TEMPERATURE CHANGE OF A TYPE IV CYLINDER DURING HYDROGEN FUELING PROCESS

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ABSTRACT

The temperature of the hydrogen cylinder needs to be carefully controlled during fueling process. The maximum temperature should be less than 85℃ according to the ISO draft code. If the fueling period is reduced, the maximum temperature should increase. In this study, temperature change of a Type IV cylinder was measured during the hydrogen fueling process up to 35 MPa. Fueling period was 3 to 5 minutes. Twelve thermocouples were installed to measure inside gas temperature and seven were attached on the outside of the cylinder. An infrared camera was also used for measuring temperature distribution of outside of cylinder. The maximum gas temperature was higher than 85℃ inside of the cylinder. Significant temperature difference between the upper and lower part of the vessel was observed. Temperature near the plug and the valve was quickly increased and maintained higher than that of the other region. Temperature increases for the partial refueling process were also discussed.

1.0 INTRODUCTION

World-wide concerns about the alternative energy resource are increasing due to the exhaustion of natural resource, global warming, environmental pollution, and so on. Hydrogen as an alternative energy has been considered as one of the clean energy in the future and replacement of traditional fossil fuel [1]. The US have studied for the safety codes and regulations related with hydrogen safety since 2003 [2]. Many EU countries and Japan have competitively made efforts on the development of the primary technology on infrastructure for hydrogen economy including hydrogen production, transportation and storage. Since 2005, the Korea government had declared the 'Hydrogen era' and built a master plan for hydrogen energy research. Matters of public concern are increasing with the global importance of the hydrogen as an alternative energy. At the same time, the hydrogen safety is raising as a challenging issue for practical use of commercialized hydrogen utilizing system. The dangers of hydrogen leakage always exist during the hydrogen production, storage, and transportation process due to its low density, small molecular size and rapid dispersion rate [3]. When the hydrogen gas leak in the enclosed compartment, it can be formed a dangerous combustible mixture with its wide range of flammability limit of 4-75%, including its low ignition energy and fast flame propagation velocity [4]. Therefore, proper safety precautions, regulations and standards based on the understanding of hydrogen properties are the keys to successful use of hydrogen as an alternative energy.

The present study has been performed to investigate the existing international safety code on the hydrogen fueling process based on the experimental study on the temperature change and expansion rate of type IV hydrogen tanks which are being used by many automotive manufacturers.

2.0 EXPERIMENTS

2.1 Experimental Setup

Fig. 1 shows the photographs of the tested experimental setup and components used in the present study. All experiments are performed in a hydrogen fuelling station with 350 bar dispenser and high pressure storage at SK Institute of Technology, Daeduk, Korea.

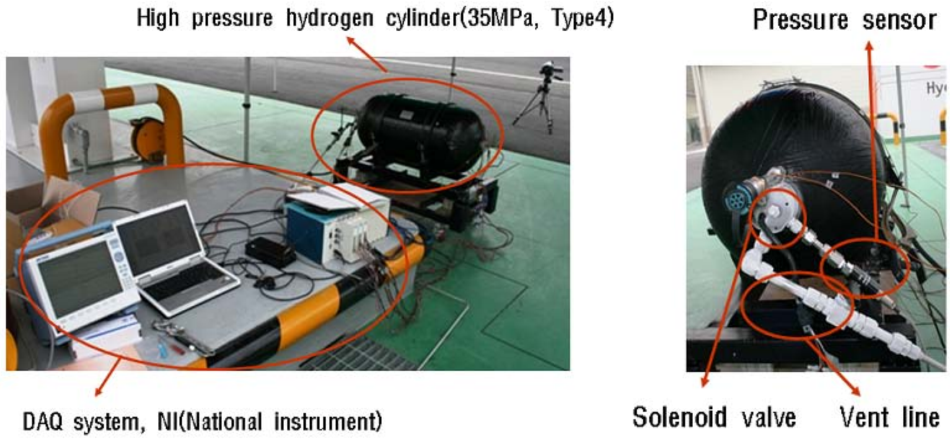

Figure 1 Photographs of Experimental Apparatus tested in this study.

The experimental setup consists of type IV cylinder, refuelling receptacle, thermocouple mounting unit, data acquisition unit and thermal imaging camera. Fig. 2 shows the photographs of the thermocouple mounting unit, the T-type thermocouples were installed to measure the gas temperature at six positions in the cylinder. The thermocouples were inserted through the end plug of the gas cylinder. All temperature data are recorded with constant sampling rate of 1 Hz using NI-DAQ. Table 1 represents the specification of type IV cylinder used in the present test series.

Figure 2 Photographs of thermocouple mounting unit inserted into the cylinder.

Table 1. Specification of type IV Cylinder

Items	**Specification**
Working Gas	Hydrogen
Volume	72ℓ
Diameter	403mm
Length	900mm
Weight	37kg
Working Pressure	35 MPa

2.2 Measurements

According to the ISO/DIS 15869.2, the gas temperature within the hydrogen cylinder should not be exceed over 85 ℃ for the type IV cylinder[5]. Therefore, the present study intend to examine the acceptability of ISO draft code for a type IV cylinder, which is manufactured in Korea, during fueling process of hydrogen. The time history of gas temperature within the type IV hydrogen cylinder was measured for the condition of charging pressure from 0 MPa to 35 MPa. The gas temperature distributions during the fueling process were also investigated for the different initial amount of hydrogen. As seen in Fig. 3, strain gauges were attached on the surface of the dome and cylinder part to measure the order of expansion of cylinder during the fueling process. Thermocouple mounting units with six T-type thermocouples were inserted into the cylinder through the end plug side, and positioned near the dome and cylinder part. The external surface temperatures on the valve, the end plug, dome and cylinder part were measured with the T-type thermocouples, and a infrared camera was used to observe the overall external temperature distribution during the fueling process. In practice, the hydrogen cylinder may not be completely empty when the hydrogen fuel vehicle arrives at the refueling station. The present study examines the effect of initial pressure of hydrogen cylinder on temperature change during the fueling process. The gas temperature inside the cylinder and outside surface temperature were measured under the different conditions of initial pressure of 0 MPa, 5 MPa, 10 MPa, 15 MPa and 20 MPa. The initial conditions of fueling tests are listed in Table 2. The complete and partial fueling tests were conducted 11 times and 3 times, respectively.

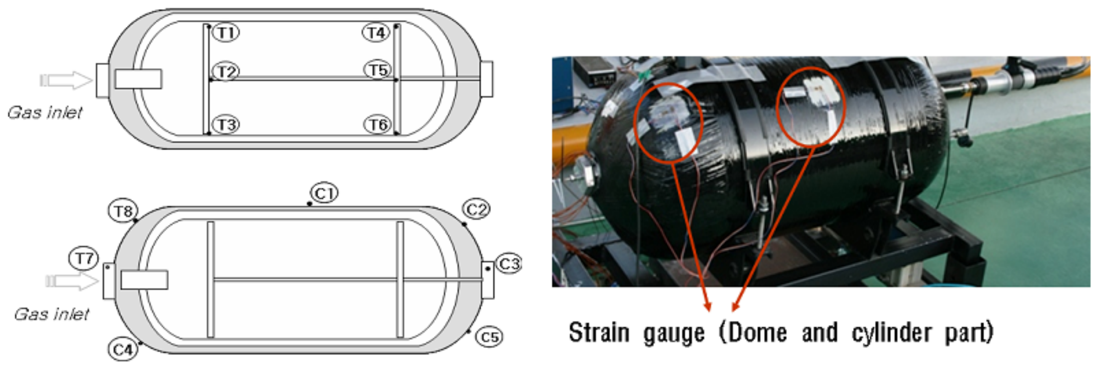

Figure 3 Locations of thermocouples and strain gauge.

Table 2. Initial conditions of the test

Type of tested cylinder	Type IV
Volume of the cylinder	72 liter
Ambient temperature	18 ~ 20 °C
Initial temperature within the cylinder	17 °C
Charging pressure	0 → 35 MPa
Charging mass	1.423 kg
Filling time	294 s

3.0 RESULTS

3.1 Temperature change within the cylinder during fueling process.

Fig. 4 shows the time history of the local temperature within the type IV cylinder during the fueling process. The pressure inside the cylinder was raised up to 35 MPa. The maximum temperature was observed at 5 minutes after fueling start of hydrogen, the gas temperature at T1 and T2 was reached to 88.4 °C and 85.3°C, respectively. The measured gas temperature was higher than 85 °C for overall measurement locations. Due to the buoyancy of the hydrogen gas, the gas temperature in the upper part of the cylinder was higher than that of the lower part [6]. After the fueling process, the temperature distribution is vertically stratified from relatively low temperature at the bottom of the cylinder to high temperature near the upper part At 10 minutes after fueling start, the maximum gas temperature within the cylinder was recorded to 69.6 °C at T4 and the minimum gas temperature was reached to 62.0 °C at T6.

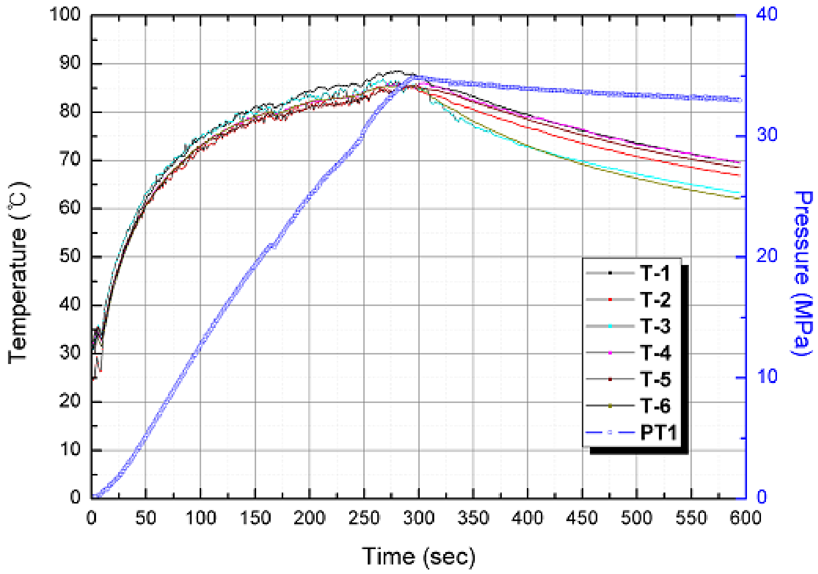

Figure 4 Time history of temperature within the type IV cylinder during the hydrogen fuelling process.

Fig. 5 compares the measured temperature along the horizontal direction at the same vertical position of the cylinder. When the measured gas temperature in the dome part of the cylinder is compared with that of the end plug part, the temperature near the dome part is higher than that of the end plug part. The measured gas temperature at T2 which is located in the middle of cylinder was almost similar with T5 during the fueling process.

Fig. 6 compares the measured gas temperature along the vertical direction of the cylinder at the location of dome part and end plug part. During the fueling process, the gas temperature in the middle of cylinder were lower than that of the lower part of the cylinder because of direct influence of incoming hydrogen gas from inlet. After the complete of charging process, the flow inside the cylinder is stabilized, the thermal stratification may occur due to the buoyancy.

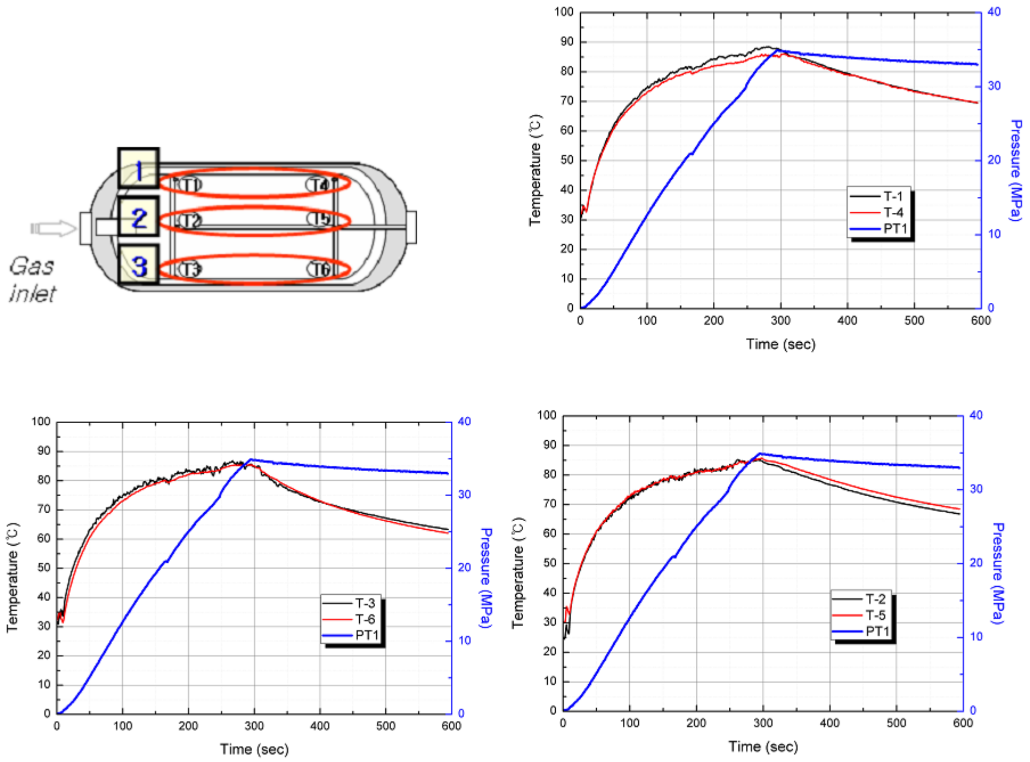

Figure 5. Comparisons of gas temperatures along the horizontal locations in the cylinder.

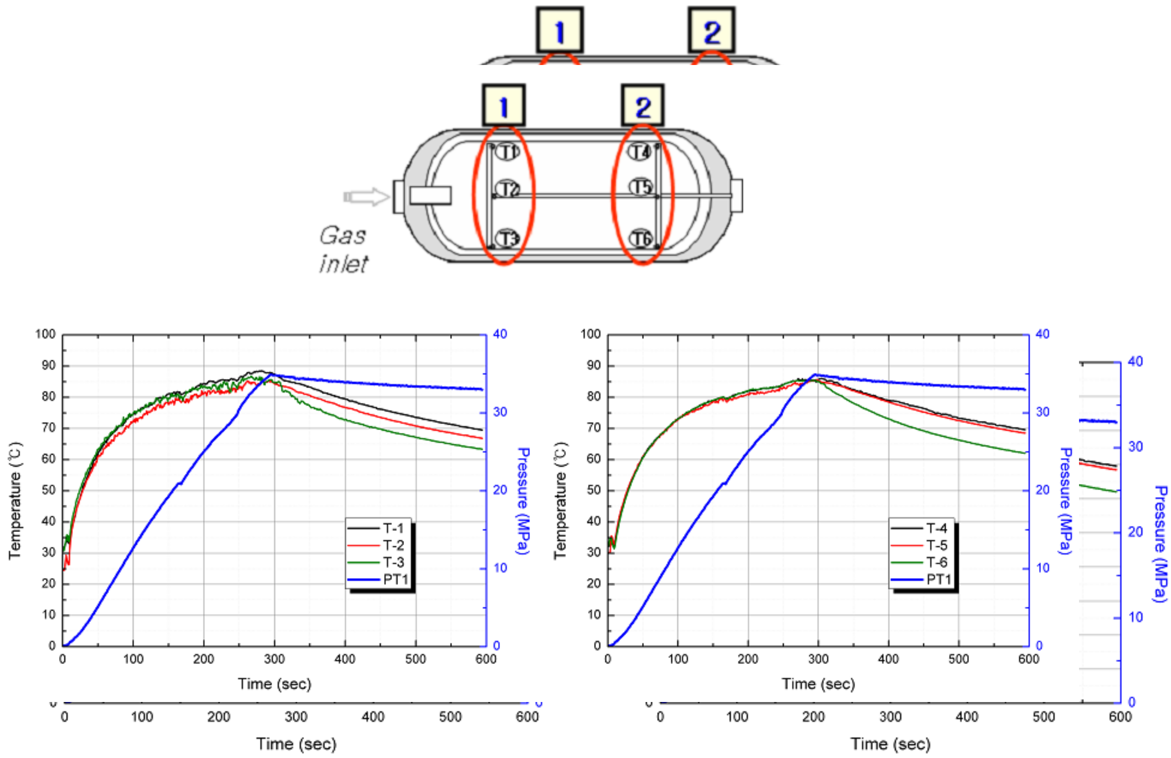

Figure 6. Comparison of the measured gas temperature along the vertical locations of the cylinder.

Fig. 7 shows the external temperature distribution on the cylinder surface taken by thermal imaging camera during the hydrogen fuelling process with pressurizing up to 35 MPa. The thermal images were taken every 30 seconds. As seen in the figure, the temperature near the nozzle, both end side of cylinder, was most quickly raised up during the fueling process. The external surface temperature of the main body was gradually increased because both of hoop and helical winding was applied to form the cylinder body, while the surface temperature near the dome which was applied only helical winding was more quickly increased than that of main body.

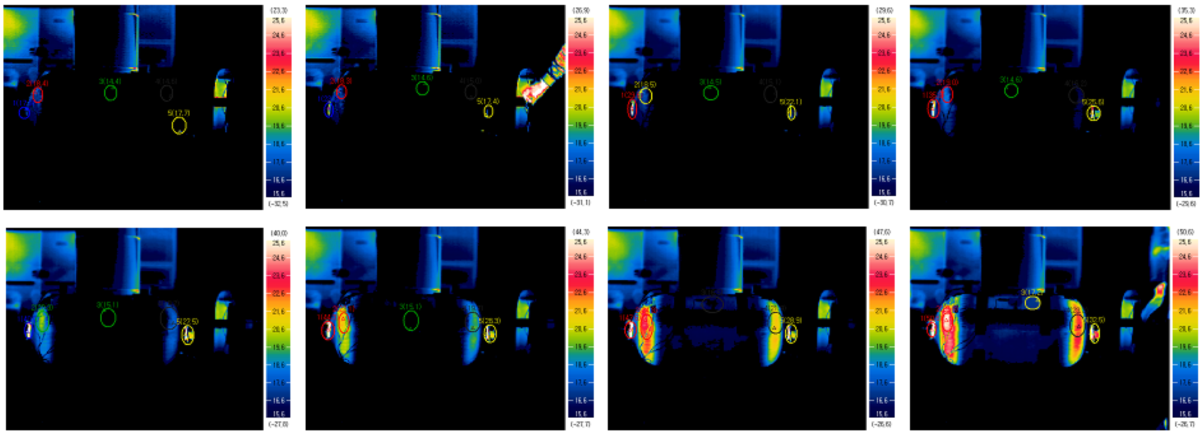

Figure 7. External surface temperature distributions measured by thermal imaging camera.

Fig. 8 shows the external surface temperature measured by the attached thermocouples on the cylinder and thermal imaging camera. The surface temperature near the nozzle was reached to maximum value 150 seconds after fueling start. Time to reach maximum temperature for the dome part and main body were taken 12 minutes and 16 minutes, respectively. The external surface temperature measured by thermocouple shows a similar trend with that of the thermal imaging camera.

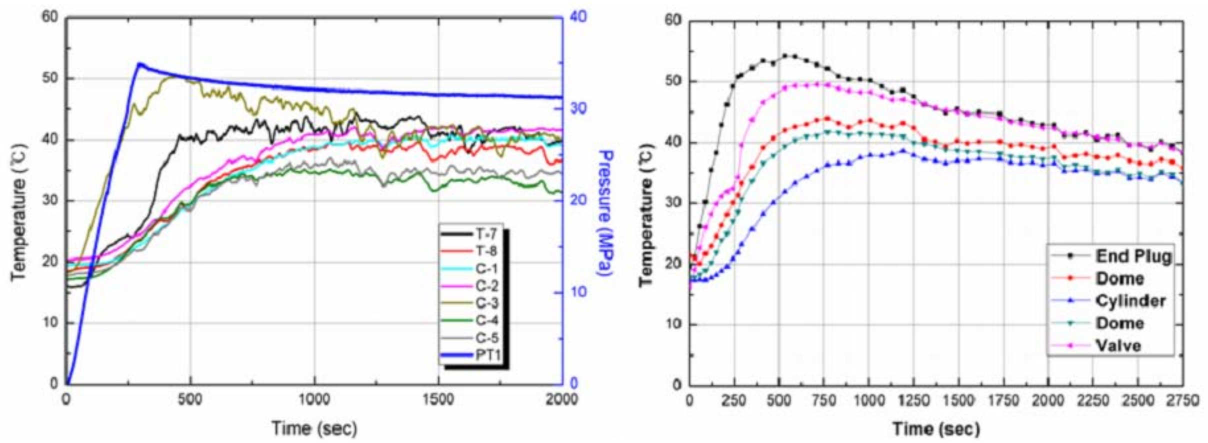

Figure 8. External surface temperature measured by thermocouple (a) and thermal imaging camera (b).

Fig. 9 shows the temperature change at T1 locations within the gas cylinder during the fueling process for the case of different initial mass of hydrogen. The initial pressures before fueling were 5 MPa, 10 MPa, 15 MPa and 20 MPa. The measured temperature at T1 reached the maximum value when the fueling process was just finished. The gas temperature within the cylinder dose not exceed 85 °C for the case of partially filled hydrogen gas cylinder.

Fig. 10 shows the charging mass of the hydrogen with different filling time. The fast fueling of hydrogen causes increase in gas temperature within the cylinder and decrease in total charging amount of hydrogen.

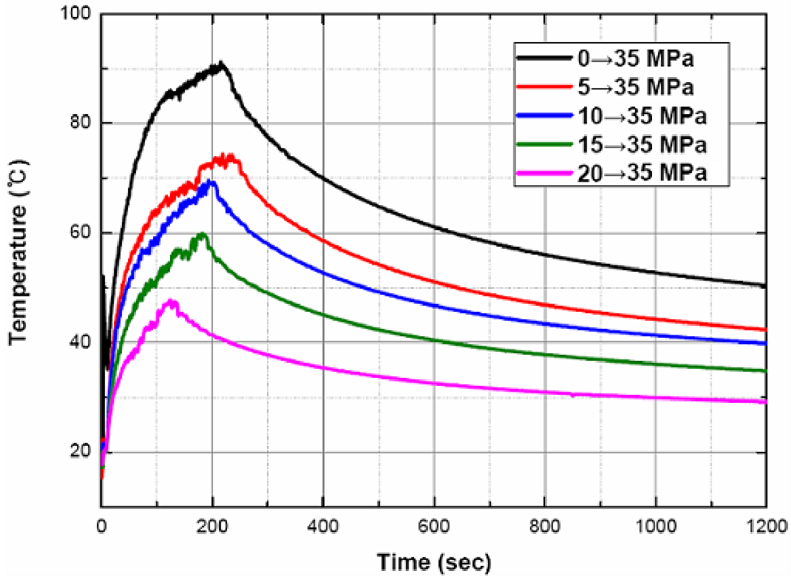

Figure 9. Temperature change at T1 location within the cylinder for different initial mass of hydrogen..

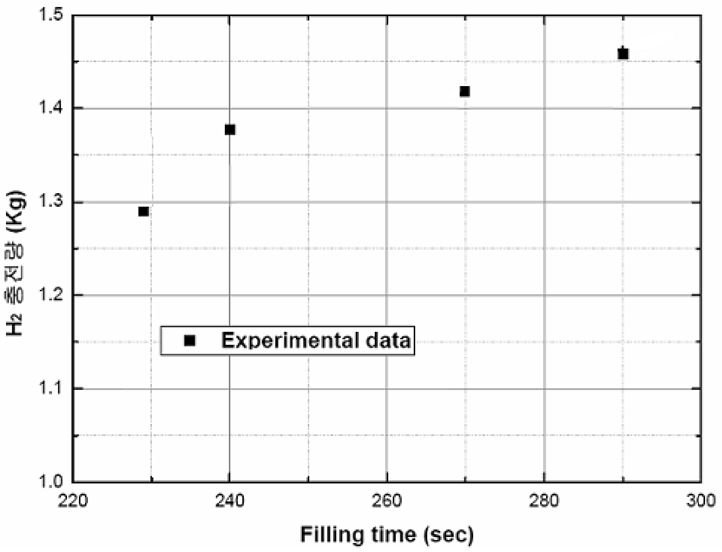

Figure 10. Total charging mass of hydrogen for the different filling time.

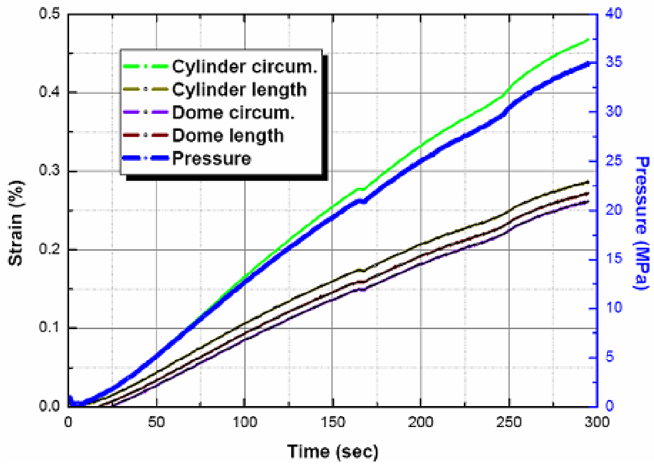

Figure 11. Expansion of cylinder during the fueling process

Fig. 11 shows the order of expansion of cylinder during the fuelling process measured by strain gauges attached on the cylinder surface. The measured strain along the circumference of main body cylinder was about 2 times higher than that of the other part of the cylinder.

4.0 CONCLUSIONS

The present study has been conducted to investigate the temperature change within the type IV high-pressure hydrogen gas cylinder during the fueling process. The conclusions are summarized as follows:

1. The measured gas temperature within the tested cylinder has been exceed 85 °C which is the limit of the ISO draft code when the pressure was raised up to 35 MPa during about 5 minutes.

2. The measure gas temperature in the upper part of the cylinder was higher than that of the lower part due to the buoyancy of pressurized hydrogen gas.

3. The gas temperature within the cylinder dose not exceed 85 °C for the case of partial refueling process and the maximum temperature within the cylinder decreases as the initial mass of hydrogen increases.

4. The fast fueling of hydrogen gas causes increase in gas temperature within the cylinder and decrease in total charging amount of hydrogen.

The current safety code in ISO/DIS 15689.2 limits the operating temperature condition ranging from -40°C to 85°C for the type IV hydrogen cylinder. But, the present study does not support the safety code during the fueling process with pressurizing from 0 MPa to 35 MPa. In practice, the temperature in the cylinder may be higher than the result of the present study for the case of higher ambient temperature condition and enclosed cylinder in the vehicle compartment. From the present study, extensive additional study needs to guarantee the safety of the type IV hydrogen gas cylinder.

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