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3D Printed Prototype for Water-soluble Polymer Preparation: PLC Operation

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Abstract - Water-soluble polymers (WSPs) are commonly used in different oil and gas applications, such as enhanced oil recovery (EOR), drilling fluids, disposal water treatment, and partially in cementing. Water-soluble polymers are prepared manually in small amounts at laboratories. However, such a preparation method could have multiple disadvantages, such as: human error, poor consistency, high process lead time, adjustment of powder batches, and waste materials.

To overcome such limitations, we propose a novel methodology to automate the polymer preparation processes through implementing multiple advanced stages. These processes consist of initial design, software programming, as well as advanced 3D printing and manufacturing. First, the solid work design software is utilized to make the original model. Second, the generated model is constructed using 3D printing technology. Finally, the programmable logic controller (PLC) is connected to operate the automation process including polymer doses and mixing time.

At the designing stage, internal components might hinder the preparation and mixing processes. Therefore, the placement of such internal components is considered to ensure flow continuity and solution homogeneity. The system components consist of funnel, hollow pipe, screw extruder, vertical powder banks, electrical valves, rotating motor, and nozzle. The optimum design is then sent to 3D printing for manufacturing at high resolution. The PLC is operated to function the whole system. The applied PLC components and setup are: three input gates, three timers, and five output gates.

In short, the novel automated preparation system in this study will eventually produce more homogenous and consistent polymeric solutions. In addition, it will minimize the common encountered uncertainties in the conventional methods. It will produce a more representative solution and improve the mixing process. The new system can be also upgraded to improve chemical mixing procedures at large volumes in oil and gas operations.

***Keywords*:** Automation – Consistency – Accuracy – 3D printing – Programmable logic control

Introduction

There are two main types of polymers: highly water soluble and highly insoluble polymers. In addition, there are intermediate categories, such as hydrophobically modified water-soluble polymers, swollen microgels, alkali soluble emulsions, alkali swellable emulsions, and water-reducible polymers [1]. Beside the wide range of water-soluble polymer (WSP) applications, polymers have been utilized in oil and gas fields for several decades. Enhanced oil recovery (EOR) is one of the main applications that uses WSPs for improving sweep efficiency of hydrocarbons in underground reservoirs.

In EOR laboratories, and for relatively high quantities, WSPs are commonly prepared manually; however, manual preparation has several limitations. Human error is one of the most significant disadvantages for manual preparation, which also includes poor process consistency as a sub-disadvantage. Due to the need of having consistent polymer powder pouring for high quantity processes, the lead time of preparation and mixing might be unfavourably affected. The whole process lead time refers to the time from the beginning through the end of operations, and it usually consists of waiting time, setup time, and actual operation time [2].

Plastics have myriad uses in fields as diverse as household appliances, packaging, construction, medicine, electronics, automotive, aerospace components [3], and EOR applications. A great amount of chemicals could be wasted in different ways while performing the manual preparation processes.

In sophisticated environments like Command and Control (C2), in which human errors can make tragic consequences, smart automated systems are highly recommended [4]. Therefore, we proposed to automate the manual preparation process through three different sequenced stages: design drawing using solid work software, prototyping using 3D printing technology, and system operation via programmable logic controller (PLC). The PLCs play a critical role in manufacturing automation by enhancing efficiency, reducing cost, and improving product quality across various industries [5].

To come up with the optimum design, several recommendations and proposals were delivered. The selected design was then printed using 3D printing technology. **Fig. 1** shows the isometric view of the 3D model with the demonstration of all components. The material used for printing the system was called polyethylene terephthalate glycol (PETG), which is basically a thermoplastic that is frequently utilized in 3D printing technology [6].

The final stage is the control (operation) method. To operate this system safely, it is highly preferred to use a closed-loop control system (feedback control system). The feedback system can be described as an electrical signal that is transferred from the output to the processor. The processor will have the ability to compute how the output is different from the required value [7]. Programmable logic control components include three input gates, three timers, and five output gates.

The aim of this paper is to develop a novel automation process for a polymer preparation system. In this development, we intend to reduce the operation lead time by mitigating the human intervention. A homogenous polymer solution will be achieved. Moreover, the implementation of such a novel system will eliminate the material waste that might be produced from the defective parts while preparation.

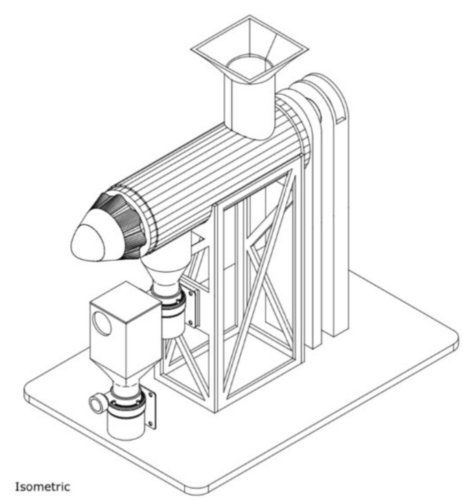


Fig. 1: Demonstration of the Components of Polymer Preparation System in a 3D Model

Material And Tools

1. MATERIAL

Different types of water-soluble polymers with a solid content of 92.75%, such as polyacrylamide and polymeric surfactant, were used as a preparation pattern. For the 3D printing, and as mentioned previously, PETG, or polyethylene terephthalate glycol, was used. PETG comes in a filament form with an excellent chemical resistance.

2. TOOLS

A programmable logic controller unit was utilized to operate the system and for the setup for programming purposes. Two electrical valves (DC water pump), and a 12 A motor were also used for system processing.

Prototyping Stages

1. DESIGN AND SYSTEM COMPONENTS

A wide funnel is located at the top of the system to permit pouring a large polymer quantity easily. The funnel is then connected to a horizontal hollow pipe in which it contains a screw extruder trapped inside. The pipe is then blanked close to the other edge at the bottom of the pipe. An aperture is placed to permit the powder passing through the screw threads. The first valve is mechanically connected with a temporary powder bank (PB1) from the top and connected with the aperture in the pipe. Valve-1 is also connected with another temporary bank (PB2) from the bottom. Valve-2 is connected with PB2 from the top and with a nozzle from the bottom. The nozzle is installed to direct the powder to the beaker and to deaccelerate the flow of the powder.

2. MODEL MANUFACTURING

The selected design is manufactured using 3D printing technology. The printer type is Pursa MK3 with a layer height of 0.2 mm. A comprehensive study is recommended to re-evaluate the material used for the system construction. The current material is PETG. **Fig. 2** shows the 3D printed model.

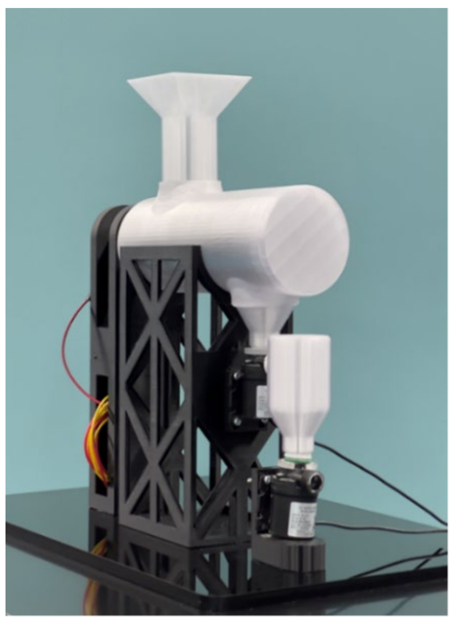
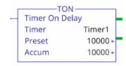
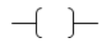


Fig. 2: 3D Printed Prototype

3. OPERATION METHOD AND MECHANISM

Method: Among several methods applied to operate the automated system, we have selected the PCL due to its simplicity and accuracy. The selected PLC method for this system is ladder diagram rung. Table 1 illustrates the utilized logic gates, symbols, and quantities.

Table. 1: Utilized Logic Gates, Symbols, and Quantities

Logic Gate	Quantity	Symbol
Input (I.124.0, I.124.2, & I.124.5)	3	
Timer off delay	2	
Timer on Delay	1	
Output (Q.124.0, Q.124.1, Q.124.2, Q.124.5, & Q124.6)	5	

Mechanism: By turning the switch on, three signals will be sent. The first signal is to run the screw extruder, the second signal is to open the upper valve (V-1), and the third signal is to start up the off-delay timer. Timer (T1) will be set for a certain period. Once the timer stops, it will send another four signals. Signals one and two, will stop the screw and close (V-1) respectively. Signals three and four will run the other timer (T2) and will open (V-2). Timer (T2) will be set for a certain time period. Once the timer stops, four signals will be sent again. Signal one, will close (V-2), while signal two and three, will run the screw again and will open (V-1), respectively, and signal four will run the third timer (T3) that will be as a reset to the whole process. By concluding the final step, the process will be operated in an oscillating mode. **Fig. 3** shows the program used in the PLC unit.

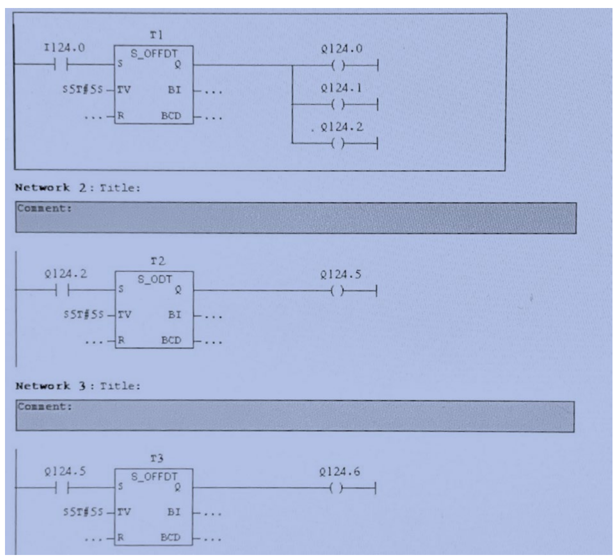


Fig. 3: Designed Program in the PLC Unit

Conclusion

The transition from a conventional manual procedure to an advanced automated preparation process will advance oil and gas operation, specifically in the area of complex fluids like polymers and surfactants. The new proposed automated process can be implemented at both small and large scales. Below are some of the advantages that can be attained from using the automated preparation process:

- Enhancing process consistency through automating the polymer powder mixing process. Powder batched will be poured through the nozzle with an equal time interval as the timer is set.
- Human intervention will be minimized to mitigate the preparation errors which can lead to process redundancy. Hence, short process lead time will be achieved.
- Prevention of tests redundancy will eliminate the resulted material waste and expected experimental error.
- Dosing equal powder batches will provide more precise concentration that can produce homogenous mixtures.

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