COMPARISON OF THE ENERGY EFFICIENCY AND ENVIRONMENT EFFECTS OF ABSORPTION CHILLER AND VAPOR COMPRESSION REFRIGERATION

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Abstract: *Today, most chiller and heat pumps for heating and cooling are mechanically driven. However, increased efforts to reduce CO_2 emissions and continuous increases in fossil energy prices have led to stronger legislation concerning energy utilization efficiency in the refrigeration and air conditioning sector. In the case of the developing countries such as Vietnam having a hot and humid climate, the absorption chiller technology is a promising alternative to electrically driven one. The use of conventional air-conditioning systems infers major drawbacks such as electrical peak demand during daytime. Nevertheless, only few research works have been performed on CO_2 emissions. In the attempts to fill the gaps of studies on the topic, the paper presents the calculations of energy consumption with two plans for a room: i) Vapor compression refrigeration (Baseline); and ii) Absorption chiller (Alternative). Then, analysis of CO_2 emissions of the plans has been carried out in this work, also. The results show the quantitative data on the potential for energy efficiency and CO_2 emissions as well as the operating costs of the absorption refrigeration. Consequently, it will optimize the energy use and reduce the price of the alternative, and thus, would be feasible for commercializing at the Vietnamese market in the years to come.*

Keywords: *Absorption chiller, vapor compression, COP, exergy, CO_2 emissions*

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I. INTRODUCTION

Currently, the clinate change is the hot topic in the world. Developing and using renewable energy technologies often are prioried by government incentives to phase out CO_2 emissions and to make ecological conservation in the future. Refrigeration and air-conditioning system also contribute to the increasing CO_2 directly and indirectly. By one calculation, replacing chillers that endanger the atmosphere will reduce the total greenhouse gas emissions to 90 billions tons of CO_2 in 2050. Making these devices more energy efficient can double the number above. Therefore, technical measures to save energy and reduce CO_2 emissions for air conditioners are of primary concern. One of the measures is to use absorption chiller system. The biggest advantage of absorption chiller to vapor compression refrigeration is that they do not need to use electricity but only use heat sources with temperatures not as high as solar energy, waste heat... And absorption chiller systems cause no ozone depletion because they don't use any CFCs or HFCs refrigerant as working fluidand. But any change in refrigeration technology by means of introducing new refrigerants or by adopting new techniques must be carefully balanced to reduce the overall environmental impact (Ure 1995, 1996a, 1996b). This has recently been classified as Total Equivalent Warming Impact (TEWI), in which the influence upon the Greenhouse Effect referred to as Global Warming Potential (GWP), can be judged for the operation of individual refrigeration plants. The direct component relates to release of refrigerants like HFCs, and the indirect one to carbon dioxide production in powering the equipment. The indirect effect, caused by the emission of CO_2 for producing the electrical power needed to run the equipment. In addition to this the absorption chillers considered use the binary mixture H_2O/LiBr where water is the refrigerant. By doing so, the direct refrigerant impact on TEWI is eliminated from these absorption options.

The most recent surveys ascertain that the demand for building cooling has been increasing in the past few years and will continue to do so dramatically in the near future. The analysts forecast the Global Precision Air Conditioning market will grow at a CAGR of 12.77 % over the period 2013-2018, and it will triple by the year 2050. And the electricity consumption will be a lot. So, with the aspect of energy shortage and the environmental point of view, the sorption technology is strongly investigated since the 1970s. From the data of the Global Industry Analysts (2015), the global market for absorption refrigeration is projected to reach 983 million USD by 2020. So the study of it is really necessary.

Many researchers have developed solar assisted absorption chiller systems. Most of these systems have been produced experimentally and computer codes were written to simulate them. At the same time, there have also been many studies project evaluating the energy efficiency of vapor compression refrigeration and absorption chiller. Radhouane Ben Jemaa and associates [3] studied energy and exergy of vapor compression refrigeration using R1234ze and R123a. Manoj Dixit [4], T. Avanessian [5] studied energy, exergy, and economic analysis of single and double effect absorption chillers. But there are no studies on CO_2 emissions of absorption chillers.

The paper presents the calculations of energy, exergy, CO_2 emissions of vapor compression refrigeration and absorption chiller. The results show the quantitative data on the potential for energy efficiency and CO_2 emissions as well as the operating costs of the absorption chiller compare to vapor compression refrigeration.

II. MAIN CONTENTS

2.1. Energy and exergy analysis of vapor compression refrigeration and absorption chiller

2.1.1. Working principle of vapor compression refrigeration and absorption chiller

The based cycle of the vapor compression refrigeration and the absorption chiller is shown in Figure 1, Figure 2. In order to simulate this system the principles of mass continuity, the first law, the second law and exergy analysis are applied to each component of the cycle taking into account the following assumptions: steady state operation, kinetic and potential energy are not considered and negligible pressuredrops.

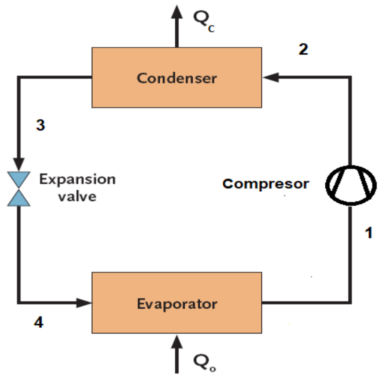

Figure 1. *Schematic diagram of vapor compression refrigeration*

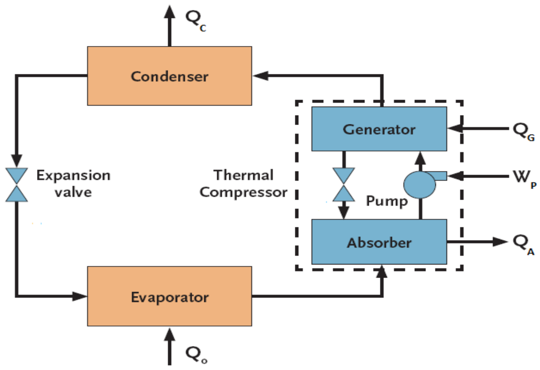

Figure 2*. Schematic diagram of absorption chiller*

2.1.2. Coefficient of Performance COP

The thermal performance of refrigeration units expressed in terms of the "Coefficient of Performance" (COP) [3]. COP for the two technologies, is defined respectively as:

$$COP_{VC} = \frac{Q_0}{P_{el}} \qquad COP_{AC} = \frac{Q_0}{Q_G} \tag{1}$$

Where,

Q_0 - The cooling capacity [kW],

P_{el} - The electricity required to drive the vapor compression refrigeration [kW],

Q_G - The thermal power offered to the generator of the absorption chiller [kW].

On the basis we should not conclude that electric chillers are better than thermal chillers, because such a comparison is not properly stated. Indeed the two definitions of COP refer to energy of different quality: electricity (P_{el}) for the vapor compression refrigeration and heat (Q_G) for an absorption chiller. A more rational basis for comparison is exergy.

2.1.3. Exergy and exergy efficiency

Several theories have been described regarding how the energy costs are to be allocated to the thermal and electric energy, exergy is the thermodynamic variable that best quantifies the usefulness of energy.

When dealing with exergy balances, we usually refer to the first law of Termodynamics, which states that energy is a conservative property. The exergy measures irreversibility in a system and principle irreversibility in a process leading to these losses is due to various factors such as friction, heat transfer under temperature difference and unrestricted expansion (ASHRAE, 1997).

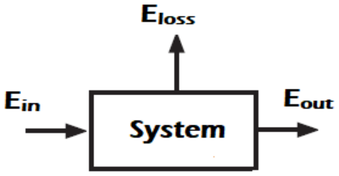

Figure 3*. Exergy flows across a system*

Where,

Exergy input (E_{in}): The amount of exergy entering the system;

Exergy output (E_{out}): The amount of exergy useful to the system;

Exergy loss (E_{loss}): The amount of exergy loss.

According to this approach, the exergy efficiency of the system is: $\eta_e = E_{of}^{-} / E^{+}$ (2)

Exergy balance of the system is: $E_{of}^{-} = E^{+} - \Pi$ (3)

The exergy loss of the system are the total exergy loss of each equipment: $\Pi = \sum_i \Pi_i$ (4)

For vapor compression refrigeration [1]:

Specific exergy in any state : $\psi = (h - h_0) - T_0(s - s_0)$ (5)

For evaporator: $Q_e = \dot{m}(h_1 - h_4)$

$$\Pi_{ev} = \dot{m}(\psi_4 - \psi_1) + (1 - T_0 / T_e)Q_e \quad (6)$$

For compressor: $W_c = \dot{m}(h_2 - h_1)$

$$\Pi_{com} = \dot{m}(\psi_1 - \psi_2) + W_e \quad (7)$$

For condenser: $W_c = \dot{m}(h_2 - h_3)$

$$\Pi_{con} = \dot{m}(\psi_2 - \psi_3) + (1 - T_0 / T_c)Q_c \quad (8)$$

For expansion valve: $\Pi_{val} = \dot{m}(\psi_4 - \psi_3)$ (9)

For absorption chiller[6]:

For pump: $\dot{m}_1 = \dot{m}_2 = \dot{m}_p$, $W_p = \dot{m}_p w_p$

$$\Pi_{comp} = \dot{m}_1(\psi_1 - \psi_2) + W_p \quad (10)$$

For generator: $\dot{m}_3 = \dot{m}_4 + \dot{m}_7$

$$\Pi_{gen} = \dot{m}_3 \psi_3 - \dot{m}_4 \psi_4 - \dot{m}_7 \psi_7 + (1 - T_0 / T_g)Q_g \quad (11)$$

For condenser: $\dot{m}_7 = \dot{m}_8$

$$\Pi_{con} = \dot{m}_7(\psi_7 - \psi_8) - (1 - T_0 / T_c)Q_c \quad (12)$$

For evaporator: $\dot{m}_9 = \dot{m}_{10}$

$$\Pi_{eva} = \dot{m}_9(\psi_9 - \psi_{10}) + (1 - T_0 / T_e)Q_e \quad (13)$$

For absorber: $\dot{m}_1 = \dot{m}_6 + \dot{m}_{10}$

$$\Pi_{ab} = \dot{m}_6 \psi_6 + \dot{m}_{10} \psi_{10} - \dot{m}_1 \psi_1 - (1 - T_0 / T_a)Q_a \quad (14)$$

For expansion valve (for weak solution and for refrigerant):

$$\Pi_{val1} = \dot{m}_5(\psi_5 - \psi_6) \qquad \Pi_{val2} = \dot{m}_8(\psi_8 - \psi_9) \quad (15)$$

2.2. Total Equivalent Warming Impact TEWI

Global warming effect can be determined using different methodologies. The widely used Total Equivalent Warming Impact (TEWI) and LCCP concept was adopted in the present work. Compared to TEWI, LCCP includes discharging directly and in-directly of wastes during its operation process including manufacture, assembly and transportation. There has not been any statistics on the transport of equipment, emission from vehicles. Also, statistics on emissions from manufacture is limited, therefore, it is difficult and in appropriate to apply LCCP methods to calculate emissions of household air-conditioners in Vietnam. As a result, the TEWI method has been chosen to calculate the emissions of household air conditioners in Vietnam.

According to [7,8], TEWI is calculated in accordance with equation (16):

$$\begin{aligned} TEWI &= \text{Direct global warming potential} + \text{Indirect global warming potential} \\ &= GWP.L.n + GWP.m.(1-\alpha) + n.E.\beta \end{aligned} \quad (16)$$

Where,

GWP	- Refrigerant Global Warming Potential (equivalent to CO_2) [kg CO_2/kg refrigerant],
L	- Annual leakage rate [%],
n	- System operating life time [years],
m	- Refrigerant charge [kg],
α	- Recycling factor [%],
E	- Annual energy consumption [kWh/year],
β	- CO_2 emissions on energy generation [kg CO_2/kWh].

The objective of this paper is calculate the energy consumption and analysis of CO_2 emissions with two plans for a room: Vapor compression refrigeration and Absorption chiller. The typical room considered has a floor area of 15 m^2 and details of the room are presented in [2], were considered in order to minimise the room load. The specific subject of the study is a vapor compression refrigeration with capacity of 3.5 kW unit and the refrigerant is R410A. And an absorption chiller with capacity of 3.5 kW unit and H_2O/LiBr without using solar energy.

Total annual energy consumption E is calculated by the bin method:

For vapor compression refrigeration [2]: $$E = \sum_{i=1}^{n} E_{bin}^{i} = K_{tot}.\sum_{i=1}^{n} n_{bin}^{i} \frac{\left(t_{bin}^{i} - t_{bal}^{i}\right)}{CSPF} \quad (17)$$

For absorption chiller [2]: $$E = U.I.\cos\varphi.\tau \quad (18)$$

E, kWh/year \ T_c, °C	30	32	34	36	38	40	42	44
Vapor compression refrigeration	26.61	34.99	96.73	158.01	265.26	148.57	206.88	53.20
Absorption chiller	12.75	10.29	20.65	25.93	34.09	14.88	17.09	4.25

Other quantities have specific values as shown in Table 2.1.

Table 2.1. Values of the quantities in TEWI

	Vapor compression cooling	Absorption chiller
GWP [kg CO_2/kg refrigerant]	2088 [7]	0 [7]
L [%]	3 [7,8]	3 [7,8]
n [year]	15 [7,8]	15 [7,8]
m [kg]	1 [7]	-
α [%]	75 [7,8]	75 [7,8]
β [kg CO_2/kWh]	0.847 [7]	0.279 [7]

2.3. Results and discussions

2.3.1. COP

The variation of COP for for vapor compression refrigeration and absorption chiller with condensation and evaporation temperature is shown in Figure 4. And from figure it can be seen that with an increase in condensation temperature, COP shows a decreasing trend. The reason for this behaviour is that as condensation temperature increases, system pressure will increase, as a result, less refrigerant vapours are allowed to release from compressorand generator, thereby decreasing COP as well as exergy efficiency of the system. From the condensation temperature of 20°C to 50°C, COP of absorption chiller are less than 78.7% in vapor compression refrigeration. At the same, tendency for COP there were a very small increase as the evaporation temperature rose and at higher evaporation temperature the trend becomes almost flat. This is due to the fact that the higher the evaporation temperature will cause higher absorption pressure, then increases the absorption efficiency. From the evaporation temperature of 0°C to 20°C, COP of absorption chiller are less than 79.3% in vapor compression refrigeration. This result is completely obvious because the vapor compression refrigeration uses electricity and the absorption chiller uses solar energy. Therefore, to compare the energy efficiency between these two types of equipment we need to use more exergy efficiency to evaluate.

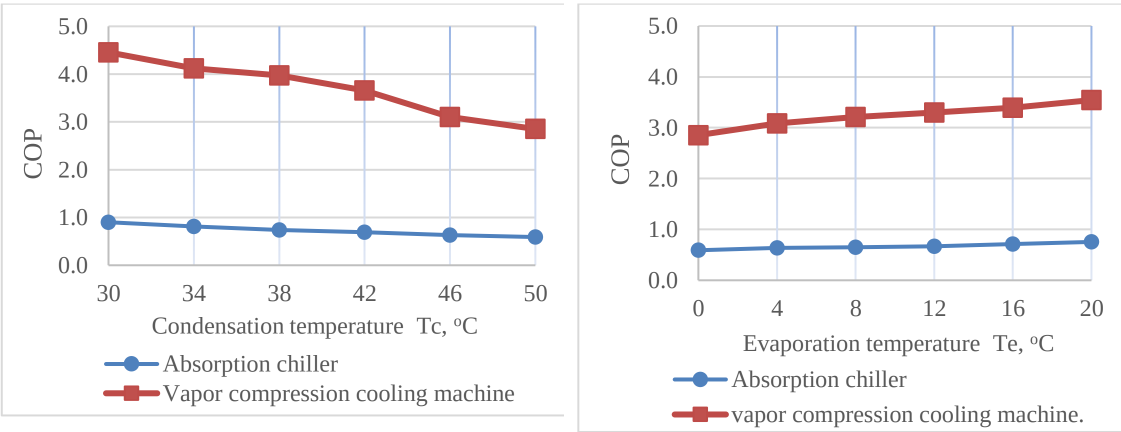

Figure 4. *Variation of COP for vapor compression refrigeration and absorption chiller with condensation and evaporation temperature*

2.3.2. Exergy efficiency

The variation of exergy efficiency for vapor compression refrigeration and absorption chiller with condensation and evaporation temperature is shown in Figure 5. And from figure it can be seen that with an increase in condensation temperature, exergy efficiency shows a decreasing trend. The reason is similar to the case of COP. From the condensation temperature of 20°C to 50°C, exergy efficiency of absorption chiller are greater than 8.5% in compression cooling machine. At the same, tendency for exgery there were a very small increase as the evaporation temperature rose and at higher evaporation temperature the trend becomes almost flat. This is due to the fact that the higher the evaporation temperature will cause higher absorption pressure, then increases the absorption efficiency. From the evaporation temperature of 0°C to 20°C, exergy efficiency of absorption chiller are greater than 9.1% in vapor compression refrigeration.

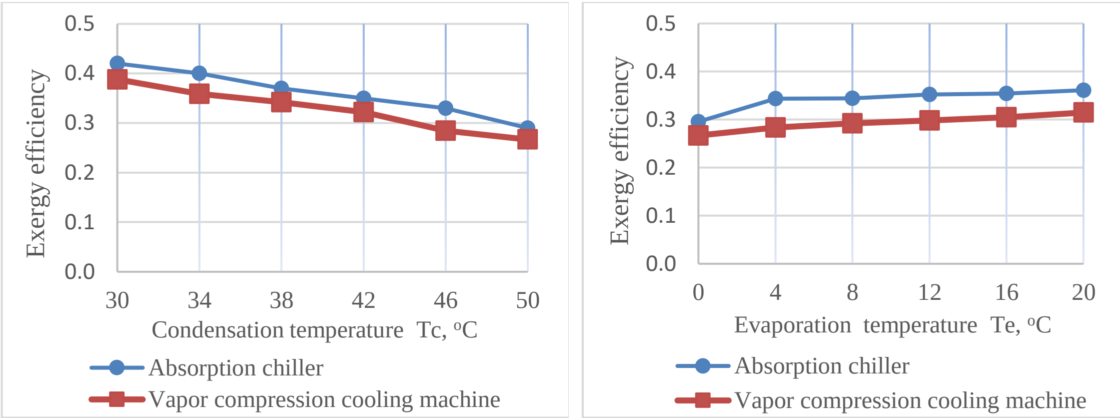

Figure 5. *Variation of exergy efficiency for vapor compression refrigeration and absorption chiller with condensation and evaporation temperature*

2.3.3. TEWI

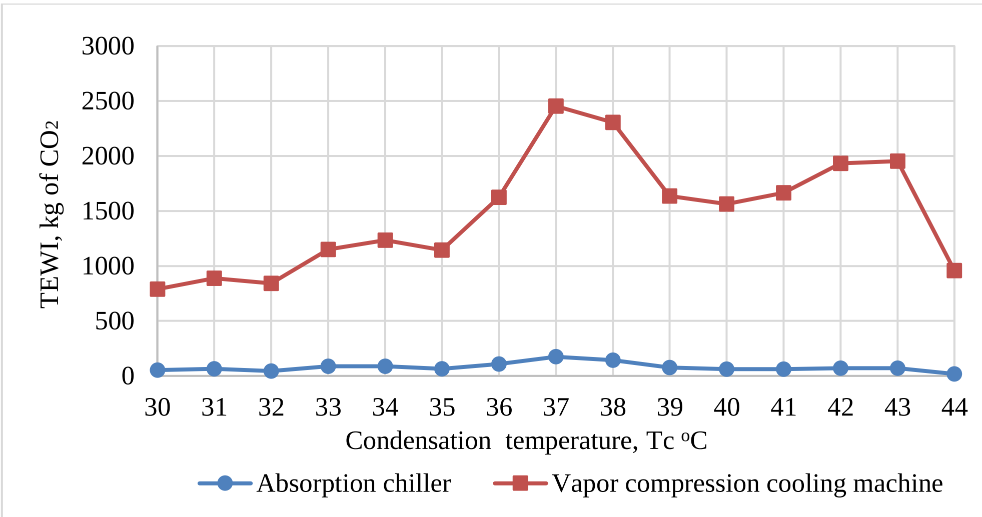

Figure 6. *Variation of TEWI for vapor compression refrigeration and absorption chiller with condensation temperature*

TEWI calculation for the vapor compression refrigeration and the absorption chilller depend on the condensation temperature in Figure 6. From the temperature of 30°C to 44°C, the CO_2 emission for absorption chiller system are greater than 5.5% in vapor compression cooling system.

When the temperature is in the range of 36°C and 38°C, the difference between the two values is greatest. Because the number of hours at bin method is maximum.

III. CONCLUSIONS

The calculations of COP, exergy and CO_2 emission of the vapor compression refrigeration and the absorption chiller in the Vietnamese climate have been implemented in the paper. Accordingly, some conclusions are drawn:

(1) COP of absorption chiller are less than 78-79% in vapor compression refrigeration.
(2) Exergy efficiency of absorption chiller are greater than 8-9% in vapor compression refrigeration.
(3) The CO_2 emission for absorption chiller system are greater than 5.5% in vapor compression refrigeration.

COP of the vapor compression refrigeration is higher than of the absorption chiller is obvious. But absorption chiller is more beneficial than vapor compression refrigeration both in terms of energy and environment, so it is an effective measure to gradually replace air compressor in the future when fossil fuel resources are exhausted and polluted environment.

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