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PRACTICAL USE OF LNG COLD ENERGY FOR UCR COOLING

Main author

H. Y. Kim

South Korea

ABSTRACT

The present city-gas law doesn't permit to set up a common electrical air conditioner for UCR (Unloading Control Room) cooling because of an explosion-proof area. To avoid this legal restriction, KOGAS considers to apply LNG cold energy from no-insulated pipes of unloading arm. Thus, this study is to design an cooling system employing LNG cold energy for UCR cooling.

First of all, we need to construct a frost model to predict frost thickness from the cold pipes to estimate the heat transfer of LNG cold energy. The dynamic frost growth model is compared with Schneider frost growth model and O'Neal & Tree frost growth model. The model shows a good agreement with two other models and then is applied to design a cold air jacket, which is a device to recover the cold energy from LNG. We numerically obtained the maximum thickness of frost under the possible operation conditions of UCR cooling. The detailed design data of the air jacket could be determined through numerical investigation on air flow, air temperature, and pressure drop as design factors. The thermal features of air jacket are carried out with an one-dimensional in-house code and are double-checked by a commercial CFX code for 3-dimensional flow analysis.

The technical specifications of an explosion-proof fan are estimated through a pipeline network analysis known as the Newton method. From the results, the rated air flowrate, air head, and required power are obtained for the final decision of technical fan specifications. We employed not an electrical fan but an air-driven fan for the safety of the unloading area. Also we performed a thermodynamic simulation on the UCR cooling system under targeted summer season. The cooling load of UCR is estimated by considering window glasses and sandwich-panels as a wall. The cooling capacity of the air jacket reveals about 0.24 RT (Refrigerating Ton), which can cool down a room of about 7.8 m^2. It is possible for two air jackets to keep the room temperature of UCR to about 22.0 ^oC.

Finally we investigated the ventilation efficiency in relation to the position of diffusers. We design duct size to keep the air speed of 8.0 m/s in the duct. The diffusers which supply and return cooling air at the end of the duct were designed to lower the air speed and uniformly blow out cooling air. It was identified through 3-dimensional flow analysis by the CFX commercial code.

We'll address the effect on the practical use of UCR cooling based on the results of this work. Presently Tongyoung R/T (Receiving Terminal) is processing the installation and field test of UCR cooling system. We will be able to show the effect of substantial use on UCR cooling, which employs LNG cold energy. This technology will be beneficial for the cooling of local residential buildings in LNG receiving terminals.

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PRACTICAL USE OF LNG COLD ENERGY FOR UCR COOLING

1. INTRODUCTION

This paper describes the practical use of LNG cold energy for UCR cooling in the presence of the restrictions of Korean city-gas law. KOGAS considers LNG cold energy from the bared pipes of unloading arm for UCR cooling. Thus, the present paper deals with concerns regarding the design of UCR cooling system.

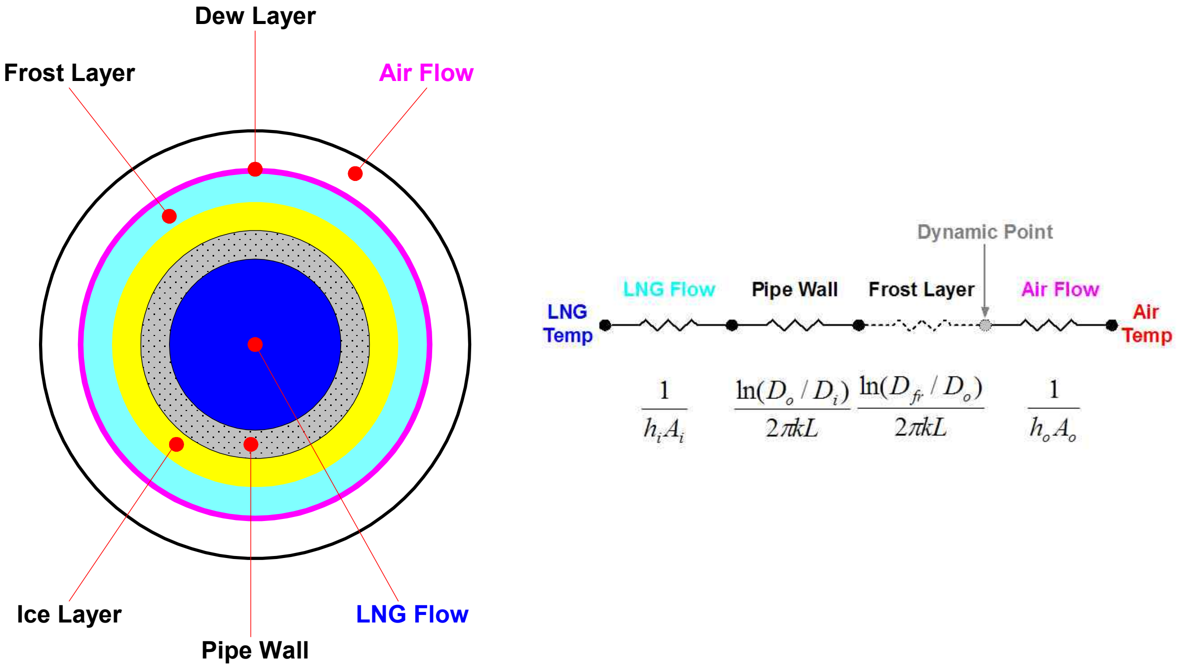
A dynamic frost model, which employs a numerically iterative method, is developed to predict frost thickness from the bared pipe. An air cold jacket to recover LNG cold energy is designed as considering the maximum frost thickness from the surface of bared pipe. The thermal characteristics of the air jacket are conducted with an one-dimensional in-house code and a three-dimensional commercial CFX code. As a matter of course, these results approximately coincide with each other. The cooling capacity of a jacket reveals 0.24 RT, which can cover a room space of 7.8 m^2 in summer season. Air flow is determined to keep a constant heat transfer rate in the jacket, and a fan & duct sizes are done to minimize cost and pressure drop. Finally ventilation efficiency are investigated in relation to the position of diffusers. It is identified through three-dimensional flow analysis with the CFX commercial code.

The details of this work will be discussed on only the design of the UCR cooling system in the subsequent sections. Because the installation and the field test of the system are still continuing, this manuscript doesn’t include them.

2. DYNAMIC FROST GROWTH MODEL

When air contacts a cryogenic pipe, it is condensed and then is changed to frost. The frost layer results in a significant heat transfer resistance and acts to restrict the air flow as blockage. This mechanism has come to occupy an important position in designing the air cold jacket as a recovery device of LNG cold energy. The frost thickness are deeply related to heat flux from air to LNG. However, the mechanism has not been reported to our knowledge. Prior to the design of the jacket, we have to devise a frost growth model of wetted air flow.

A physical model consists of air flow, dew layer (condensed water), frost layer, ice layer, pipe wall, and LNG flow as shown in Fig. 1a. The dew layer from moisture air is considered as the condensed heat transfer of air flow and the ice layer is replaced with the frost layer to reflect severe cases. Fig. 1b shows a mathematical model as expressed with a thermal circuit. The dynamic point indicates the variable thickness of frost with heat flux. The sensible temperature of the point is fixed as the temperature of 0.0 ^{o}C all the way. This means that we can calculate the thickness of frost with the



(a) (b)

Fig. 1. Frost growth model : (a) physical model, (b) mathematical model.

numerically iterative method. If the air and LNG flow are constant, we can easily find the heat flux from air to LNG. Then the thickness of frost layer could be determined with both the surface temperature of frost layer and heat flux. This model is compared with Schneider frost growth model [1] and O'Neal & Tree frost growth model [2], which are time dependent as empirical correlations. On the other hand, the dynamic mode is time independent and heat flux dependent. When unloading LNG starts from LNG ship, it takes about a hour from rate-up to full-rate. Fig. 2 shows the comparison of frost models.

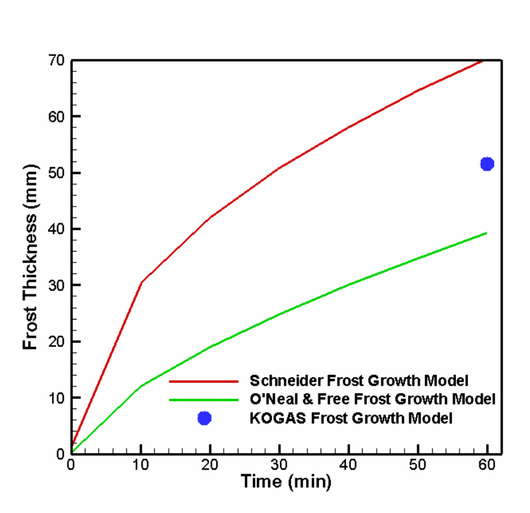


Fig. 2. Identification of KOGAS's frost model.

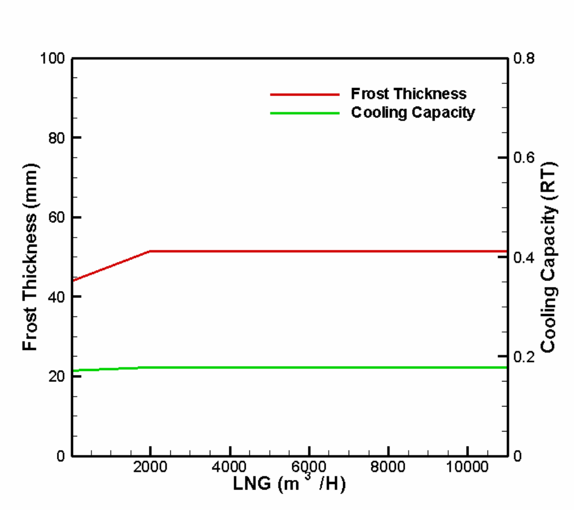


Fig. 3. Frost thickness with LNG flow.

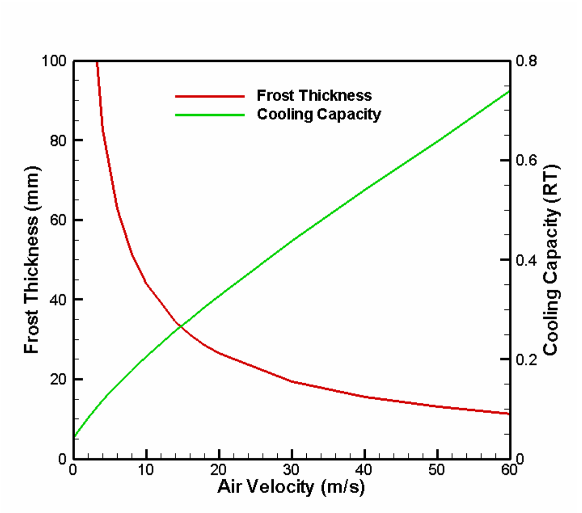


Fig. 4. Frost thickness with air speed.

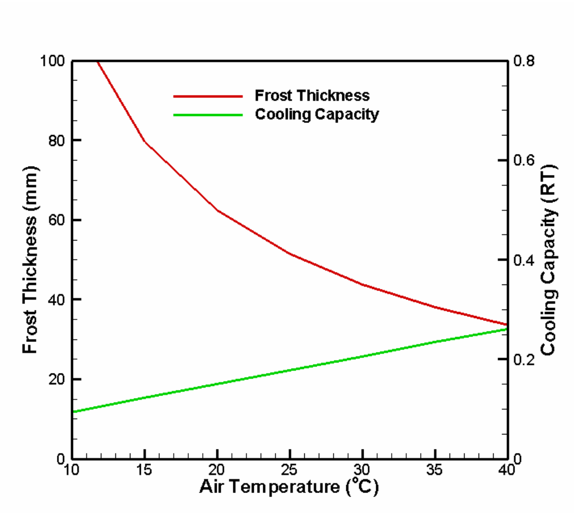


Fig. 5. Frost thickness with air temperature.

The dynamic model developed from KOGAS is in good accord with two models described above. We performed the prediction of frost thickness with LNG flow, air flow, and air temperature. Fig. 3 shows frost thickness and cooling capacity with the change of LNG flow when the speed and temperature of air are 8.0 m/s and 25.0 ^{o}C, respectively. We could find that the frost thickness and cooling capacity are independent of LNG flow above 2,000 m^{3}/H. They are fairly sensitive with the air speed as shown in Fig. 4. Also, they are easy to change with the air temperature as illustrated in Fig. 5.

From the results, we could determine the maximum thickness of frost from air flow contacted on ultracold pipe. Under the ordinary operational conditions, the maximum thickness, which doesn’t give an effect on the blockage of air flow, is revealed as 60.0 mm.

3. DESIGN OF UCR COOLING SYSTEM

3.1 Air Cold Jacket

As we consider the maximum thickness of frost on the cryogenic pipe and the air speed available, we can find the optimum diameter of air cold jacket. The air jacket is mathematically modeled by the thermodynamic energy equation [3], and the heat transfer of conduction and convection [4]. A one-dimensional code is developed to predict the cooling effect with the jacket configuration.

Fig. 6 shows required air flowrate and cooling effect with jacket diameter, and constant air speed and temperature. As the jacket diameter is decreased, the cooling effect is increased. However it can cause the air blockage in the jacket. From the results, we could find the optimum diameter of the jacket, which is revealed as about 0.55 m. And the proper size of inlet/outlet on the jacket could be determined under reasonable pressure drop and air. As illustrated in Fig. 7, the optimum size of the air

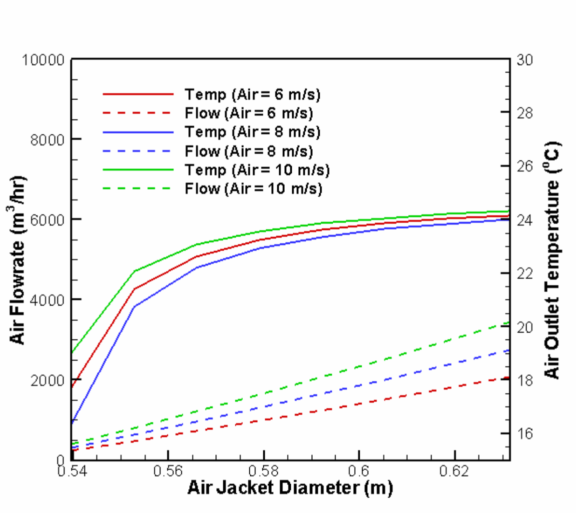


Fig. 6. Cooling effect with jacket diameter.

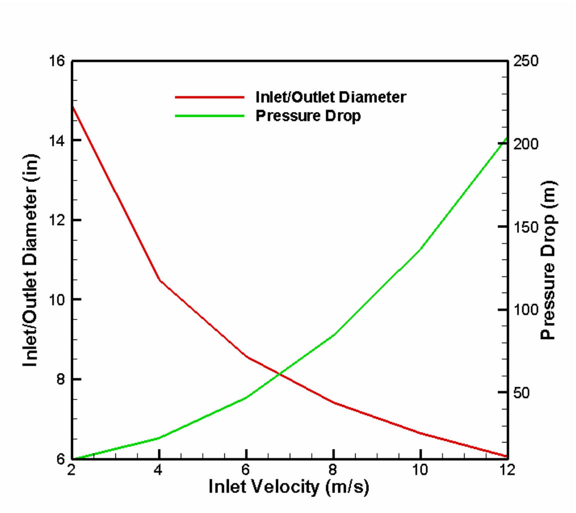


Fig. 7. Inlet/outlet size with the inlet velocity of air.

gate is suggested to 200.0 mm. The gate is connected to corresponding ready-made circular duct on the market by manufacturers.

The devised air jacket is simulated to analyze the cooling effect with frost thickness. The physical domain of the jacket is considered only fluid region except the frost layer and the pipe wall. The frost layer is replaced as a thermal boundary condition, which is set to a constant temperature of 0.0 °C. The geometry, which is embodied with Design Modeler, as a three-dimensional model is shown in Fig. 8. The temperature field of air jacket is illustrated in Fig. 9. Although the path of air flow is very short, the temperature is lowered more or less at the outlet of the jacket. The results of each case are given in Table 1. At the frost thickness of 60.0 mm, the air speeds of case 1, 2, and 3 are 6.0, 8.0, and 10.0 m/s, respectively. And the air speeds of case 4, 5, and 6, under the frost thickness of 40.0 mm, are 2.5, 3.3, and 4.1 m/s, respectively. Case 2 and 3 are nearest to the condition of a real system. We could

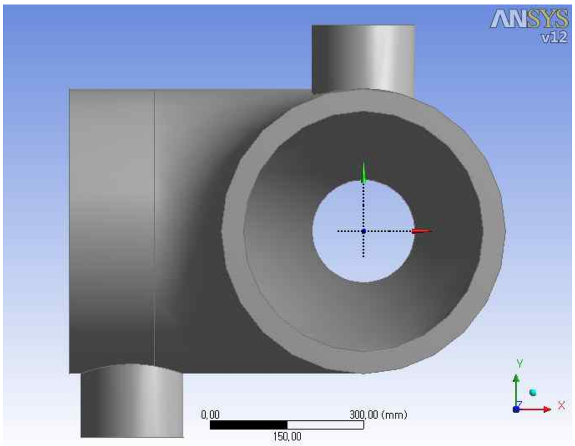


Fig. 8. Geometry of the air cold jacket.

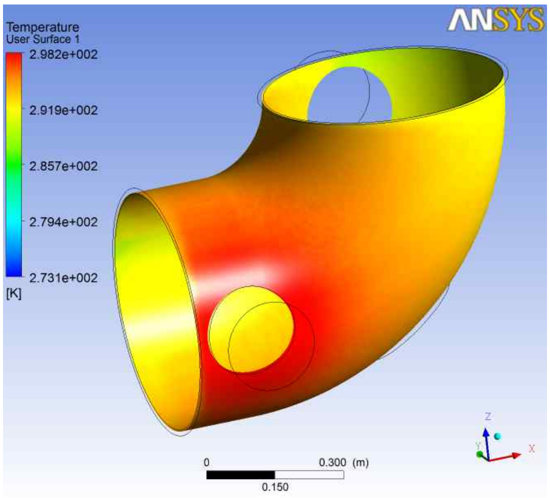


Fig. 9. Temperature field of the air cold jacket.

Item	Frost Thickness (60.0 mm)			Item	Frost Thickness (40.0 mm)		
	Cooling capacity (RT)	Pressure drop (Pa)	Temperature drop (^{o}C)		Cooling capacity (RT)	Pressure drop (Pa)	Temperature drop (^{o}C)
Case 1	0.277	322.2	6.65	Case 4	0.183	79.98	4.41
Case 2	0.342	564.3	6.16	Case 5	0.239	131.6	4.30
Case 3	0.405	876.3	5.84	Case 6	0.292	207.8	4.21

Table 1: Thermo-fluid characteristics of the air jacket with frost thickness and air speed.

identify similar cooling capacity to that of Fig. 5. Because the results of CFX were computed under an ideal condition, the values are a little higher than those of one-dimensional analysis.

3.2 Air Axial Fan

An air axial fan should have enough head to supply UCR with required cold air. To obtain technical specifications of the axial fan, we considered the UCR cooling system as a pipeline network as illustrated in Fig. 10. The pipeline network was numerically solved by the Newton method [5] as a Head-oriented method. The method employs Hazen-Williams equation as an empirical equation of pressure drop. Especially the pressure drop of the air cold jacket uses the results of the CFX commercial code. Also the pressure drop in UCR is ignored, and the entrance effect of a return port and the enlargement effect of a supply port are considered. After all, we could obtain the technical specifications of the air axial-flow fan. The rated air flow needs 11.1 m^3/min, the rated air head of 60.1 m is required, and the rated power becomes 0.13 kW.

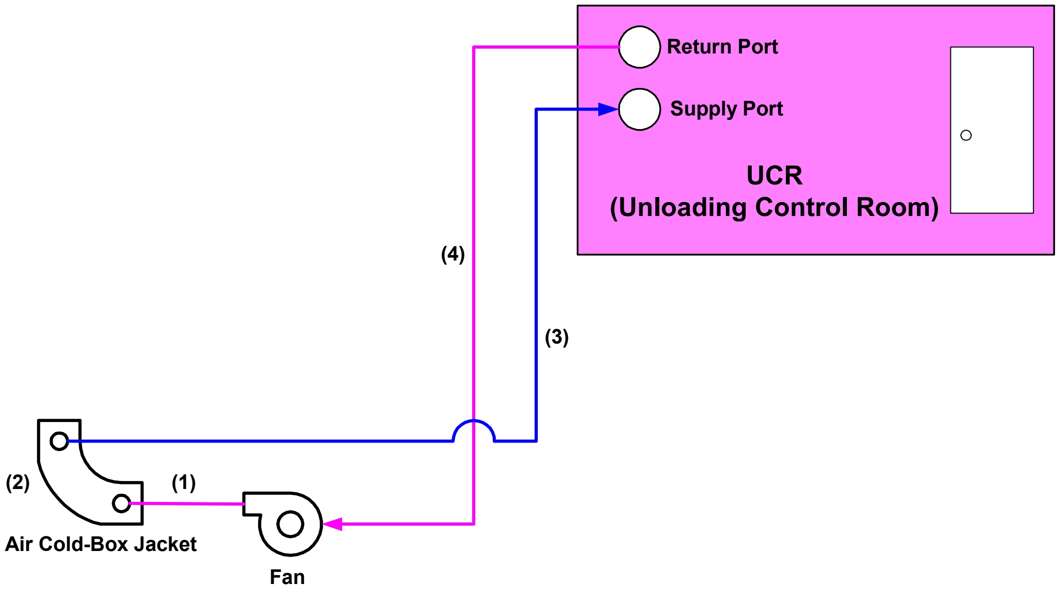


Fig. 10. Pipeline network model of the UCR cooling system.

3.3 Diffuser and Ventilation

Diffusers are examined to reduce air speed concerning comfort index and trailing edge noise in UCR. The diffusers are modeled as three-dimensional geometry as shown in Fig. 11. Also the ventilation is investigated by three dimensional flow simulation as illustrated in Fig. 12. Although the air speed is a little fast, the distribution of cold air in UCR is verified fairly good. We could identify that the cold air from the supply port directly doesn't go into the return port without any circulation.

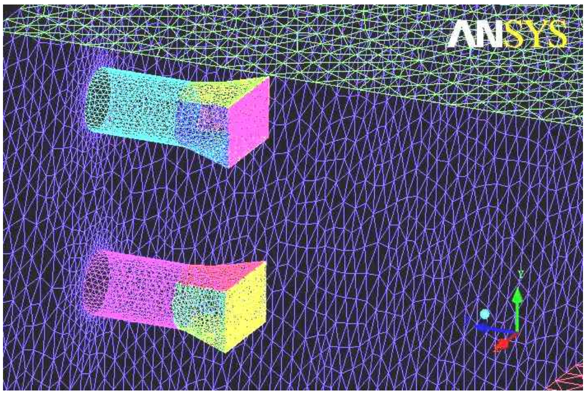


Fig. 11. 3-D modeled & meshed diffusers of UCR.

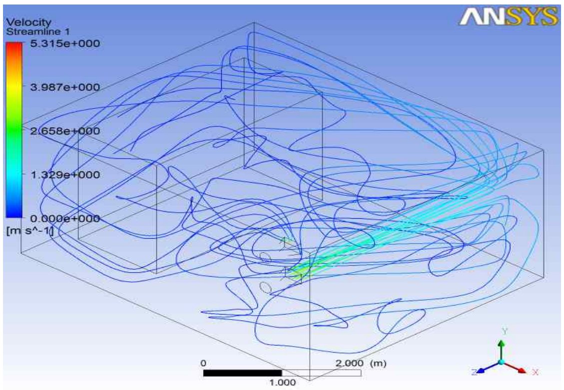


Fig. 12. Air streamlines in UCR.

3.4 System Simulation

To identify the number of the air cold jacket, we should examine the cooling load of UCR, circular duct, and fan and do a thermodynamic modeling regarding the entire system. As a governing equation, we employ the energy equation of USUF (Uniform State Uniform Flow) as follows,

$$\frac{dE_{cv}}{dt} = \sum_j \dot{Q}_j - \sum_j \dot{W}_j + \sum_i \dot{m}_i h_i - \sum_e \dot{m}_e h_e$$

where dE_{cv}/dt is the time rate of change of energy contained within the control volume, and $\dot{Q}$ and $\dot{W}$ are the net rates of energy transfer by heat and by work, respectively. And others indicate flow works, which are related to the flow of fluid. As assuming the control volume of each component, we could systematically obtain six energy equations. The system equations are numerically solved for the simulation of UCR cooling.

When one jacket operates at the outdoor temperature of 35.0 ^{o}C, the room temperature is decreased to about 27.0 ^{o}C as shown in Fig. 13. We could find that one jacket don't recover the required cooling capacity from the bared pipe. Thus, we determined to set up two jackets for UCR cooling, which is the floor area of 22.7 m^2, and needs the cooling capacity of about 0.7 RT. Fig. 14

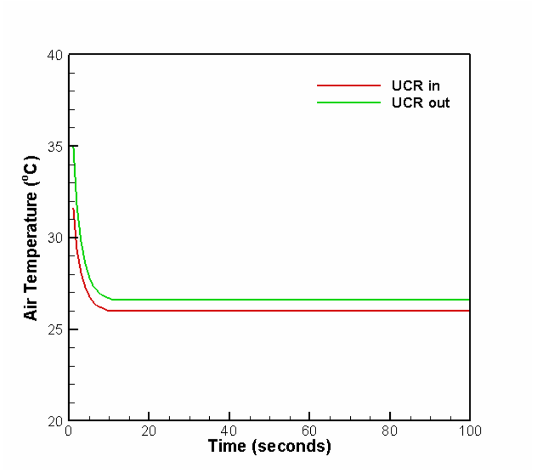


Fig. 13. Time history of UCR cooling (1 jacket).

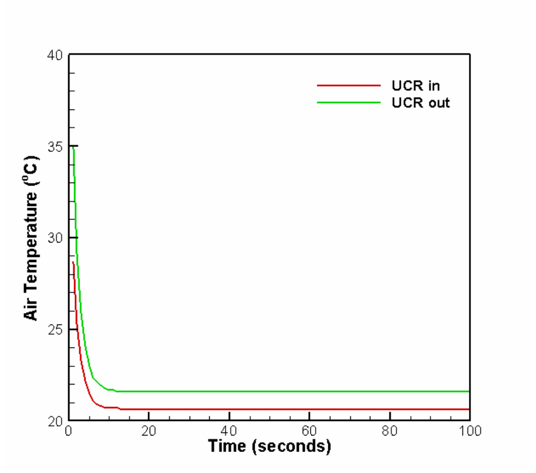


Fig. 14. Time history of UCR cooling (2 jackets).

shows the time history of inlet and outlet temperature of UCR when two jackets operates at the same time. The room temperature of UCR is dependent on the temperature of outlet. Hence the room can be kept to about 22.0 °C under the outdoor temperature of 35.0 °C.

4. CONCLUSIONS

From this study, KOGAS developed an UCR cooling system employing LNG cold energy for a residential building in the Tongyoung receiving terminal. Although the system is numerically investigated and devised, the real system, which is now being set up and tested in the Tongyoung receiving terminal, is showing the possibility of practical use.

In conclusion, if the system is identified as being beneficial for improving the work environment of UCR operators, KOGAS will apply this technology to other receiving terminals in near future.

5. REFERENCES

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