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Simulation Model to explore the Characteristic Pump Curve of an Injection Molding Machine: A case study of ABUAD water plant

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***Abstract**: The Injection molding machine is one of the commonly used machines for the production of domestic and industrial plastic products, which differ in sizes, shapes, complexities, and applications. Inadequate pressure load to push the molten plastic pellets through to filling the mold during the molding processes is one of the problems reported in literature. Hydraulic pressure to force the melt into the mold is initiated from the hydraulic pump to the main spindle that often results to product defects. In this work, the characteristics of the pump driving the main spindle of an injection molding machine by an hydraulic motor is explored using the Afe Babalola University Ado Ekiti water plant as a case study. The research designed and simulated a hydraulic model with the FluidSIM® 5.1 and benchmarked with a workbench model. The feeding motion for the tool carriage was investigated with a hydraulic cylinder. The behavior of the pump was determined by analyzing the resultant curve from the experiment and simulation. It was discovered that for resource efficiency and sustainable production of plastic bottles with the injection molding machine, the shutoff valve should be set at 65° displacement angle. This angle resulted to the optimum pressure and flow rate for the hydraulic motor. The hydraulic motor also reaches its specified speed at the optimum displacement angle for the injection molding machine as the operation progresses.*

***Keywords**: Optimum, Model, Simulation, Resultant Curve, Flow rate, shutoff valve and FluidSIM®.*

I. INTRODUCTION

An Injection molding machine, which is also refer to as an injection press, is a machine for manufacturing plastic products by the injection molding process [1-2]. Few researchers have investigated and analyzed the performance characteristics of the molding system with different material composition [3-5]. It was reported that the injection molding machines are better and more efficient if they are used for manufacturing in the horizontal or vertical positions (references). Hence, most of the commercially available injection molding machines is horizontally oriented in position. However, some vertical injection molding machines are for product-based applications. For example the molding of cutting tool inserts, the ram of the vertical product-based injection molding machines usually fall under gravity thereby reducing the applied load for material extrusion [6-7]. Injection molding machine are classified, based on the type of driving systems that controls them (i.e. mechanical, electric, hydraulic, or hybrid) [8]. Hydraulic presses have been commercially adopted for part molding until the introduction of the injection molding machine in 1983 by Nissei Plastic Industrial Co., LTD [10]. Hydraulics is a means to transfer energy from one point to the other through the use of actuators that are driven by oil pressure. Hydraulics of this type is restricted to liquid of high viscosity in order to transfer energy from the inlet to the outlet [9-10]. Pneumatics on the other hand, uses air pressure to transfer energy from one point to the other [10]. The transfers of energy in hydraulics (i.e. pumping of oil into a cylinder) are usually controlled with through valves. The pressure input to a system can be 1) manually regulated through the opening of the valves, 2) by automatic pressure sensing, or 3) by sending an electrical signals to regulate the pressure. The combination of hydraulic control and electrical impulses is known as electro-hydraulic systems [11]. In today's injection molding designs, it has been a common practice to adopt the electro-hydraulic pressure control strategy [12]. Hence, the increasing trend of the usage of injection molding machine despite their inaccurate characteristics to replicate the designed component more accurately with minimum error [9-10].

A. Afe Balalola University Ado Ekiti Water Botling Plant

One of the ventures at the Afe Babalola University Ado Ekiti, ABUAD is the commercial production of bottled water. An electro-pneumatic and electro-hydraulic control injection molding machine is used to mold the 50cl and 75cl plastic bottles as shown in Figure 1. The major driving part of the machine is hydraulically operated shown in Figure 2.

During the molding operations series of problems were usually encountered. For example, uneven shrinkage due to discrepancy in mould surface cooling, thinned-neck defects, shrinkage, incomplete molding, thin walled bottles, etc. It is envisaged that these and other related problem facing Afe Babalola University Ado Ekiti Nigeria water plant could be as result of inadequate pressure load to push the molten plastic pellets through to filling the mold during the blow molding processes. This is as a result of inadequate consideration not been given to the core and cavity dimensions during the design process of the mold. The designer of the mold should consider the addition of 'shrinkage allowance' to the mold cavity at the mold design stage [16]. Some injection molding defects could also be attributable to cooling and production circuit design [14]. The design of the gating systems to accommodate pressure drop across the gates [16], the effect of the hold-on pressure and time fluctuating from high to low indiscriminately [17], etc contributes to the blowholes and thin walls of the molded plastic bottles at the ABUAD water plant. The rate of defect and waste are of concern for resource efficiency and sustainable manufacture globally and at the ABUAD water plant. Hence the need for this research to simulate the driving mechanism at the point of production [16-17] of the injection molding machine with the FluidSIM® and a workbench model in order to test and understudy the ranges of suitable pressure for the forming of the ABUAD water plant plastic bottles. This prompted experimental investigation and simulation of the injection molding system model.

Defect thin neck bottle at Abuad water Plant

Damaged Shrink Bottle

Damage Shrink Bottle

ABUAD-Mold for 50cl bottle

Sample ABUAD mold of 75cl bottle

Operational pressure of 3.6 bar for the Pnuematic system at Abuad Water Plant

Figure 1: Investigation process into ABUAD Water Plant

Using the FluidSIM® Hydraulic simulation software from FESTO Germany, it is easy to test the feasibility of any hydraulic systems and designs. Hence, it was adopted for this research.

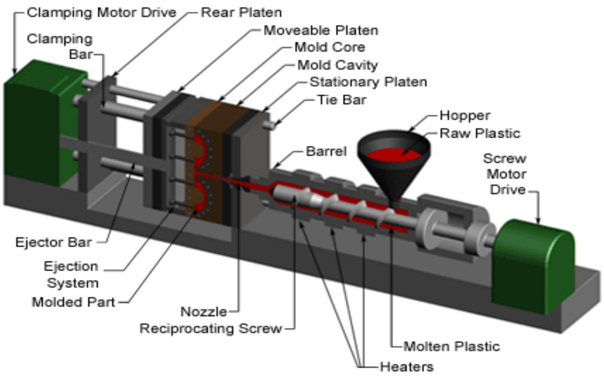

Figure 2: Isometric view and the sectional view of the mold of a Plastic Injection Molding Machine [13].

B. Aim and objectives of the study

The aim of this study is to automate and simulate the driving mechanism of an injection molding machine powered by a hydraulic motor and the feed motion for the tool carriage. This is to replicate the manufacturing process involved in the injection molding manufacturing industries.

The specific objectives include:

1) The design of injection molding machine driving mechanism on the hydraulic workbench
2) Creating a similar injection molding driving mechanism units with the hydraulic FluidSIM®
3) Experimental analysis on the workstation
4) Simulate the drive mechanism with FluidSIM®

II. Research Methods

In order to simulate the driving mechanism of an injection molding machine powered by a hydraulic motor and the feed motion for the tool carriage, the model was designed with the FluidSIM® and replicated on the hydraulic workbench. This is done to identify the likely causes of error during the molding process. The FluidSIM® model and setup before and after simulation is as shown in Figures 3 and 4 respectively.

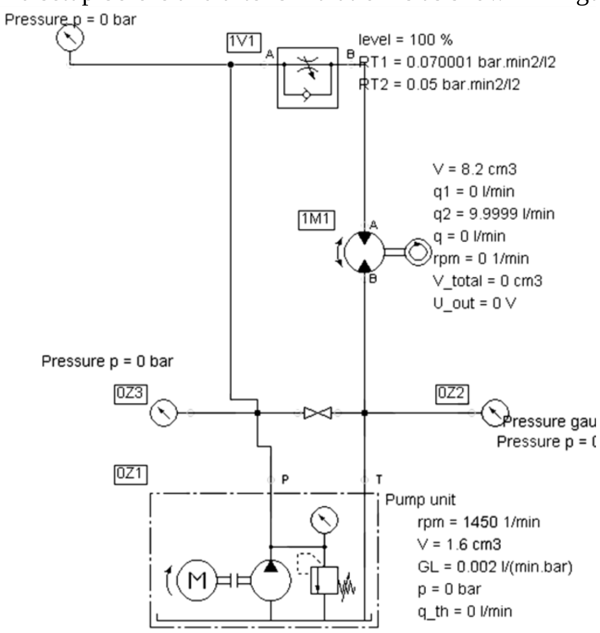

Figure 3: FluidSIM® setup and description before simulation

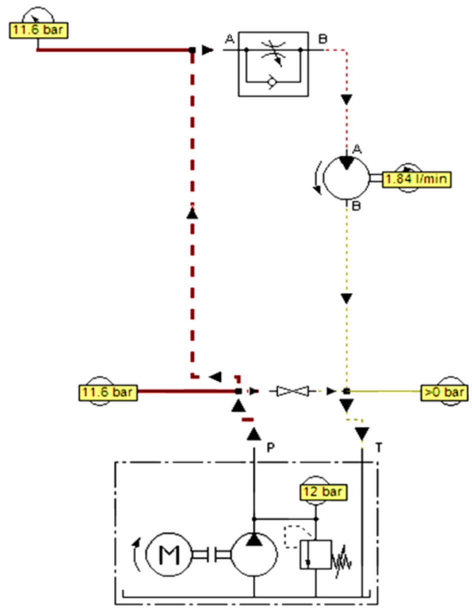

Figure 4: FluidSIM® setup and description after simulation using the Flow meter

This investigation was carried out at the ABUAD injection molding machine water plant to identify the possible problem in the manufacturing processes that causes failure in machine operation and product deformation. An experimental simulation was conducted with different hydraulic circuit to determine the possible workable circuit. This circuit was simulated and experimented and data were collated for evaluations. This is to simulate the molding system in order to identify likely causes of error during the molding process in ABUAD water plant system. It is anticipated that the results could bring about reduction in the need for man-power or skilled workers and at the same time enhances the reduction of man-machine errors usually caused by the machine operators.

III. The Analysis of the Cylinder Speed

A. Volumetric Flow Rate

Volumetric flow rate, (also rate of fluid flow or volume velocity) is the volume of fluid which passes per unit time [14].; commonly represented by the symbol Q in m^3/s. Volumetric flow rate is defined by the limit as shown in Equation 1.

$$Q = \dot{V} = \lim_{\Delta t \to 0} \frac{\Delta V}{\Delta t} = \frac{\mathrm{d}V}{\mathrm{d}t} \quad (1)$$

Where *V* represents the volume of fluid in m^3 and *t* is the flow time in *s*.

B. Descriptions of Component Use and Design Calculation.

B.1. Hydraulic motors

Hydraulic motors are components of the drive section. They are power components (actuators) that converts hydraulic energy into mechanical energy for rotary motion (rotary drive). The oscillating motors are used to confine the rotary motion to a particular angle range [15]. In order to design the hydraulic motor capacity, it is important to evaluate the pressure requirement. Hence,

$$P = \frac{M}{V} \quad (2)$$

And,

$$Q = n \times V \quad (3)$$

Where, P is the pressure in MPa, M is the mass in kg, V is the geometric or displacement volume in cm^3, Q is the volumetric flow rate in dm^3/min and *n* is the speed in *rpm*.

From the FluidSIM® software design, the motor displacement volume, V = 8.19995901761781 cm^3 occurs at the motor speed of 1 rpm, it therefore implies that the pump's volumetric flow rate can be estimated with Equation 3.

$$Q = n \times V = 8.19999\ cm^3 \times 1rpm = 0.008199\ dm^3/min$$

If the pump delivers 2.3 dm^3/min as the highest value, then the rotational speed n, of the motor is as shown in Equation 4.

$$n = {}^{Q}/_{V} = {}^{2.3dm^3}/_{8.1999cm^3/min} \quad (4)$$

= 280.4888 rpm.

C. To Calculate the Flow Rate at ABUAD Water Plant

The volume of the bottle at the Afe Babalola University water plant are 50cl and 75cl. For the purpose of this analysis, 50cl plastic water bottle was considered as the loading volume from the hopper of the injection molding machine.

Therefore 50cl is equivalent to $500cm^3$,

Since n=280.488rpm it therefore implies from Equation 4 that the volumetric flow rate to fabricate the 50cl plastic bottle is equivalent to;

Q=n*v = 280.488rpm* $500cm^3$= $140244dm^3$/min

3.2.3 The equipment used in the experiments

The double-acting pneumatic cylinders made by FESTO Company Germany were adopted for the experiment as shown in Figures 5 and 6. The hydraulic pressure and flow-rate measurement were recorded and evaluated through the hydraulic motor and the flow meter shown in Figure 6.

The pump unit supplies a constant volumetric flow. The operating pressure is limited by the internal pressure relief valve. The pump unit has two tank connections.

The One-way flow control valve is set by means of a rotary knob. A check valve is located parallel to the throttle valve. The rotary knob does not allow the setting of the 'absolute resistance' value. This means that, in reality, different throttle valves can generate different resistance values despite them having identical settings.

The shutoff valve can be manually opened or closed. The hydraulic resistance relates to the completely opened valve.

The flow meter consists of a hydraulic motor connected to an RPM gauge. [18]

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Figure 5: Experimental set up at the FESTO Lab ABUAD

Figure 6: Readings taken on multi-meter at FESTO Lab ABUAD

IV. Result and Discussion

After the experimental investigation and simulation it was discovered that the dimensions of the mold could be restricted by controlling cooling rate in different areas of the mould with a stipulated optimum pressure, even when wall thickness is not constant. Injection speed profile and 'hold-on' pressure profile can only be minimized to some extent during the molding process. Gas injection molding technique can be adopted for improved efficiency in this regards [16]. It is reported that the injection speed can be influence by lowering barrel temperature and pressure of operation [17].

Figures 7 and 8 shows the average of the experimental value recorded after two different experiments were carried out on FESTO workstation at different time and operational conditions. The voltage value readings taken from the multi-meter configure to voltage is taken to be the flow rate of the fluid in the system [15]. This is to say that 1*volt* is directly proportional to 1 $liter/m^3$

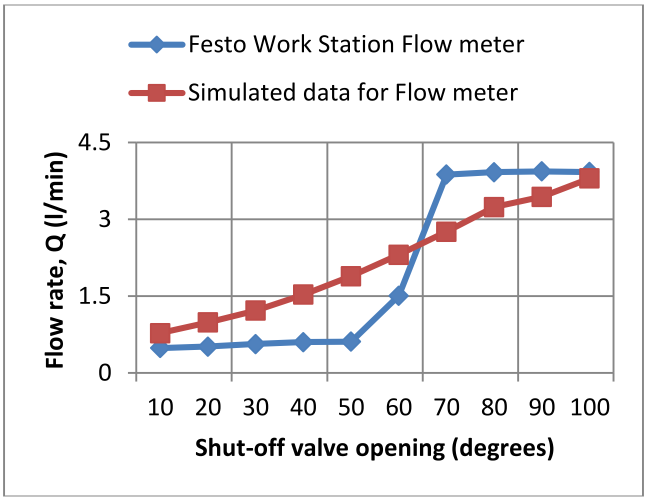

Figure 7: Simulated and Experimental Data graph for flow rate

Figure 7 depicts the graph of the flow rate Q plotted against the shut-off valve openings that was varied between 10^{o} to 100^{o}. It can be deduced that a correlation existed between the FESTO work station flow meter and the simulated data obtained from the FluidSIM® software. The flow rates of both the FESTO work station and the FluidSIM® tallied at an angle of 65^{o}. This is an indication that for optimum performance at the ABUAD injection molding machine, the shut-off valve should be set at 65^{o} angle as shown through the analysis. Also, from Figure 8, correlation exited between 55^{o} and 62^{o} shut-off valve angle. These shut-off valve angles are deduced based on simulated and experimental analysis. It is not a representation for all injection molding machines which could differ in sizes and brand.

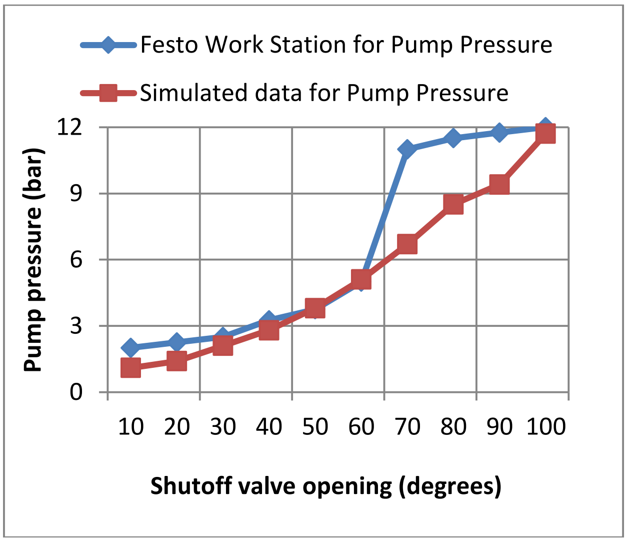

Figure 8: Simulated and Experimental Data graph for Pump Pressure

V. Conclusion

This research work is presented to show the automation of different pressure possibilities in an injection molding machine using the ABUAD Water Plant as a case study in order to determine the optimum valve pressure and flow rate that is required for optimum performance of the machine. Simulation and modeling are better alternatives for performance evaluations that could save time and cost of production machines. Hence, this paper made significant approach towards automation of an injection molding machines. The following conclusions can be deduced from this research:

1. It is shown that at 65^{o} angle displacement of the shutoff valve, the flow rate and the pressure values were constant. This is an indication of continuous plastic molding during the production process. It is deduced therefore that the optimum pressure and flow rate values existed at 65^{o} valve angle.
2. This research is a step change towards the automation of an injection machines using electro-hydraulics in ABUAD Water Plant.

3. Also, the FESTO FluidSIM® 5.1 version software can be adopted to simulate the hydraulics circuits for the injection molding machines. This will ensure resource efficiency and optimum performance of the injection molding machines.
4. It is also believed that using the software based analysis could save the maintenance and labor costs and also the overall time of operation.

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