Heat Transfer Analysis of Recuperator for Waste Heat Recovery Purpose Using LMTD & NTU Method

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Abstract: The dumped heat from captive industry like power generation plant, steel plant, refineries, etc. has tremendous potential for multiple energy effect like cooling, power and heating effect. The novel thermodynamic system has been invented for waste heat recovery (WHR) purpose as organic Rankine cycle, kalian thermal system, etc. The recuperator type heat exchanger (HEx) can support for WHR at category of medium and high-grade heat discharge. The design and operating parameters of recuperator is essential for complete development and its thermodynamic analysis. The proposed title of research deals with the heat transfer modeling using LMTD & NTU approach with the help of MATLAB R2017 analytical tool. And ANSYS is used for design work of mentioned heat exchanger. The major outcomes of this paper are maximizing the heat transfer rate, improve overall efficiency by operating parameters, and HEx effectiveness. The shell and tube material, diameter, number of turns of tubes.

1. Introduction

A Recuperator is a form of counter flow heat exchanger (as shown in Fig. 1) that is used for energy recovery in air handling systems or in exhaust gases from industry or plant processes [1]. The Recuperator is simple to make and can be used for a variety of purposes in the factory, including waste recovery in gaseous and liquid mediums at high pressures and temperatures. This form of Recuperator is used in thermal plants, food plants, refineries, and chemical plants, among other places [2-3]. In this paper, a standard method for designing the Recuperator is derived, which is coded with the aid of MATLAB in order to obtain the Recuperator's outlet temperature using the Epsilon-NTU method [4-5]. Waste energy is the energy released into the atmosphere by industry's flue gases, which accounts for 27% of total energy [6-8]. To recycle waste energy by reusing flue gases with the aid of a suitable heat exchanger for switching from one state to another. The first benefit of waste energy is that it improves the performance of the Recuperator by thermal efficiency. The second aspect involves minimizing emissions by reducing the size of the Recuperator [9-11]. The term "recuperator" refers to a heat exchanger that is used to recover waste energy [12]. The Recuperator has a wide range of applications and is primarily used to recover waste energy in industries such as metallurgy, petrochemistry, mechanical engineering, chemical industry, and shipbuilding. The other type of Recuperator is Radiation Recuperator which is defined as indirect contact flow heat exchanger which is used for recovering the waste energy at high temperature application [12].
2. Experimental Analysis

2.1 Heat Transfer Analysis of Recuperator

In this paper the design of recuperator with giving standard tube length and tube diameter dimension are followed by TEMA (tabular exchange manufactures association) and the code is written in MATLAB. Program is run for the obtaining maximum heat transfer by comparing the heat transfer is obtained by the LMTD method and heat transfer is obtained by the NTU method. The comprehensive heat transfer analysis is obtained from Fraas and Green D. model [2-3].

Let us assume the length and diameter of tube under the TEMA specification [2]

\begin{align*}
0.067 < \frac{\text{shell diameter (S.D)}}{\text{tube length(l)}} < 0.201 \\
1.20 < \frac{\text{diameter of tube}}{1.499} < 1.499
\end{align*}

\text{(1)} \text{ and } \text{(2)}

For laminar flow-

\begin{equation}
\text{Nusselt number} = \frac{hD}{k_1} = 0.023 \times (Re^{0.8}) \times (Pr^{0.33}) \times (\eta^{1.25})
\end{equation}

\text{(3)}

Where-

\begin{align*}
\text{Re} &= \text{Reynolds number} \\
\text{Pr} &= \text{Prandtl number}
\end{align*}

Fixing the Recuperator’s the inlet & outlet temperature for H.F. (hot fluid) as well as C.F. (cold fluid), considering the operating temperature values as per source-

\begin{align*}
T_{hi} &= 353 K; 
T_{ho} &= 323 K; 
T_{hc} &= 293 K; 
T_{hc} &= 283 K
\end{align*}

\text{(4)}

\begin{equation}
U = 20 W/m^2 K
\end{equation}

\text{(5)}

\begin{equation}
\text{LMTD} = \frac{T_1 - T_2}{\ln(T_1/T_2)}
\end{equation}

\text{(6)}
\[ T_1 = T_{hi} - T_{hc} \]  
\[ T_2 = T_{ho} - T_{hc} \]  
\[ Q = U * A * \text{LMTD} \]  

The above equation is coded in MATLAB in this way for obtaining the value of heat transfer as well as the graph of heat transfer also by variation in the size of tube.

Now taking the other parameter of Recuperator for finding the maximum heat-transfer effectiveness of Recuperator also.

300kg/s < hot fluid’s mass flow rate \((m_h)\) < 500kg/s

\[ C_{ph} = 1.005\text{kJ/kg-K} \]  
\[ C_{pc} = 4.18\text{kJ/kg-K} \]  

30kg/s < cold fluid’s mass flow rate \((m_c)\) < 130kg/s

\[ X = \frac{C_{max}}{C_{min}} \]  
\[ \text{NTU} = \frac{U * A}{C_{min}} \]  
\[ Q_1 = m_h * C_{ph} * (Th_{fi} - Th_{fo}) = m_c * C_{pc} * (Th_{ci} - Th_{co}) \]  
\[ C_{min} = \min(m_h * C_{ph}, m_c * C_{pc}) \]  
\[ Q_{max} = C_{min} * (Th_{fi} - Th_{ci}) \]  
\[ \text{Effectiveness (E)} = \frac{1 - e^{-\text{NTU}(1-X)}}{1 - X * e^{-\text{NTU}(1-X)}} \]  

These above equations are coded with the help of MATLAB in this way to find out maximum heat transfer and effectiveness of Recuperator which is essential for any type of Recuperator. From the Eqn (19) this is clear that Effectiveness is the function of Capacity Ratio \((R)\) and \(\text{NTU}, E = f(\text{NTU}, R)\).

3. Result and Discussion

The resultant graphs generated by using the LMTD equation with the help of MATLAB. So, from Fig. 2 and 3 this is clear that heat transfer from the Recuperator depend upon the diameter of tube which means that as slow as the diameter of tube increases then heat transfer from Recuperator also increases. The maximum value of heat transfer \((Q)\) is \(8.56 \times 10^6\text{kW}\) at the value of tube diameter \((D) = 3\text{m}\).
The Figure 2 is obtained by using the NTU method which is coded in the MATLAB in this way to obtained the maximum value of HT (heat-transfer) to satisfy the value of HT (heat-transfer) which is obtained by using LMTD equation. From Figure. 3 & 4 this is clear that the maximum value of heat transfer (Q)=8.56×10^5 kW at the value of tube diameter (D) = 3m.

Fig 5 is shown below which indicate the graph between X and Effectiveness, and from the eq^a (19) which shows the relationship between effectiveness, NTU and X (capacity ratio) or from the equation (19).
From the figure it is clear that effectiveness for counter flow depends on the NTU and X. From Fig. 5 effectiveness ramps on with decreasing the capacity ratio(X) and from the Figure 5 value of effectiveness is 1.21. Figure 6 indicate 3-D graph of effectiveness which is generated by the MATLAB

![Figure 5. Effectiveness vs capacity ratio](image)

![Figure 6. 3D graph of NTU, X and Effectiveness](image)

- From the above graph the value of tube diameter, maximum value of heat transfer and effectiveness are mentioned in table which is shown below.

4. Conclusion

The proposed recuperator type heat exchanger is basically designed for waste heat recovery purpose. The selective diameter, material, and other essential parameters have been considered as per available heat source for heat recovery. The measure highlights have been concluded-

- A MATLAB code is written in such a way to find out the value of heat transfer which is essential for the Recuperator and taking the tube diameter under the consideration of TEMA specification.
- The method to find out maximum value of heat transfer for shell and tube type Recuperator by coding in MATLAB and solving the LMTD Equation and NTU method Equation by analyzing the
graph which has shown in above figure. That graph represents the heat transfer on x-axis and Tube diameter on y-axis.

- In case of Fig.2, the value of $C_{min}$ (mass flow rate x heat capacity) on y-axis, heat transfer on x-axis and tube diameter on z-axis which appears to be stationary.
- Effectiveness of Recuperator measures the performance of Recuperator. Effectiveness and Heat transfer play important role in the designing of Recuperator.
- The final value of tube diameter, heat transfer and effectiveness are obtained with the help of Matrix Laboratory which is $D=3$ meter, $Q=8.56 \times 10^5$ kw and $\epsilon=1.21$ respectively.

**Nomenclature**

- Dynamic viscosity = $\eta$ (Ns/m^2)
- $Q$ = heat transfer (W)
- $Th_{fi}$ = hot fluid temperature at inlet (K)
- $Th_{fo}$ = hot fluid temperature at outlet (K)
- $Th_{ci}$ = cold fluid temperature at inlet (K)
- $Th_{co}$ = cold fluid temperature at outlet (K)
- m.h = hot fluid mass flow rate (kg/s)
- m.c = cold fluid mass flow rate (kg/s)
- $C_{ph}$ = hot fluid’s heat capacity (kJ/kg-K)
- $C_{pc}$ = cold fluid’s heat capacity (kJ/kg-K)
- $U$ = overall heat transfer coefficient (W/m^2K)
- $A$ = Recuperator’s area (m^2)
- $h$ = Heat-transfer coefficient, (W/m^2K)
- $D$ = diameter (m)
- $K_1$ = (W/mK) material’s thermal conductivity
- $X$ = (C.R.-Capacity Ratio)
- C.R. = Capacity Ratio
- NTU = Number of Thermal Unit
- HX = Heat Exchanger
- MATLAB = Matrix Laboratory
- HF = Hot Fluid
- CF = Cold Fluid
- TEMA = Tabular Exchange Manufacturing Association
- LMTD = Logarithmic Mean Temperature Difference

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