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Research, designing and manufacturing the equipment of evaporation, reflux condensation and definition for absorption refrigeration model in vibration condition

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Abstract

This paper presents the results of research, manufacturing and integration equipment of evaporation, condensation and refluxed solvent definition for model of NH_3/H_2O absorption refrigerator with capacity of 1.5 kW using waste heat and solar energy in conditions of vibration. Equipment has been manufactured and installed and operated in testing conditions. Testing results showed that combined equipment manufactured, operate stably and meet the technical requirements in vibration operation.

Keywords: Absorption Refrigeration, NH_3/H_2O refrigeration, solar energy, waste heat, vibration.

I. INTRODUCTION

Using the absorption refrigerator (AR) is one of the effective solutions to save energy. AR applications for ocean ships the purpose of cooling storage is one solution in terms of energy efficiency. Conditions on board showed energy sources for this type of refrigerator have been potential. The heat sources from the engine exhaust fumes and solar energy are available in ocean ships and if combined they can create a steady source of energy to operate AR.

However, vibration on board of ships is one of the key factors determining the operation efficiency of AR. Therefore, remediation and improvements of vibration tolerance for AR system is one of the solutions to put AR application into the fact.

Research, manufacturing equipment of evaporation, condensation reflux and solvent definition for experimental model of NH_3/H_2O absorption refrigerator using solar energy and waste heat capable of operating in vibration conditions to conduct in-depth AR research is essential.

II. PURPOSES AND SOLUTION RESEARCH

1. Purpose

Research, manufacturing and integration equipment of evaporation, condensation and refluxed solvent definition for model of NH3 / H2O absorption refrigerator with capacity of 1.5 kW using waste heat and solar energy in conditions of vibration. Equipment has been manufactured and installed and operated in testing conditions. This experimental model will be the basis, equipment to carry out further experimental studies on the ability and efficiency of AR operation in conditions of vibration. Research results will be assessed, determine the AR application capacity on seafood fishing and cargo ships. The technical requirements of the experimental model are studied and designed with the following parameters:

Refrigerating capacity: $Q_0 = 1,5$ [kW].
Heating water temperature: $t_{sh} = 95$ [^oC].
Cooling Temperature: $t_{cw} = 25^OC$
Condensing temperature: $t_k = 30$ [^oC].
Evaporation temperature: $t_o = -15$ [^oC].
Vibration amplitude: A = 40 [mm]
Vibration frequency: f = 50 [time/min]

2. Solution research

AR technology for ships should has specific technical issues, mainly the handling of refrigerant in a accelerated moving system. Falling membrane configuration used widely in normal AR thermal devices might be broken by the constant movement, harmful affect to heat and mass transfer process. Test is performed in actual ocean conditions. COP of the system is decreased by 14% compared to normal operation when the chiller working continuously at dynamic tilting degree ± 200 [10].

Thus, Solvent pair NH_3/H_2O with higher working pressures allows using of absorbent devices type foam and steam generator. Heat exchanger type plate is considered to be less affected by the angle of the machine. In [9] and [12] documents it is investigated the absorption process of the mixture NH_3/H_2O using the heat exchanger type plate in operating conditions with vibration. Experimental results show the feasibility of the absorption cycle using heat exchanger type plate. Restriction of the use of pairs of NH_3/H_2O in absorption cycle is steam after going off the steam generator must be rectified before entering the condenser. Therefore, there should be a rectifying tower at the top of the steam generator. However, document [11] indicates that the operation of the distillation column can also be affected by the tilting angle of the ship and by the shortage of pure NH_3 with significant water content can reach the evaporator (where water tending to be accumulated) resulting in cycle efficiency reduced. In [8] E.W. Zavaleta-Aguilar and J.R. Simões-Moreira used distillation tower type membrane in the steam generator overseas to enhance the performance of steam generator and also decrease of impact of vibration environment to the steam generating of device.

In summary, the steam via the steam generator output is a problem should be solved when using solvent pair NH_3/H_2O. In normal conditions, (without vibration we use more refined towers placing after the steam generator. However, in the vibration working conditions it is needed more solutions to ensure good heat exchange and anti tampering and steam leaking in the steam generator output.

By experimental research and through the results of a number of researchers, the authors chose to use the vertical steam generator combined with walls to eliminate fluctuation of solution in the steam generator. Simultaneous using distillation tower type falling membrane is to increase steam generating efficiency and the steam generator is also capable of avoiding mixing the part of concentrated and diluted solution in the steam generator.

III. CALCULATION RESULTS

1. Calculating nodes of the cycle

Our target is the model on board of ships and using the sea water for cooling without pump. Therefore, condensers and absorption devices are arranged natural convection cooling by seawater. Reflux condenser will use concentrated solution with average low temperatures in absorption tank in order to absorb heat. Thus, the model used cycle with the principle diagram shown in Figure 1.

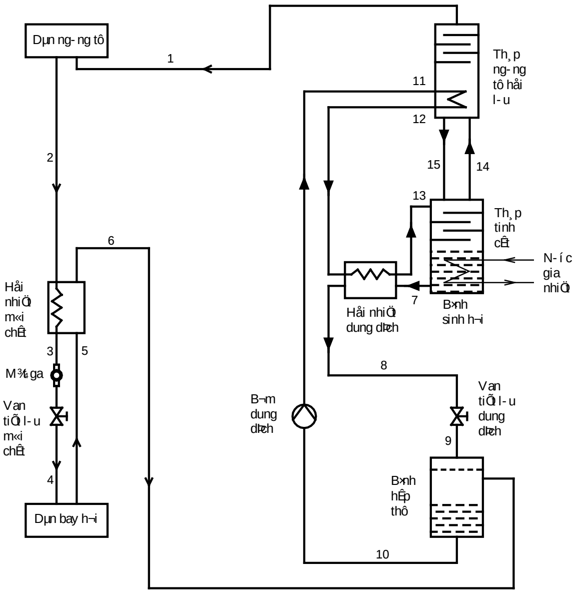

Fig 1. Principle diagram of AR NH_3/H_2O

Corresponding to the principle diagram above, the status points of the cycle is shown on the graph h - ξ as in Figure 2.

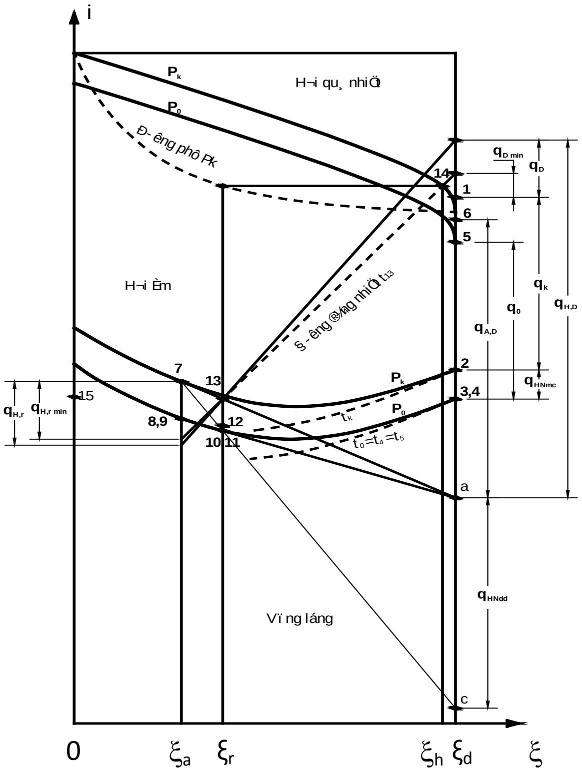

Fig 2. Graph h-ξ of AR NH_3/H_2O circle

AR calculations conducted on the above cycle with suggested data we have the results in Table 1 as follow:

Table 1. Status parameters of circle

Point	Status	t [^oC]	P [bar]	ξ [kg/kg]	H [kJ/kg]
1	NH_3 vapor out of reflux condenser tower	69.12	11.83	1	1746.96
2	NH_3 liquid out of reflux condenser unit.	30	11.83	1	484
3	NH_3 too cold liquid out of the heat recovery device with cold solved.	9.7	11.83	1	389.55
4	NH_3 liquid from the refrigerant throttle	-15	2.39	1	389.55
5	NH3 vapor from the evaporator unit.	-15	2.39	1	1587
6	NH3 overheated vapor from the cold solved heat recovery equipment.	25	2.39	1	1681.45
7	NH_3/H_2O low concentration solution out of the steam generator.	89	11.83	0.389	301
8	NH_3/H_2O low concentration solution out of liquid heat recovery equipment.	37.85	11.83	0.389	68.38

Point	Status	t [^oC]	P [bar]	ξ [kg/kg]	H [kJ/kg]
9	NH_3/H_2O low concentration solution out of liquid throttle valve.	37.85	2.39	0.389	68.38
10	NH_3/H_2O high concentration solution out of adsorption jar.	30	2.39	0.411	29.55
11	NH_3/H_2O high concentration solution out of liquid pump.	30	11.83	0.411	29.55
12	NH_3/H_2O high concentration solution out of reflux jar.	32.85	11.83	0.411	42.167
13	NH_3/H_2O high concentration solution out of liquid heat recovery equipment	70.86	11.83	0.411	256.6
14	NH_3 vapor mixed steam out of refining tower.	89	11.83	0.967	1818
15	Water vapor from refluxing jar back to the steam generator	69.12	11.83	0	289.3

2. Calculation the additional loading of AR system

Based on documents [3], [5], additional loading factors are summarized in the Table 2.

Table 2. Table of thermal loading values

No	Paremeter	Symbol	Value	Unit
1	Refrigerant flow	m_d	0.00125	[kg/s]
2	Dimensionless concentrated solution flow	$\overline{m}_r$	12.78	-
3	Concentrated solution flow	m_r	0.016	[kg/s]
4	Dimensionless Diluted solution flow	$\overline{m}_a$	11.78	-
5	Diluted solution flow	m_a	0.0148	[kg/s]
6	Dimensionless Refluxing water flow	R	0.059	-
7	Heat load of the evaporator	Q_0	1.5	[kW]
8	Heat load of the condenser	Q_k	1.58	[kW]
9	Heat load of the adsorption jar.	Q_A	2.64	[kW]
10	Heat load of the refluxing device.	Q_{hl}	0.20	[kW]
11	Heat load of the steam generator	Q_H	2.72	[kW]
12	Heat load of solved heat recovery device.	Q_{HNmc}	0.12	[kW]
13	Heat load of liquid heat recovery device.	Q_{HNdd}	3.42	[kW]
14	Capacity of liquid pump.	N_B	$23.75x10^{-3}$	[kW]

3. Calculation, design and manufacturing complex of steam generation, refining and reflux condensing equipment.

The steam generator where the concentrated solution NH_3/H_2O existing receives heat to separate NH_3 from the solution. NH_3vapor after the split (steam remaining) will be flowed through refining and reflux condensing equipments to become pure NH_3 vapor.

In this combination of equipment, the steam generator is a heat exchanger type coil tower. Concentrated NH_3/H_2O solution will be flowed from the top of the falling membrane system and circulated outside coils become diluted solution at the boredom of the jar. In the steam generator baffles arranged to eliminate oscillation of the solution when working in vibration.

Refining tower is a complex with effect to separate steam flowing with NH_3 vapor after the steam generator.

Reflux condenser is heat exchanger with cylindrical coils. Coils will separate condensate water from the vapor NH_3 to ensure vapor outputting equipment is pure NH_3.

The process of calculating the steam generator and reflux condenser is made similar to calculation for condensing units and calculation results are summarized in Table 3. 4.

Table 3. Calculation results for steam generator

No	Paremeter	Symbol	Value	Unit
1	Heat transfer coefficient	k’	976.2	[W/m^2K]
2	Heat exchanger area	F	0.93	[m^2]
3	Pipe length	L	3,500	[mm]
4	Number of round tubes	n	7	[round]
5	Box height	H	210	[mm]

Table 4. Calculation results for reflux condenser

No	Paremeter	Symbol	Value	Unit
1	Heat transfer coefficient	k’	60.78	[W/m^2K]
2	Heat exchanger area	F	0.07	[m^2]
3	Pipe length	L	1,200	[mm]
4	Number of round tubes	n	4	[round]
5	Box height	H	150	[mm]

From the calculated results, the equipment complex including steam generator, refining towers and reflux condenser is designed and manufactured as shown in Fig 3.

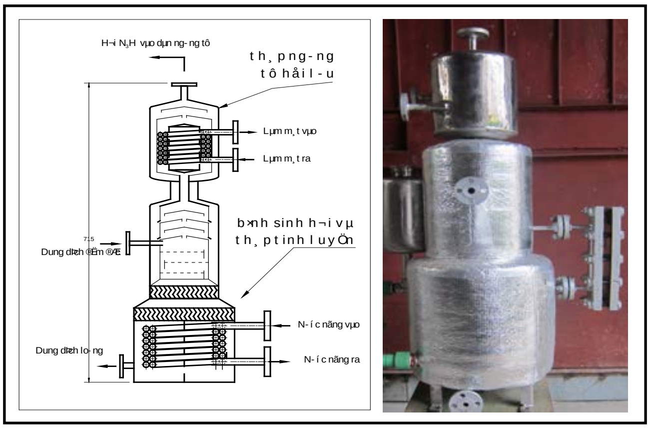

Fig.3. Equipment complex including steam generator, refining towers and reflux condenser

4. Model Manufacturing and Installing

From the calculated results, the authors have carried out the design, fabrication and installation of the experimental model as Figure 4.

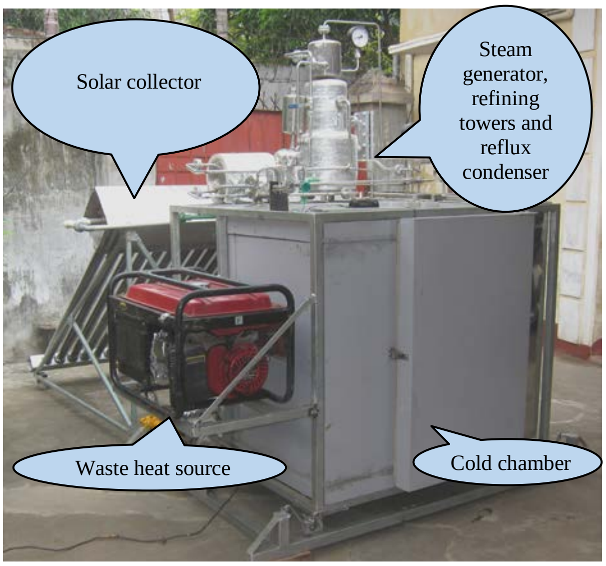

Fig 4. Experimental Model of absorption refrigerator using waste heat and solar energy

IV. EXPERIMENTAL OPERATION

After having final manufactured experimental models, authors have conducted testing operation to check in the condition without vibration (static conditions) and vibration conditions. In particular, in the vibration conditions the system is operated in conditions fluctuated with amplitude A = 0 ÷ 70 [mm] and the oscillation frequency f = 0 ÷ 100 [times / min]. Each working mode of work will be conducted 05 times, and the result will be the average value of the 05 exprimental batches. For details, the results of the operational testing are shown as follows:

1. Operating by waste heat from the engine power

a. Operation in static condition

Table 5 shows the results of empirical model operation by the heat source from the engine fumes in static conditions

Table 5. Experimental results in static condition

No	Time, [min]	t_{sh} [^oC]	t_k [^oC]	t_o [^oC]	t_{ch} [^oC]
1	0	30.0	24.0	30.0	30.0
2	40	56.5	24.0	30.0	30.0
3	80	76.0	24.0	30.0	30.0
4	120	88.5	24.0	30.0	30.0
5	130	90.8	24.0	30.0	30.0
6	140	92.5	24.0	30.0	30.0
7	150	94.2	24.0	30.0	30.0
8	160	95.0	24.0	30.0	30.0
9	170	94.5	28.0	15.0	25.0
10	180	93.5	29.5	-11.0	13.0
11	190	93.0	30.0	-15.0	0.8
12	200	93.5	30.5	-15.0	-2.8
13	210	94.0	30.0	-15.0	-4.2
14	220	94.5	30.5	-15.0	-5.0
15	230	95.0	30.0	-15.2	-5.0
16	240	95.5	30.0	-15.5	-5.0

b. Operation in vibration condition

Table 6 shows the results of empirical model operation by the heat source from the engine fumes in vibration conditions

Table 6. Experimental results in vibration condition

No	Time, [min]	t_{sh} [^oC]	t_k [^oC]	t_o [^oC]	t_{ch} [^oC]
1	0	30.0	24.0	30.0	30.0
2	40	60.0	24.0	30.0	30.0
3	80	78.5	24.0	30.0	30.0
4	120	90.0	24.0	30.0	30.0
5	130	92.3	24.0	30.0	30.0
6	140	94.0	24.0	30.0	30.0
7	150	95.0	24.0	30.0	30.0
8	160	94.5	27.5	17.0	24.0
9	170	94.0	28.0	-6.0	12.0
10	180	93.5	29.5	-14.0	1.0
11	190	94.0	30.2	-15.5	-3.0
12	200	94.5	29.4	-16.0	-4.5
13	210	95.0	30.0	-16.0	-5.5
14	220	95.5	30.0	-16.0	-5.5
15	230	96.0	29.5	-16.0	-6.0
16	240	96.5	29.5	-16.5	-6.0

c. Comparison the operation in static and vibration conditions

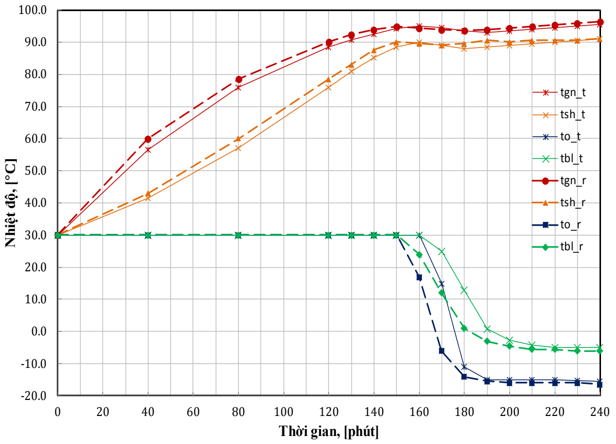

Fig 5.Temperature variation in static and vibration conditions when heating by flue gas.

2. Operation by solar energy

a. Operation in static condition

Table 7 shows the results of empirical model operation by solar energy in static conditions..

Table 7. Experimental results in static condition

No	Time, [min]	t_{sh} [°C]	t_k [°C]	t_o [°C]	t_{ch} [°C]
1	0	35.0	24.0	35.0	35.0
2	40	52.0	24.0	35.0	35.0
3	80	68.5	24.0	35.0	35.0
4	120	81.0	24.0	35.0	35.0
5	130	83.5	24.0	35.0	35.0
6	140	85.5	24.0	35.0	35.0
7	150	87.0	24.0	35.0	35.0
8	160	88.5	24.0	35.0	35.0
9	170	89.5	24.0	35.0	35.0
10	180	90.0	24.0	35.0	35.0
11	190	89.5	28.5	20.0	32.8
12	200	89.0	29.5	-10.0	24.5
13	210	88.5	30.5	-14.0	12.0
14	220	89.0	31.0	-15.0	4.0
15	230	89.0	30.5	-15.0	0.0
16	240	89.2	30.5	-15.0	-1.0

b. Operation in vibration condition

Table 8 shows the results of empirical model operation by the heat source from solar energy in vibration conditions

Table 8. Experimental results in vibration condition

No	Time, [min]	t_{sh} [°C]	t_k [°C]	t_o [°C]	t_{ch} [°C]
1	0	35.0	24.0	35.0	35.0
2	40	52.0	24.0	35.0	35.0
3	80	68.5	24.0	35.0	35.0
4	120	80.5	24.0	35.0	35.0
5	130	83.0	24.0	35.0	35.0
6	140	85.5	24.0	35.0	35.0
7	150	87.0	24.0	35.0	35.0
8	160	88.5	24.0	35.0	35.0
9	170	89.5	24.0	35.0	35.0
10	180	90.0	24.0	35.0	35.0
11	190	89.5	27.5	19.5	32.0
12	200	89.0	28.5	-10.5	23.5
13	210	88.5	29.5	-14.5	11.0
14	220	88.5	30.0	-15.0	3.0
15	230	89.0	29.5	-15.0	-0.5
16	240	89.0	30.0	-15.0	-1.2

c. Comparison the operation in static and vibration conditions

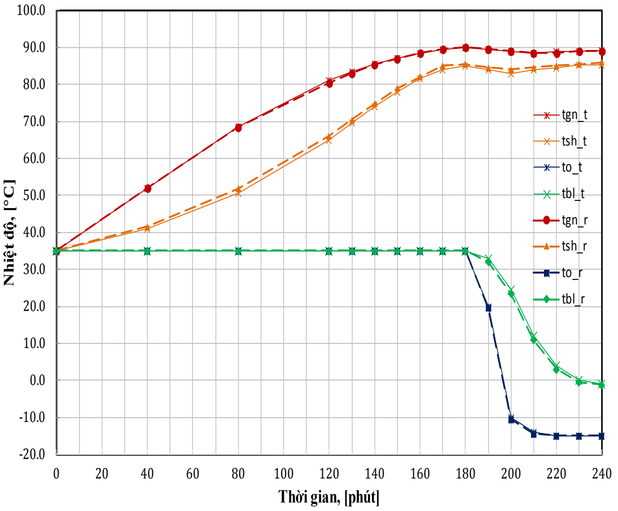

Fig 6. Temperature variation in static and vibration conditions when heat source by solar energy

3. Operation combined with two heat sources

a. Operation in static condition

Table 9 shows the results of empirical model operation by the dual generating heat source in static condition.

Table 9. Experimental results in static condition

No	Time, [min]	t_{sh} [°C]	t_k [°C]	t_o [°C]	t_{ch} [°C]
1	0	35.0	24.0	35.0	35.0
2	40	69.5	24.0	35.0	35.0
3	80	87.0	24.0	35.0	35.0
4	120	94.5	24.0	35.0	35.0
5	130	95.0	24.0	35.0	35.0
6	140	94.0	28.0	18.0	28.0
7	150	93.0	29.5	-11.0	14.0
8	160	93.6	30.0	-15.0	0.5
9	170	94.0	30.5	-15.0	-2.6
10	180	94.5	30.0	-15.0	-4.0

11	190	94.5	30.5	-15.2	-5.0
12	200	95.0	30.0	-15.3	-5.1
13	210	95.0	30.0	-15.5	-5.2
14	220	95.5	30.0	-15.5	-5.3
15	230	95.5	30.0	-15.5	-5.5
16	240	96.0	30.0	-15.5	-5.5

b. Operation in vibration condition

Table 10 shows the results of empirical model operation by the dual generating heat source in vibration condition.

Table 10. Experimental results in vibration condition

No	Time, [min]	t_{sh} [^oC]	t_k [^oC]	t_o [^oC]	t_{ch} [^oC]
1	0	35.0	24.0	35.0	35.0
2	40	71.0	24.0	35.0	35.0
3	80	88.0	24.0	35.0	35.0
4	120	95.0	24.0	35.0	35.0
5	130	94.5	27.5	21.0	27.0
6	140	93.5	28.5	-6.0	13.0
7	150	93.6	29.5	-14.0	0.7
8	160	94.5	30.2	-15.5	-3.0
9	170	95.0	29.4	-16.0	-4.9
10	180	95.0	30.0	-16.0	-5.5
11	190	95.5	30.0	-16.2	-5.7
12	200	95.5	29.5	-16.3	-6.0
13	210	96.0	29.5	-16.5	-6.0
14	220	96.2	29.5	-16.8	-6.0
15	230	96.4	29.5	-17.0	-6.0
16	240	96.5	29.5	-17.0	-6.0

c. Comparison the operation in static and vibration conditions

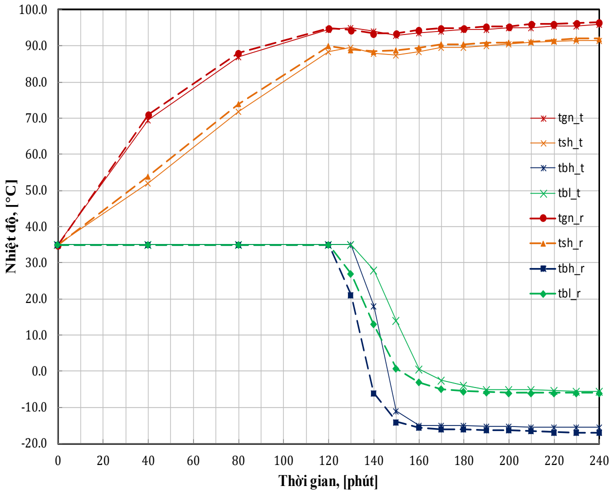

Fig 7. Temperature variation in static and vibration conditions by the dual generating heat source

Operation the device by dual generating heat source combined solar energy and the flue gas in vibration conditions is show in Figure 8.

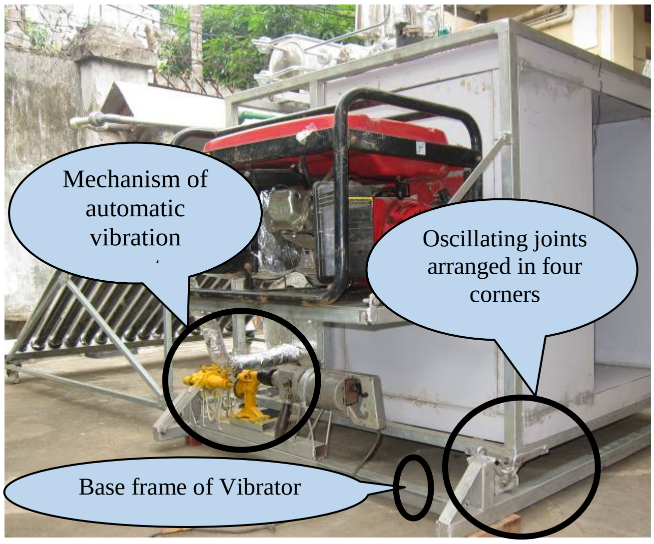

Fig 8. Model testing operation in vibration conditions

The testing results showed that: The model has stable operation, and realibility also meet the designing requirements. Specifically, when the experimental operation with dual generating heat source in vibration condition, heating temperature up to 95 [C] for 120 [minutes], Evaporation r temperature reaches -17 [° C] and the temperature of cold chamber reaches -6 [° C].

Thus, with the dual generating heat source in the vibration condition has stable operation, realibility and meet the designing requirements. This result confirms the effectiveness of device in the anti-vibration requirement. However, it should be more conducted experiments with many different vibration modes to evaluate model comprehensively. Here are the results for the initial feasible solution to expand this model application in the transportation means as ships.

V. CONCLUSION

Having successful manufacturing complex equipment of steam generator, condenser and solvent refluxing refiner for model of absorption refrigerator NH_3/H_2O with capacity as 1.5 kW using waste heat and solar energy in vibration condition.

From the results of manufacturing and testing operation it is shown that: complex equipment of steam generator, condenser and solvent refluxing refiner in experimental model has stable operation, reliability and meet the designing requirements.

Experimental operation results show this device is useful, necessary to permit for conduction of empirical research, expansion of research results in order to put research results into practical applications.

NOMENCLATURE

Symbol	Unit	Parameter
A	[mm]	Vibration range
m	[kg/s]	Flow NH$_3$ solution concentration
$\bar{m}$	[-]	Dimensionless flow
h	[kJ/kg]	Enthalpy
Q	[kW]	Heat flow
f	[lần /phút]	Frequency vibration
t	[^{o}C]	Celsius temperature
ξ	[kg/kg]	Solution concentration NH$_3$

Subscript

a	Dilute solution	hn	Heat recovery
d	Refrigerant	k	Condensation
dd	Solution	mc	Solvent
ch	Cold chamber	o	Evaporation
hl	Reflux	R	Concentrated solution
cw	Cooling water	sh	Supply heat

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AUTHOR’S BIOGRAPHY

Dang Tran Tho was born in Huong Khe District, Ha Tinh Province of Viet Nam on 20th May 1977. He got Engineer’s and PhD degrees from Ha noi University of science and technology in 2001 and 2008, respectively. Since 2001, he has been a lecturer at the School of Heat Engineering and Refrigeration of Ha noi University of Science and Technology.

Hoang Mai Hong was born Nam Dinh Provine of Viet Nam, He got Engineer’s and Msc degrees from Ha noi University of science and technology in 2008 and 2014, respectively. Since 2008, he has been a lecturer at the School of Heat Engineering and Refrigeration of Ha noi University of Science and Technology