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Experimental Study on Gasification Characteristic by Using Liquefied Gas Vaporizer with Various Shape

다양한 형상을 갖는 액화가스용 기화기의 기화특성에 관한 실험적 연구

Y. H. Lee, D. Eldwin, H. M. Jeong and H. S. Chung
이용훈 · 엘드윈 자디위나타 · 정효민 · 정한식

Key Words : LN_2(액화질소가스), Super Low Temperature(초저온), Vaporizer(기화기), Fin(핀)

요약 : 액화천연가스(LNG : Liquified Natural Gas)는 연료로 사용하기 위하여 기화하는 과정을 거치게 되는데 기화하는 방식에는 해수에 의한 기화와 공기에 의한 기화의 두 가지 방식으로 나뉘게 된다. 해수에 의한 기화는 LNG 인수기지에서 대량의 LNG를 NG로 기화하기 위하여 사용하며, 공기에 의한 기화는 LNG 위성기지에서 사용처에 적합한 온도를 얻기 위해서 일반적으로 많이 사용하고 있는 공기식 기화기를 이용하여 기화를 하는 방식을 취하고 있다. LNG가 NG로 기화하는 과정에서 1kg당 200kcal의 냉열을 외부로 방출하고 있으며, 이러한 냉열의 방출로 인하여 공기식 기화기의 표면에 결빙현상을 발생시킨다. 또한 현재 사용하고 있는 기화기는 2~3개의 기화기를 연결하여 사용하고 있어 그 비용의 손실이 크다고 할 수 있다. 그리하여 본 연구는 최근 사용빈도가 증가하고 있는 공기식 기화기에 관한 것으로 작동유체는 실제 LNG와 특성이 비슷한 초저온 액화가스인 LN_2를 사용하였다. 이번 연구에 사용된 변수는 다음과 같다. 첫째, 각각의 기화기의 길이를 4000mm, 6000mm, 8000mm으로 하였고 핀의 type을 finless, 4fin, 8fin으로 하여 적용하였다. 두 번째는 봄, 여름, 가을, 겨울철에 따른 기화기의 성능을 알고자 각각의 계절별 온도와 습도를 적용하였다. 마지막으로 계절별 풍속과 실험을 하는 시간 동안의 유량을 알고자 압력을 1 bar로 적용하였다. 그리하여 이번 연구의 목적으로는 각각의 변수를 통하여 실험을 진행 한 후 vaporizer type과 길이에 대한 최적의 성능을 가지는 기화기에 대한 자료를 제시하고자 한다.

Nomenclature

V_L : Length of vaporizer $[mm]$
r_i : Inner diameter of tube $[mm]$
r_o : Outer diameter of tube $[mm]$
F_L : Length of vaporizer fin $[mm]$
F_T : Thickness of vaporizer fin$[mm]$
F_N : Number of vaporizer fin
V_a : Air velocity of test room $[m/s]$
T_a : Air temperature of test room $[K]$
H_a : Air humidity of test room [%]
Q_{LN_2} : Mass flow of LN_2 $[kg/\min]$

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정효민(책임저자) : 경상대학교 기계항공공학부, 해양산업연구소
E-mail : hmjeong@gnu.ac.kr Tel. 055)640-3184
이용훈, Eldwin : 경상대학교 대학원 정밀기계공학과
정한식 : 경상대학교 기계항공공학부, 해양산업연구소

1. INTRODUCTION

LNG is consisted of CH_4 as main component, which is produced by cooling and compressing process of natural gas. LNG is carried and saved as a liquid below 111 K from the outside. But, LNG must be vaporized for its using like fuels in industries and home and so on. The cold energy generated about latent heat of 120 kcal/kg and 80 kcal/kg of sensible heat, while the vaporization process. Most of cooling heat is wasted during vapor generating process. Otherwise, the tremendous energy imported from sea for using its energy. It is very important to save and re-circulate the wasting energy such as the cooling heat during the gasification process. When we reserve and re-circulate this wasting heat, we save about 180,000t (TOE) energy.[1~4)]

There are many different ways of gasification, such as the method of heating by sea water, the method of heating by air and the method of converting gasification. The first method is taking out cooling heat from the LNG convert to NG process using sea water. The second method is the reserved LNG convert to gasification. The former method called sea water method and the later method called ambient heating method which is using ambient air instead sea water. The later method mainly use in huge industrial area and wide resident area. Air has a small heat capacity, so it can produce only a small volume of NG, but as LNG expands 600 times from its original volume, systems can supply NG to the surrounding more conveniently. Since the systems are changing in the way that energy sources for large size apartment and industrial complexes are concentrated, there is increasing demand for systems that vaporize directly with air at domestic terminals. To meet this demand, the general characteristics of super low temperature vaporizers should be examined and air type vaporizer should be developed first. Air type vaporizer is applicable to domestic terminals to be installed around industrial complexes or at large size apartment complexes. Because air type vaporizer can't effect its vaporization performance properly due to the condensation of moisture in air outside the vaporizer, 2~3 vaporizers are used alternately. To solve the low performance and redundant installation, many researchers are carrying out the optimization of design technology through performance analysis and experiments.[5~8)] The present study was carried out an experiment on air type vaporizer focused on shape parameters. After experiment was conducted for each parameter, we presented the vaporizer design with the optimal performance for each type and length.

2. Experimental model and method

Fig. 1 shows the structure of the vaporizer system used in the experiment. The structure has the form of a closed circuit, in which temperature, humidity and wind velocity circulate through a duct while experiment was performed through the control panel. The condition of the room was maintained constant. Moreover, in order to measure the flow rate, we used a scale to determine difference of the weight of the tank of LN_2 between the beginning and the end of the experiment. In addition, to measure change in temperature inside the duct and the end of the fin, we installed K type and T type thermocouples. The experiment was conducted for an hour and data was collected every 6 seconds by using a PC and data logger. According to the result of a previous research by Kong[9)] and Yi[10)] on the heat flux of atmospheric vaporizers for LNG through numerical analysis and experiment using CFD, the optimal thickness of vaporizer fins was 2 mm and performance was relatively high when four fins were installed at intervals of 90°. In addition, according to the results of experiment on the arrangement characteristics of atmospheric vaporizers based on the outputs of numerical analysis, 4fin80le and 8fin55le were suggested as the optimal shapes. Where, 4fin80le means that the vaporizer has four of fin number and 80mm of fin length.

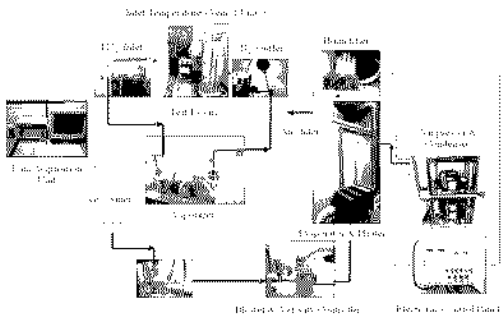
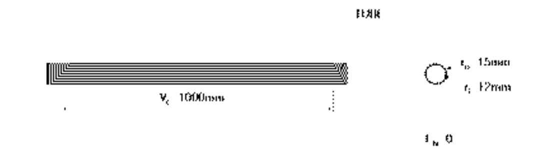
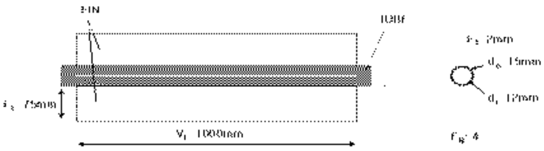


Fig. 1 Various photos of components comprising the vaporizer system

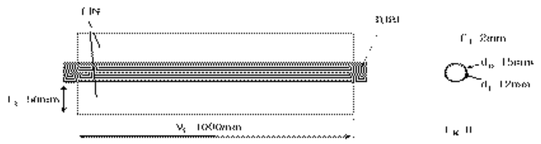
Fig. 2 shows the schematic diagram of the vaporizer models used in this study. Models in our experiment are divided into models, which were designed and manufactured at a length of 4000mm, 6000mm and 8000mm. In the actual models, basic modules were connected through U tubes, and the material of the vaporizer model was aluminum (A6053S). In addition, the length of the vaporizers and variables related to the fins are presented in Table 1.



(a) Model 1



(b) Model 2



(c) Model 3

Fig. 2 Basic module of vaporizer system

Table 1 Specification of Vaporizer arrangement

	Array (N×N)	V_L (㎜)	r_i (㎜)	r_o (㎜)	F_L (㎜)	F_T (㎜)	F_N
Finless	2×2	1000×4	12	15	none	none	none
	2×3	1000×6					
	2×4	1000×8					
4fin80le	2×2	1000×4	12	15	80	2	4
	2×3	1000×6					
	2×4	1000×8					
8fin55le	2×2	1000×4	12	15	55	2	8
	2×3	1000×6					
	2×4	1000×8					

As working fluid of super low temperature for the experiment, we applied LN_2, which was similar property to LNG used in domestic terminals or receiving terminals. Table 2 shows variables during the progress of the experiment. Room temperature was maintained at 293K, and it was controlled within ±0.5 for precise experiment.

Inflow wind velocity was opened 15%, coming evenly through the duct at a rate of 3.5m/s~4.0 m/s. Humidity was maintained constant at 50% by using a ultra sound hygrometer, and was controlled within ±3% to keep the optimal condition during the experiment. Pressure was 1 kg/cm^2 in absolute pressure, which was used to measure flow rate during the experiment. Flow rate was expressed by measuring the weight of LN_2 tank at the beginning and end of the experiment.

Table 2 Experimental condition of vaporizer system

	V_L (㎜)	υ_a (%)	T_a (K)	H_a (%)	Q_{LN2} (kg/min)	test time (hr)
finless	4000	3.5	293(±2K)	50(±3%)	0.38	1
	6000	3.5			0.37	
	8000	3.8			0.39	
4fin80le	4000	3.6			0.50	
	6000	3.5			0.41	
	8000	4.0			0.41	
8fin55le	4000	3.7			0.36	
	6000	3.8			0.41	
	8000	3.5			0.45	

3. Result and discussion

Fig. 3 shows the variation of temperature for inlet and outlet as a function of time at same length. The 8fin55le model shows the highest temperature difference between inlet and outlet at same length. The temperature variation is decreasing between inlet and outlet as increasing length and time. Fig. 3(a) shows the temperature difference is very wide because of enough heating surface at 4000 mm length. However, it is shown that 4fin80le model is higher temperature difference between inlet and outlet in Fig. 3(b). In case of 8fin55le model case, the distribution of temperature has shown similarity between inlet and outlet because of low temperature difference between inlet and outlet for 8000 mm length in Fig. 3.

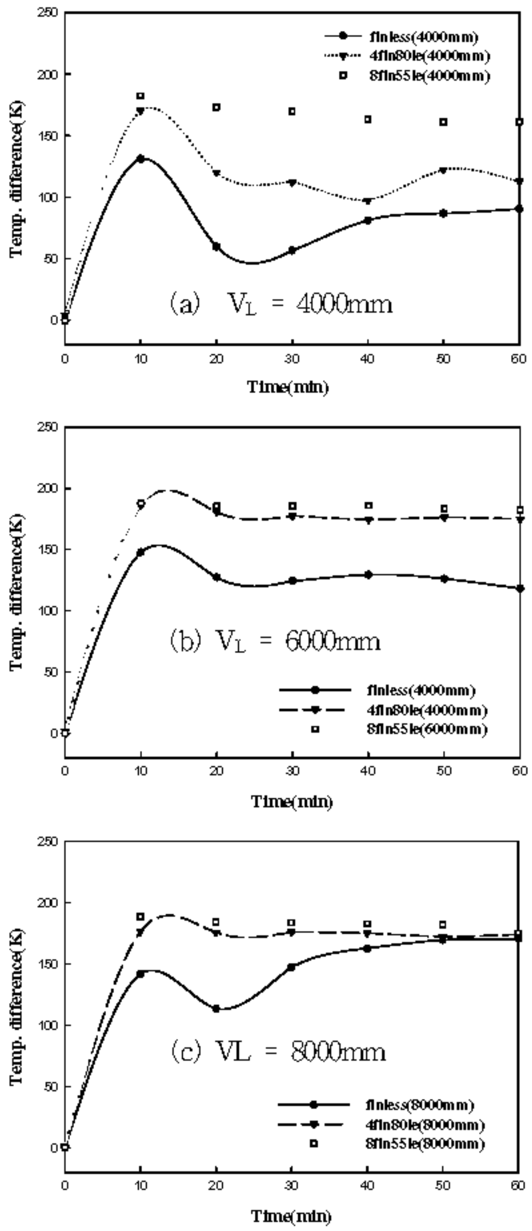


Fig. 3 Comparison of temperature difference distributions between inlet and outlet of each vaporizer with same length according to time variation

Fig. 4 shows the distribution of temperature between inlet and outlet as a function of length for same vaporizer model. The temperature difference is raised as increasing length for finless case as shown in Fig. 4(a). When outlet temperature increases, it requires longer length than 4fin80le model case and8fin55le model case which has fin equipped. The temperature difference is slightly increasing at 4000 mm between inlet and outlet, tremendous increasing phenomenon observed at 6000 mm length in case of 8fin55le model. This phenomenon continued until 6000 mm length. Therefore, it is shown that the model of vaporizer which has 8000 mm length lower efficiency comparing with the model of vaporizer which has 6000 mm length even though the heat is more absorbed the former case for heating surface.

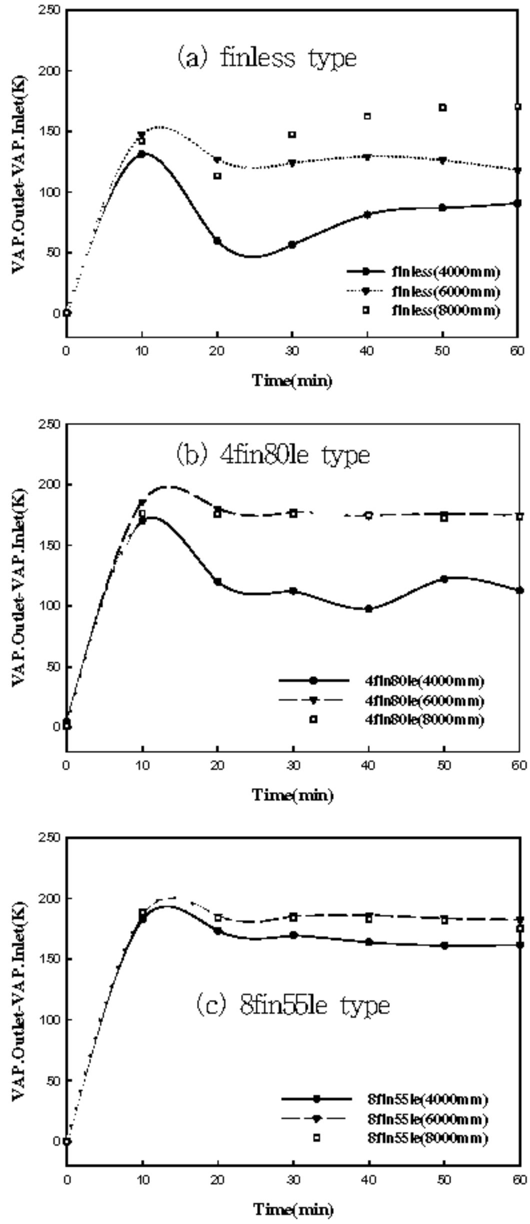


Fig. 4 Comparison of temperature difference distributions between inlet and outlet of same vaporizer with different length according to time variation

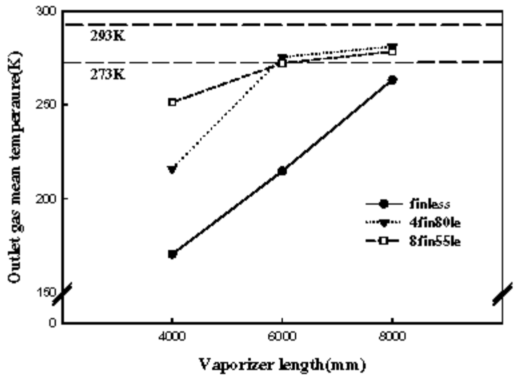


Fig. 5 Outlet gas temperatures of each vaporizer models according to length variation

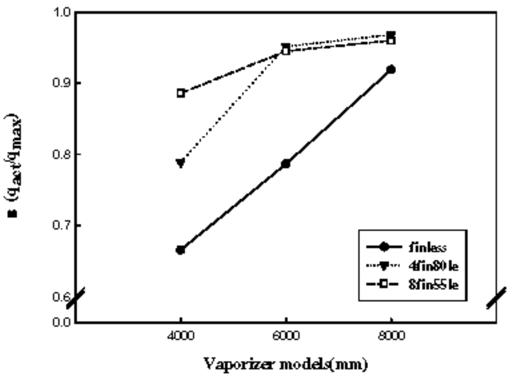


Fig. 6 Heat exchange effectiveness of each vaporizer models according to length variation

The experiments for 4000mm length, the highest gas temperature in 8fin55le model case. Otherwise, the amount of supply for LN_2 at 4000mm length case is lower than other length cases for each vaporizer mode in Table 2. It is observed that the gas temperature is high in 4000mm length case and the amount of frost is low in this case comparing with other length case. In 4000mm length case for three vaporizer case shown that the amount of supply for LN_2 is very similar between these cases. Especially, the amount of supply for LN_2 is same between in 4fin80le model case and 8fin55le model case. In this point, the out let gas temperature is marked over 273K; the 4fin80le model case is higher than 8fin55le model case. The 4fin80le case supplies LN_2 higher than other two cases. The gas temperature is high in 6000 mm length case for same amount of supply gas comparing with 6000mm length case, the flow rate difference of 0.04kg/min is not changing for the gas temperature. The performance of vaporizer is very similar between in 4fin80le model case and 8fin55le model case as a function of different length tests as shown in Fig. 5.

But, the production cost is higher in 4fin80le case because this case require more heating surface than 8fin55le model case. Also, we suggest in 4fin80le model case is more advantageous for economic and manufacturing aspect.

Fig. 6 shows the ratio of heat exchange as different length for various models. It is shown that the ratio of heat exchange curve is similar with gas temperature curve as function of different length. Also, the ratio of heat exchange which imply the maximum absorb heat rate and the actual absorb heat rate from experiments at the temperature achieve at 293 K. The same phenomenon observed in this graph such as the ratio of heat exchange is higher in 4fin80le model case than 8fin55le model case at 4000 mm and 8000 mm length.

Table 3 Fin effectiveness on vaporizer

	4fin80le	8fin55le
4000 mm	1.544	1.280
6000 mm	1.301	1.297
8000 mm	1.115	1.210

$$N = \frac{Q_{fin}}{Q_{finless}} \quad (1)$$

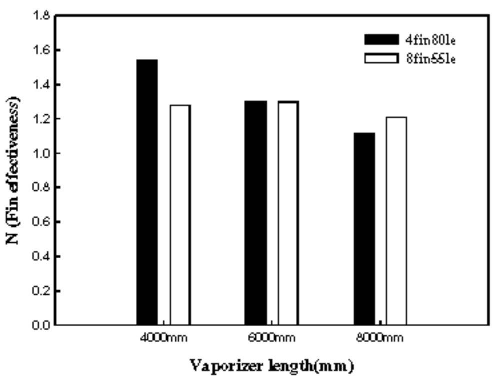


Fig. 7 Fin effectiveness on 4fin80le and 8fin55le vaporizer at same vaporizer length

The efficiency of fin was listed in Table 3 and Fig. 7 shows the curve of the efficiency of fin. The efficiency of fin is calculated using equation (1), fin and finless of absorption ratio for 4fin80le model case and 8fin55le model case at same length. In 4fin80le model case, the efficiency of fin comparison 8fin55le model case at 4000 mm length was shown in Fig. 7.

The reason of this, the amount of supply for LN_2 is higher and higher absorb ratio in 4fin80le model case. On the controversy, in 8fin55le model case is higher efficiency of fin compare with 4fin80le model case at 8000 mm length from the high amount of supply for LN_2. But, 4fin80le model case is higher efficiency of fin compare with 8fin55le model case at 4000 mm length even though same amount of supply for LN_2. When the efficiency of fin is decreasing as increasing vaporizer length, the efficiency of fin is become useless in infinite length. In special case, the efficiency of fin decreased as disturbances of heat transfer between gas and fin.

4. Conclusion

From the results of experiment on the vaporization characteristic using the length 4000 mm, 6000 mm and 8000 mm of three vaporizer models finless, 4fin80le and 8fin55le as a variable, we drew conclusions as follows.

1) At a length of 4000 mm, gas temperature was highest at the outlet of vaporizer model 8fin55le, but at a length of 6000 mm and 8000 mm, the distribution of gas temperature was high at the outlet of vaporizer model 4fin80le.
2) LN_2 showed a vaporization rate of 100 % by discharging overheated gas through the outlet in all of the three vaporizer models. In addition, in vaporizer 4fin80le and 8fin55le at a length of 6000 mm, gas temperature at the outlet was over 273 K.
3) Temperature of vapor in the vaporizer was constant or decreasing, but the temperature in the direction length increasing and decreasing. This phenomenon resulted from the pulsation of pressure.
4) The vaporizer of 4fin80le showed higher vaporization performance than 8fin55le at a length of 6000 mm and 8000 mm. 4fin80le is considered superior in vaporization performance and economic efficiency.

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