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Evaporator Evaluation as a Heat Exchanger in Refrigeration Systems at Constant Thermal Load and Fouling Factor

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ABSTRACT: Heat exchangers are widely used in various industrial installations, one of which is their use in air conditioning systems. In the design process of heat exchangers, the main focus is to determine the dimensions of the device. This is done to determine the performance of the heat exchanger, where the calculation is based on a constant thermal load and a constant fouling factor. When the heat exchanger is first operated, the mass flow rate of the cooling fluid must be lower than the design point to maintain a constant cooling load. However, the conditions for the formation of deposits on the surface of the heat exchanger cannot be known. Therefore, designing a heat exchanger with a constant fouling factor is less realistic.

KEYWORDS: Heat exchanger, fouling factor, mass flow rate, thermal, cooling load

I. INTRODUCTION

The use of heat exchangers in various industrial installations of products and processes is something that cannot be avoided because the equipment is one of the vital components of the energy exchange process. Heat exchangers are designed according to function or needs because the types are very diverse. The key component of most power conversion systems is a heat exchanger, which is used for various needs such as energy recovery/waste heat applications, power generation, and energy conversion [1]. Heat transfer from or to a tube bundle either in unidirectional, countercurrent, or transverse flow is relevant to various industrial uses, such as steam generators in boilers and cooling systems such as air conditioners.

Today's cooling needs are increasing in relation to housing, industry, and food. The cooling system is closely related to heat exchangers. In the design process of a heat exchanger, the main focus is usually on determining the dimensions of the device according to the specifications of the predetermined process data, such as thermal load, process conditions and other limitations. The role of heat exchangers in various engineering applications is to increase heat transfer from a small exchange area so that it is widely used for heat recovery [2]. Heat exchangers are an implementation of the heat transfer process between two fluids separated by walls and having different temperatures [3]. After a heat exchanger design is obtained, a re-evaluation process of performance before the device is made is generally carried out. The process is intended to re-check whether the designed equipment has been able to transfer heat energy in the amount specified, whether the design results meet safety requirements, or to predict how the device will perform when operated under operating conditions as stated in its design specifications.

Heat exchangers play an important role in a refrigeration system's energy conversion. Heat exchangers such as evaporators greatly affect the performance of the refrigeration system because they play a role in increasing the efficiency of heat exchange [4]. The evaporator influences the performance of the refrigeration system as one of the most important factors because the cooling capacity is determined by the enthalpy and mass flow rate between the inlet and outlet of the evaporator [5]. Heat exchangers (APK) function as a medium for exchanging heat energy (heat) from a fluid to another fluid that has a different temperature flowing in the device. The type of heat exchanger is designed based on certain functions and needs because the types are very diverse. The arrangement of tubes in a heat exchanger is arranged in an aligned (in a row) and staggered (alternating) manner. Where the staggered tube arrangement will be used in this paper, considering its ability to exchange heat with a much smaller pressure drop compared to the aligned tube arrangement. The staggered tube arrangement is preferred over aligned to improve the performance of the heat exchanger [6]. During the operation process of the heat exchanger, its performance will be affected by the fouling factor.

The role of fouling factors in the design process will affect its thermal resistance. After being used for some time, the heat transfer surface of the heat exchanger will be coated with various deposits that are usually found in the flow system, or the surface will corrode as a result of the interaction between the fluid and the materials used in the construction of the heat exchanger. The growth of the deposit layer (fouling) can increase rapidly if the surface of the deposit formed has strong enough adhesive properties, as well as due to a large enough temperature gradient in the area near the surface. The fouling factor is a theoretical resistance to heat flow due to the accumulation of dirt or other contaminants on the surface of the heat exchanger tube, such as biological fouling, precipitation, and corrosion [7]. The fouling factor affects the thermal efficiency and can be used to assess the performance of the heat exchanger [8, 9].

Deposits formed on the surface generally have a fairly high thermal conductivity, so it will reduce the total heat transfer coefficient. In extreme conditions, the deposit layer can cause higher pressure losses in the heat exchanger. In the process of designing a heat exchanger, to anticipate the fouling phenomenon, what is usually done is to choose and determine the right fouling thermal resistance value for the working fluid used.

A heat exchanger designed at a constant fouling factor will experience operating conditions outside its design point, this is done in the cooling fluid flow of a phosphate cooler [10]. Refrigeration performance is affected by room temperature and thermal load. In contrast, constant thermal load affects the increase in the temperature of the fresh food compartment as an impact of increasing room temperature [11].

II. RESEARCH METHODS

The heat exchanger chosen in this paper is an evaporator with several related things, such as the influence or impact of choosing a constant fouling factor on a constant thermal load and a constant evaporation temperature on the evaporator. In the design process, the characteristics of the mass flow rate of the R-134a cooling fluid were carried out sometime after the heat exchanger was operated. The study was conducted on an evaporator using refrigerant 134a (R-134a), and data was obtained from an air conditioner repair shop. This heat exchanger is planned to work with a constant thermal load and with one of its working fluids working at a constant evaporation temperature column.

To determine the estimated dimensions, the method of calculating the average logarithmic temperature difference and calculating the energy balance in the hot fluid flow and cold fluid flow based on the data above will be used. Then, based on the total heat transfer coefficient (overall) in the heat exchanger, determine the size of the heat transfer surface area. The ability to exchange heat energy can be predicted based on the basic equation as in Equation 1 [3].

$$Q = h.A.\Delta T_{lm} \qquad (1)$$

A heat exchanger installed in a particular process installation's performance will depend on its operating conditions, such as temperature, pressure, type of fluid, and flow rate of the working fluid. Operating conditions that may occur in a heat exchanger include the initial condition, namely the condition when a heat exchanger starts operating where the heat transfer surface is still clean from deposits. The heat transfer coefficient in the initial state can be solved by Equation 2.

$$h_{cl} = \frac{Q_{cl}}{A_{cl}.\Delta T_{lm,cl}} \qquad (2)$$

The second is the real condition, namely the operating condition after the initial condition, in which the heat transfer surface begins to experience dirt from deposits. The heat transfer coefficient is calculated based on Equation 3 [12].

$$h_f = \frac{Q_f}{A_f.\Delta T_{lm,f}} \qquad (3)$$

with

$$\frac{1}{h_f} = \frac{1}{h_{cl}} + R_f \qquad (3a)$$

The assumption taken is $A_{cl} = A_f = A$ because, in practice, the dimensions of a heat exchanger are, in principle, determined during the design calculation process. Heat Exchangers operated under operating conditions with constant thermal load follow Equation 4, which is obtained by rearranging Equations 2 and 3.

$$\Delta T_{lm,f} = \Delta T_{lm,cl}[1 + h_{cl}.R_f] \qquad (4)$$

Heat transfer in the evaporator, as a heat exchanger with a constant evaporation temperature, is calculated based on the logarithmic average temperature using the equation given by Pita [13].

$$\Delta T_{lm,CF} = \frac{(T_{hi}-T_c)-(T_{ho}-T_c)}{\ln\frac{(T_{hi}-T_c)}{(T_{ho}-T_c)}} \qquad (5)$$

Constant evaporation temperature means the correction factor (F) is one, and $\Delta T_{lm,CF} = \Delta T_{lm}$.

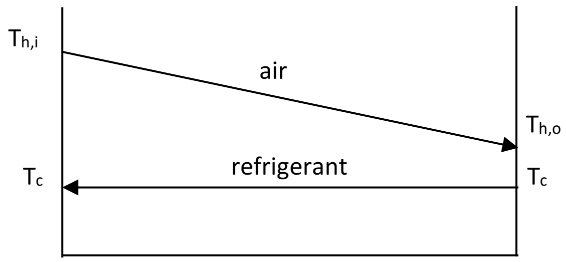

Figure 1. Logarithmic mean temperature difference In the evaporator with constant evaporation temperature

The overall heat transfer coefficient in the aligned and staggered tube bundles is calculated based on Equation 6 [3].

$$h = \frac{1}{\frac{1}{h_o}+R_{fo}+\frac{r_o}{k}\ln\left[\frac{r_o}{r_i}\right]+\left[\frac{r_o}{r_i}\right]R_{fi}+\left[\frac{r_o}{r_i}\right]\frac{1}{h_i}} \quad (6)$$

Redesign or estimating the performance of a heat exchanger is very important by obtaining the relationship between the total heat transfer rate based on the inlet and outlet fluid temperatures, the overall heat transfer coefficient, and the total heat transfer surface area. This can be obtained by using the total energy balance of the hot and cold fluids. The energy balance equation is presented in Equation 7 [3].

$$Q = \dot{m}_h C_{p,h}(T_{h,i} - T_{h,o})$$

And (7)

$$Q = \dot{m}_c C_{p,c}(T_{c,o} - T_{c,i})$$

III. RESULTS AND DISCUSSION

Based on the results of a study conducted on an air conditioner workshop, the data obtained were as in Table 1. The logarithmic mean temperature for R134a is 9.76ºC. When first operated, the overall heat transfer coefficient in the heat exchanger in a clean state is 60.01 W/m^2.ºC and the correction factor at constant evaporation temperature is one. The heat exchanger without considering the dirt factor, the heat transfer surface area is 23.732 m^2. Meanwhile, the heat transfer surface area by considering the dirt factor can be calculated based on Equations (3) and (3a). The cooling fluid is refrigerant 134a (R-134a) and has a dirt factor (R_f) of 0.0002 m^2.ºC/W [14], so the heat transfer surface area becomes 24.017 m^2.

Table 1. Details of heat exchanger design conditions

Thermal load (Q) = 13,9 kW	**R-134a**
Inlet air temperature ($T_{h,i}$)	23ºC
Outlet air temperature ($T_{h,o}$)	12.4ºC
Air velocity (v)	2.6 m/s
Refrigerant evaporation temperature (T_c)	7ºC
Refrigerant mass flow rate ($\dot{m}_c$)	367 kg/h
Tube arrangement	Staggered

Here it can be seen that after the heat exchanger is operated and with the presence of a fouling factor, if it is re-planned there will be a change in the surface area of heat transfer. This is not in accordance with the principle that in practice, the dimensions of a heat exchanger are determined during the design calculation process. While the average logarithmic temperature difference in this condition is 9.88ºC which affects the temperature of the outgoing air to 12.564ºC, and this exceeds the design point outgoing air temperature of 12.4ºC. This means that the average temperature of the air flowing in the heat exchanger becomes higher, so that the temperature gradient in the heat exchanger tubes becomes higher. With a higher temperature gradient, the rate of formation of the deposit layer will accelerate, especially deposits originating from particles. So to reduce the effects that occur due to this condition, the use of additives (antifouling) is required.

Based on the energy balance equation for cold fluid flow in the heat exchanger, the mass flow rate of cold fluid (R-134a) is 362.9 kg/h, while the mass flow rate of cold fluid at the design point is 367 kg/h. Here it can be seen that when it starts operating, the mass flow rate of cold fluid must be operated at a lower price than its design point. Based on this, the average velocity of cold fluid in the heat exchanger pipes is lower than its design point. This causes less favorable operating conditions which can accelerate the rate of deposit formation on the surface.

With the increasing operating time of the heat exchanger, the refrigerant mass flow rate tends to increase, this is because the deposit thermal resistance increases due to the deposit formed on the surface which is estimated to be thicker as the operating time increases. In addition, the pumping power of the cold fluid must be made larger or the pump used must be larger than required.

CONCLUSIONS

Heat exchangers designed at constant thermal load and fouling factor will experience operating conditions beyond their design point. By taking into account the fouling factor, the heat exchanger when it starts operating, the outlet air temperature is higher than its design point value and the refrigerant mass flow rate is lower than its design point value. Designing a heat exchanger using a constant fouling factor is less realistic, because it cannot take into account the fact that deposits formed on the surface of the heat exchanger grow gradually during the operating time.

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