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On the Dimensionless Absorption Heat Pump Widespread

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ABSTRACT

Climate change has a huge challenge to 2050. Some renewable energies can be installed to reduce CO2 production. Unfortunately, the photovoltaic systems, wind energy, and ocean energy devices do not have direct thermal applications. These systems are useful for people's electricity consumption. Absorption heat pumps (AHP) are thermal devices for increasing the temperature level from an energy source at medium temperature level, such as plane solar collectors, to another energy sink. The main problem with design, power calculations and device construction is a lack of education about this technology, which is more complex than compression heat pumps but with 90 % less electric energy consumption that would be supplied by photovoltaic cells. This paper shows an approximation for future engineers designing several absorption heat pumps to avoid global warming beyond the Paris Agreement. Future engineers should be encouraged to analyze this technology with this first and basic approach.

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1. Introduction

1.1. Climate Change

The climate changes for several reasons, not only as a function of time. Even the pandemic for Sar-Cov-2 (or Covid19) leads to a decrease in energy consumption, as shown by the International Energy Agency [1], but the predicted tendency would return to the predicted levels of World Energy Demand in 2023. This is bad news for an energy supplier because the renewable energy sectors have a lower impact on the industrial sector calculated for 2030. Natural Gas will increase 3 % this year, and this will increase to 14 % in 2030, compared whit 2019 values. So the Global Warming Gases [2] will be increased from 2020 to 2050, producing 1.5 °C or 6.0 °C warming effect [3].

1.2. Renewables Energy

The technology for reducing CO_2 emissions includes renewable energy systems. This idea is not new and must remain constant to avoid undesirable natural effects due to several factors, including energy, as The European Commission Disaster Risk Management Knowledge Centre reported in 2020 [4]. Renewable energy would not be able to supply entire power for 2050 or beyond. The people would need energy every day. The energy sources include transformed oil, and this energy consumption would be 99 $x10^{18}$ Joules in 2060 with IEA data [5]. For this energy transformation, we must be efficient 38 % or higher to avoid Global warming. An example of this is México, 155 EJ are 30 % of energy loss by the transformation in the whole the country because all processes have thermal efficiency lower than 100%.

1.3. Energy Efficiency

Heat pumps are used in energy-efficient systems for thermal purposes. People use a compression heat pump for air conditioning and water heating, mainly [6], but it is used in only 5% of the entire residential heat demand. Even with 12 % installation growth every year, this technology is not widely used, although heat pumps could supply 90 % of the global heating requirements without gas-fired boilers. So, the question is: why are we not using heat pumps to diminish the CO_2 emissions? The answer reveals a lack of education in this specific area for engineering experts.

1.4. Absorption Heat Pumps

Heat pumps are well-known technology, the similarity with refrigeration systems is attractive for technicians around the world for being easy to install, but the installation number of this is 3 million units in the U.S.A, half a million in Japan, and 100 thousand in Europe for the 2019 year [6]. The greatest advantage of this technology is the thermal efficiency of the cycle, operating like a domestic refrigerator or industrial freezer: an electrical compression, a condenser, an expansion valve, and an evaporator in a cycle.

Absorption heat pumps are a different technology compared with compression heat pumps. Instead of the electrical compressor, two components replace the compressor to raise the pressure with just 5 % of the energy of the compressor for the same operating conditions. But this technology study is not part of the Bachelor's education in engineering programs in several countries. Chemical engineers, mechanical engineers, industrial engineers, energy engineers, and similar bachelor’s degree programs have separate courses for unit operations, physic-chemical, thermodynamic, differential equations, energy, and mass balances, that could prepare the students to design, construct, install, operate and evaluate an absorption heat pump.

1.5. Methodology for Teaching Absorption Heat Pumps

In January 2021, the *ScienceDirect* web listed just 30031 papers for “heat pumps” from 1997 to nowadays. The same web also listed 2686 for the exact phrase “absorption heat pump” during the same time. Eight specialized journals had published the papers: Energy Conversion and Management, Applied Thermal Engineering, Energy, International Journal of Refrigeration, Applied Energy, Renewable Energy, International Journal of Heat and Mass Transfer, and Journal of Cleaner Production, mainly in the last years [7].

The concept of absorption heat pumps has a misunderstanding; the concept and name do not encourage its study among young engineering students, but these thermal machines would be helpful in reducing CO_2 emissions in the thermal process to be designed in the following years. It is ecologically beneficial in reducing CO_2 using thermodynamic cycles without making it so complex or simplistic. The AHP concept is included in the thermodynamics teaching bachelor's program, but an analysis may require an entire course for designers.

Literature for the heat pumps is lack for absorption process. The main books for heat pumps have different points of view for introducing the basic concepts of the energy process cycle into a heat pump. Some courses have been shown in Academic meetings from experiences in Spain [8], Hungarian and other European countries [9]. These papers indicate the use of software to help the students to approach themselves at heat pump teaching. There are specialized books for heat pumps [10 - 17] which are classified for energy engineering, sustainability, green energy, renewable energy, and economic aspects for formal courses. Every book has detailed aspects of compression heat pumps. Enthalpy and Entropy concepts are part of the chapters to give the students tools for comprehension of the thermodynamics cycles. Some books introduce two main concepts for the heat pump, thermal efficiency, and coefficient of performance.

2. Basic Concepts

The thermal efficiency (op. cit.) (h) is defined as the ratio between two temperature zones for the heat pump, higher and lower thermal levels. The definition was proposed by Carnot a long time ago, and it is easy to find the physical meaning for any AHP. A heat pump takes energy at a lower level, and a thermodynamic cycle raises the temperature at a higher level. 9

$$\eta = \frac{T_H}{T_L} \tag{1}$$

Where TH is the higher temperature into the cycle and TL is the lower temperature in the same cycle, in absolute units. The thermal efficiency is dimensionless.

This is not an academic challenge for any student to understand. This is useful for comparison of several thermal machines in papers and books.

Another main concept is the Coefficient of Performance (C. O. P.) that is an arbitrary or subjective definition for the ratio between the useful energy and the given energy. This is not a permanent formulation. This definition depends on the heating or cooling purpose. It is based on power instead of temperatures from the cycle. This is not a complex relation, again:

$$COP_H = \frac{Q_H}{W_C}, \; COP_C = \frac{Q_C}{W_C} \tag{2}$$

Where QH is the useful heat or useful thermal power from the cycle at a higher temperature, QC is the refrigerant capacity at a lower temperature, and WC is the compression work for liquid transport from low to high pressures zones. The COP is dimensionless.

For absorption heat pumps, the compression process is substituted for two separated pressurized physicochemical processes: desorption and absorption of a gas into a liquid. Thermodynamically this energy process is equivalent to a thermochemical compressor. The process takes vapour from the desorbed unit, and the absorption of this vapour could be at a higher or lower pressure as a function of the equilibrium pressure.

The process cycle may be described as short as desorption or vapour generation (G), condensation (C), evaporation (E), and absorption (A), cyclically. The power energy for each process corresponds to QG, QC, QE and QA, respectively (ibid.). The main advantage of this absorption cycle compared with the compression process is a misunderstanding: compression energy is substituted by a vapour generator and a vapour absorber unit. The energy balance leads to:

$$W_C = Q_G - Q_A \tag{3}$$

Where QG and QA are the thermal power for the vapour generator unit and the absorber unit, respectively, the sing between these values is conventional thermodynamic input and output thermal loads.

Here is a great opportunity to express the advantage of a thermal device compared with an electric heat pump: the QG is always lower than WC (see equation 3). This is the main advantage for the absorption heat pump COP, and if the thermal devices are operated with solar energy or waste energy without CO_2 emissions, then an absorption heat pump is, as the International Energy Agency indicates [18], an opportunity for a global energy-efficient program.

$$COP_H = \frac{Q_A+Q_C}{Q_G}\text{, } COP_C = \frac{Q_E}{Q_G} \tag{4}$$

"In the modelled energy efficiency scenario for Europe on 2050, Direct Heat (DH) is supplied mostly by decarbonised energy sources, and large-scale Heat Pumps meet 25% of the total DH demand. This scenario would bring a wide variety of energy supplies to the DH, which will increase the system's flexibility and the security of supply. The Heat Roadmap Europe 2050 scenario shows that it would be possible to achieve a much more decarbonized DH in 2050 than in the Base Line scenario, which reduces CO_2 emissions by more than 70%" cited from [19].

2.1. Use of OOP

There are several software programs to calculate operating conditions for compression and absorption heat pumps. Some software enterprises have an academic version with reduced cost, as Engineering Equation Solver. Human resources to compare this technology are required; students with thermodynamics concepts to develop the calculation for each scenario from Physic or Engineering Bachelor programs need to be involved. Object-Oriented Programming is a tool that may be useful to include other dimensionless parameters as Flow Ratio [20].

$$FR = \frac{X_G}{X_G - X_A} \tag{5}$$

Where XG is the higher mass fraction concentration and XA is the lower mass fraction in the absorption heat pump cycle.

2.2. Type II Absorption Heat Pump

A statement from the first thermodynamic law is that energy goes from a higher temperature level to a lower temperature level side into a defined system. But there is a defined type II heat pump [12] that takes energy at a low-temperature level and delivers almost half part to a higher level using thermal power. The process is an inverse heat pump. The name inverse is given because it is not a typical heat pump, with the evaporator pressure lower than the condenser pressure. In the Type II heat pumps, the condenser pressure is higher than the evaporator pressure, but the utility would be useful to achieve the 2050 scenarios with recycled thermal energy from the industrial process [21 - 23], and the hypothesis for operating conditions [24] is successful for academic purposes. The process implies vapour generation (G), condensation (C), pumping (p), evaporation (E), and vapour absorption (A).

The COP is now defined for type II absorption heat pump (or absorption heat transformers) as:

$$COP_{II} = \frac{Q_A}{Q_G + Q_E + W_p} \tag{6}$$

Where the Wp is close to 5 % of vapour Generator for electrical power solution pumping from lower pressure to higher pressure, as the experimental laboratory device was evaluated, the experimental prototype is shown in Figure **1**. The absorption heat pump project education must be clear for students.

Experts say, “To achieve a sustainable heat supply that includes a significant proportion of alternative heat sources, the implementation of further demo sites is necessary. Success factors are Strong partners (companies, institutes, start-ups), Projects (demo, best practice, show up experiences and motivation to install Heat Pumps), Learning by doing (requires pioneers who are willing to "pay its dues“), Energy spatial planning (localizing waste heat, avoiding double infrastructure), Standardized solutions (R&D, cost degression / economy of scale), Price signals (to the use of fossil fuel; reduce the burden from tax and levy on clean energy)” [23].

Figure 1: Type II absorption heat pump for academic experimental evaluations.

2.3. The Usefulness of the Dimensionless Concept

The classical representation of the function of COP as a function of the absorption process temperature is shown in Figure **2**. Specialized literature explains in this kind of figure the higher COP values at the lower absorption process temperature and lower COP values for higher absorption temperatures. Unfortunately, the non – linear behaviour of the COP confuses the students. It is not clear for the students how to understand the design. Then the dimensionless concepts help them to associate the absorption process as a function of temperature variation.

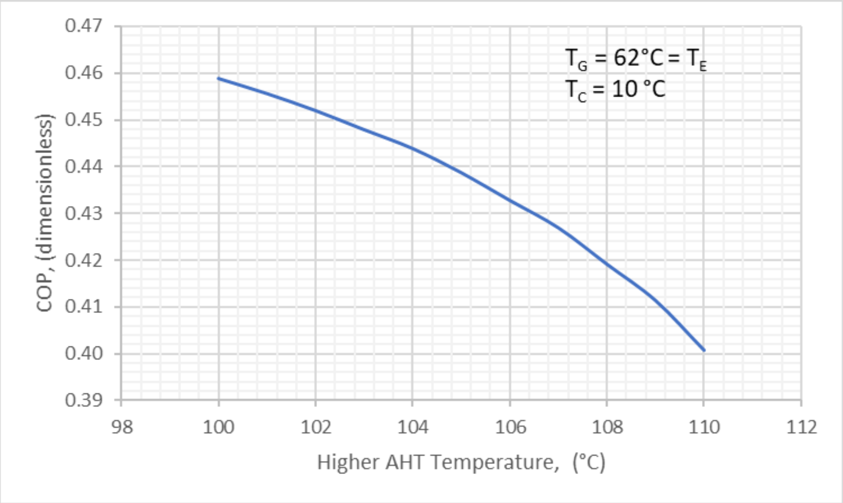

Figure 2: Coefficient of Performance as a function of the absorption process.

It is easy to understand the Flow Ratio as a function of the dimensionless thermal efficiency, as shown in Figure **3**. This is linear, and it means an increase of the dilution (expressed as Flow Ratio) leads to higher thermal efficiency. Of course, this experimental evaluation is for a short temperature range, but it is enough for students to clear the misunderstanding regarding the absorption concept compared with the compression heat pump, where there is no mass concentration variation. But now, the bachelor students associated this linearized behaviour at thermodynamic dilution heat as a response to the thermal process. This is not obvious in Figure **2** but clear enough in Figure **3**. The lowest FR value is obtained at 100 °C for the absorption process.

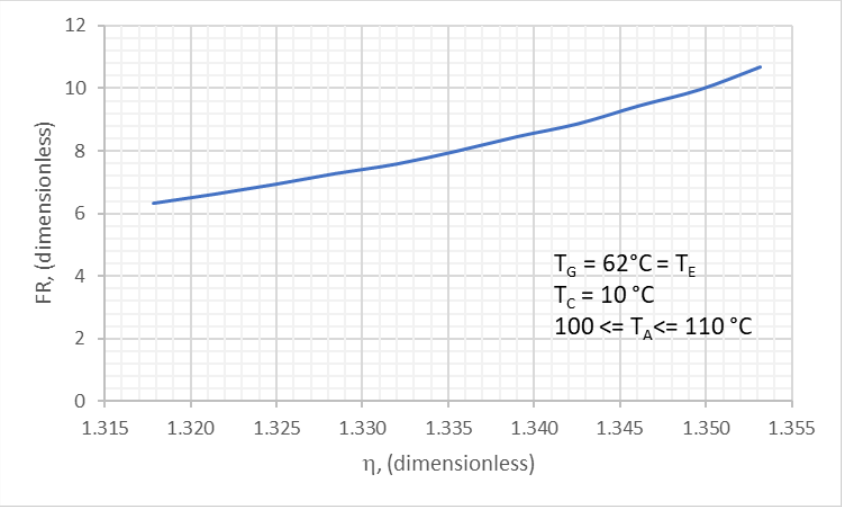

Figure 3: Flow ratio as a function of thermal efficiency.

In Figure **4**, the lower temperature of the process is plotted as an independent variable to analyse the coefficient of performance behaviour for several operating conditions at an AHT. The shown non-linear data correlate the diminished COP as function of the condenser temperature, which is the lower temperature of the thermodynamic cycle. This is in agreement with several papers for AHT [25-36] with consistent typical decreasing shape. For the same data, shown in Figure **5**, the flow ratio as a function of thermal efficiency is observed as an asymptotic tendency for a lower FR value while thermal efficiency increases. The lower FR value is obtained for the lower condenser value at 10 °C.

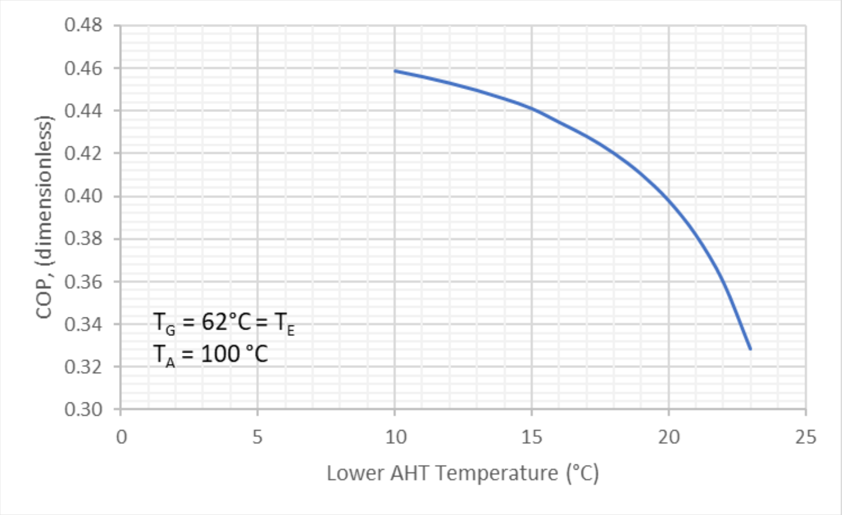

Figure 4: Coefficient of Performance as a function of the condensation process.

In Figure **6** and **7**, the coefficient of performance and the flow ratio were plotted as a function of AHT's higher temperature level and thermal efficiency, respectively. These data were calculated for the Carrol – Water pair. Carrol is lithium bromide and ethylene glycol in weight ratio 3.5:1 proposed by Carrier Co. [37]. This pair at room temperature has high relative viscosity, and the absorption process for heat pump Type I [12] and the use is not recommended for that configuration. An Absorption heat transformer is a heat pump type II, and the absorption process takes place at the highest temperature of the cycle. This pair is an excellent option to operate for water purification purposes.

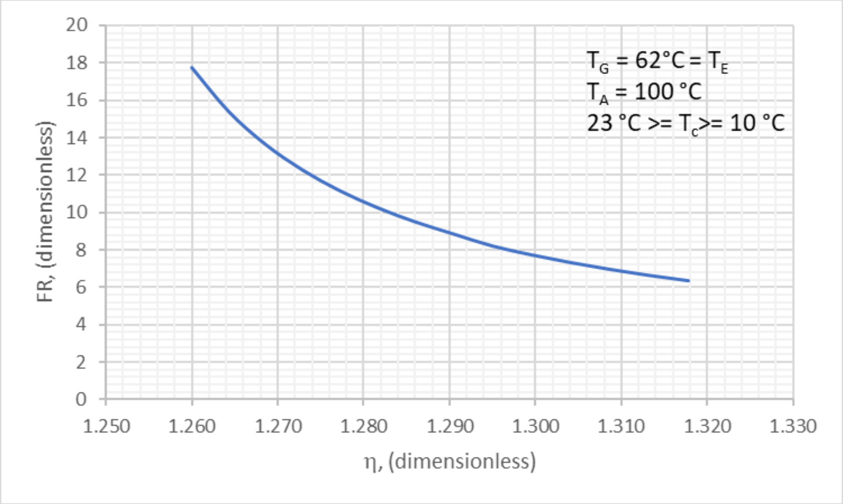

Figure 5: Flow ratio as a function of thermal efficiency.

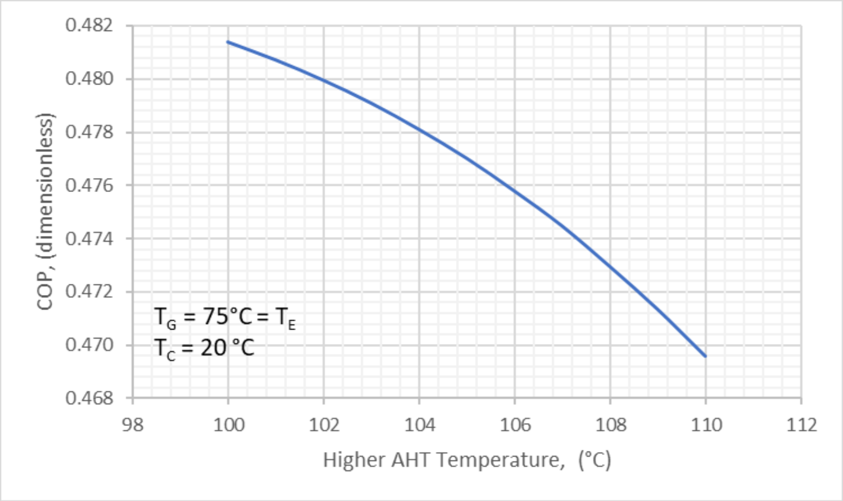

Figure 6: Coefficient of Performance as a function of the absorption process.

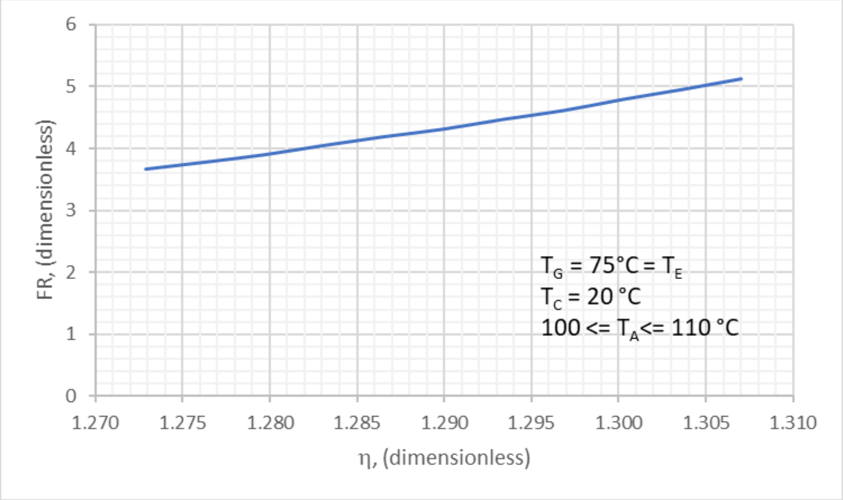

Figure 7: Flow ratio as a function of thermal efficiency.

Figure **6** and **2** show typical COP plots; while the absorption temperature increases, the COP decreases. It could be explained as follow: if the cycle delivers energy at a high-temperature level, the ratio between useful and inlet energy diminishes because it led a greater demand for high-quality energy.

When both dimensionless values are plotted in Figure **7**, the flow ratio (depending on mass concentration) for constant surroundings temperature (TC) is perfectly proportional to the increment of the ratio between temperatures highest and lowest of the cycle. This means for constant room temperature, the absorption process increases the temperature while concentration has closer values to each another.

Figure **8** and **9** show COP as a function of TC and FR as a function of η. The main difference from Figure **4** and **5** is the inlet temperature for generator and evaporator processes. The value for vapor generation in Figure **8** and **9** is 75 °C to get the absorption process at 100 °C, for water distillation mainly [38-50] with absorption heat pumps. For this specific purpose, the absorption temperature is kept constant, and the COP has a variation from 0.483 to 0.479 while TC goes from 15 °C to 25 °C. It means for energy balance, the condensation process delivers heat at a higher temperature has no significant effect on the absorption process for this distillation purpose. This is confirmed in Figure **9**. The FR is a function of η with the highest FR value at 25 °C of TC. FR is dependent on mass concentration. The 4.14 value is a consequence of XG = 70.89 %w and XA = 53.79 %w, and the other end of the plot indicates FR value 3.33 for XG = 76.90 %w and XA = 53.79 %w with agree in the literature for this operating conditions [50].

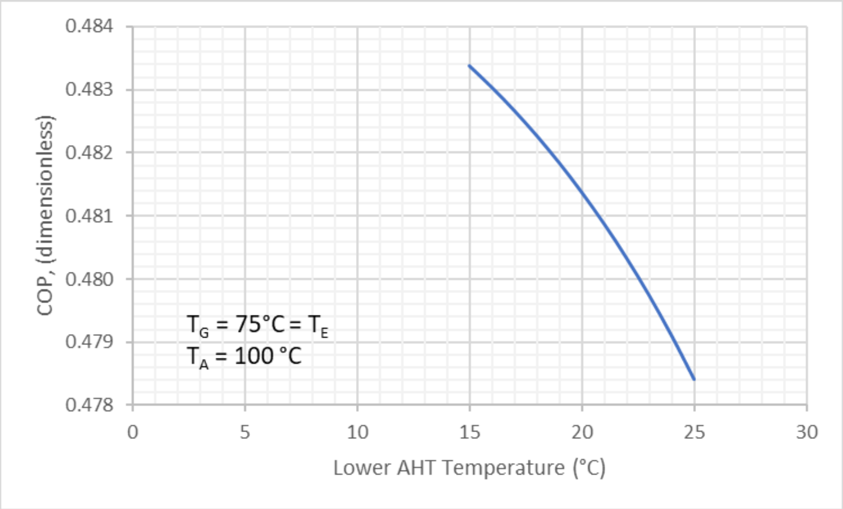

Figure 8: Coefficient of Performance as a function of the condensation process.

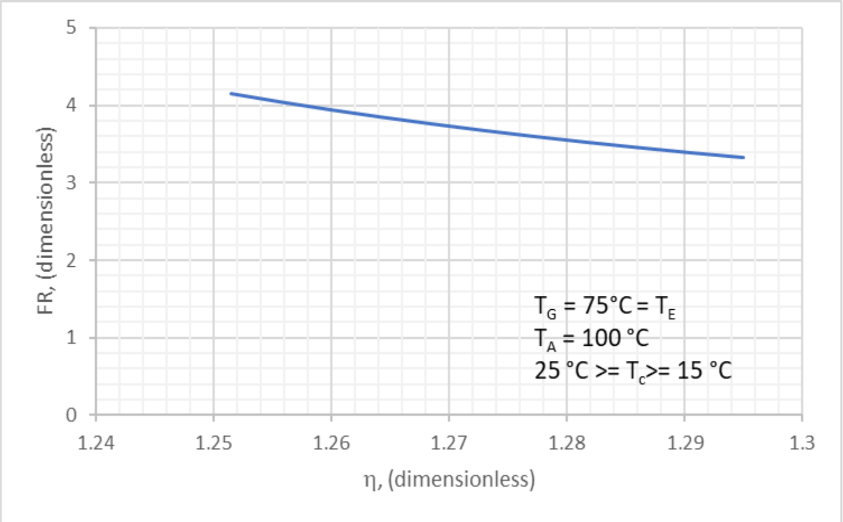

Figure 9: Flow ratio as a function of thermal efficiency.

3. Conclusions

The education for heat pumps needs to have clear concepts. Dimensionless concepts are common in the heat pump process. The coefficient of performance is useful for the ratio of power. Flow ratio and thermal efficiency are previously defined concepts to avoid the students' misunderstanding of the absorption heat pump process. The experimental device shows linear behaviour for Flow ratio as a function of thermal efficiency for educational purposes. Same data expressed in dimensionless function are linearized to help comprehension of the students of thermodynamic cycles. The analysis of the absorption heat pump (AHP) for absorption temperature values from 100 °C to 110 °C at 62 °C generation and evaporations processes show for FR dimensionless values almost linear behaviour at 10 °C condenser process. But for a constant absorption process at 100 °C, with the same generator and evaporator temperatures, the FR value has non-linear variation explained as a function of mass concentration and the dependence of the thermal equilibrium for all calculated thermodynamic data.

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