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Thermal Modeling of Heat Exchanger: A Review

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Abstract: This paper mainly deals with the study of thermal modeling of heat exchanger. Heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, at different temperatures and in thermal contact. In this problem of heat transfer involved the condition where different constructional parameters are changed for getting the performance review under different condition. The shell and tube type of heat exchanger offers unique advantage over other variants in applications like the case for this dissertation work. The purpose of this research is to perform the modeling of single staggered wire and tube heat exchanger. This paper presents a study of the thermal models of wire-on-tube and shell and tube type of heat exchanger. Thermal modeling as well as performance parameter used by researchers is discussed. This review will be useful for research and development of heat exchanger.

Keywords: Wire on-tube heat exchangers, Heat exchangers, Thermal Modeling

NOMENCLATURE

A	Heat transfer area (m2)
Cp	Specific heat capacity (KJ/kg K)
D	Equivalent hydraulic diameter (m)
F	Friction factor
H	Height of air channel (m)
H	Convective heat transfer coefficient (W/m2 _C)
K	Thermal conductivity (W/m _C)
m	Mass flow rate of air (kg/s)
Nu	Nusselt number
Pr	Prandlt number
Q	Heat transfer rate (KW)
Re	Reynolds number
T	Temperature (C)
Tm	Logarithmic mean temperature difference (C)
V	Average axial velocity (m/s)
µ	Dynamic viscosity
V	Kinematic viscosity

Subscripts

C	cold fluid
H	hot fluid
i	inlet
o	outlet
t	total

1. Introduction

Heat exchangers are widely used in engineering applications such as refrigeration and air conditioning systems, automobiles, thermal power plants, chemical and textile processing industries, etc. Heat exchangers are the devices to evaluate effective heat transfer between the two fluids. The difficulty in the analysis of heat exchangers shall be due to its geometry and the physical phenomena of the heat exchange between the two fluids. In general, the heat exchangers are studied both analytically and experimentally using first and second laws of thermodynamics **[1].** Shell-and-tube heat exchangers have been widely used in practical applications like power generation, petro-chemical industry, food processing, environment engineering, and waste energy recovery. The broad utilization results from its structural simplicity, high cost effectiveness, design adaptability, and convenient maintenance **[2].**

A wire-and-tube condenser consists of a copper tube bended into a single-passage serpentine shape, with wires spot welded perpendicularly on both sides, as illustrated in **Fig. 1**. These heat exchangers may be assembled with tubes in a vertical or horizontal position and the air movement can be forced or natural. Since wire-and-tube condensers are relatively inexpensive, they have been widely applied in household refrigerators and freezers – appliances that consume a considerable amount of energy since hundreds of millions are currently in use, and dozens of millions are coming onto the market every year.

Regardless of the calculation procedure, detailed information on the behavior of each system component is necessary. However, it was noted that there is still a need for a heat transfer correlation for natural draft wire-and-tube condensers that is applicable to the typical operating conditions of greenhouse solar dryer **[3].**

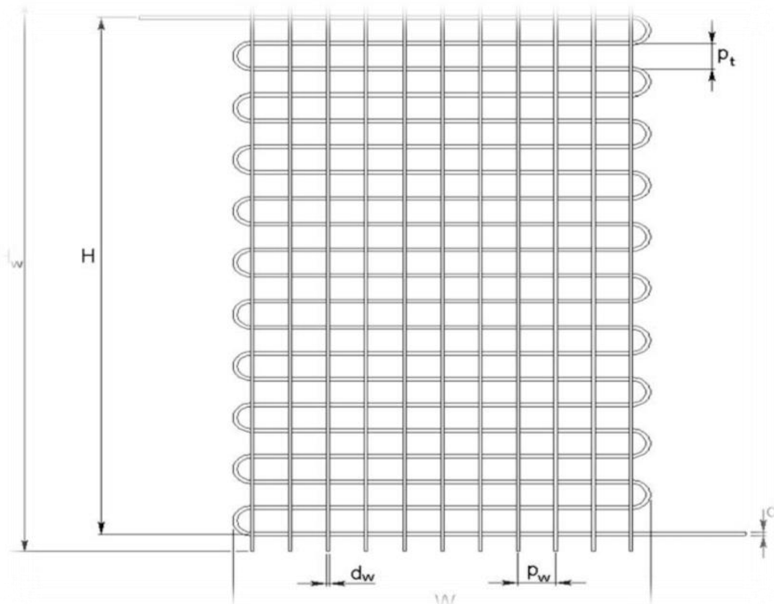

Fig. 1 –Wire-and-tube condenser geometry **[3].**

The analysis of heat transfer through wire-on-tube heat exchangers is very complex in view of the number of parameters involved such as the wire diameter d_w, the tube diameter d_t, the wire spacing p_w, the tube spacing p_t,the overall wire length H_w, the length of the tube H, the multilayer stacking of the coil, flow of refrigerant, etc. Another types of heat exchanger also used in greenhouse solar dryer. This is shown in fig.2.

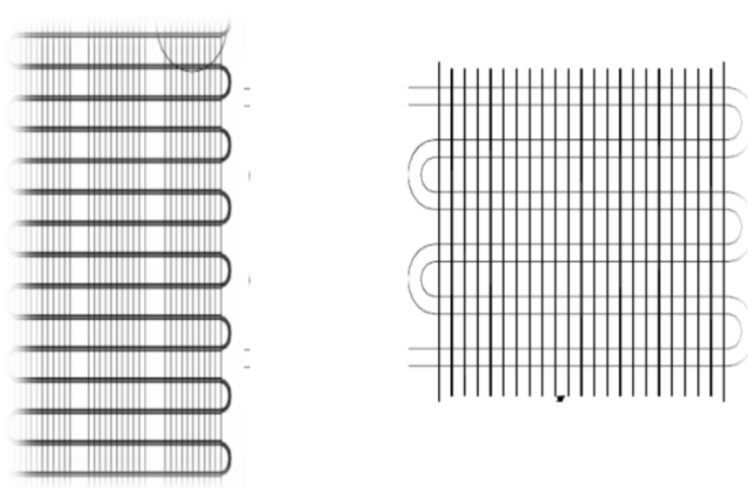

Fig. 2 Schematic of a wire-and-tube type & plate fin type condenser are used in greenhouse solar dryer.

2. Literature review

The wire-on-tube condensers, used in the R-12 based refrigerators, were numerically and experimentally studied by **Ameen et al. (2006)** when used with R-134a based refrigerators. The authors used the FEM method to analyze free convection around this type of condensers. They tracked the refrigerant flow to check the location where condensation inception occurs. The authors investigated two different condenser coils with different tube-and-wire pitch, number, and length. They reported that the two-phase change locations are shifted downstream with either the increase in the refrigerant mass flow rate or increase in ambient temperature **[4].**

Bansal and Chin (2003) proposed useful analysis for the wire-and-tube condenser. They optimized the condenser capacity per unit weight by varying wire-and-tube pitches and diameters. They reached an optimization factor that led to an improved design with 3% gaining capacity and 6% reduced of condenser weight. In the same study, the authors reported that the outer heat transfer resistance contributes to about80% for single-phase flow and 83–95% for two-phase flow. Further, the dominant heat-transfer mode is by convection, which contributes to 65% of the total heat transfer **[5].**

Bansal and Chin (2002) presented the performance of the hot wall condensers, as a replacement of the wire-and-tube condensers. The authors analyzed the heat transfer characteristics for the condenser. They claimed that a 10% over prediction in condenser capacity was attributed to the heat infiltration into the refrigerator compartment, which they did not consider in their model. They concluded that the outer heat transfer resistance contributes to about 80% and 83–95% of the total heat transfer for single and two-phase flow respectively **[6].**

Tanda and Tagliafco experimented a Nusselt number correlation as a function of the geometric and operating parameters to predict free convection heat transfer from a vertical wire-on-tubeheat exchanger to ambient air based on their experimental results **[7].**

Hoke et al. carried out experiments to investigate the air-side convective heat transfer for wire-on-tube heat exchangers used in most refrigerators. They were able to give a correlation valid for all the experimental data for seven wire-on-tube heat exchangers studied under forced convection regime. The importance of angle of attack for locating the wire-on-tube exchangers that are cooled by forced convection is also highlighted **[8].**

Martynov [9] studied new and effective heat exchangers with tubes finned with wires and spirals were conducted by

Melo et al. (2004) gathered and analyzed experimental data on the wire-and-tube condenser performance under various operating conditions to establish whether the confining walls – particularly the effects of thegaps between the refrigerator and the back, side and bottom walls – play a dominant role in the heat transfer from this unit **[10].**

Collicott et al presented an experimental study to calculate heat transfer factor by free convection and shape factor for wire-and-tube condenser. It was found that the diameter of tube or wire proportional to space between the tube or wire. **[11]**

Che´rifBougriou• KhireddineBaadache studied a new type of heat exchanger for cooling industrial oil from 120°C to 60°C and compare the data with each other. They modified the simple shell and tube and also tube and wire type heat exchanger with concentric tube heat exchanger. The performance and the heat exchanger length are strongly dependent upon the tube radii that form the heat exchanger. [12]

The following figure is the configuration of wire and tube heat exchanger with the array of inline wire on both sides of heat exchanger. On the other hand the fins’s array of wire and tube heat exchanger has another configuration, which uses the array of staggered wires between both sides of heat exchanger as shown in figure 3. By the array of staggered wires, there is no face-to-face position of wire in a small distance. It makes the convection heat transfer performs better because the thermal boundary layer from both sides of wires are not merged. [13]

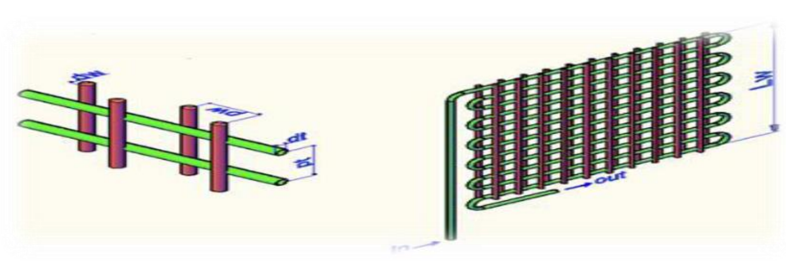

Figure no.3 configuration of wire and tube heat exchangers

3. Previous study on various types thermal modeling of heat exchanger

Basically there are various kinds of heat exchanger used for industrial purpose and other thermal applications. Most of them shell and tube and tube on wire type heat exchanger. Which are discussed below respectively.

Table 1

Summary of previous study of thermal modeling on shell and tube type of heat exchanger.

Sr.no	Author & reference no.	Thermal model	Outcome
1	N. R. Chaudhari et al. [14]	Q=(WCΔT)c = (WCΔT)h Q =UA(LMTD) $\mathrm{Nu} = 0.023\mathrm{Re}^{0.8}\mathrm{Pr}^{0.3}$	Calculating the film heat transfer coefficient for the tube side flows as mentioned in step 6, requires one to know viscosity ,Reynolds number, Prandtl number, Nusselt number, and conductivity of water,
2	Vedhagiri Eswaran et al. [15]	$\mathrm{Nu} = 0.023\mathrm{Re}^{0.8}\mathrm{Pr}^{0.3}$	As the shell-side Reynolds number is increased, the pressure Losses increases for all the cases consider.
3	Chetan Undhad et al. [16]	Exergy Analysis E=mv[cpv[(tv1-tv2)-to*ln(tv1/tv2)]+hfg-to*sfg]-(mc*cpc)*[(tc2-tc1)-to*ln(tc2/tc1)] Efficiency ηex=[(tc2-tc1)-to*ln(tc2/tc1)] [mv[cpv[(tv1-tv2)-to*ln(tv1/tv2)]+hfg-to*sfg]]	Experimentally carried out Maximum inlet temperature there are exergy is decrease at that time efficiency increase.
4	B. V. Bhuva et al[17]	$Q_{h=m_h \times c_{ph}}(T_{hi-}T_{ho})$ $Q_{c=}m_c \times C_{pc}((T_{ci-}T_{co})$ $\mathrm{Nu} = \mathrm{hd/k}$	Observed that the exergy loss was increased up to 99.93% compared to a heat exchanger with the empty tube and simple twisted tape insert was obtained 93.69% compared to a heat exchanger with the empty tube.
5	Rohit Rajbaidya et al. [18]	$Q_{c=}m_c \times C_{pc}((T_{ci-}T_{co})$ $Q_{h=m_h \times c_{ph}}(T_{hi-}T_{ho})$ $\mathrm{Nu} = \mathrm{hd/k}$ $\mathrm{Re} = \mathrm{VD_h/v}$	Investigated that Pressure drop using Snail Entrance was found to be maximum 1.7 times compared to that of plain tube.
6	Tulin Bali et. al [19]	$Q_{con} = m_{sw} \times h_{fg}$ $Q = hA\Delta T_{lm}$ $\mathrm{Nu} = \mathrm{hd/k}$	Experimentally carried out An increase in the Reynolds number results in increasing irreversibility, but would decrease effectiveness number.

Table 2
Summary of previous study on thermal modeling of wire on tube type heat exchanger.

Sr no.	Author and reference no.	Thermal model	Outcome
1	Melo et al. [20]	A heat transfer correlation was also proposed, $$\frac{hd}{k} = 0.0188 \times Gr^{0.7556}$$	Given most efficient correlation for the combined radiation and convection heat transfer at the air side of natural draft wire-and-tube.
2	Ramadan Bassiouny [21]	$$h = \frac{Nuk}{H}$$ where Nu= $$0.66\left(\frac{RaH}{d_{t0}}\right)^{0.25}\left\{1-\left(1-0.45\frac{d_{t,0}}{H}^{0.25}\right)\right\}$$	Investigated that decrease the driving force to reject heat out of the condenser surface.
3	Ahmed Abdulnabi Imran et al. [22]	$$Nu = 0.023Re^{0.8}Pr^{0.3}$$ Where $$Nu = \frac{hd}{k}$$ $$Re = VD_h/v$$ $$Pr = \mu C_p/k$$	Carried out that model can be used for the design the wire-and-tube condenser used in the refrigeration system work and other thermal related work.

4. Conclusion

Exchanging of heat is paramount application of heat exchangers, so as the designing and analysis of heat exchanger as well. Because of that much importance of heat exchangers applications. Such as some of experimented a Nusselt number correlation as a function of the geometric and operating parameters to predict free convection heat transfer from a vertical wire-on-tube heat exchanger to ambient air based on their experimental results**[7]** gathered and analyzed experimental data on the wire-and-tube condenser performance under various operating conditions to establish whether the confining walls – particularly the effects of the gaps between the refrigerator and the back, side and bottom walls – play a dominant role in the heat transfer from this unit **[10].** It has a long history for research and development. Such activity is by no mean complete however, as many talented worker continue to seek ways of improving design and performance.

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