A Survey of Entropy Generation in a Helical Coil Heat Exchanger

K. Ashok Reddy

Abstract: ***In this technical paper, the review of literature for entropy generation in a helical coil heat exchanger was presented. The pressure drop, friction factor, heat transfer rates and flow distribution like velocity and temperature field are essential properties to control the entropy generation in a heat exchanger process are fairly presented in this article.***

Keywords: entropy, heat transfer, friction factor

I. INTRODUCTION

Shaukat Ali [1] presented in their technical paper a better characterizing dimensionless group for steady isothermal flow of Newtonian fluids in helically coiled circular tubes. Pressure drop versus flow rate data has been experimentally obtained for helical coils made from thick-walled polyethylene tubing. Generalized pressure drop correlations have been developed in terms of Euler number, Eu, Reynolds number, Re, and the obtained geometrical group, $G_{rhc} = (d^{0.85}D_{eq}^{0.15}/L_c)$, where d is the inside diameter of the tube, D_{eq} is the equivalent diameter which accounts for the torsion effect, and L_c is the length of the coil. The Fanning friction factor for helical coil tube is found to depend on Reynolds number and a geometrical number,d/D_{eq}, separately both, and not by a dimensionless number obtained by any combination of Reynolds number and some geometrical number as is the case of Dean number, De = Re $\sqrt{(d/D)}$, where D is the diameter of the coil. There exist four regimes of flow for the flow through helical-coiled circular tubes. The obtained pressure drop correlations are simple to use.

T. H. Ko [2] **presented in their technical paper**, laminar forced convection and entropy generation in a helical coil with constant wall heat flux are investigated numerically. Both the entrance and fully developed regions are included. Water (Prandtl number 5.98) has been selected as working fluid in the present study. The cases studied cover a Reynolds number range from 1,000 to 7,500, and wall heat fluxes of 160, 320, and 640 W/m^2. The development of flow fields, including secondary flow motion, distributions of temperature, Nusselt number, and friction factor, are given and discussed. In particular, the distributions of entropy generation rate in the helical coil are highlighted. According to the minimum entropy generation principle and thermodynamic second law, the analysis of optimal Reynolds number for the helical coil flow with constant wall heat flux is carried out, through which the optimal Reynolds numbers are found to be related to the wall heat flux. The optimal Reynolds number was suggested to be chosen as the flow operating condition so that the thermal system can have the least irreversibility and best exergy utilization

T.H. Ko , K. Ting [3] presented in their technical paper the entropy generation of the fully developed laminar convection in a helical coil with constant wall heat flux and presents the optimal design based on the minimum entropy generation principal. The important design parameters, including Reynolds number (*Re*), coil-to-tube radius ratio (δ) and nondimensional coil pitch (λ) are varied to investigate their influences on the entropy generation. The results presented in this paper cover *Re* range of 100–10,000, δ and λ range from 0.01 to 0.3. Compared with *Re* and δ, the coil pitch λ was found to have minor influence on the entropy generation. For a demonstrated case, the minimum entropy generation occurs in the range bounded by *Re* from 2271 to 4277 and δ from 0.17 to 0.3, within which the irreversibility of the system is lowest and the system performance would be optimum. The details show that there was an optimal *Re* for a helical coil with a fixed δ; meanwhile for a helical coil flow with a specified *Re*, the smaller δ should be selected when the *Re* was larger than 5000, and the larger δ should be selected when the *Re* was less than 5000. These results provide worthwhile information for heat exchanger designers to find the optimal helical coil design from the viewpoint of the thermodynamic second law.

T.H. Ko [4] presented in their technical paper the optimal mass flow rate for steady, laminar, fully developed, forced convection in a helical coiled tube with fixed size and constant wall heat flux by the thermodynamic second law based on the minimal entropy generation principle. Two working fluids, including air and water, are considered. The entropy generation analysis covers a coil curvature ratio (δ) range of 0.01–0.3, two dimensionless duty parameters related to fluid properties, wall heat flux and coiled tube size, α_1 range of 0.01–3.0 and α_2 range of 0.1×10^{-6}–1.2×10^{-6}. The optimal mass flow rate, denoted by a dimensionless parameter, β_{opt}, for cases with various combinations of the design parameters was given in the present paper. In addition, a correlation equation for β_{opt} as a function of α_1, α_2 and δ is proposed through a least square error analysis. For a thermal system composed of helical coiled tubes with fixed wall heat flux and tube size, the optimal mass flow rate β_{opt} should be selected so that the system can have the least irreversibility and the best exergy utilization. T.H. Ko [5] presented in their technical paper the optimal curvature ratio for steady, laminar, fully developed forced convection in a helical coiled tube with constant wall heat flux was analyzed by thermodynamic second law based on minimal entropy generation principle.

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Two working fluids, including air and water, are considered. The entropy generation analysis covers a Reynolds number (Re) range of 100 to 10 000, a coil curvature ratio (δ) range of 0.01 to 0.3, and two dimensionless duty parameters related with fluid properties, wall heat flux and mass flow rate, η_1 range of 0.1 to 3.0, and $\eta_2/^{1020}$ range of 0.01 to 1.0. The optimal δ for cases with various combinations of the design parameters was given in the present paper. In addition, a correlation equation for the optimal δ as a function of Re, η_1 and η_2 was proposed through a least-square-error analysis. For a thermal system composed of helical coiled tubes with fixed Re, wall heat flux and mass flow rate, the optimal δ should be selected so that the system could have the best exergy utilization and least irreversibility.

Mohammad Ahadi, and Abbas Abbassi [6] presented in their technical paper combined effects of length and heat flux of the coil as well as the effects of temperature dependence of thermophysical properties on entropy generation rates and optimal operation of uniformly heated helical coils with laminar forced convection have been analyzed analytically. For these purposes, comprehensive analytical formulas, which could be used for any duct shape and flow regime, are derived for thermal, frictional, and total entropy generation rates, and the effects of involved parameters on the entropy generation rates are examined for laminar forced flow of water through uniformly heated helical coils. Then, using the minimal entropy generation principle, the inlet Reynolds number was optimized for various values of the involved parameters, and some correlations are proposed for optimal values of this parameter which extend and modify the existing correlations of water. It was found that the entropy generation rates are highly dependent on the combined effects of length and heat flux of the coil, introduced by the parameter ηC, and temperature dependence of thermo physical properties, such that all of them noticeably augment with increase in ηC and the inlet temperature.

T.H. Ko and K. Ting [7] presented in their technical paper to analyzed the optimal Re for the steady, laminar, fully developed forced convection in a helical coiled tube with constant wall heat flux based on minimal entropy generation principle. Two working fluids, water and air, are considered. It was found that the entropy generation distributions are relatively insensitive to coil pitch, λ.
Through the entropy generation analysis for cases of coil curvature ratio, δ ranging from 0.01 to 0.3, and two dimensionless duty parameters, η_1 from 0.1 to 3.0, and $\eta_2/10^{20}$ from 0.01 to 1.0, the optimal Re for cases with various combinations of the design parameters was reported. In addition, a correlation equation for the optimal Re, δ, η_1, and η_2 was proposed after a least-square-error analysis. The optimal Re should be adopted as the operating condition according to the relevant design parameters of the helical coils so that the thermal system can have the best exergy utilization with the least irreversibility.

T.H. Ko and K. Ting [8] presented in their technical paper to analysed the entropy generation of the fully developed laminar convection in a helical coil with constant wall heat flux and presents the optimal design based on the minimum entropy generation principal. The important design parameters, including Reynolds number (Re), coil-to-tube radius ratio (δ) and no dimensional coil pitch (λ) are varied to investigate their influences on the entropy generation. The results presented in this paper cover Re range of 100–10,000, δ and λ range from 0.01 to 0.3. Compared with Re and δ, the coil pitch λ is found to have minor influence on the entropy generation. For a demonstrated case, the minimum entropy generation occurs in the range bounded by Re from 2271 to 4277 and δ from 0.17 to 0.3, within which the irreversibility of the system is lowest and the system performance would be optimum. The details show that there was an optimal Re for a helical coil with a fixed δ; meanwhile for a helical coil flow with a specified Re, the smaller δ should be selected when the Re was larger than 5000, and the larger δ should be selected when the Re is less than 5000. These results provide worthwhile information for heat exchanger designers to find the optimal helical coil design from the viewpoint of the thermodynamic second law.

Jiangfeng Guo and Xiulan Huai [9] presented in their technical paper the heat transfer characteristics of helically coiled tube are numerically investigated from the viewpoint of field synergy principle, and the simulation results have a good agreement with experimental results. The heat transfer enhancement of helically coiled tube can be attributed to the improvement of the synergy between the velocity vector and temperature gradient due to secondary flow, and the effects of Reynolds number, curvature ratio, and coil pitch on heat transfer performance can be well described by the field synergy principle. Moreover, the entropy dissipation augmentation number was proposed to evaluate the heat transfer performance of helically coiled tube, which was found to be suitable to evaluate heat transfer augmentation techniques.

M. Hasanuzzamana, R. Saidura, and N.A. Rahim [10] presented in their technical paper found that convective heat transfer coefficient of Cu-water, AI-water, Ah03-water and Ti02-water nanofluids are 81 %, 63%, 66%and 64% higher compared to pure water respectively. It was found that overall heat transfer coefficient of Cu water, AI-water, Al203-water and Ti02-water nanofluid sare 23%, 20%, 21 % and 20% higher compared to pure water respectively.
M. Mohanraj, S. Jayaraj , C. Muraleedharan [11] presented in their technical paper the applications of ANN for thermal analysis of heat exchangers are reviewed. The reported investigations on thermal analysis of heat exchangers are categorized into four major groups, namely (i) modeling of heat exchangers, (ii) estimation of heat exchanger parameters, (iii) estimation of phase change characteristics in heat exchangers and (iv) control of heat exchangers. Most of the papers related to the applications of ANN for thermal analysis of heat exchangers are discussed. The limitations of ANN for thermal analysis of heat exchangers and its further research needs in this fieldare highlighted. ANN is gaining popularity as a tool, which can be successfully used for the thermal analysis of heat exchangers with acceptable accuracy.

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M.A. Khairul , R. Saidur , M.M. Rahman , M.A. Alim , A. Hossain , Z. Abdin [12] presented in their technical paper the thermodynamic second law analysis of a helical coil heat exchanger using three different types of nanofluids (e.g. CuO/water, Al2O3/water and ZnO/water). Heat transfer coefficient and entropy generation rate of helical coil heat exchanger were analytically investigated considering the nanofluid volume fractions and volume flow rates in the range of 1–4% and 3–6 L/min, respectively. During the analyses, the entropy generation rate was expressed in terms of four parameters: particle volume concentration, heat exchanger duty parameter, coil to tube diameter ratio and Dean number. Amongst the three nanofluids, CuO/water nanofluid, the heat transfer enhancement and reduction of entropy generation rate were obtained about 7.14% and 6.14% respectively. Furthermore, heat transfer coefficient was improved with the increasing of nanoparticles volume concentration and volume flow rate, while entropy generation rate went down.

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