperature range of – 20 to 40 °C and a pressure of 20 MPa. Pressure and temperature sensors which are connected to a data logging system are installed in the reactor to measure pressure and temperature changes for every fixed interval.

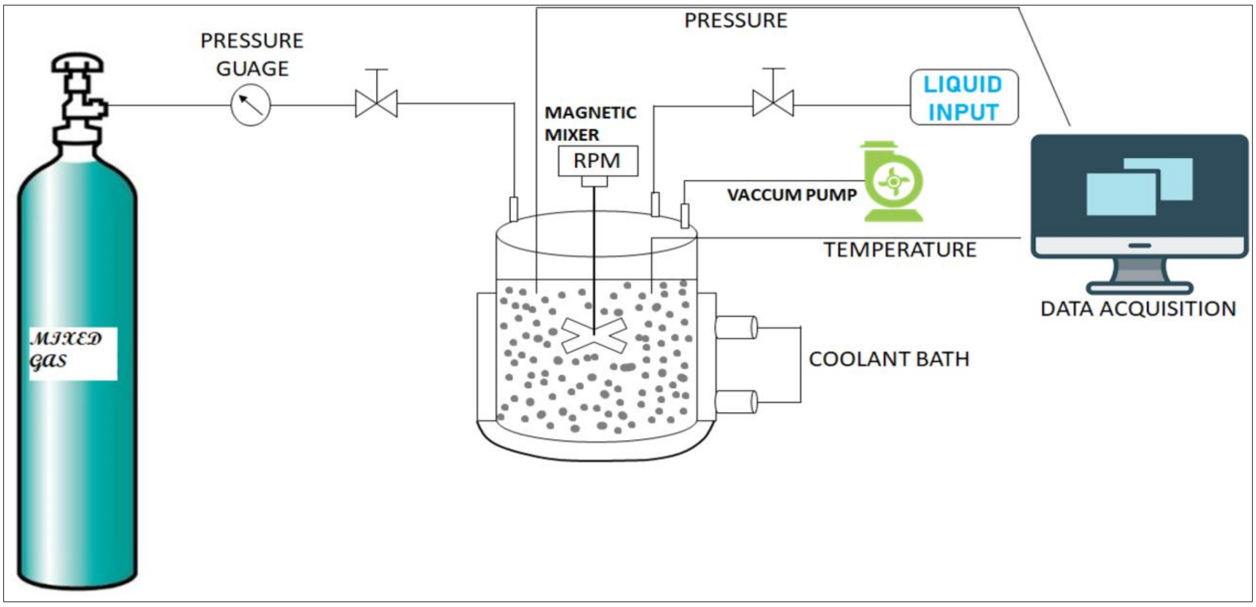

Figure 4 Schematic representation of the experimental setup (Jai et al 2020)

Trung et al (2017) conducted experimental flow loop study on methane hydrate formation and agglomeration in high water cut emulsion systems. The experiments were performed in the Archimede flow loop at Ecole des Mines de Saint Etienne. A schematic of the flow loop is shown in Fig. 5. The flow loop is constructed with the following conditions: maximum pressure is 100 bar, the temperature is controlled between 0°C and ambient temperature, the flow rate is between 0 and 500L/h. The flow loop is designed with 30m of horizontal pipe with 1cm diameter, a riser and a descending pipe (both of them have a height of 12m and a diameter of 1.5cm), a gas injection system, and one sapphire window. The total liquid volume is 11.5L and gas volume is 15L. In this experimental apparatus, some probes are equipped to monitor the gas hydrate formation and agglomeration, including: the sensors of temperature (thermocouples) and pressure; the probes of pressure drop (differential pressure transducer) for evaluating the viscosity afterwards, and identifying the plugging troubles; the Focused Beam Reflectance Measurement (FBRM) probe for detecting particle size distribution of emulsion droplets and hydrates (via their chord lengths); the Particle Video Microscope (PVM) probe to observe the emulsion, the gas hydrate formation and agglomeration phenomena; the Attenuated Total Reflection (ATR) probe for determining the concentration of methane and phase inversion of emulsion in fluid flow. Also, the mass flow meter is installed for measuring the flow rate and density. A pump Moineau and/or a gas-lift system are used to circulate the fluids in the flow loop. In this experimental set-up, gas-lift and ballast system were used. The cooling systems control the temperature in the flow loop at (4-5^{0}C) by using the water/ethanol circulation jacket attached to the flow loop. The gas compensation system (pressure controller) keeps the total pressure at a constant value (75bar).

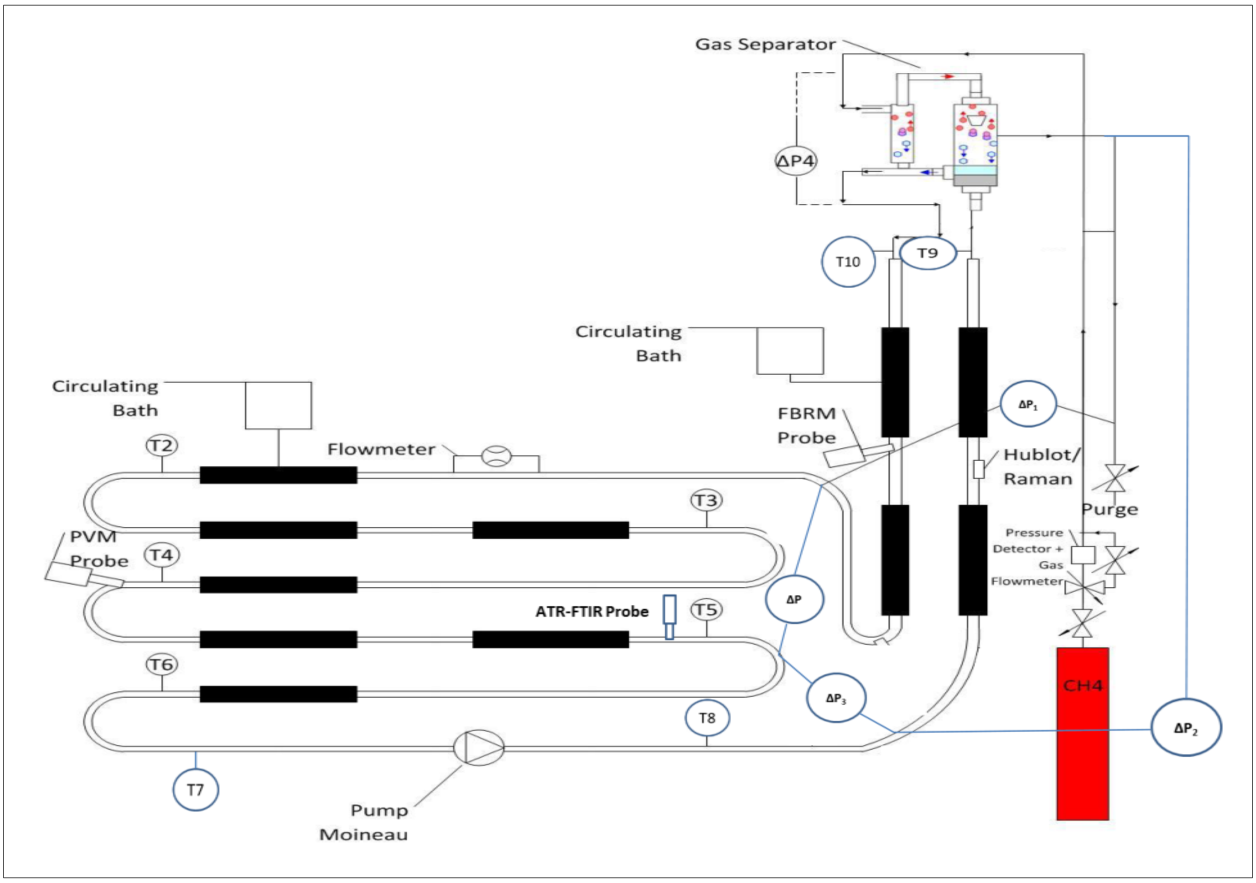

Figure 5 Schematic of Archimede experimental flow loop: simplified with ballast system and details with pump Moineau (Trung et al 2017)

Delroisse et al (2020) experimentally evaluated the performance of a new biodegradable AA-LDHI in cyclopentane hydrate and CH/CH gas hydrate systems. The experiments were conducted in Total Flow Loop facility. The unit mainly consists of a pipe (1-inch diameter and 35.6m total length), Moineau type pump and storage tank. The shape of the loop is a double vertical ring of 32m linked to the inlet and outlet of the pump. The whole pipe is jacketed to control its temperature via the circulation of a cooling/heating fluid inside the jacket. It is designed to circulate fluids at a pressure as high as 165 bar and a temperature ranging from 40 to -10°C. The main parameters recorded are: density, flow mass, pressure drops, temperature changes and gas flow. In the experiment conducted, a real Middle East condensate was used together with a CH_4/C_3H_8 (98/2 mol%) hydrate-forming gas. Results obtained with this flow loop have been shown to be well correlated with other testing equipment. A simplified scheme of the hydrate loop is shown in Figure 6.

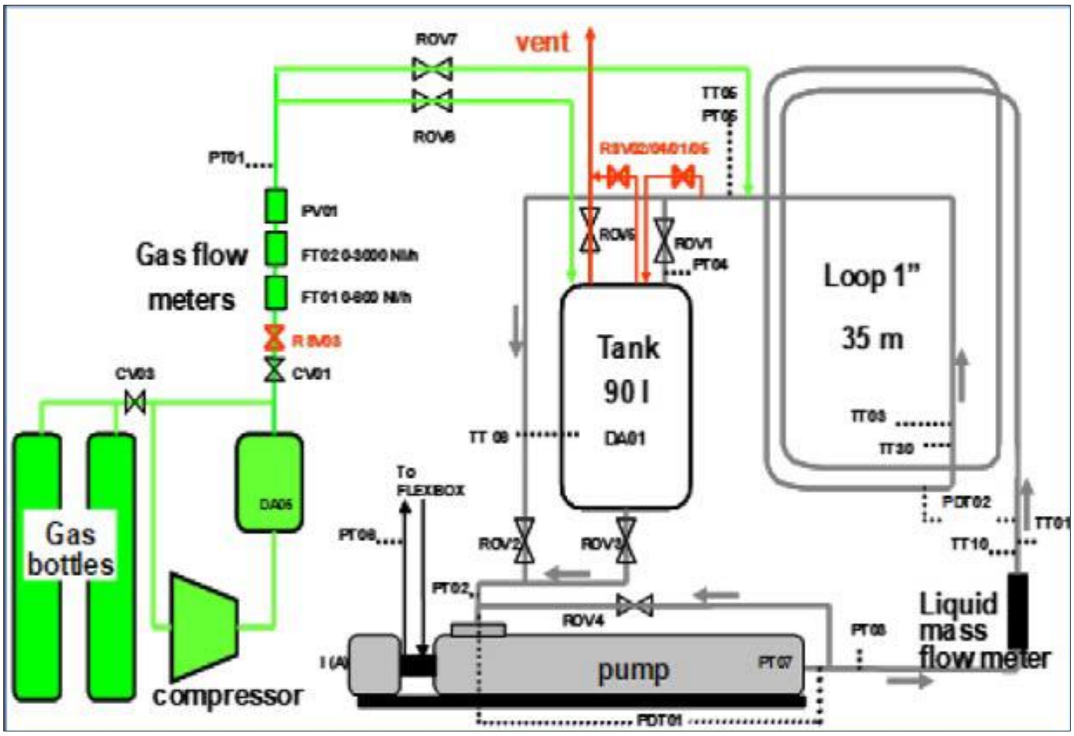

Figure 6 Simplified flow scheme of the 165bar hydrate loop (Delroisse et al 2020)

Cuiping et al (2017) experimentally analysed the flow characteristics of methane hydrate slurries in low flow rates. All experiments were performed in a flow loop (Figure 7). The flow loop has three sections: gas injection section, liquid injection section and the main loop. These sections are made of 316 stainless steels. The main loop was 51.85m long, with an internal pipe diameter of 2.54cm, including a horizontal part of 42.35m and a connection part. There were three transparent visual windows, two of them located at the middle of the horizontal straight pipe and the other at the vertical section. One of the visual windows was equipped with a digital camera. The maximum designed pressure that the flow loop could be pressurized with was 15MPa. The temperature of the flow loop was controlled in the range from -20 to 50^{0}C with the help of a refrigerating unit. Eight thermocouples (±0.15^{0}C) were used to measure the temperature of the fluid in the different sections of the flow loop. The temperature sensing elements of four of them were located at one-third of the pipe cross section and the others at two-thirds of the cross section. Eight pressure sensors (±0.25% full scale, FS) and a differential pressure transducer (±0.065% FS) were used to measure the gas pressure in the loop and differential pressure across the inlet and outlet of the horizontal pipe. The flow rate was measured by a C7B5D0B1AD1E1Z mass flow meter (Xian Dongfeng Machinery and Electronic Co., Ltd. Xi'an, China) with an accuracy of ±0.065% FS. A 3DXP-2.2/10-30-T7 piston pump (Chongqing Pump Industry Co., Ltd., Chongqing, China, this pump was custom-designed to minimize shear effect on hydrate slurries and influence of operation mode) was used to recycle the fluid with a maximum reciprocating time of 338min^{-1}. The data of temperature, pressure, flow rate, and differential pressure throughout the experiments were collected using a data-acquisition system at an interval of 10s.

Douglas et al (2005) experimentally studied formation of hydrate obstructions in pipelines using ExxonMobil flow loop in Houston. They investigated hydrate particle development and slurry flow in the loop equipped with Focused beam reflectance method (FBRM). The flow loop (Figure 8) is a triple pass loop which consists of a 9.7cm inner diameter pipe and 93.0m long. The loop is driven by a sliding vane pump and is enclosed in an environmentally controlled room, except for a short extension containing a dipped section. View ports are located just before and at the bottom of the dip section. An FBRM particle size analyzer was installed in the up-flow portion of the dip section. This location ensured investigation of the cross-section of all fluids in the loop. As gas was consumed by hydrate formation, gas pressure in the loop was kept constant through use of a gas accumulator.

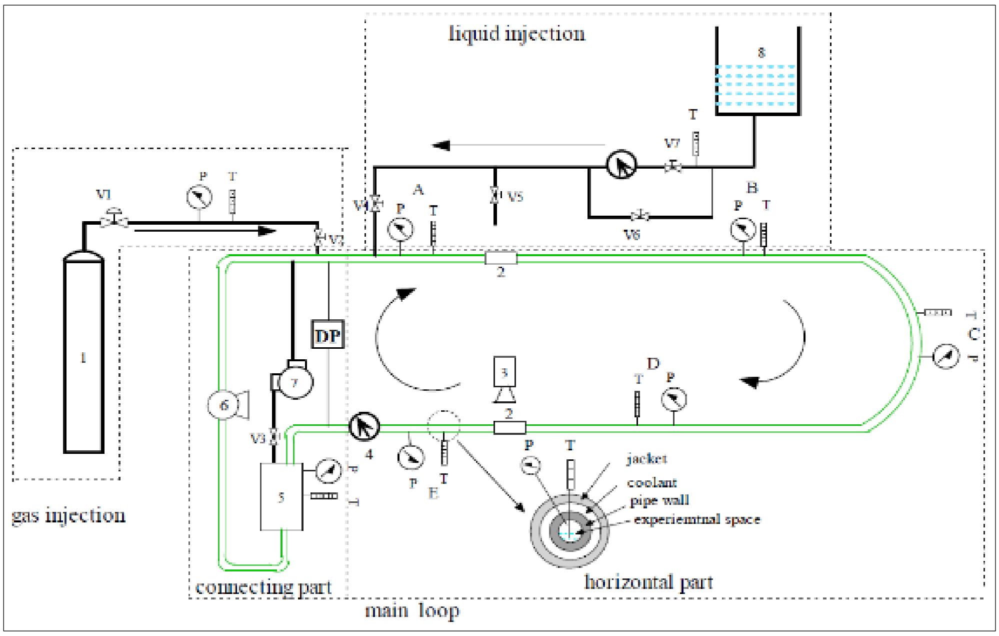

Figure 7 Schematic of the hydrate flow loop system (Cuiping et al 2017)

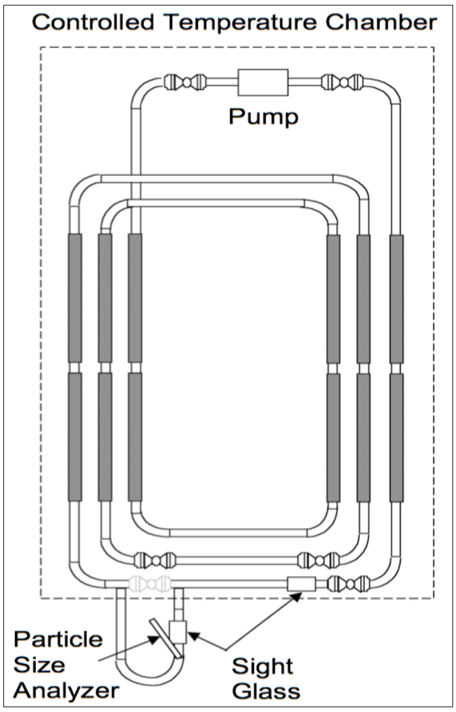

Figure 8 Schematic diagram of ExxonMobil flow loop (Douglas et al 2005)

Erlend et al (2016) studied gas hydrate formation and deposition mechanisms in hydrocarbon systems. The experiments were performed at Colorado School of Mines in a high-pressure cylindrical rocking cell with an internal diameter of 50.8 mm, internal length of 274 mm, and a total pressurized volume of 578 ml (Figure 9). It is installed horizontally and can be oscillated by a motor between positive and negative pipe inclinations, which results in mixing and gravity driven flow inside the rocking cell. The rocking cell is submerged in a water bath with transparent walls. The water is circulated through a chiller in order to maintain a constant temperature in the bath throughout an experiment. The upper surface in the rocking cell has a cooling chamber connected to a separate chiller that can be set to a different temperature than the bath temperature to induce local formation of hydrate deposits in the upper part of the cell. The rocking cell is connected by a flexible hose to the gas filling and draining system, which consist of the gas supply line connected to a gas cylinder with the gas mixture used in the experiment, a safety pressure release valve, and the gas vent line. The pressure transducer measuring the total pressure of the system is installed where the flexible hose is connected to the gas filling and draining system. Temperatures are measured by thermocouples located in the following three positions in the rocking cell: at the upper pipe wall surface, in the gas phase close to the upper wall, and in the liquid phase close to the bottom. The development of flow characteristics, hydrate formation and deposition are visually monitored and documented by means of video recording through the windows (made of polycarbonate) measuring 145 × 34 mm on both side walls of the rocking cell.

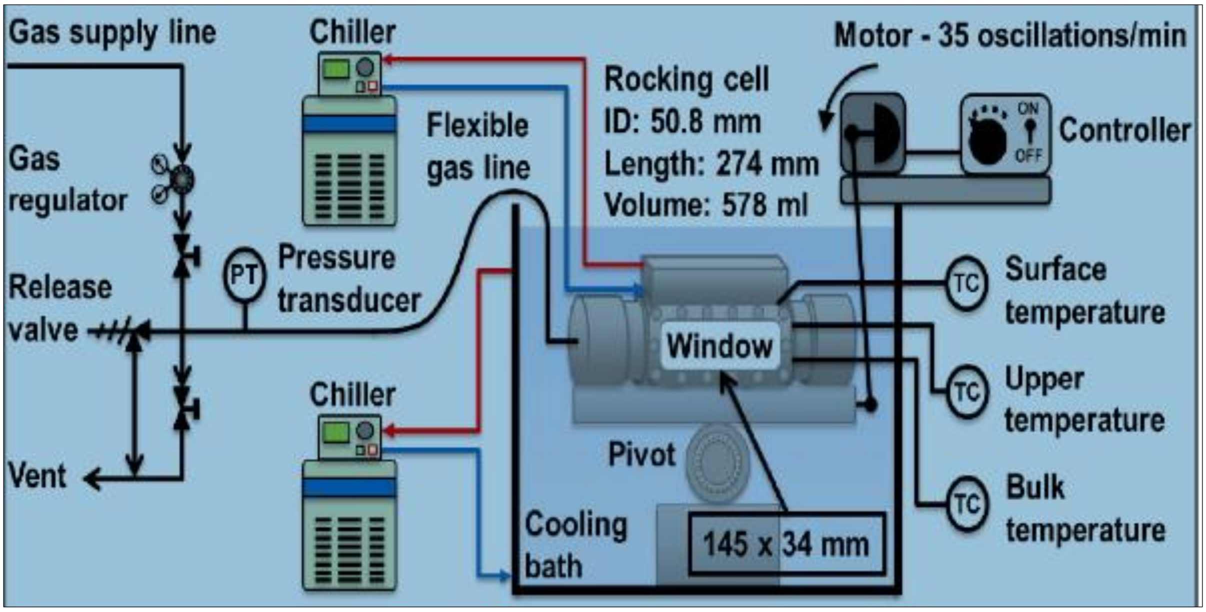

Figure 9 Schematic of the experimental setup for the rocking cell system for hydrate experiments (Erlend et al 2016)

Guang Chun et al (2017) investigated hydrate plugging in natural gas+diesel oil+water systems using a high-pressure flow loop. A high-pressure flow loop, which is shown in Figure 10, was newly designed and constructed by the Shandong Key Laboratory of Oil-Gas Storage and Transportation Safety in China University of Petroleum (East China). The main body of the flow loop is composed of several stainless-steel double pipes with an inner diameter of 26mm and a total length of 24 m. Together with a 21litre mixing tank and the high-pressure hoses used for connecting, the whole volume of the flow loop system is approximately 40 L. The design pressure of the system is 15 MPa and the design temperature ranges from 253.15 to 373.15 K. In order to observe the plugging process conveniently and directly, a circular visual window (Φ65 mm) and a rectangle visual window were equipped on the flow loop. In the present work, hydrate morphological evolvements were all observed through the circular visual window due to the vision-field limitations of the rectangle visual window. The system temperature is controlled by two water chilling units and a magnetic centrifugal pump (circulating pump rather than booster pump) with a rated flow rate of 3000 kg h^{-1} was applied to circulate the mixture in the flow loop. In addition, flow parameters such as temperature, pressure, flow rate, and pressure drop can be collected by different sensors installed on the flow loop and then recorded by a PC-based data acquisition system during the experiments. The schematic diagram of the flow loop system is shown in Figure 10.

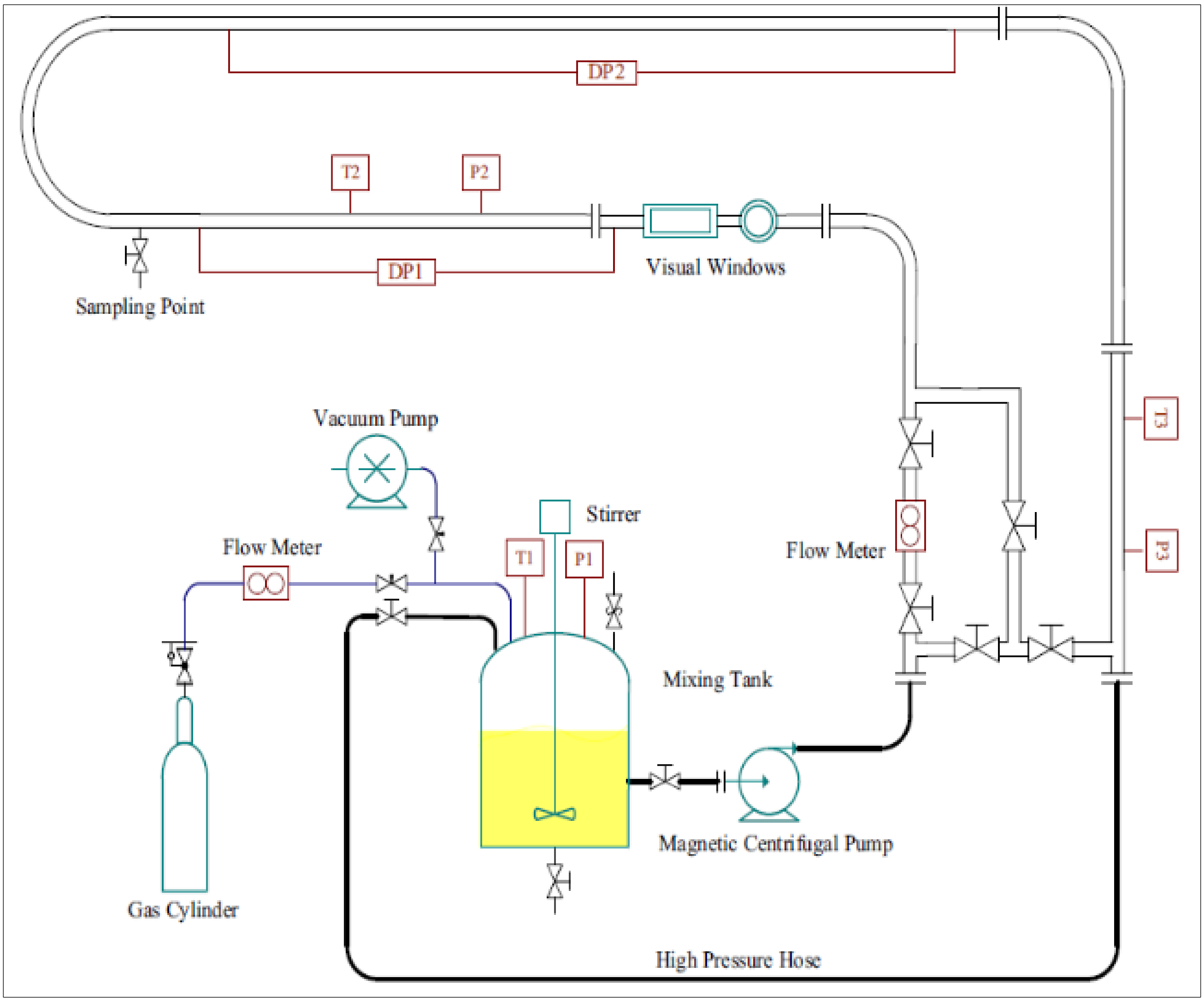

Figure 10 Schematic diagram of the high-pressure flow loop (GuangChun et al 2017)

Peytavy et al (2007) explained laboratory tests done in a hydrate loop (Figure 11) to model operating parameters in offshore environment. The flow loop is made up of 1inch, 316 stainless steel pipe-pipe that is 35.6cm long. The equipment also contained screw pump and storage system. The screw pump is used to circulate gas saturated fluid in the envelope. The screw pump is operated to ensure flow rate between 0 to 6m^3/h. The speed of the liquid is maintained at 3m/s. The flow loop is designed to operate at a maximum pressure 165 bar.

The density and mass flow rate are measured and display in the mass flow meter. The differential pressure readings are measured and displayed in the pressure differential cells. The gas in the system is compressed to 200 bar with the compressor. The system ensures constant temperature by regulating the pressure with a gas make-up system. The system is also equipped with a computerize data gathering system to measure and record time variation. The reading obtained in this experiment are pressure differences. The quantity of hydrate formation is determined by calculating the total gas rate. The drawback of this laboratory equipment is the crushing of hydrate crystals by the screw pump. The inhibition efficiency of low dose hydrate inhibitors cannot be accurately evaluated (Peytavy et al 2007).

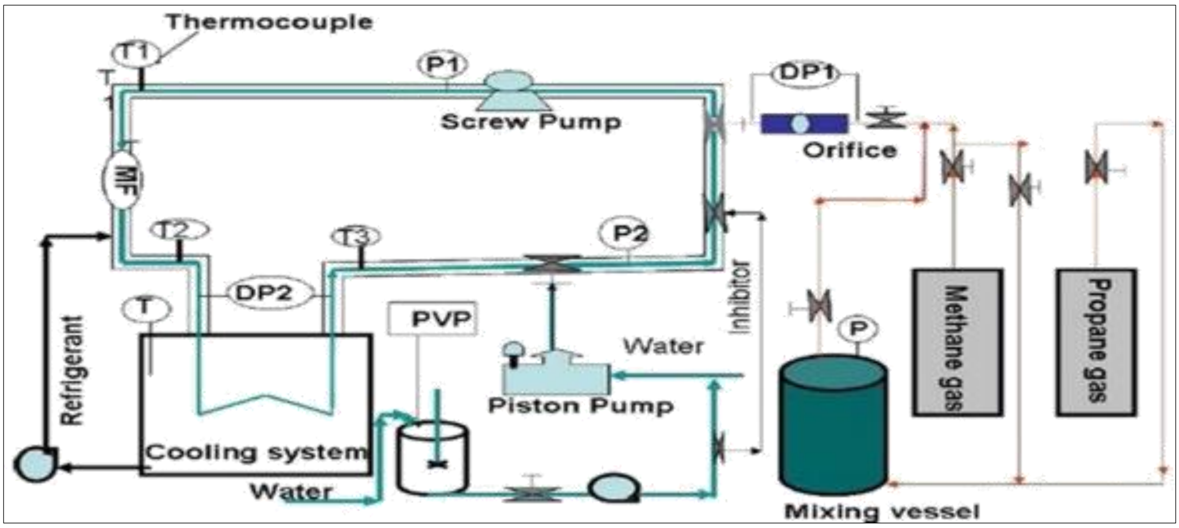

Figure 11 Pipe flow diagram of 35.6m hydrate loop (Peytavy et al 2007)

Talaghat (2011) studied the induction time for gas hydrate formation in the presence of low dose hydrate inhibitors. These experiments were performed in a mini flow loop system (Figure 12), designed to mimic deep offshore environment. 316 stainless steel was used to design the flow loop. The length of the laboratory flow loop is 12meters with inner diameter of 10.6mm. The system is designed to operate at a pressure rate of 10Mpa. Water and inhibitors are injected into the flow loop through a piston pump device. A screw pump of variable rate 0.8m^3/hr is used to circulate the fluid. The system temperature is controlled by distribution pump. The distribution pump circulates a mixture of water and ethylene glycol through a 23mm internal diameter pipe that covers 10.6mm 316 stainless steel loop. The flow behavior is measured by a flow meter. The pressure drop is measured by a transmitter. The temperature readings were measured by sensors. Two additional sensors were used for pressure readings. The flow loop is designed to operate a constant pressure system (Talaghat 2011).

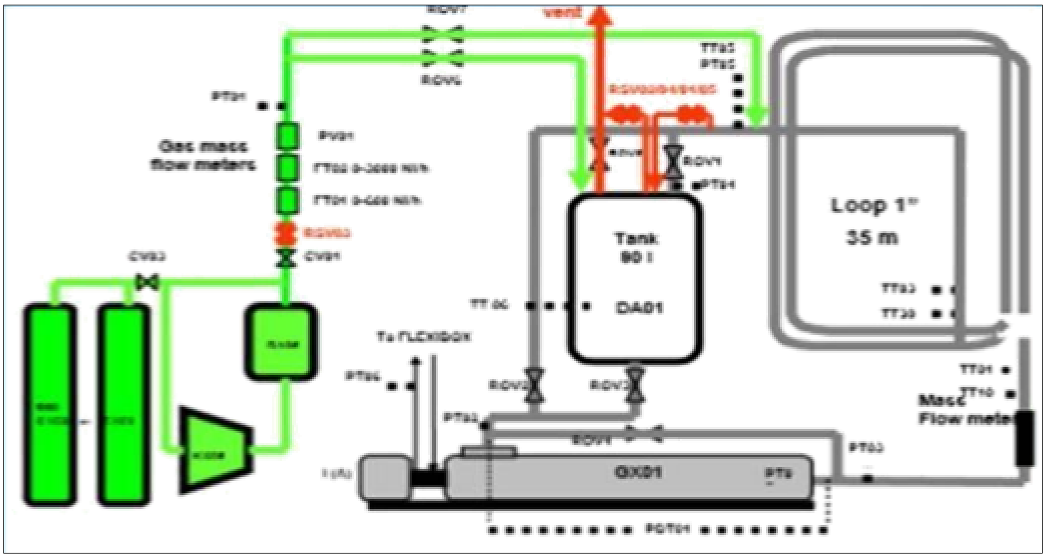

Figure 12 Shiraz University of Technology Flow Mini-Loop Apparatus (Talaghat 2011)

Vijayamohan et al (2014) experimentally studied hydrate characteristics in partially dispersed flow at the University of Tulsa. The flow loop (Figure 13) used for these experiments comprises of 2.9inch internal diameter pipe and length 162 feet. The fluid circulation in the flow loop was achieved with a twin-screw pump. The temperature is regulated between 80^{0}F to 32^{0}F by coolant fluid in the jargeted loop. Transducers were installed across the loop system to measure the pressure drop and differential. Thermocouples were installed across the loop to measure the temperature. The added gas mass is measured with mass flow meter. The internal occurrence in the flow loop is monitored through four viewports. Hydrate formation and dissociation was observed through the viewports and pressure differential in the flow loop (Vijayamohan et al 2014.

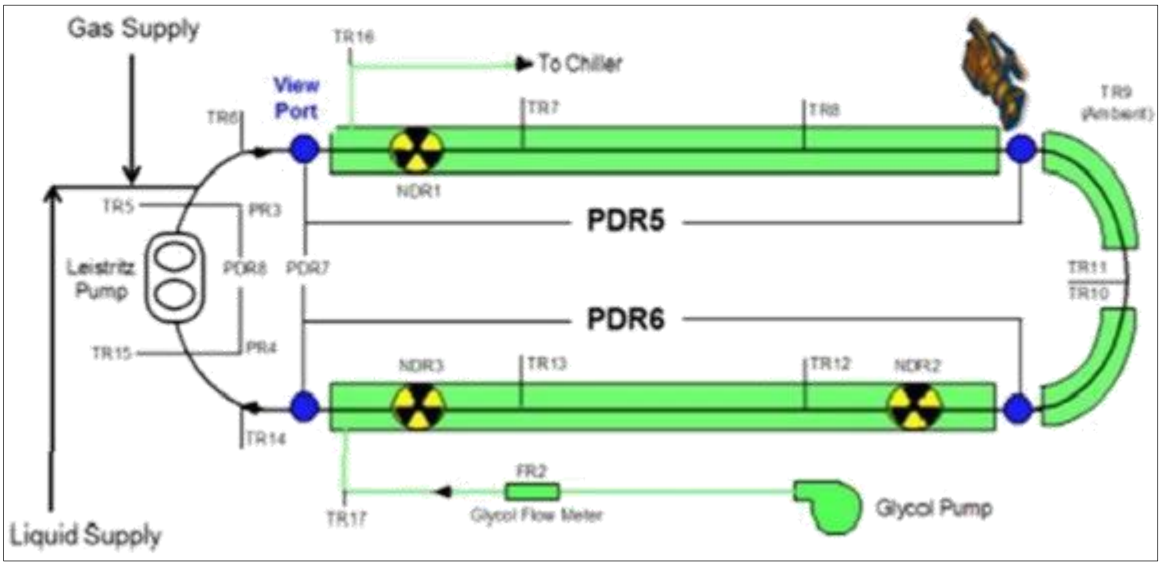

Figure 13 Schematic of University of Tulsa flow loop (Vijayamohan et al 2014)

Lv et al (2014) carried out laboratory tests on hydrate occurrence in a flow loop (Figure 14). The equipment is 30m long pipe in pipe. The inner pipe has internal diameter of 2.54cm that is covered with a pipe of internal diameter 5.08cm. The space in between the sepipes is filled with a mixture of water and glycol to control the temperatures to as low as minus 20^{0}C. It is a constant pressure system with a makeup gas tank. View ports are installed at two locations in the test sections to closely observe the behavior of the hydrate occurrence. The flow rate and liquid mixture density are monitored and measured by an installed flow water. The mean density of the multiphase fluid is measured with an installed gamma ray densitometer. The formation of bubbles, droplets and particulars are closely monitored with an installed focused beam reflectance measurement (FBRM) probe. The system temperature is measured and recorded by installed couples. Sensors are installed across the facility to measure the pressure differential. Magnetic pump is installed to circulate fluid across the loop (Lv et al 2014).

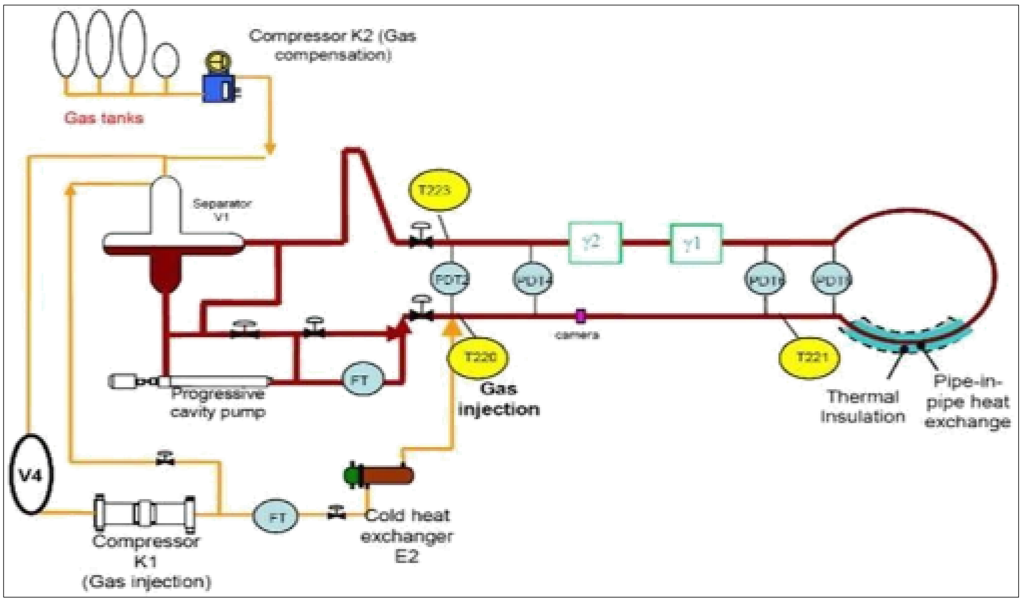

Figure 14 Schematics of Petroleum Flow Loop in China University (Lv et al 2014)

Sinquin et al (2015) conducted multiphase experiments in the lyre flow loop (Figure 15). The facility is 140m of length and 2inch internal diameter. The loop double jacketed to ensure flow of colorific fluid in opposite directions. Energy losses are mitigated by insulation of the line. The flow loop is operated within the temperature range of O^0 to 50^0C. The operated pressure range is between 1bar to 100bar. Positive displacement pump is used to move the fluid across the loop. The positive displacement pump is operated at speed of $20m^3/h$. A compressor is installed to function at a flow rate of $200Nm^3/h$. Tests were conducted to evaluate the inhibition efficiency of low dose hydrate inhibitors in dissociating hydrate nucleation. The flow loop is designed with a gas makeup tank of size $12m^3$. The facility has a computer system that operates at a frequency of 0.25 hertz for monitoring of hydrate formation and dissociation processes (Sinquin et al 2015).

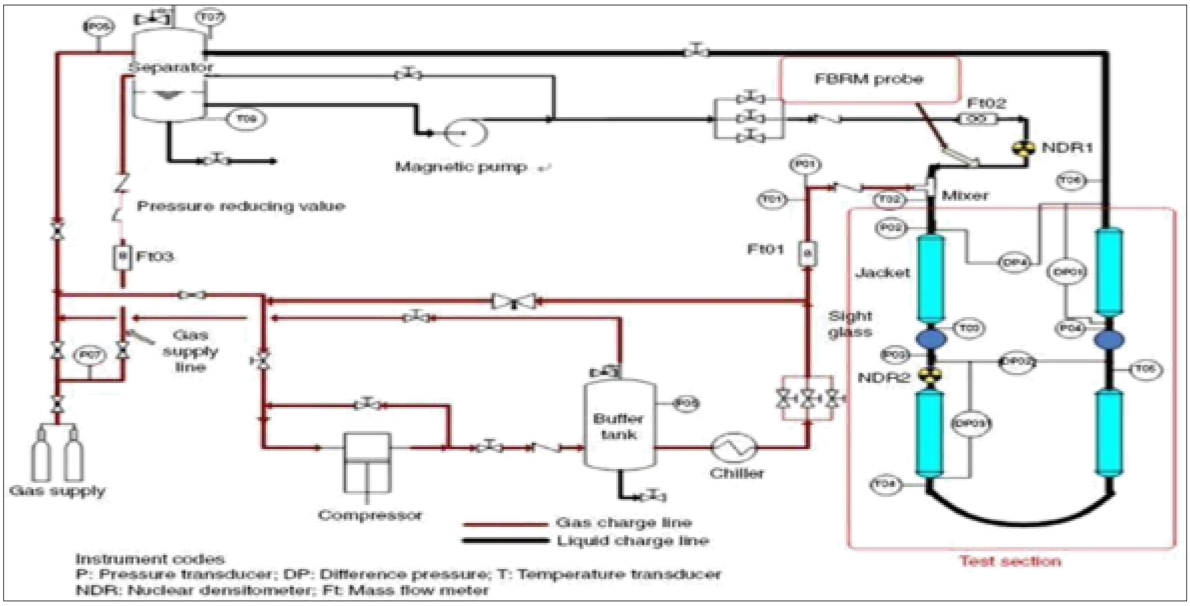

Figure 15 Schematic of the lyre loop main sensors (Sinquin et al 2015)

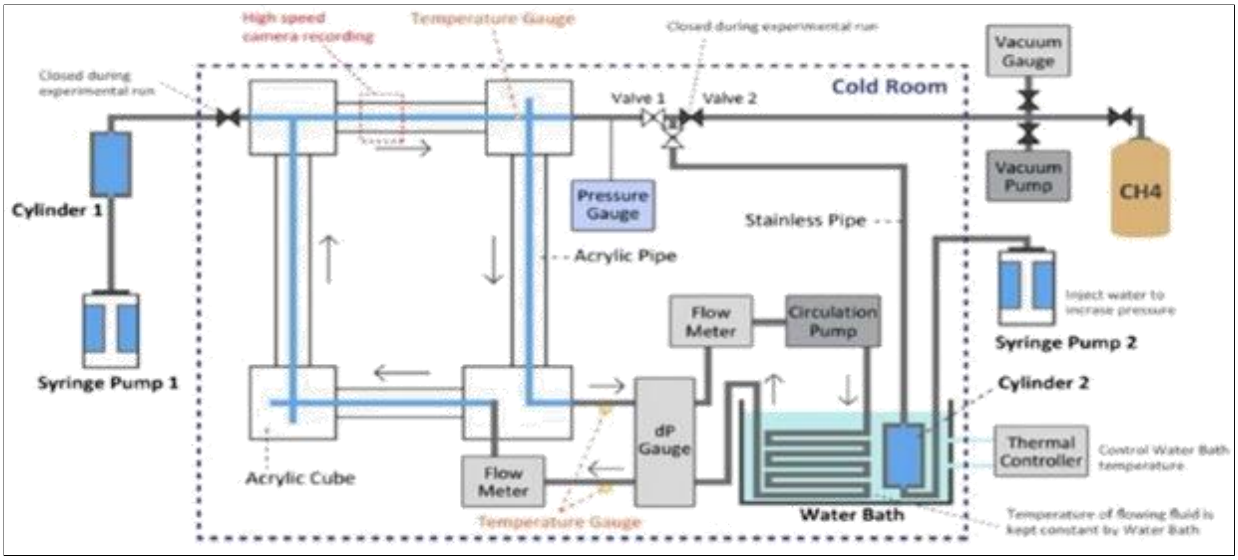

Figure 16 Schematic of JOGMEC and OPT Flow Loop (Sakurai et al 2014)

Sakurai etal (2014) explained hydrate loop modeling that simulate offshore environment. The flow loop (Figure 16) was designed and fabricated by Japan Oil, Gas and Metal National Corporation (JOGMEC) as well as Oil Field Production Technologies (OPT). The loop is 20m long and has two sections. The first section is 6m long and equipped with acrylic optical material with an internal diameter of 8mm. Flow images can be captured in both vertical and horizontal directions along this section. The second section is made up of stainless-steel tube of length 14m and internal diameter of 8mm. The flow loop contains variable speed gear pump flow calculations. It also contains flow meter for measuring the density and mass flow rate. The hydrate loop contains data categorization system that records the flow meter and gauges reading every six second. The system temperature is maintained at a constant value by bath water. Syringe is used to control the system pressure. High speed cameras are installed to capture flow processes. The fabricated flow loop is installed in a cold room (Sakurai et al 2014).

Callum (2020) experimentally analyzed gas hydrate formation and dissociation in a laboratory flow loop. The experiments were performed to analyze the influence of nitrogen and carbon dioxide in gas hydrate dissociation. The flow loop pipe is 0.25 inch in diameter. The coolant used in the system is liquid nitrogen to obtain system temperature of -160^{0}C. The loop pressure is design to operate up to 500 bar. The length of the loop is 74cm. The system is built with insulated materials that reduces heat transfer to/from the environment. The schematic diagram is given in Figure 17. The loop is designed to have pressure and temperature sensors. Values are installed to control the fluid flow into the loop. Magnetic actuator is used to circulate fluid in the system (Callum 2020).

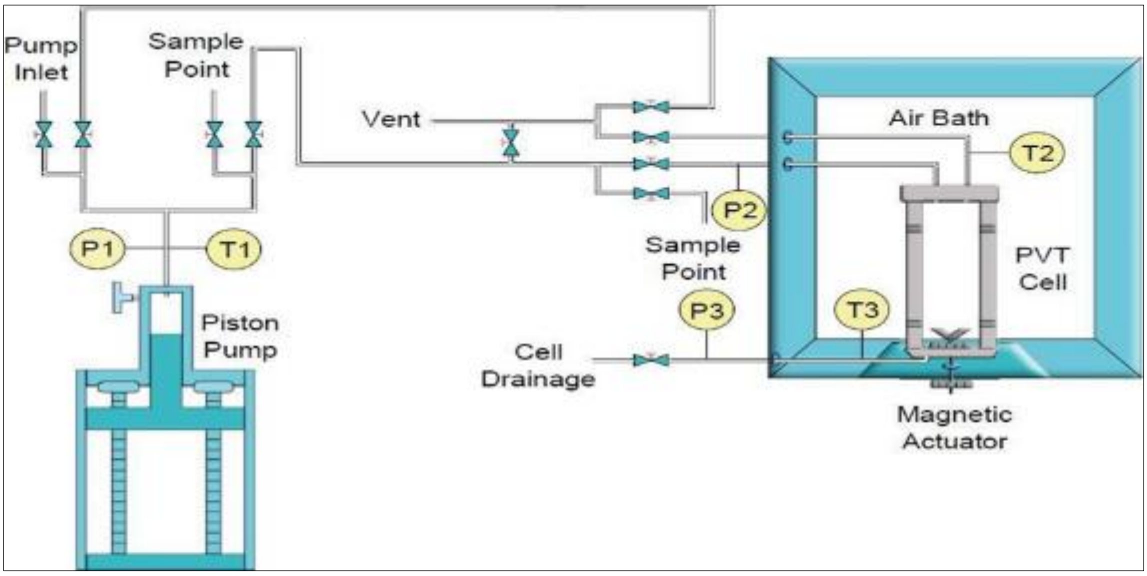

Figure 17 Schematic diagram of test equipment (Callum 2020)

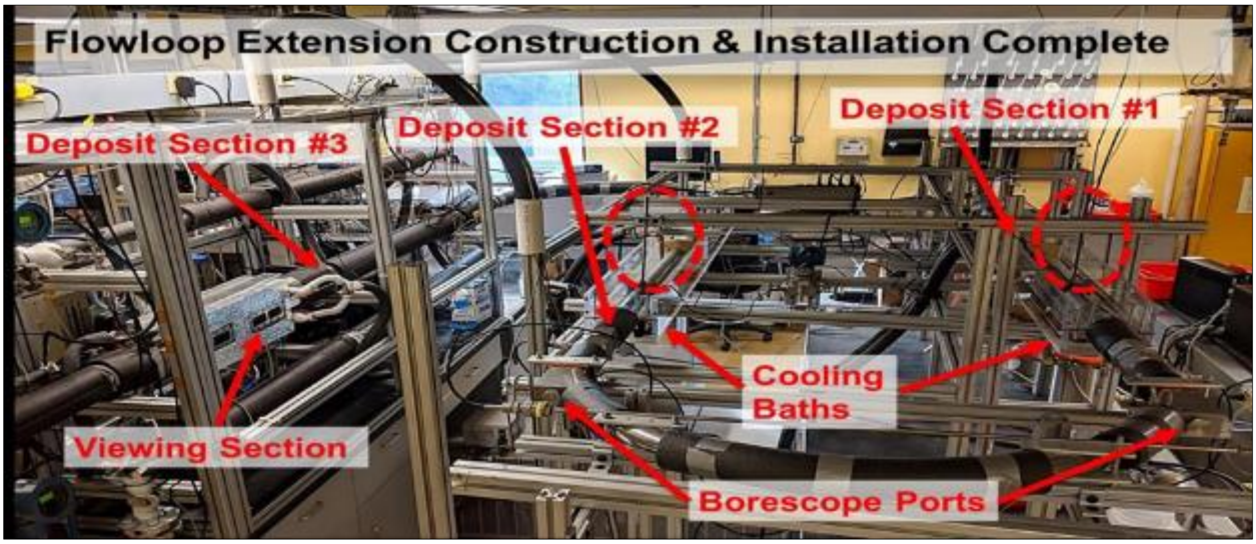

Figure 18 Pictorial view of hydrate deposition loop (Koh et al 2021)

Koh et al (2021) experimentally investigated the effect of coating equipment on hydrate formation in laboratory test loop that mimics deep water operations. The flow loop is 225 inches long and has outer diameter of 2 inches. The test loop contained gas and water storage vessels. It has borescope ports and view sections to study the fluid condition inside the pipe. It has valves, pumps, temperature and pressure sensors to control and monitor the flow conditions. It is also equipped with computer data system that displays the flow loop information during experiment. The schematic and pictorial view of the laboratory flow loop are shown in Figure 18.

Wei et al (2020) studied the influence of kinetic reaction in methane and propane formation. The laboratory equipment was designed to function as a constant volume system (i.e. without a make-up tank). The experimental equipment is shown in Figure 19. The test equipment is equipped with temperature and pressure sensors. The differential pressure is measured and displayed in the pressure transmitter. The system is kept cool with a coolant circulated from the refrigerating unit. The gas tank supplies a mixture of methane and propane gases into the test equipment. Computer system was connected to the test equipment to monitor and record data of the flow condition.

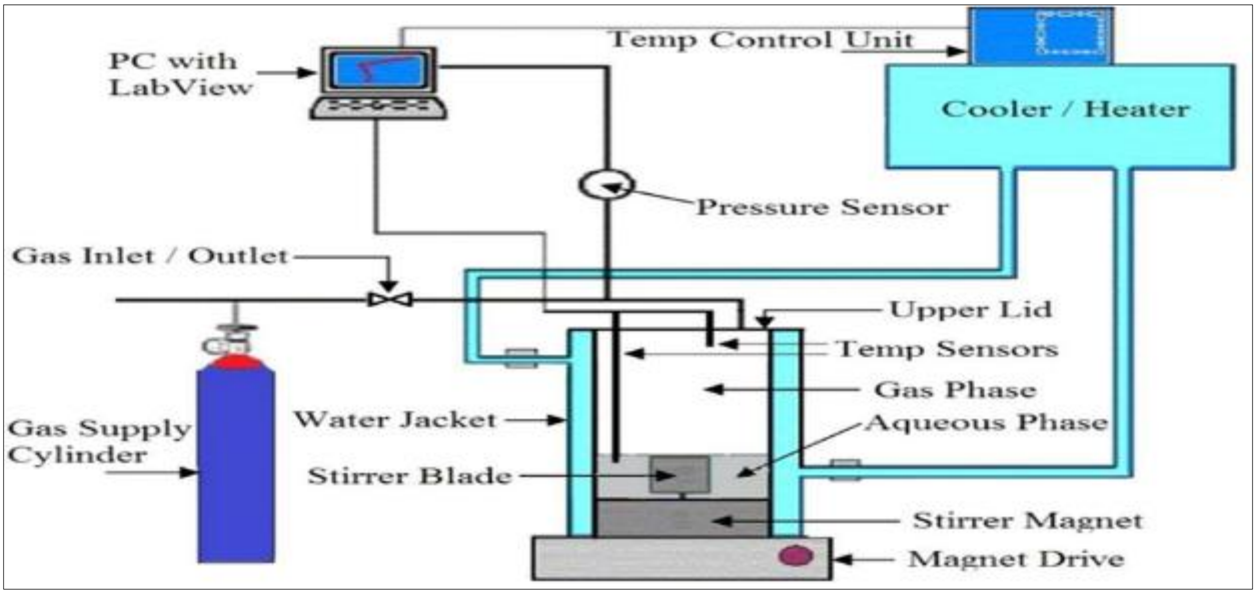

Figure 19 Test setup used in gas-hydrate studies (Wei et al 2020)

Vinicius et al (2022) used acoustic emission technique to investigate gas hydrate process in multiphase flow system. A high pressure Archimede flow loop was used to monitor hydrate formation and analyze the multiphase particle data. The experimental flow loop is illustrated in Figure 2.44. The total length of the Archimede flow loop is 56meters. At hydrate condition, the fluid is circulated and monitored. The flow loop comprises of gas liquid vessels. Gas is injected manually or automatically with flow meter. The pipeline is in three sections. The first section is vertically downward, 9.5m long and diameter of 15.7mm. The second section is incline 3.6^0 downward with length of 36m and diameter of 10.2mm. The third section is vertically upward with length of 10.5m.

Moineau pump is used for fluid circulation. The test loop has ten (10) temperature probes, two (2) pressure probes, four (4) pressure differential probes, gas flow meter and coriolis device that reads the flow rate and density of the fluid that circulates in the loop. In the vertically downward section, Focus Beam Reflectance Measurement (FBRM) is installed to monitor the morphological pattern of the hydrate flow. In the second section (i.e. slightly inclined section), Particle Vision and Measurement (PVM) is installed to determine the flow distribution of the fluid. The Archimede flow loop is equipped with Acoustic emission sensors that has high speed camera and permittivity probe. Figure 20 illustrates the Acoustic emission probe which displays system change transient waves.

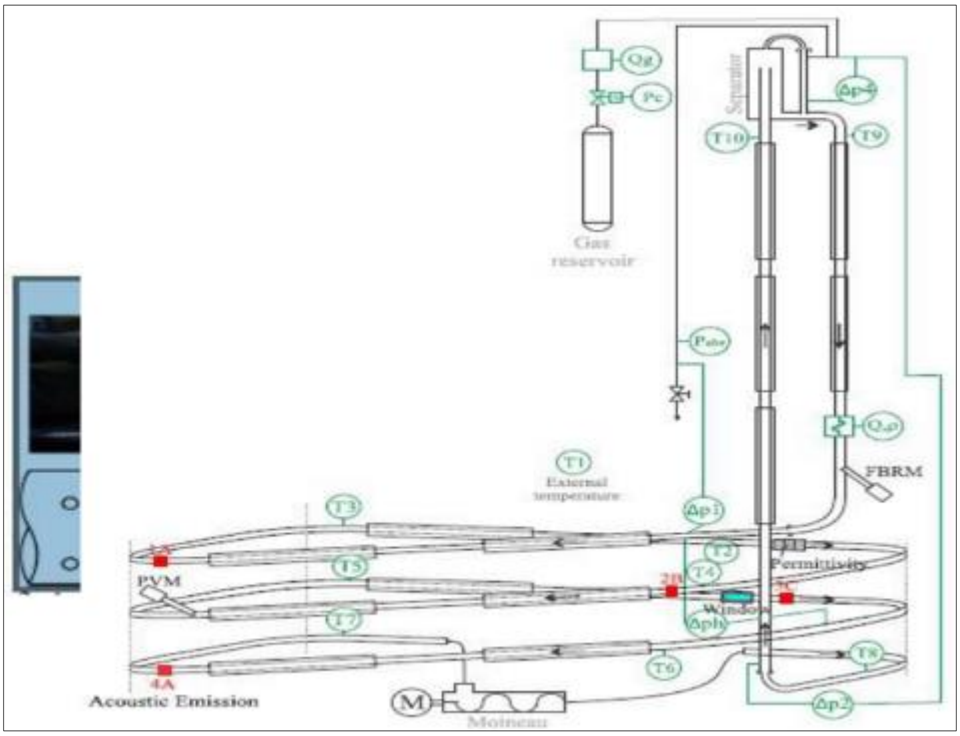

Figure 20 Acoustic emission sensor installed in the Archimede flow loop Vinicius et al (2022)

Hao (2020) simulated hydrate growth and control in multiphase flow system. Figure 2.45 illustrate the high-pressure hydrate loop used for the experiment. The test loop which is situated at the centre for hydrate study comprises of different components such as pumps, testing section, gas blower, phase separator and pre-coding section. The separator ensures that the liquid and gas are not in contact before getting to the pre-cooling section. The gas blower is used to flow out the gas at high pressure from the separator that is 8ft long and 917 inches internal diameter jacketed refrigerating system Hao (2020). Centrifugal pump is used to flow out oil and water from the separator that is 8.5ft long and 0.917inches internal diameter jacketed heat exchanger. At the pre-cooling section, liquid and gas are mixed that gives a multiphase flow through 10ft length and 1.75inches internal diameter pipe. The coolant is glycol/water mixture from the refrigerating unit. Fluid leaving the pre-cooling enters the testing unit that is 30inches long. The testing section contains four view ports for visual observation. Inbuilt camera is installed for recording of the process. Syringe pump was used to inject the gas and maintain isobaric process until the reserve gas cylinder becomes empty (Hao 2020). This test operation started as constant pressure process and later became a constant volume system when the gas cylinder became empty.

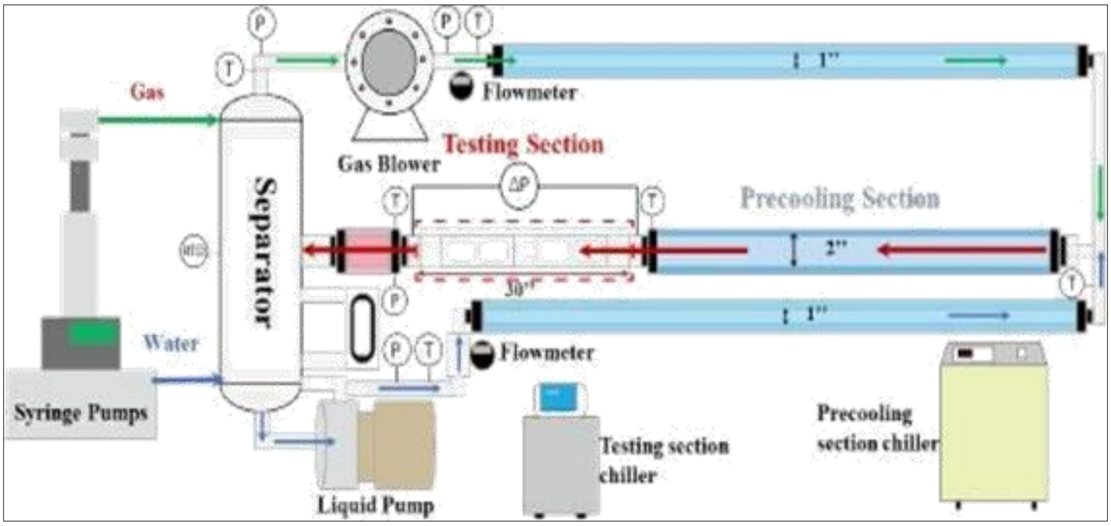

Figure 21 IlLab scale high pressure deposition loop at Center for Hydrate Research (Hao 2020)

Two thermocouples were used to read the temperature at the pump and pre-cooling section. Two thermocouples were used to read the temperature at the blower outlet and top of the separator. Two thermocouples were used to read the temperature at the inlet and outlet of the multiples testing section (Hao 2020). The pressure differential across the separator, gas blower, liquid pump and testing section were recorded with two transducers. The pressure differential across the separator, gas blower, liquid pump and testing section were obtained with four transducers. Orifice and carioles flow meters were used to read the gas and liquid flow rates respectively. Computer logging data acquisition system was used to process the flow every 30 seconds during the experimental runs (Hao 2020).

3. Conclusion

The primary objective of this paper is to review recent advances in the development of hydrate flow loops for industrial and academic study. To safely implement hydrate management strategies, it is important to study and understand mechanisms and behaviours connected to hydrate formation in different multiphase systems involving gas, oil and water. Several laboratory flow loops have been fabricated to conduct and study hydrate formation, agglomeration and dissociation. Various stages of hydrate formation have been measured and observed under continuous mixing, as a factor of different variables (temperature, pressure, presence of thermodynamic inhibitors and anti-agglomerants). Data obtained from experimental hydrate studies in literature can be used to develop predictive models applicable for oil and gas transportation in deep water operations.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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