Study on the Effect of Season Conditions to the Performance of Longitudinally-Finned Air-Heating Vaporizer

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Key Words : LNG (Liquefied Natural Gas), LN_2 (Liquid Nitrogen), Vaporizer, Fin

Abstract

To return LNG to a gaseous state, it is fed into a regasification plant. For inland area, where pipelines do not exist or difficult to construct, the LNG is delivered to the inland-receiving terminal available at that area, regasified and delivered to consumers. At inland-receiving terminal, air-heating vaporizer type is usually used. To contribute in developing an efficient air-heating vaporizer, experiment on finned type air-heating vaporizer using 8 fins, 50 mm fin length (8fin50le) and 4 fins, 75 mm fin length (4fin75le) were conducted. The experiments were conducted by varying the ambient condition and the length of the vaporizer. The ambient air was controlled so that it has the same condition with air condition in every season available. LN_2 is used to substitute LNG because of safety reason. The results show that characteristics of the finned type 4fin75le vaporizer are comparable to finned type 8fin50le vaporizer at all season.

Nomenclature

ΔT	Temperature difference (inlet-outlet temperature difference) [K]
Δh	Inlet-outlet enthalpy difference [kJ/kg]
Cp	Specific heat at const. P [kJ/kg.^{o}C]
h_o	Average convection coefficient [W/m^2.K]
$\dot{m}$	Mass flow rate [kg/s]
$\dot{Q}$	Heat transfer rate [W]
$T_{m,os}$	Tube outer surface mean temperature [K]
T_∞	Room or ambient temperature [K]
$T_{m,in}$	Tube inlet mean temperature [K]
$T_{m,out}$	Tube outlet mean temperature [K]
A_{os}	Tube outer surface area [K]
$\Delta h_{,act}$	Actual inlet-outlet enthalpy difference of LN_2
$\Delta h_{,max}$	Maximum inlet-outlet enthalpy difference

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1. Introduction

Liquefied natural gas (LNG) is natural gas (NG) that has been cooled to the point that it condenses to a liquid, which occurs at a temperature of approximately -162^{o}C and at atmospheric pressure. Liquefaction reduces the volume by approximately 600 times thus making it more economical to transport between continents in specially designed ocean vessels. Thus, LNG technology makes natural gas available throughout the world. LNG generally contains more than 90% methane (CH_4). At present time, LNG demand of world increases.

To return LNG to a gaseous state, it is fed into a regasification plant. For inland area, where pipelines do not exist or difficult to construct, the LNG is delivered to the inland-receiving terminal available at that area, regasified and delivered to consumers. At inland-receiving terminal, air heating vaporizer type is usually used. It is because of the construction and running costs of this type of vaporizer are low. Besides that, it has the simplest operation system. The constraint of this type of vaporizer is the small to medium production capacity due to the small heat capacity of air as its heat sources, **Sugano [1]**.

Vaporizer actually is a heat exchanger. Many studies about heat exchanger had been conducted. One of the main problem occurred in heat exchanger is frost formation due to condensation and freezing of water vapor contained in the air. This ice deposits will cause decrease in heat transfer rate because thermal conductivity of ice is less than one fortieth that of aluminum alloy. The thicker the ice becomes, the less heat transfer efficiency becomes. In addition, when fins covered with thick ice (for finned type vaporizer) until their configuration becomes almost invisible, effective heat transfer area decreases, **Morimoto *et al* [2]**. **Lee *et al* [3]** conducted experiment to find the effects of various factors (fin pitch, fin arrangement, air temperature, air humidity, and air velocity) on the frost growth and thermal performance of a fin-tube heat exchanger. General solutions for optimum dimensions of convective longitudinal fins with base wall thermal resistances were solved analytically by **Chung *et al* [4]**. **Yang *et al* [5]** conducted research to find optimal values of the design parameters for a fin-tube heat exchanger of a household refrigerator under frosting conditions. Experiment of finless type and finned type vaporizer of 4 fins 75 mm long and 8 fins 50 mm long had been conducted at constant room temperature by **Lee *et al* [6]**. Moreover, **Kong *et al* [7]**, conducted numerical analysis in order to find the best fin shape. **Jeong *et al* [8]** concluded that the optimum vaporizer geometry is a vaporizer which has angle between fins of 90^o and fin thickness of 2 mm. It means the vaporizer using 4 longitudinal fins. This is because it has the optimum heat transfer rate if the presence of frost deposit is considered. On the other hand, it was also concluded that without the presence of frost deposit, the decrease of angle between fins, which means the fin quantity increases, will increase the heat transfer rate due to the increase of heat transfer area.

Now, the study in this paper tries to compare, by experiment, the heat transfer performance of vaporizer with 8 fins 50 mm long to vaporizer with 4 fins 75 mm long which operate in various season. The 4 fin type of vaporizers are taken based on the numerical analysis conducted by **Jeong *et al* [8]** with a little modification on the length and the 8 fin type is taken because it is the common type which exist in the market.

2. Heat Transfer Basic Theory

From Newton's law of cooling we know that average convection coefficient is proportional to the convection heat transfer rate. Hence:

$$\dot{Q} = hA_{os}\left(T_\infty - T_{m,os}\right); \quad if\ T_{m,os} < T_\infty \text{ ....(1)}$$

And, because the flow in a tube (and a vaporizer is actually a long tube) is completely enclosed, an energy balance may be applied to determine the convection heat transfer rate in terms of the difference in temperatures at the tube inlet and outlet. If the flow rate is constant and assuming that fluid kinetic and potential energy changes are negligible, there is no shaft work and regarding Cp as constant, the energy rate balance equation is

$$\dot{Q} = \dot{m}Cp\left(T_{m,out} - T_{m,in}\right) \text{..........................(2)}$$

From equation (1) and (2) we get

$$\dot{m}Cp\left(T_{m,out} - T_{m,in}\right) = h_o A_{os}\left(T_\infty - T_{m,os}\right) \text{.........(3)}$$

These equations show us that, if the mass rate constant, the increase of ambient or room temperature (T_∞) will also increase the heat transfer rate which will also increase the tube outlet temperature ($T_{m,out}$). On the other word, the room temperature is proportional to the tube inlet-outlet temperature difference ΔT**.**

3. Experimental Setup

The experimental setup **(Fig. 1)** consists of four parts. Those are:

(1) Test Room
(2) Room conditioning unit
(3) Data acquisition unit
(4) Electronic control unit

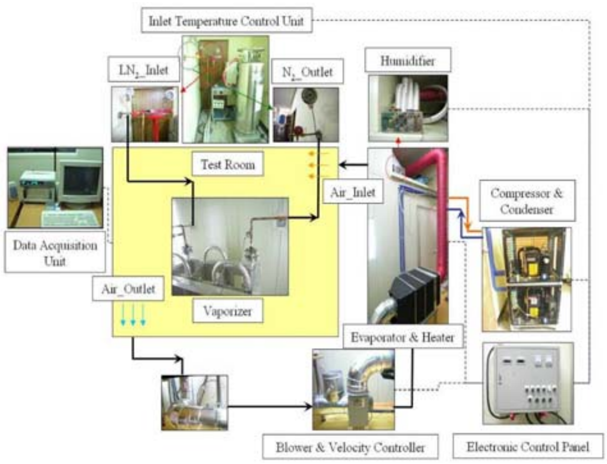


Fig. 1. Schematic diagram of experimental setup for vaporizer system

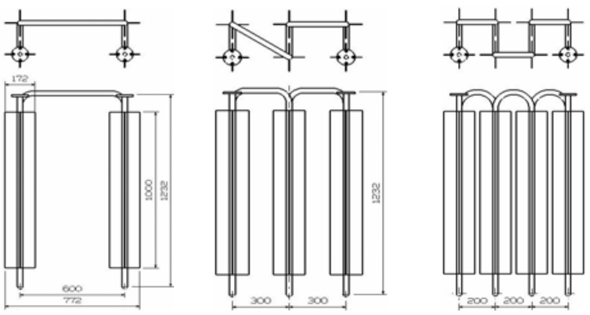
The vaporizer is located in a room which size is 1.99m x 1.34m x 2.9m. This room is called test room. The condition of the test room is maintained using room conditioning unit so that it has the same condition with the season average condition available in Tong young City, South-Korea. This data was taken from the government **[9]**. Liquid nitrogen (LN_2) is used instead of LNG in this experiment for safety reason.

The vaporizers are made of aluminum alloy. Thermocouples are inserted into the vaporizer every 500 mm to measure the temperature of the Nitrogen inside the vaporizer. All of these temperature data were recorded using data logger. The type of the thermocouple used is K-Type.

The experiment was conducted at four different conditions for each length. Those conditions were spring, summer, autumn and winter condition. The types of vaporizer used in the experiment were finned type with 4 fins, 75 fin length (**Fig. 2** and **Fig. 3**) and finned type with 8 fins, 50mm fin length (**Fig. 4** and **Fig. 5**). The notation for the former finned type is 4fin75le and for the latter is 8fin50le. Note that for finned type 8fin50le, the fins protrude 50mm outward from the outer surface of the pipe and 2mm inward from the inner surface of the pipe. Thickness of the pipe is 3 mm. And for finned type 4fin75le, the fins protrude 75mm outward from the outer surface of the pipe and 2mm inward from the inner surface of the pipe. Thickness of the pipe is 3 mm. The lengths which were tested for each type of vaporizer were 4000 mm, 6000 mm and 8000 mm. The condition of each season is stated below.

Season conditions:

- Spring : temp 285 K, RH 65%, air velocity 2.5 m/s
- Summer : temp 303 K, RH 80%, air velocity 2 m/s
- Autumn : temp 290 K, RH 70%, air velocity 2.5 m/s
- Winter : temp 273 K, RH 55%, air velocity 3 m/s



(a) 4000mm (b) 6000mm (c) 8000mm

Fig. 2. Drawing of the test vaporizer of finned type 4fin75le vaporizer.

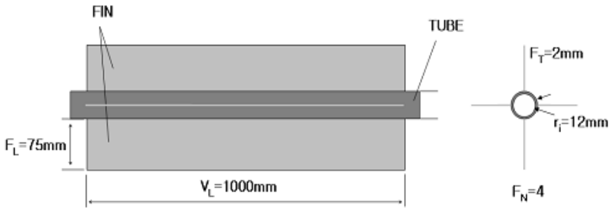
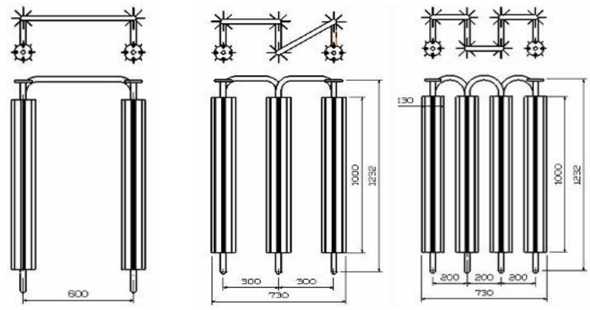


Fig. 3. Basic pipe shape of the finned type 4fin75le used.

The room conditioning unit consisted of dehumidifier, heater, refrigerator and humidifier. The electronic control unit controlled the operation of these room conditioning equipments so that the equipments operates automatically when needed.

If the temperature of the test room was higher than the set-temperature, the refrigerator will operate and the heater will stop. If the opposite condition happened, the heater will operate and the refrigerator will stop. The humidifier and dehumidifier would also operate reversely one to another; depends on the humidity of the test room.



(a) 4000mm (b) 6000mm (c) 8000mm

Fig. 4. Drawing of the test vaporizer of finned type 8fin50le vaporizer.

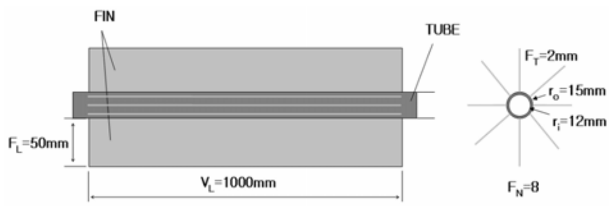


Fig. 5. Basic pipe shape of the finned type 8fin50le used.

In this experiment the pressure was maintained constant, 2 bar absolute pressure, using pressure regulator. The flow rate was 0.4-0.43 kg/min. The flow rate was measured by dividing the change of the LN_2 tank weight with the time duration of the experiment. The experiment was held in 60 minutes and the data was taken every 6 seconds by means of data acquisition system.

The inner diameter of the vaporizer tube was 24mm and the outer diameter was 30mm. The inlet temperature was constant at -173±2°C (100±2K).

4. Results And Discussions

In this study, the heat transfer rate will be represented by the enthalpy difference of LN_2 inlet and outlet. The enthalpy is taken from NIST with ASHRAE Standard State Convention **[10]**.

From the graph Time Vs inlet-outlet temperature difference in different season for the 8fin50le, **(Fig. 6)**, it can be seen that the graph is nearly steady. Although ice deposit is formed on the vaporizer, it doesn't really influence its performance for one hour experiment because of the existence of the fins. So, it needs more time for the ice deposits to cover whole of the vaporizer's surface. Besides that, **Lee *et al* [3]** found that the ice-like frost nuclei generated during the crystal growth period acts as a small fin which results in the increase in roughness and surface area. During the frost layer growth period, frost nuclei grow to form a porous frost layer, and the thermal insulation effect of the frost layer increases because it acts like a thermal insulator**.** Based in this statement, it is concluded that for one hour experiment, the porous frost layer is formed on the vaporizer area near inlet, which will cause decrease of heat transfer rate. But on the vaporizer area near outlet, crystal frost is formed which will cause increase of heat transfer rate. Hence, the resultant is approximately zero**.**

From the experiment conducted by **Yan *et al* [11]**, it was found that a higher surface temperature is detrimental to the frost formation, but higher moisture is favorable for the frost growth. Therefore, in summer, when the relative humidity is high and the temperature is also high, the ice growth is deteriorated due to the high temperature. On the other hand, in winter, when the temperature is low and the humidity is also low, the ice growth decreases due to the low moisture content in the air. Additionally, the graphs show that the inlet-outlet temperature difference increases if the temperature of ambient air also increases. On the finned type 4fin75le vaporizers, the trend of inlet-outlet temperature differences is the same with the 8fin50le **(Fig. 7)**.

Next, from the experimental results, it is seen that the Δh, which represents the heat transfer rate, of finned type 8fin50le vaporizers are comparable with that on the 4fin75le vaporizers. These phenomena can be observed more clearly from the performance data **(Table 1)** and the outlet average temperature table **(Table 2)**. The performance is defined as:

$$\textbf{Performance} = \frac{\Delta h_{act}}{\Delta h_{max}} \times 100\% \quad \ldots\ldots\ldots\ldots..(4)$$

Δh_{max} is inlet-outlet enthalpy difference of vaporizer if the outlet temperature reaches the temperature of ambient air.

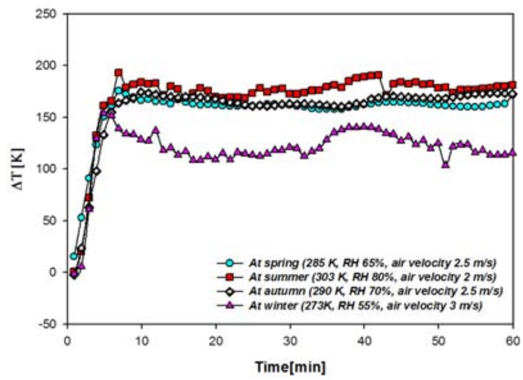
Since the performance of these two types of vaporizers is comparable, the proposed vaporizer type is based only on economical consideration. Hence, the 4fin75le is proposed as the better type because its production cost is cheaper than 8fin50le. The amount of material which is needed to produce 8fin50le type vaporizer is more than to produce 4fin75le (the difference is 200mm^3 per unit length). Additionally, heat transfer rate of vaporizer on 8fin50le type will decrease steeper than on 4fin75le type when the ice formed on the vaporizer is getting thicker. It is because the angle between fins of vaporizer 8fin50le type is smaller than vaporizer 4fin75le type, **Jeong *et al* [10]**.

Table 1. Performance of vaporizers based on Δh

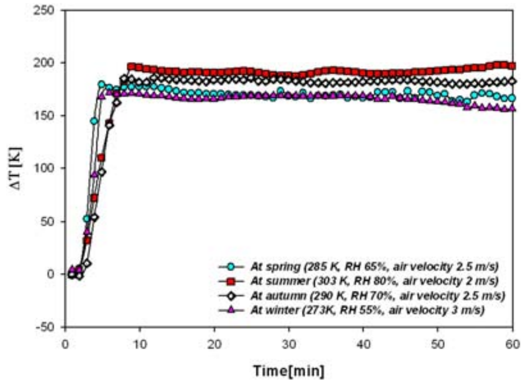
		Performance (%)			
		Spring	Summer	Autumn	Winter
8fin50le	4000 mm	88.0	87.8	88.1	71.2
	6000 mm	92.3	94.6	96.3	95.4
	8000 mm	97.9	96.9	98.6	98.5
4fin75le	4000 mm	86.2	87.6	87.2	84.7
	6000 mm	94.9	96.1	94.9	92.8
	8000 mm	99.1	98.8	97.4	99.7

Table 2. Average outlet temperature of the vaporizers for every length and season condition.

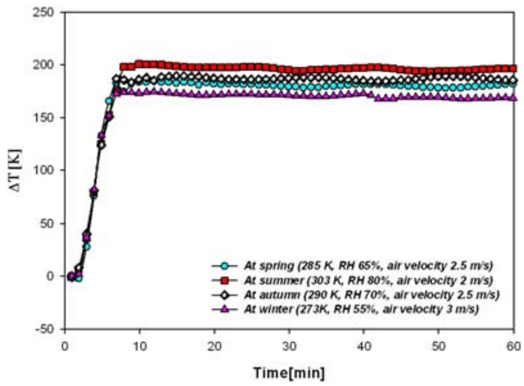
		Average outlet temperature (K)			
		Spring	Summer	Autumn	Winter
8fin50le	4000 mm	262.6	***277.9***	267.1	222.6
	6000 mm	270.6	***292.0***	***282.8***	265.0
	8000 mm	***281.1***	***296.7***	***287.3***	270.3
4fin75le	4000 mm	259.1	***277.5***	265.4	246.2
	6000 mm	***275.4***	***295.1***	***280.2***	260.4
	8000 mm	***283.3***	***300.5***	***285.0***	272.5



(a) 8fin50le 4000 mm vaporizer.

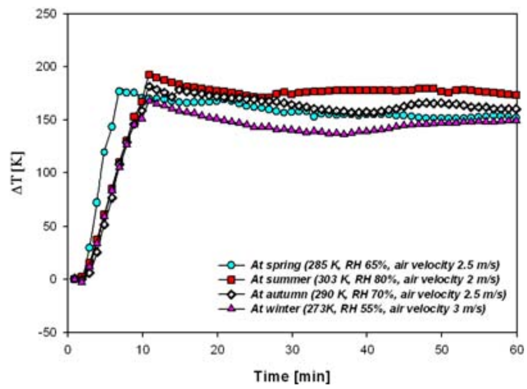


(b) 8fin50le 6000 mm vaporizer.

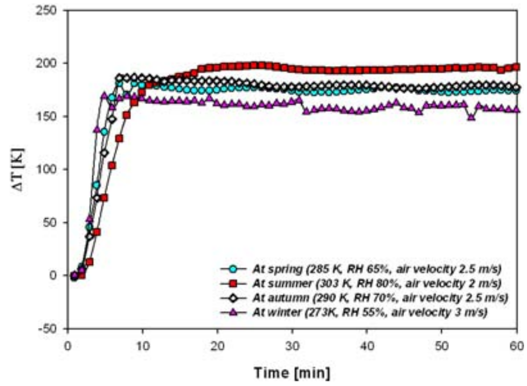


(c) 8fin50le 8000 mm vaporizer.

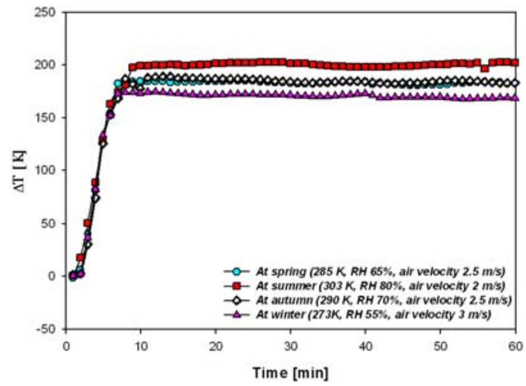
Fig. 6. Inlet-outlet temperature differences related to time for finned type 8fin50le vaporizers in different seasons.



(a) 4fin75le 4000 mm vaporizer.



(b) 4fin75le 6000 mm vaporizer



(c) 4fin75le 8000 mm vaporizer

Fig. 7. Inlet-outlet temperature differences related to time for finned type 4fin75le vaporizers in different seasons.

Next, the optimum vaporizer length for each season among the 8fin50le and 4fin75le vaporizers should be taken. They will be evaluated based on the outlet temperature and the length. The shortest length which can achieve outlet temperature of 273K will be chosen. The temperature 273K is taken as the reference because, on that point, the water vapor contained in the ambient air will not freeze on the outer surface of the delivery pipe or the natural-gas storage tank.

Based on the bolded-italic-underlined values in Error! Not a valid bookmark self-reference., the chosen 8fin50le types are the 8000mm, 4000mm and 6000mm long for spring, summer and autumn conditions respectively. At winter condition, the outlet temperature must be below 273K because the ambient temperature is 273K. However, as an approximation, the 8000mm is chosen for the winter condition. Then, for the 4fin75le vaporizer, the chosen types are 6000mm, 4000mm and

6000mm long for spring, summer and autumn conditions respectively. And in winter condition by using the same reason, as an approximation, the 8000 mm is chosen.

Finally, we can conclude that to accommodate the condition at all seasons, the 8000mm length of 8fin50le and 4fin75le types is chosen as they can fulfill the requirement to reach the minimum outlet temperature of 273K (except for winter season as mentioned before).

5. Conclusions

The information from this study can be summarized as follow:

1. The heat transfer rate on finned type 8fin50le vaporizer is comparable with that on 4fin75le vaporizer.
2. Since the heat transfer rate between 8fin50le and 4fin75le vaporizer are comparable, finned type 4fin75le vaporizer is proposed as the optimum finned type because its production cost is cheaper and its performance is better when the ice deposit becomes thicker as showed in the numerical result by **Jeong *et al* [8]**.
3. Effect of ice deposits on the vaporizer which operates in a long duration must be conducted to know further effects of moisture to the heat transfer rate.
4. Finally, we can conclude that to accommodate the condition at all seasons, the 8000mm length of 8fin50le and 4fin75le type is chosen as it can fulfill the requirement to reach the minimum outlet temperature of 273K (except for winter season as mentioned before).

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