Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(Special Issue 1) (2021) 145-148
DOI: 10.22060/mej.2019.16127.6281

Experimental Investigation of Water Level Control System of Liquid-Gas Separator in the Fuel Cell

A. Shojaei[1], S. M. Rahgoshay [2*], M. Rahimi[2], A. H. Pahnabi[3], K. Mohammadi[3]

[1] Department of Mechanical Engineering, Babol University of Technology, Babol, Iran
[2] Department of Mechanical Engineering, Malek Ashtar University of Technology, Tehran, Iran
[3] Department of Mechanical Engineering, Malek Ashtar University of Technology, Fereydunkenar, Iran

ABSTRACT: Water is the product of the interaction between reactants in the fuel cell. The purpose of this study is to introduce a water level control system that prevents the loss of reactant gases by improving the process of water separation from these gases. In this paper, due to fuel cell characteristics and construction constraints, the performance of a venturi-based flow control system is quantified. Effective parameters for controlling the discharge valve, such as the length of the connection path, the angle of the sensor, the time lags, have been investigated. The path length check showed that if the path length being too high, the pressure changes oscillate, failing to establish a pressure condition for the minimum critical time, and the system loses its performance. Finally, in order to control the water level control system automatically, relations are proposed based on the pressure. The performance of the fuel cell has been investigated at 0.4 to 2 bar and the system is efficient in this range. The sensor angle only affects the maximum critical time, somehow reaches its maximum by placing the sensor at the 90-degree angle. In addition, according to the tests performed, the time between 0.3 and 0.5 seconds is recommended for the minimum critical time.

Review History:

Received: 2019-04-14
Revised: 2019-09-29
Accepted: 2019-11-05
Available Online: 2019-11-13

Keywords:

Fuel cell
Venturi
Water level control
Quantification
Reactant gas

1. INTRODUCTION

A lot of research has been done to find ways for separating produced water from reactant gases at the fuel cell. Charlat [1] used the centrifugal force to separate water from gas in a fuel cell. Bette et al. [2] used the voltage drop as a control signal to open the discharge valve for separating. orifice and venturi are the equipment used in the separation process, which operates based on the pressure difference of the passing fluid. Zhou et al. [3] investigated the dynamic cavitation properties of nitrogen passing through a venturi at different pressures. Lavante et al, [4] conducted a numerical and laboratory study of the flow in critical ventilation nozzles to measure gas flow. This paper introduces a water level control system; although, the control system process has been qualitatively described by Illner et al. [5].

2. METHODOLOGY

The performance of the water level control system is shown in Fig. 1, in the first stage, the valve is open. According to the experimental results, a mixture of gas and water passes through the system at the initial moment, so the pressure measurement begins after ΔT_{cr-H} in order to discharge the remaining gas from the previous cycle. The water then enters the venturi through the separator outlet, and simultaneously the differential pressure of the passing fluid is measured by a pressure sensor and sent to the electrical control system. The electrical control checks whether a sudden change in differential pressure has occurred or not. The sudden change indicates that the flow is changing from liquid to gas, but if the phase change does not occur (-), the differential pressure is still measured and sent to the control unit. However, if a sudden change occurs (+) the controller waits for ΔT_{cr-L}, then sends a message to close the valve. After closing the drain valve, the control unit checks whether the fuel cell is on. If the fuel cell is switched off, the cycle ends. However, if the fuel cell is turned on, it holds the discharge valve shut for ΔT_{off} seconds.

*Corresponding author's email: rahgoshay@mut.ac.ir

3. DISCUSSION AND RESULTS

3.1. Pipe length

As the length of the connection pipe becomes longer, the volume of gas inside the pipe increases. The small amount of gas remaining in the pipe is combined with gases, resulting in the pressure changes oscillate and the system becomes disrupted. However, if the length of the pipe is short, not only a smaller volume of gas is trapped in the pipe, but also a mixture of water and gas does not form during gas discharge. As a result, the system operates with the least reactant losses.

3.2. Angle of the pressure sensor

The maximum value of the maximum critical time is tested for 5 different angles of the pressure sensor at the inlet pressure of 1 bar. According to Fig. 2, the magnitude of this parameter at 90 and 270 angles is slightly less than other angles.

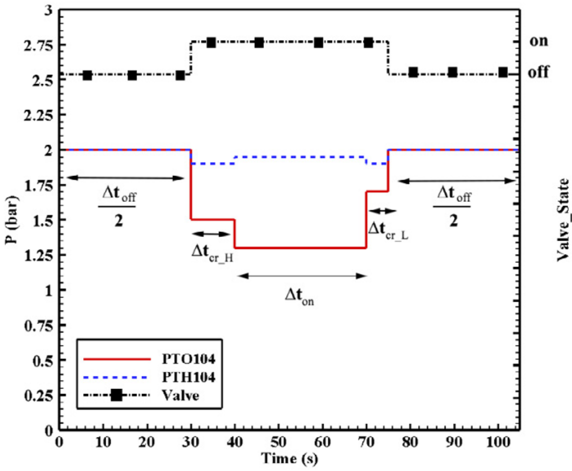

Fig. 1. Diagram of the proposed algorithm

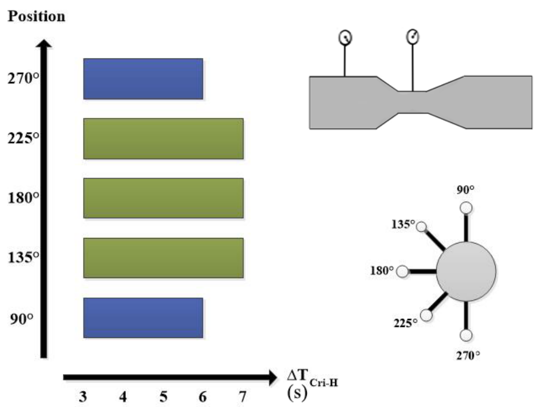

Fig. 2. Maximum of Maximum critical time based on different angles of the pressure sensor

3.3. Duration of the shut-off discharge valve

In each cycle, the discharge valve closes for a certain period. During this time, water collects in the separator tank. In the experimental sample, the separator volume is 25 cc. On the other hand, the inlet discharge at a current of 300 amp and 1 bar pressure is 0.38 cc/s. So ΔT_{off} is calculated as follows:

$$\Delta t_{off} = \frac{25\,\text{cc}}{0.38\,\text{cc/s}} = 65.8\,\text{s} \tag{1}$$

3.4. Minimum critical time

The minimum critical time is the time required to ensure that the fluid passing through the water is converted to gas. In this case, the discharge valve will be closed if the gas flows continuously for ΔT_{cr-L}. According to the experimental results, this time interval should be large enough somehow that the passage of bubbles does not cause of closing the discharge valve and remaining the water in the separator and should be small enough to waste a small amount of gas. According to the tests performed, a critical time of 0.3 to 0.5 seconds is recommended.

Table 1. Mixed discharge at 3 different pressures

Pressure (bar)	$\min[\Delta t_{cr\_H}]$ (s)	$\dot{Q}_{mix}$ (lpm)
0.6	2.5	8.64
1	2.25	9.59
1.4	2	10.79

3.5. Maximum critical time

By closing the discharge valve, the amount of gases from the previous cycle remains in the pipeline. Thus, by opening the discharge valve, the available gas first passes through the venturi. This causes the establishing of the pressure condition and closing the discharge valve, without draining the water. Therefore, ΔT_{cr-H} provides the time needed to pass through the confined gas. For this purpose, the following procedure is used to calculate the critical time.

The control system assembly consists of two sections of the separator tank and the connection path. *V1* is the volume of the separator calculated as follows:

$$\Delta t_{purge\_wtr} = \frac{V1}{\dot{Q}_{wtr}} \tag{2}$$

The amount of gas left in each cycle is equal to the volume of the connecting pipe, *V2*. The critical time must be greater than the time required to discharge this volume of gas in order to that water does not remain in the tank. This time variable is calculated as follows:

$$\Delta t_{purge\_gas} = \frac{V2}{\dot{Q}_{mix}} = \frac{A_c L_c}{\dot{Q}_{mix}} \tag{3}$$

According to Eqs. (2) and (3), to calculate the ΔT_{cr-H}, it is necessary to calculate the $\dot{Q}_{mix}$ obtained by the following equation:

$$\dot{Q}_{mix} = \frac{V2}{\min[\Delta t_{cr\_H}]} \tag{4}$$

For this purpose, a minimum of Δt_{cr_H} is required by experimental testing at various pressures. Table 1 shows the mixture flow for three different pressures.

However, to calculate the mixture flow at any pressure we need a general relation defined as follows.

$$\dot{Q}_{mix}(\text{lpm}) = (\dot{Q}_{gas} \times X) + \dot{Q}_{wtr} \times (1 - X) \tag{5}$$

In the above relation *X* is the mass fraction of the passing fluid which, with respect to water and nitrogen gas discharge, and the results from Table 1, fall within the range of 0.044 to 0.074. In the following calculation, the value of *X* is considered 0.05. Finally, the critical time of the adenine is calculated as follows:

$$\Delta T_{cr\_H} = (\alpha \times \Delta t_{purge-wtr}) + (\Delta t_{purge-gas} \times (1 - \alpha)) \tag{6}$$

In the above relation, α is considered to be 0.3.

4. CONCLUSIONS

Water is one of the products of the interaction between hydrogen and oxygen in a fuel cell. The presence of this product can reduce fuel cell efficiency. The purpose of this study was to introduce a water level control system, a system that can prevent the loss of reactant gases. Therefore, unused gases are returned to the fuel cell, thereby reducing the cost of using reactant gases to generate electricity. The system consists of a mechanical unit (venturi) and a control unit which is designed based on various reactant gases such as air and oxygen. At first, an algorithm was proposed for the control system. Then, in order to find a relationship for automatic control of the system, the parameters expressed in the algorithm were investigated.

REFERENCES

[1] P. Charlat, Gas/liquid phase separator and the fuel cell-based power production unit equipped with one such separator, in, Google Patents, 2006.
[2] W. Bette, D. Coerlin, W. Stuhler, Fuel Cell System and Method for Operating a Fuel Cell System, in, Google Patents, 2008.
[3] J. Zhu, H. Xie, K. Feng, X. Zhang, M. Si, Unsteady cavitation characteristics of liquid nitrogen flows through venturi tube, International Journal of Heat and Mass Transfer, 112 (2017) 544-552.
[4] E. Von Lavante, A. Zachcial, B. Nath, H. Dietrich, Numerical and experimental investigation of unsteady effects in critical venturi nozzles, Flow measurement and instrumentation, 11(4) (2000) 257-264.
[5] D. Illner, I. Mehltretter, O. Voitlein, Method for monitoring the discharge of media out of fuel cell, and a fuel cell system, in, Google Patents, 2008.

HOW TO CITE THIS ARTICLE

A. Shojaei, S.M. Rahgoshay, M. Rahimi, A.H. Pahnabi, K. Mohammadi, Experimental investigation of water level control system of Liquid-Gas separator in the fuel cell, Amirkabir J. Mech Eng., 53(3) (2021) 145-148.

DOI: 10.22060/mej.2019.16127.6281