# DESIGN OF A TRANSPARENT PIPELINE SYSTEM FOR CONTROLLED LABORATORY FLOW EXPERIMENTS

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**Abstract**

Multiphase flow behavior in surface production flowlines significantly affects separator performance, flow assurance, and overall production stability. Among the intermittent flow regimes commonly encountered in oil and gas production systems, slug flow is particularly challenging because of large pressure oscillations, liquid holdup, and unstable operating conditions in surface facilities. Conventional slug flow diagnostics rely on indirect measurements such as pressure fluctuations, acoustic monitoring, and fiber-optic sensing, which often require interpretation. Transparent pipe sections offer an alternative approach by enabling direct visualization of the gas-liquid interface, improving the understanding of slug dynamics, and supporting improved prediction and analysis of slug flow. Transparent pipes have been widely used in laboratory-scale flow loops for multiphase flow studies. However, most visualization experiments are conducted in small-diameter, low-pressure systems, limiting their applicability to conditions representative to production surface facilities. The implementation of a transparent pipe section in moderate-pressure experimental systems could provide valuable diagnostic capabilities.

**1. Introduction**

Multiphase flow is routinely encountered in oil and gas production operations, where mixtures of gas and liquid are transported through surface flowlines toward processing facilities. Among the intermittent flow regimes present in these systems, slug flow is particularly challenging because it induces large pressure oscillations, intermittent liquid holdup, and unstable operating conditions that can degrade separator performance and overall production stability. Early studies such as Fabre and Liné (1992) emphasized the importance of understanding slug dynamics and their influence on pipeline behavior. Several diagnostic approaches have been developed for slug flow monitoring, including pressure fluctuation measurements, acoustic monitoring, and distributed sensing techniques (Shimomoto et al. 2021). Although these methods provide valuable information regarding flow conditions, they rely on indirect measurements that require interpretation and may not fully capture the physical structure of the gas-liquid interface.

Transparent pipe sections allow direct observation of slug formation, interface behavior, and flow-regime transitions, improving interpretation of measured signals, and providing insight into the mechanisms governing multiphase flow behavior. Such observations can support a clearer understanding of slug dynamics relevant to production operations. Laboratory flow systems using transparent pipes have demonstrated the usefulness of direct visualization for investigating gas-liquid interactions and flow-regime transitions (Xu et al. 2020). However, most existing visualization systems operate in small-diameter setups and at relatively low pressures, limiting their applicability to conditions representative of production surface facilities. This limitation motivates the development of a direct visualization system capable of operating under conditions closer to those encountered in production surface facilities, allowing experimental observations that can be more easily correlated with slug behavior encountered in field operations.

## 2. Experimental Design

The experimental system design is intended to provide a controlled laboratory platform for conducting multiphase flow experiments while enabling direct visual observation of the fluid and injected gas bubbles within a transparent pipeline. The proposed setup focuses on developing a modular flow loop configuration capable of maintaining controlled operating conditions while allowing flexibility for future experimental studies.

Several design considerations were thought of for the development of the system. First, the experimental platform should allow stable fluid circulation through the transparent pipe section under controlled pressure conditions. Second, the configuration should allow clear visual observation of flow behavior within the pipeline. Third, the system should be flexible enough to support future experiments involving different fluid types or multiphase flow conditions. Finally, the design must incorporate safety considerations to account for the mechanical limitations associated with transparent polymer piping materials.

### 2.1 Flow Loop Configuration

The proposed experimental setup is designed as a closed-loop circulation system intended to allow controlled fluid flow through a transparent pipeline section. The system is planned to consist of a fluid reservoir, compressed air tank, a circulation pump, the transparent pipeline section, a control valve, and a return line directing the fluid back to the reservoir.

In this configuration, fluid would be pumped from the reservoir through the transparent pipe segment and subsequently returned to the reservoir, allowing continuous circulation during operation. Such a configuration is intended to maintain stable operating conditions during laboratory testing. The conceptual layout of the proposed flow loop configuration is illustrated in **Figure 1**.

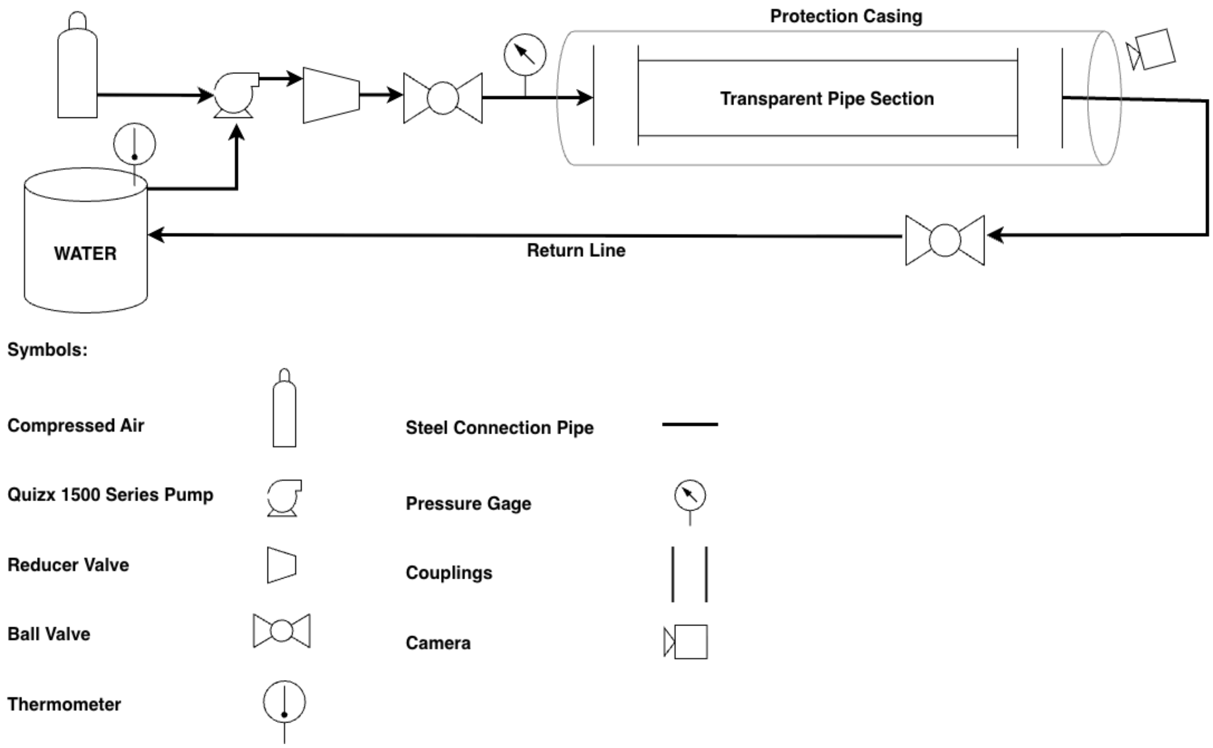


**Figure 1**

A control valve is proposed to be installed downstream of the transparent pipe section. The valve is intended to perform two key functions within the system. First, it will allow regulation of the flow rate through the pipeline. Second, partially closing the valve will introduce flow resistance, which can be used to pressurize the pipeline during testing. This capability is necessary for evaluating system behavior under controlled pressure conditions.

When the valve is fully opened, the system would simulate an open-flow condition in which the fluid flows freely through the pipeline. Under such conditions, the flow rate through the system could be measured to evaluate the hydraulic behavior of the experimental configuration.

## 2.2 Major Components of the System

Fluid circulation within the proposed experimental loop will require a pump capable of delivering controlled flow rates while maintaining stable pressure conditions. In addition to circulating the working fluid, the pumping system must provide sufficient flexibility to support different experimental conditions.

Future experiments conducted using the system may involve multiphase flow conditions including the injection of gas and liquid phases such as air, water, oil, surfactants, or mixtures of these fluids. Therefore, the pumping system must be capable of providing accurate flow control while maintaining stable pressure conditions during operation.

A suitable pump for this application is a Ametek Chandler Quizix 1500X pump, which provides high-precision flow control and pressure monitoring capabilities. Pumps of this type are designed for laboratory applications requiring accurate fluid injection and stable operating conditions. Their ability to maintain controlled flow rates and consistent pressure makes them well suited for use in experimental flow loop systems involving transparent pipelines.

An example of the pump considered for this system is shown in **Figure 2**.


**Figure 2**

### 2.3 Pipe Connections and Mechanical Assembly

Reliable pipe connections are necessary to ensure structural stability and sealing performance within the experimental pipeline system. The proposed transparent pipeline segments are intended to be assembled using modular mechanical connections that allow flexible system configuration.

One possible connection system is the Victaulic HP-70ES coupling, which provides mechanical support and sealing between pipe segments while allowing rapid assembly and disassembly of the pipeline. Clamp-based couplings of this type allow the experimental system to be modified or reconfigured without requiring permanent bonding or welding of the pipes.

In addition to clamp-based connections, plastic NPT threaded fittings may be incorporated into the pipeline assembly. These fittings would allow connections for instrumentation such as pressure sensors or other measurement devices. Incorporating plastic threaded fittings within the system may also allow evaluation of polymer-threaded pipe connections, which are commonly used in laboratory-scale polymer piping systems.

Examples of transparent pipe sections that may be used in the experimental system are shown in **Figure 3**.

*Fig 3a: Victaulic Grooved*

*Fig 3b: Plugged Ends*

*Fig 3c: NPT*

**Figure 3**

### 2.4 Safety Considerations

Because transparent polymer pipelines generally have lower pressure tolerance than metal-based pipes, safety considerations must be incorporated into the design. The operating pressure of the system should remain within the safe working limits of the piping material.

A larger diameter protective casing made of steel is proposed around the transparent pipeline section as shown in **Figure 1** to reduce potential risk in the event of pipe failure. Such an enclosure would help contain fragments and reduce exposure to the pipeline during operation.

In addition, remote video monitoring is suggested to allow observation of the transparent pipe during experiments. A monitoring system of this type would allow visualization of the flow region while minimizing the need for being near the experimental apparatus during operation.

These safety measures are intended to ensure that the proposed transparent pipeline system can be operated safely while still enabling direct visualization of internal flow behavior during laboratory testing.

## 3. Instrumentation and Measurement:

Accurate monitoring of operating conditions is necessary for maintaining controlled laboratory experiments. The proposed experimental system includes instrumentation for monitoring both fluid temperature and pressure within the flow loop. These measurements are intended to ensure that the system operates within safe limits while also providing reliable data for evaluating the behavior of the experimental setup.

### 3.1 Thermometer for Warm Water Tests, Pressure Sensor

Temperature monitoring is required to ensure that the operating conditions of the experimental system remain within the acceptable limits of the transparent piping material. Changes in fluid temperature can influence both the physical properties of the fluid and the mechanical behavior of polymer pipes, making temperature monitoring an important component of the experimental design.

The experimental setup includes a thermometer installed in the water reservoir to allow real-time monitoring of the circulating fluid temperature. Because the selected pump system does not include an integrated temperature sensor for the circulating fluid, an external thermometer is proposed to provide continuous temperature measurements during operation.

Monitoring the reservoir temperature allows operators to track temperature variations that may occur during warm water circulation tests or during extended operation of the flow loop. Maintaining temperature awareness is particularly important when working with polymer piping materials, as excessive temperature increases may influence pipe strength and pressure tolerance.

## 4. Potential Applications of Transparent Pipe Systems in Oilfield Operations

Transparent pipeline systems provide unique opportunities for studying multiphase flow behavior that cannot be directly observed in conventional steel pipelines. In daily oilfield operations, the ability to visually observe fluid flow inside pipelines can significantly improve the understanding of complex flow regimes that affect production performance and equipment reliability.

One important application is the study of slug flow behavior in production flowlines. Slugging occurs when large liquid slugs intermittently travel through pipelines, creating significant pressure fluctuations and operational instability. Transparent pipeline systems allow direct observation of slug formation, propagation, and breakup mechanisms, which can improve the understanding of slug dynamics and assist in developing more effective mitigation strategies.

Another potential application involves the evaluation of artificial lift and surface production equipment performance. Transparent pipeline sections can be used to study how gas and liquid phases interact downstream of separators, pumps, or gas lift systems. Observing these flow patterns may help identify operational conditions that lead to inefficient flow behavior or production instability.

## 5. Conclusions:

This study presents the conceptual design of a transparent pipeline system intended for controlled laboratory investigations of multiphase flow behavior. The proposed platform integrates a closed-loop flow configuration with a transparent pipe section, enabling direct visualization of gas-liquid interactions and flow structures that are difficult to observe in conventional pipelines.

The design incorporates a high-precision circulation pump, modular pipe connections using Victaulic couplings, and plastic threaded fittings to allow flexible system that integrates instrumentation. A downstream control valve is included at the end of the transparent pipe section to regulate flow rate and allow controlled pressurization of the section during testing. Temperature and pressure monitoring are proposed to ensure safe and stable operating conditions.

Future work will focus on implementing the proposed system and conducting experimental investigations of polymer pipe behavior under controlled laboratory conditions, including evaluation of mechanical performance, pressure tolerance, and long-term stability.

## References


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