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# Thermal control and fire safety system for test launch vehicle of KSLV-II

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## Abstract

To satisfy the requirement of thermal condition and fire safety inside the compartment of test launch vehicle of KSLV-II, active method named thermal control and fire safety system adopts purging temperature controlled gas into the compartment and it can control the temperature and reduce the concentration of flammable gases. Design on the system for test launch vehicle is explained and the test results are described. As a result, thermal control and fire safety system is worth introducing for space launch vehicle in terms of temperature control, pressure adjustment and reliable fire safety during the test.

## 1. Introduction

Thermal control and fire safety are essential matters for a space launch vehicle using liquid propellants. For these important environmental issues active and passive management methods are adopted to the launch vehicle simultaneously. For the thermal control, thermal protection system is applied to the launch vehicle structure especially to the cryogenic tanks and rear fuselage such as base plate that is exposed to the hot exhaust plume. This thermal protection system is classified as passive method for the thermal control. In addition to the thermal protection system there is active method for the thermal control that is supplying the temperature controlled gas into the compartment of the launch vehicle that can convectively control the temperature of the compartment. The term compartment as used herein refers to a space inside the launch vehicle, which is adjacent to the propellant tank. Usually avionics system is mounted inside the compartment.

For the fire safety, there are passive and active methods too [1, 2, and 3]. Leakage controlling, using tight sealing system and management of static charging, etc. are the passive method to prevent the hazardous gases sources for the fire and explosion. However in reality, leakage is inevitable for the high pressure pneumatic and hydraulic system. Thus, active technique is needed to reduce the concentration of hazardous or flammable gases that can cause fire and explosion. For this purpose, inert gases such as nitrogen or helium is supplied to the compartment with positive pressure. In the normal procedure of launch vehicle preparation, temperature, humidity and cleanliness controlled air is supplied to the launch vehicle before the propellant loading for the thermal control. At the right time before propellant charging, air is changed to the inert gas such as nitrogen or helium, normally nitrogen, and the inert gas is also temperature and cleanliness controlled by the ground support system. By the way, the active methods for the thermal control and fire safety are obtained by the gas supplying we can call this combined active system as thermal control and fire safety system.

For more certain fire safety for the launch vehicle during the flight, fire prevention system would be applied. For example, Atlas space launch vehicle adopts the fire safe system that the pneumatic purge is switched from the ground to fire safety system at 9.9 seconds before lift off the launch vehicle by enabling blowdown of the airborne helium purge bottle [4]. The purge then continued until the helium supply was depleted, by which time the vehicle had cleared the atmosphere. Almost all the launch vehicle adopt the thermal control/fire safety system whereas application of fire prevention system depends on the vehicle.

In test launch vehicle of Korean Space Launch Vehicle II, thermal control and fire system is definitely adopted. The purpose of this paper is to introduce the design and analysis of thermal control and fire system of test launch vehicle of KSLV-II and test results of manufactured system also. For the system analysis the one-dimensional fluid system analysis software, flowmaster [5], was used.

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## 2. Thermal control and fire safety system design, analysis and test for test launch vehicle of KSLV-II

Thermal control and fire safe system for the test launch vehicle of KSLV-II is composed of mainly gas discharge manifold, gas supply pipe, vent device, interface with ground system and sensor block. This composition is described in Figure 1. Gas discharge manifold is used for the gas distribution inside the compartment. The distributed gas flow should not make dead zone where flow velocity is zero or flow circulates. Gas supply pipe's role is to deliver the supplied gas from ground support system to the gas discharge manifold with less pressure drop. Usually the pipe diameter is designed with regard to the gas flow velocity inside the pipe and the thickness of the pipe is selected with regard to the pressure of the gas. Vent device is used to expel the supplied gas out of the compartment, which maintain the pressure inside the compartment properly. It also prevent the dust in outside from entering into the compartment. Interface with ground system is necessary for the mating with umbilical system through which the gas is delivered from ground support system to on-board system such as thermal control and fire system. Finally sensor block which consists of temperature, humidity and pressure sensors measures the environmental condition during the gas supplying inside the compartment.

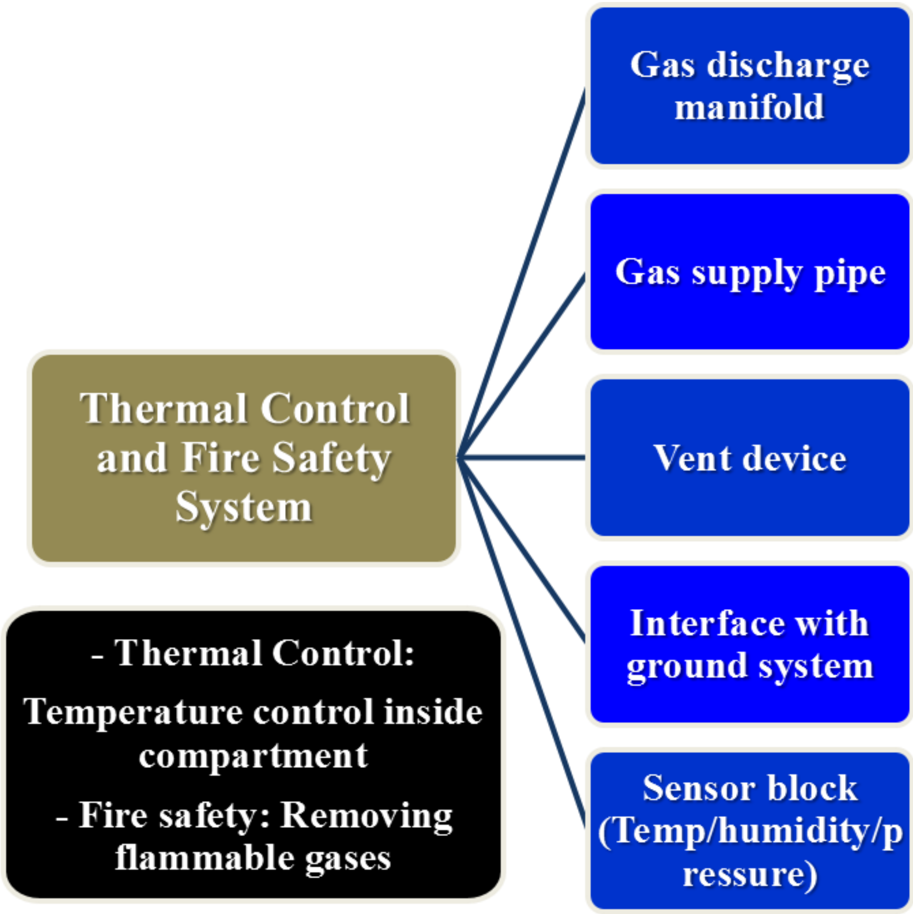


Figure 1: Composition of thermal control and fire safety system for test launch vehicle of KSLV-II

### 2.1 Design of thermal control and fire safety system for test launch vehicle of KSLV-II

The schematic diagram of thermal control and fire safe system for the test launch vehicle of KSLV-II is depicted in Figure 2 [6]. As shown in the schematic the gas source from the ground support system to rear compartment and inter-tank compartment of 1$^{st}$ stage is the same and the 2$^{nd}$ stage gas source is another one. The ground gas supply pressure is high and nearly 10 bar absolutely. The manifold is ring type and there are several holes to distribute the gas evenly

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so that the distributed gas acts like barrier. At the holes on the manifold flow choking occurs and mass flow is controlled by this flow choking. With orifice in the pipe line, flexible flow control is also available.

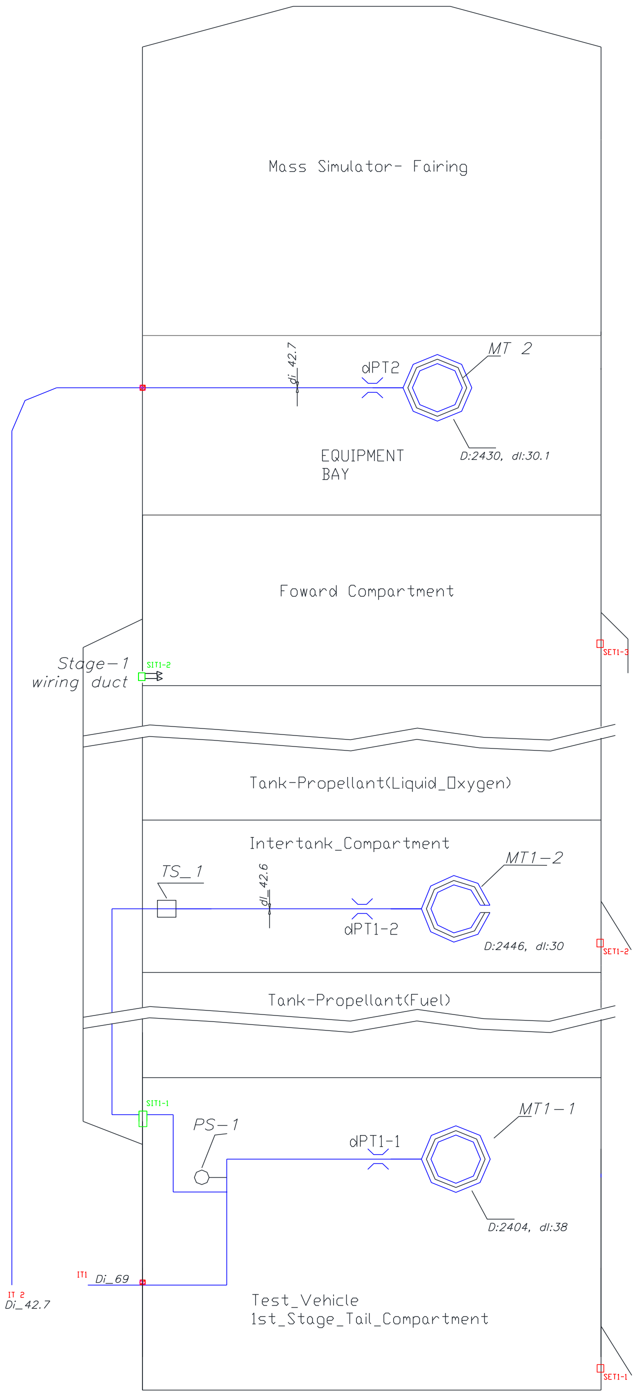


Figure 2: Overall schematic of thermal control and fire safety system for test launch vehicle of KSLV-II

In the schematic diagram, there are several notation for the system and the system hierarch and its notation are described in Table 1. The level is different from the launch vehicle system and in test launch vehicle of KSLV-II level 4 is the thermal environment just below the stage element level. In Table 1, MT means manifold, gas supply is notated as blue line, SET means vent devices, red square means interface with ground system. PS, HS and TS are pressure sensor, humidity sensor and temperature sensor. In the schematic diagram, the sensor block is not depicted separately. Only PS and TS on the pipe are included. The sensor block composed of PS, HS, and TS is installed inside each

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compartment. More detailed schematic of thermal control and fire safety system for the inter-tank compartment is shown in Figure 3

Table 1: Thermal control and fire safety system hierarch notation in schematic

| Level 4 | Level 5 | Level 6 | Notation in schematic |
|---|---|---|---|
| Thermal environment | Thermal control and fire safety | gas discharge manifold | MT1-1, MT1-2, MT2 |
| | | gas supply pipe | Blue line |
| | | vent device | SET1-1, SET1-2, SET1-3 |
| | | Interface with ground system | Red square |
| | | Sensor Block | PS, TS, HS |

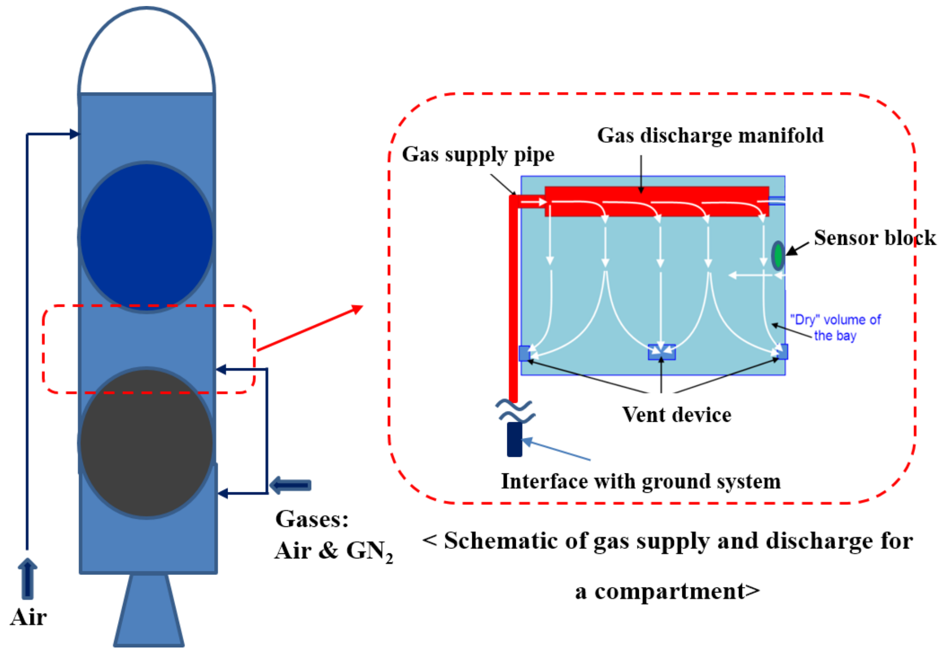


Figure 3: Detailed schematic of thermal control and fire safety system for the inter-tank compartment of test launch vehicle of KSLV-II

## 2.2 Thermal control and fire safety system modelling for analysis

In the design of thermal control and fire safety system, the main design parameter is to set the orifice size according to the flow rate requirement with regard to the pressure interface condition from the ground support system. In order to calculate the optimum orifice specification with input pressure and flow rate result, one dimensional thermal and

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fluid analysis software flowmaster is adopted and the components such as pipe, bend, T-connection parts with orifice should be modelled with program. Since the pressure is high, the real gas model RKS state equation is used [7].

One-dimensional continuity equation, momentum and energy equations are applied to simulate the steady one-dimensional compressible flow in the system. In order to derive the pressure drop coefficient due to the surface friction inside the pipe, the formula of Colebrook-White, which optimizes the values of the Moody Chart, is applied, and the roughness of the piping is chosen as 0.025 ㎜ which is the roughness value of the newly manufactured pipe [8]. The heat transfer inside the piping is mainly due to the heat transfer by the gas inside the pipe.

The orifice flow analysis is the most important process and can be obtained by iteratively carrying out the process of finding several important parameters. During the iteration, the initial shrinkage factor and loss factor are corrected to obtain the data from the incompressible flow data and then applied to the compressible flow, which is obtained by calculating the shrinkage coefficient and the loss coefficient in the compressible orifice flow. When the final corrected loss factor Kc is derived. This procedure is summarized as below [9];

- At first calculating the contraction coefficient, Cc
- Calculating the loss coefficient, Ki , to this point, incompressible data is used
- Obtaining the apparent area ratio
- Getting the discharge coefficient, Cd
- For Cc, compensating compressible effect, CCc
- Modified loss coefficient of Kc is re-calculated
- Pressure and mass flow rate equation are derived

The pressure and mass flow rate can be obtained using the pressure and mass flow equations as follows [9].

$$\frac{P_{t2}}{P_{t1}} = 1 - K_c\left(1 - \frac{P_{s1}}{P_{t1}}\right), \frac{P_t}{P} = [1 - \frac{(\gamma-1)M^2}{2}]^{\frac{\gamma}{\gamma-1}} \tag{1}$$

$$\frac{\dot{m}(ZRT_t)^{1/2}}{AP_t} = \gamma^{1/2}M/[1 + \frac{(\gamma-1)M^2}{2}]^{\frac{\gamma+1}{2(\gamma-1)}} \tag{2}$$

The continuum and incorporated momentum and energy conservation equations are as follows [9]:

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} + \frac{1}{\rho}\frac{\partial P}{\partial x} = \frac{W}{A\rho} - g \cdot sin\theta \tag{3}$$

$$\frac{\partial T}{\partial t} + V\frac{\partial T}{\partial x} + \frac{a^2}{c_p}\{1 + \frac{T}{Z}\left(\frac{\partial Z}{\partial T}\right)_P\}\frac{\partial V}{\partial x} = \frac{a^2}{c_pT}\{1 - \frac{P}{Z}\left(\frac{\partial Z}{\partial P}\right)_T\}\frac{\Omega+WV}{A} \tag{4}$$

where $\dot{m}$ is mass flow rate, Kc is orifice loss coefficient for compressible, $T_t$ is total temperature, $P_t$ is total pressure, A is flow area, M is Mach number, R is gas constant, Z is compressible factor, $P_s$ is static pressure, $\gamma$ is specific heat ratio. V is velocity of flow, x is one dimensional direction, A is area and g is gravity constant. Cp is specific heat capacity, $\boldsymbol{\theta}$ is the angle with respect to the gravity direction. With this analysis model, we can obtain the optimum orifice size for the required flow rate with regard to the pressure condition considering the pressure loss due to the pipe inner surface friction and several components such as bend and divergence and convergence parts.

Calculated orifice size is listed in Table 2 with regard to the flow rate. As described before, the reference pressure is below 10 bar absolute and temperature of nearly 20 degrees of Celsius.

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Table 2: Orifice size according to the required flow rate

| Flow rate | **Deduced orifice size** |
|---|---|
| 1400 kg/hr | 17 mm |
| 2500 kg/hr | 22.7 mm |
| 1200 kg/hr | 16 mm |

## 2.2 Thermal control and fire safety system of test

In order to perform the performance test on the thermal control and fire safety system alone before integrated to the test launch vehicle, the assembly for the whole system is performed first. The assembled photograph is shown in Figure 4 [6]. In this process, a pressure sensor is attached to the so-called umbilical-edged jig shear (frontal umbilical jig shear) to measure the pressure that is the basis of the test. The applied pressure sensor is the Keller sensor [10] and the Kulite ETM-375 [11] sensor at the back of the check valve to check the differential pressure by the check valve. The flowmeter used in the system test is the Sierra 780S [12] and the maximum measured flow rate is about 6000 kg/hr, which is a thermal mass flow meter. This thermal mass flowmeter has a compensation function for pressure conditions.


Figure 4: Integration of thermal control and fire safety system of test launch vehicle of KSLV-II

Tests for thermal control and fire safety system are to be finalized to ensure that the required flow rate is supplied for the pressure conditions of the ground-use umbilical. Currently, thermal control and fire safety testing facilities are installed in the Naro Space Center for the development of thermal control and fire safety systems, which can be used to test high pressure gas supply. Figure 5 is a graphical user interface (GUI) for the thermal control and fire safety test

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facility developed for testing thermal and fire safety systems. Through this operating program, it is possible to confirm the preconditions for the test such as the pressure state of the high pressure gas and to maintain the ground pressure condition by operating various valves.

The sequence for the flow test for the thermal control and fire safety system is shown in Table 3[6].

Table 3: Test sequence of thermal control and fire safety system

| Step | **Test condition and sequence** |
|---|---|
| 1 | Equipment high pressure gas condition check:> 22 MPa |
| 2 | Confirmation of pressure and flow sensor signal, check valve operation |
| 3 | Check heater status and heating performance |
| 4 | Test facility control program operation: Open supply valve |
| 5 | Heat control / fire safety system Input pressure regulation:<br>0.7 MPa ~ 10 MPa |
| 6 | System flow value check and stabilization wait |
| 7 | Determination of final flow value according to design pressure |

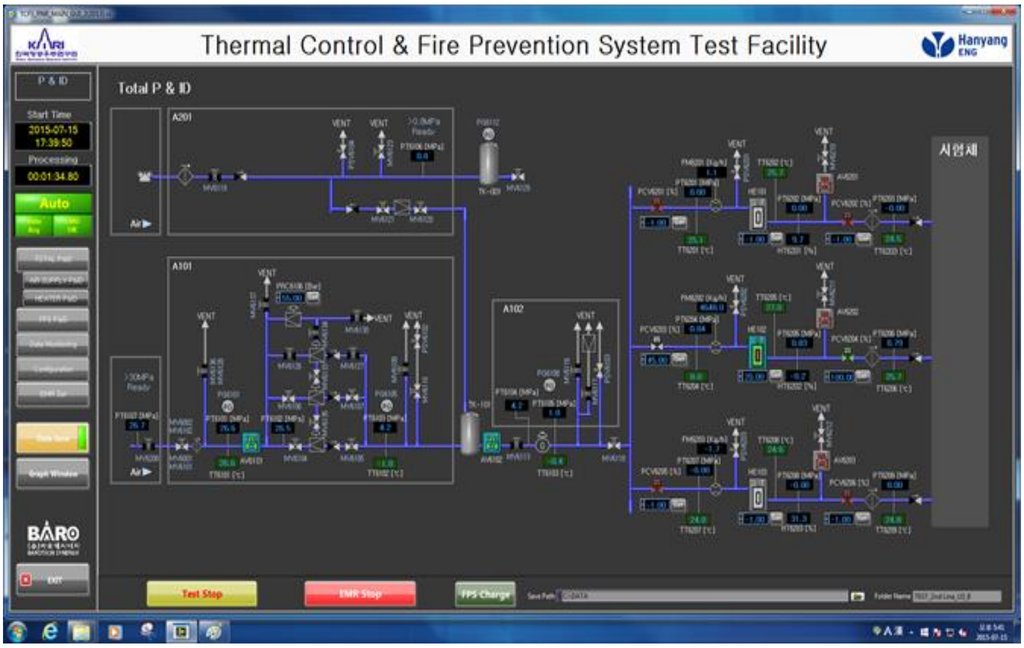


Figure 5: GUI of Thermal Control and Fire Safety Test Facility for Flow Test for TC/FSS

After finishing the stand alone test of thermal control and fire safety system, it was integrated to the test launch vehicle. According to the development sequence, integrated test launch vehicle should be qualified performing the full engine combustion with the same flight sequence. Figure 6[13] shows the integrated test launch vehicle and exhaust plume during the final stage qualification test. Compartments inside the test launch vehicle are in harsh environment condition

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because the tank is filled with liquid oxygen so the temperature is very low and rear compartment is exposed to the hot combustion plume that is the source of excessive radiative heating. Thus, during the test thermal control and fire safety system was operated and the compartments were under the temperature controlling.  During the test, supplied gas was gas nitrogen and the temperature and pressure inside the compartments should satisfy the requirement.

Figure 6: Final stage qualification test of test launch vehicle of KSLV-I

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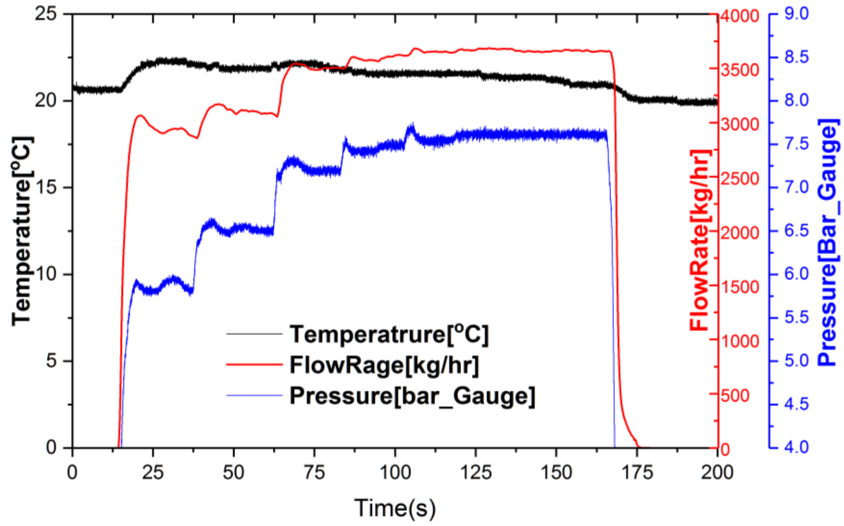
## 3. Results and discussion

### 3.1 Standalone test results of thermal control and fire safety system

Test variables that can be confirmed through this test are the flow rate value of the thermal control and fire safety system designed and manufactured for the input pressure condition, and additionally to check the change of the flow value with respect to the pressure change of the input stage. In addition, the flow rate of the gas injected from the manifold can be checked when the gas is supplied. In addition, noise is generated when the gas is injected. This noise can be measured and the change in noise value according to the flow rate can be confirmed. The flow rate test results are shown in Figure 7[6].

The red line is the flow rate value, the blue is the pressure value, and the black line is the temperature value. Typically, when the pressure value is between about 0.55 MPa and 0.75 MPa, the flow rate value is about 2700 kg/hr to about 3700 kg/hr and satisfy the requirement. As shown in the result graphs, temperature controlling was done well enough to satisfy the requirement that is 20 ℃ with deviation of ± 5℃.



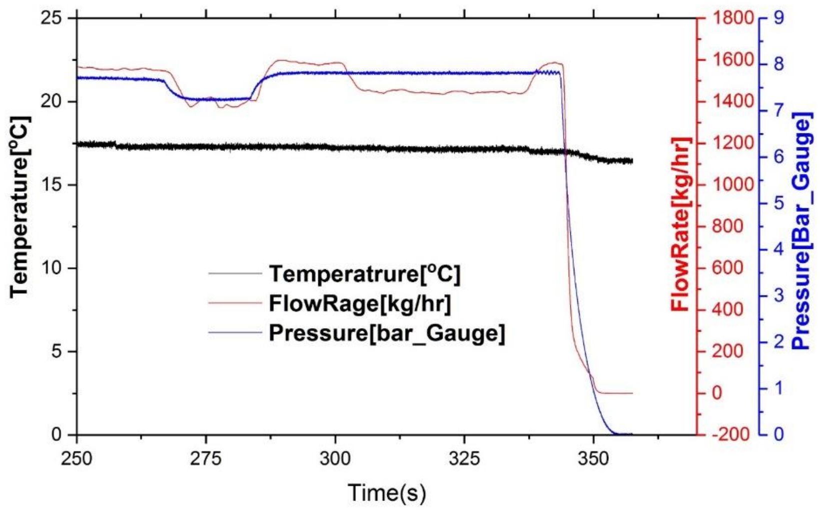




Figure 7: Standalone test results of thermal control and fire safety system

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### 3.2 Test results in the final stage qualification test

Figure 8 shows the temperature variation inside the comparments during the final stage qualification test. The temperaure range is within the requirement. From these results, it is found that the thermal control and fire safety system for the test launch vehicle of KSLV-II was designed, manufactured and integrated well satisfying the requirement.

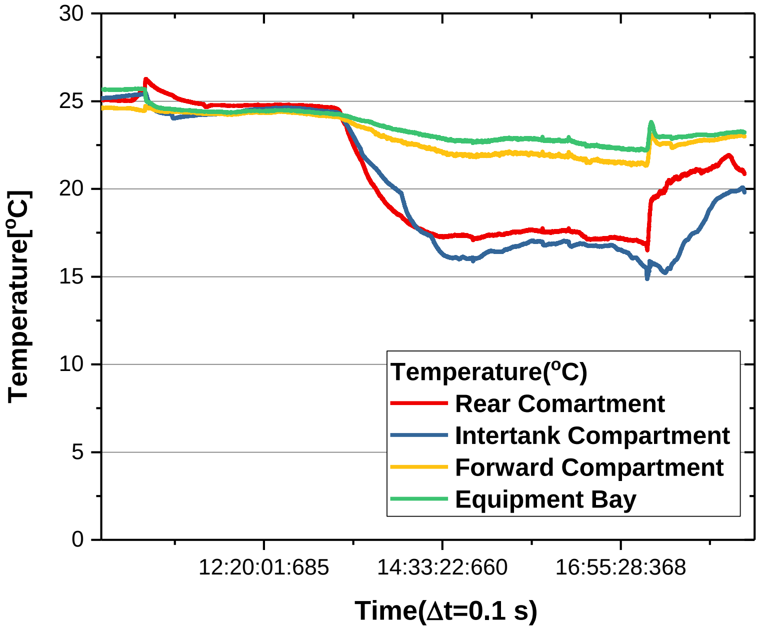


Figure 8: Temperature variation inside the compartments of test launch vehicle of KSLV-II by operation of thermal control and fire safety system during the final stage qualification test

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