DESIGNING & OPTIMIZATION OF CRYOGENIC PLATE-FIN HEAT EXCHANGER PERFORMANCE BY USING MACHINE LEARNING

POOJA RANI
Research Scholar
Department of Mechanical Engineering,
Shri Jagdish Prasad Jhabarmal Tibrewala University, Jhunjhunu, Rajasthan, India-333001.
poojavats2@gmail.com

PRAVEEN BARMAVATU
Research Guide
Department of Mechanical Engineering,
Shri Jagdish Prasad Jhabarmal Tibrewala University, Jhunjhunu, Rajasthan, India-333001.

Abstract

The demand for the efficient transfer of heat from one material to another in HEs has increased over the past one to two decades. A compact heat exchanger is one of the types of heat exchangers that has a high surface area relative to the unit's volume, resulting in better efficiency than normal heat exchangers. Therefore, one of the types of compact heat exchangers, the cryogenic plate-fin heat exchanger is used in this study. In this research, it is very important to overcome the erosion of material in the heat exchanger and also for the flow misdistribution, which affects the performance of the heat exchanger in the transient regime. Thus, this research's objective is to overcome the above-mentioned problems. The cryogenic plate-fin heat exchanger is numerically studied with the boundary conditions, steady-state, initial conditions, transient state, and data reduction techniques for the heat transfer enhancement of the heat exchanger using two fluids of water and the various coolants and the optimization technique of Quantum PSO with the neural network of Radial Basis Function is implemented to optimize the temperature value to get the accurate values. . The experimental performance of the heat exchanger using the water and the different coolants with 10% and 12% capacity at different temperatures of 60°C and 80°C are noted. Additionally, the analytical model and the optimization model of the heat exchanger with the water and various coolants are executed in the forms of tabulation to resultant the hot and cold outlet temperatures and the graphical representation which is correlated with the experimental performance with the values determined. The optimization model results in better prediction values of outlet temperature. Hence the analytical model, optimization model and experimentations are developed for flow transient, it is capable of predicting the performance of the plate-fin heat exchangers satisfactorily, under the given conditions of changed flow rates.

Keywords: *Cryogenic plate-fin heat exchanger; Performance; Optimization; Machine Learning.*

Introduction:

In the present world scenario, manufacturing industries require materials, which possess lofty force to mass ratio for application in aerospace, automotive and transportation industries. The conformist equipment such as metals, alloys, ceramics and plastics are not able to meet this requirement. These problems can be overcome by use fused materials. The world is aware composite materials for several hundred years ago, which is available in form of natural composites such as wood, rocks, bamboo, etc. In ancient days, improvement in quality life made humans construct houses with mud, bricks lime with straw, which clearly gives definition composite fabric that consists two or more noticeably express constituents. This paper clearly illustrates sorting various types' composites, its advantages, disadvantages applications. It also deals with various types matrix reinforcement substances used in metallic matrix composites and their applications.

The principal concept of heat exchangers (HEs) is heat transfer within two or more fluids at various temperatures. HEs are applied in heat pumps, land, and air vehicles, air conditioners, thermal and nuclear power plants, marine, refrigeration systems, etc. Both heating and cooling processes are carried out in the HEs. HEs are required for the protection of hazards or hazardous substances, machinery, water, gas, and other substances under complex operating conditions. Among the kinds of HEs that have a high surface area compared to the unit volume is a compact heat exchanger (CHE), resulting in better efficiency than usual HEs. The plate-fin heat exchanger is one kind of compact exchanger normally used as a multi-stream heat exchanger because its geometric features provide the ability to manage a variety of hot and cold streams in a device efficiently. The fluids transferring heat through the plates are separated with plate-fin heat exchangers. These have regular surfaces like fine or prickle and are bolted, brazed, or welded together. The key observations of PFHEs are found in the cryogenic and food industries. However, they are also beginning to be used in the chemical industry because of their high volume-to-volume field, their low fluid inventories, and their capacity to handle more than two steams. The thermal fluid systems are widely used in PHEs, and automotive thermal fluid systems, viz. radiators for engine cooling systems.

This research seeks to create a model that predicts the transient reactions of the plate-fin heat exchanger as the inlet rates change. Furthermore, heat transfers are designed and analysed in a heat exchanger with an auxiliary fluid channel that separates the hot and cold fluid channels. Experiments demonstrate the outcomes of plate-fin heat exchangers subjected to step changes in inlet flow speeds, which led to the analytical model produced has now been validated against experimental findings. In addition, to optimize the analysed values of experimental data, the optimization technique with the neural network model is implemented to get the accurate temperature values.

Research Methodology:

a. Plate Fin Heat Exchangers

Plate fin heat exchangers are widely used in automobile, aerospace, cryogenic and chemical industries. They are characterized by high effectiveness, compactness (high surface area density), low weight, and moderate cost. A PHE consists of a pack of thin rectangular plates with portholes, through which two fluid streams flow, where heat transfer takes place. Other components are a frame plate (fixed plate), a pressure plate (movable plate), upper and lower bars, and screws for compressing the pack of plates. An individual plate heat exchanger can hold up to 700 plates. When the package of plates is compressed, the holes in the corners of the plates form continuous tunnels or manifolds through which fluids pass, traversing the plate pack and exiting the equipment. The spaces between the thin heat exchanger plates form narrow channels that are alternately traversed by hot and cold fluids, and provide little resistance to heat transfer. Each of the plates is separated by a gasket which seals the plates and arranges the flow of fluids between the plates, sees figure (1). If leakage to the environment is a concern it is possible to weld two plates together to ensure that the fluid flowing between the welded plates cannot leak. However, as there are still some gaskets present it is still possible for leakage to occur. Brazed plate-fin heat exchangers avoid the possibility of leakage by brazing all the plates together and then welding on the inlet and outlet ports.

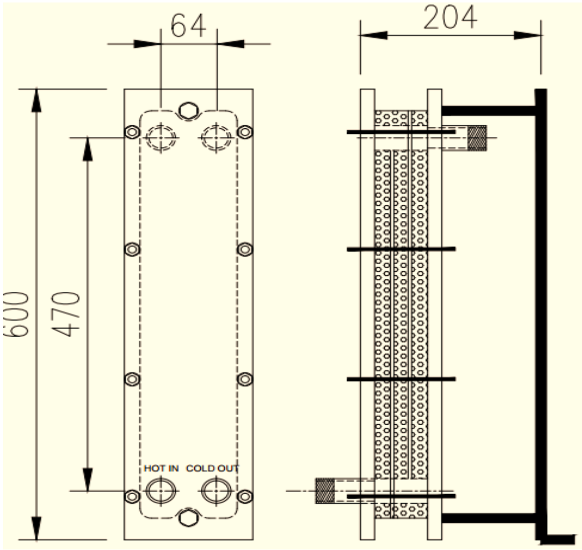


Figure.1: Cryogenic Plate Fin Heat Exchanger (CATIA Model)

The experimental setup has been built such that it can produce the sudden rise in hot fluid temperature and measure the responses at the outlet of both the fluids. Two circuits: the cold water circuit and the hot water circuit as shown in figure (2) are made to circulate both the fluids through the heat exchanger.

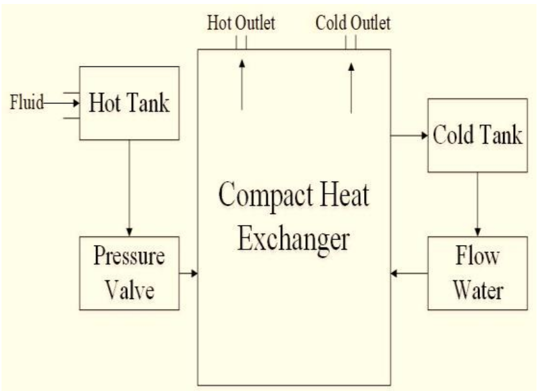


Figure.2: Schematic Diagram of Experimental Setup Test Flow

Cold fluid is sent to the thermal exchanger where heat is received through the plates from the hot fluid. Then, it is sent to the refrigeration tower where the temperature drops to the inlet state. The hot fluid is sent to the heat exchanger and is fed back to the hot water tank and, using a temperature sensor, can be maintained at a constant temperature. Hot water is generated by the use of the 42 kW submerged power heaters in the hot water tank. The flow rates can be adjusted by the control valves. The flow rates are determined by the orifice flow metres before the fluids reach the heat exchanger. To minimise heat loss to the surroundings the tunnel surface has been filled with a dense coat of 10*mm* glass wool. The tunnel structure was maintained 75*cm* above the laboratory ground surface, as it was covered by corrugated plates of steel.

b. Optimization Technique with Neural Network Model

This research incorporates an optimization approach with a neural network model in order to optimise the values of hot and cold side outlet temperature analysed from the experimental data. The optimization algorithm is mainly used for the enhancement of thermal conductivity result of numerical analysis which presents the optimized result of thermal enhancement of heat exchanger compared to the experimental and numerical analysis. The radial basis function neural network is used to train and test the values. The novel paradigm is then used to optimise the temperature values, which is Quantum Particle Swarm Optimization (QPSO).

Radial Basis Function Neural Network

The objective of the neural network algorithm is to imitate organic nerve cells' operating concept. According to figure (3), it is a neural network structure of three layers of RBF. The structure of three layers consists of an input, a hidden and an output layer. The first two transformations are non-linear while the last two transformations are linear. The neural network structure of the RBF principle is to represent the purpose of some RBFs as a sum. Due to its basic, traditional network topology, with each of the two kinds of fast convergence and local approximation, RBF neural networks are commonly employed to address the challenge of adapting non-linear high-order functions.

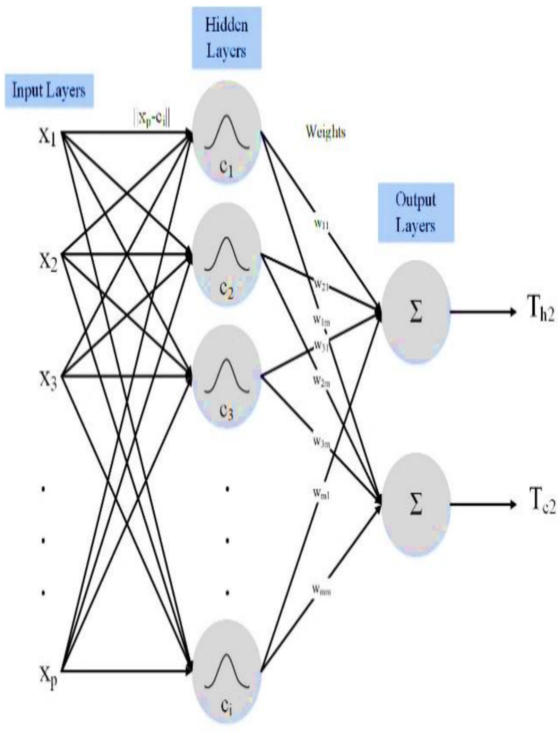


Figure.3: Neural Network Structure of RBF

Figure 3 shows that the layer of the first input is a vector with samples of size p and the transfer function is a function of linear. Each hidden neuron in the second hidden layer is related to the input vector respectively, but the hidden neurons are independent, and the transfer function is RBF. The x_1, x_2, K, x_p input is the point of discrete. By setting the function of basis and interpolating points around the sample points based on the basic function, a smoothing function may be produced. Equation (1) may be used for the activation function of a neural network with a radial basis.

$$R(x_p - c_i) = \exp\left(-\frac{1}{2\sigma^2}\|x_p - c_i\|^2 \quad i = 1,2,\ldots,r\right) \tag{1}$$

The *p*th input sample is represented as x_p, the *i*th point of centre denoted as c_i, the number of neural layers hidden is *r* and the basis function width represented as σ. When σ is low, it will sharpen the Gaussian function, meaning the weight of the edge points is tiny, causing overfitting. $x_p - c_i$ is a vector distance from every hidden layer's middle. Each node generally has an equivalent centre of the hidden layer, whereas $x_p - c_i$ is the distance between the node matrix itself and each point. The smaller $x_p - c_i$, the closer it is to the node, the greater the node's effect on the output of the system.

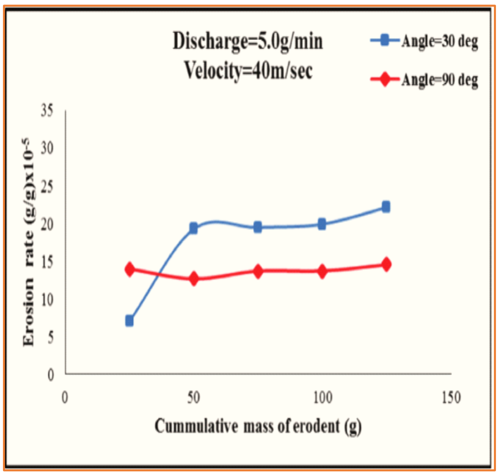
c. Performance Comparison of Cryogenic PFHE Over STHE

Welded together plates are consisting of the all-welded PFHEs. All-welded PFHEs consist of welded-together plates. For mechanical cleaning and inspection of these, all-welded heat exchangers are sealed and are not open. In contrast with shell-and-tube heat exchangers, all-welded PFHEs are compact. Due to its greater HTC and the corresponding much smaller heat transfer area, PFHEs have this benefit.

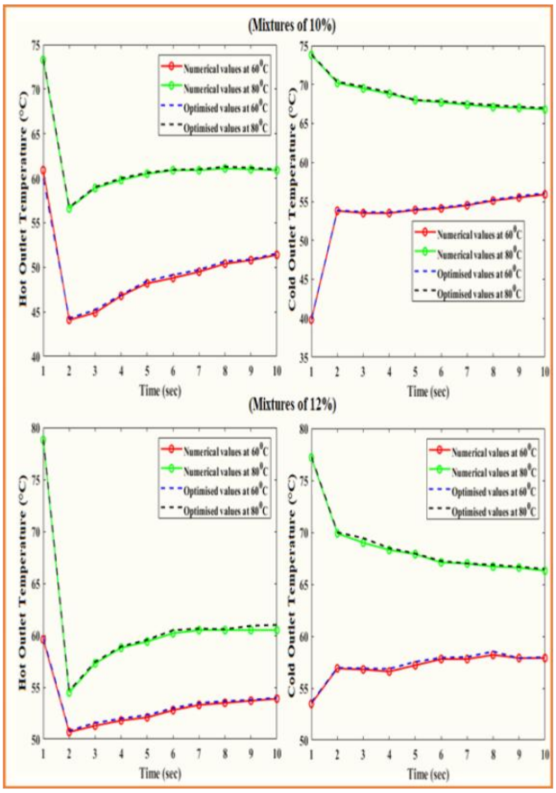
All-welded PFHEs have high coefficients for heat transfer. This is because of the high turbulence produced in the channels of the corrugated plate. Thin laminar films on the surface of the heat-transfer area arise from high turbulence. Compared to the thicker film used in a shell-and-tube heat exchanger, which has a much lower resistance to heat transfer. Instead of a shell-and-tube heat exchanger, choosing a PFHE makes it possible that will further maximize energy savings by reducing the approach to temperature. PFHEs can be more cost-effective and may provide a more realistic alternative to heat exchangers for shell-and-tube. With only a slightly longer payback time, a CHX design enables enhanced heat recovery and is, therefore, a good candidate for selection.

Experimentation and Result Discussion:
The experimental setup has been built such that it can produce the sudden rise in hot fluid temperature and measure the responses at the outlet of both the fluids. Two circuits: the cold water circuit and the hot water circuit as shown in figure (4) are made to circulate both the fluids through the heat exchanger.

Figure.4: Cryogenic Plate Fin Heat Exchanger (Experimental setup)

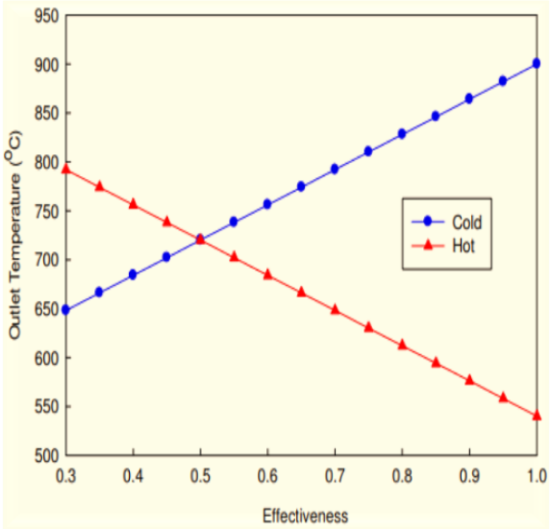


Graph.1: Rate of erosion (g / g) against cumulative eroding at D=5.0 g/min and V=40 m/s



Graph.2: Hot and Cold Outlet Temperature Variations of Water with a Mixture of 10% and 12% at 60°C and 80°C

The temperature value increases constantly in both hot and cold outlet sides from the sudden decrement of higher temperature at the time of 60 secs in the 10% and 12% of blends. However, the temperature values in the cold outlet side decrease at 80°C. Here, the accurate values are also noted for the hot and cold outlet side of the exchanger using optimization techniques.



Graph.3: Temperature Variation of Hot and Cold Side Outlet with Effectiveness

Graph 3 displays the variation of temperature in the outlet of the hot and cold side with the effectiveness. The figure represents that the temperature of the hot outlet decreases constantly along with the effectiveness. Subsequently, the temperature of the cold outlet increases constantly along with the effectiveness. Therefore, the study describes that the temperature of the hot and cold side outlet varies inversely with the effectiveness.

Conclusion:

This research studied the analytical model with the structure like initial conditions, boundary conditions, and data reduction to evaluate the numerical values from the experimental data. Moreover, the study considers the novel way of optimization technique namely the Quantum PSO technique with the neural network of Radial Basis Function. Both heat and cooling processes are carried out in the heat exchanger. The heat exchangers demand has increased the heat efficiency to transfer from one substance to another, during the last two decades. Classified among the types of heat exchangers that have a high surface area compared to the unit volume is a compact heat exchanger, resulting in better efficiency than usual heat exchangers. Therefore, the plate-fin heat exchanger is used which is one of the types of CHE. In this research, the degradation of material in the heat exchanger and also the misdistribution of flow, which affects the efficiency of the heat exchanger in the transient system is an important problem for this study. This work aims to resolve the abovementioned issues, the PFHE in a counter-flow form is manufactured with composite components such as SS316+copper and SS304+ Flyash in combination using the salt bath brazing and vacuum brazing process. It is important to establish a heat exchanger with optimized internal structures where the PFHE is chosen for analysis in the wavy fin structure. Wavy fins increase heat transfer efficiency through two mechanisms: lengthening the flow path and the heat transfer surface area to increase and providing successful vertical motion corrugation.

References:

1. *YiminXuan, Qiang Li, (2000) Heat transfer enhancement of Nano fluids. International Journal of Heat and Fluid Flow 21, 58- 64p.*
2. *Sidi El Be′ caye Mai¨ ga, Samy Joseph Palm , Cong Tam Nguyen , Gilles Roy , Nicolas Galanis. (2005) Heat transfer enhancement by using Nano fluids in forced convection flows International Journal of Heat and Fluid Flow 26, 530–546p.*
3. *Jaafar Albadr, Satinder Tayal, Mushtaq Alasadi. (2013)Heat transfer through heat*

exchanger using Al2O3 Nano fluid at different concentrations. Case Studies in Thermal Engineering 1, 38–44p.

4. *Abhishek Gakare, Ashutosh Sharma, Gaurav Saxena Review on Recent Automotive Experimental Applications of Nano Coolants. Journal of Nanoscience, Nanoengineering & Applications. 2019; 9(1): 1–10p.*
5. *Hussein AM, Bakar RA, Kadirgama K, Sharma KV. Heat transfer enhancement using nanofluids in an automotive cooling system. Int Commun Heat Mass Transf. 2014; 53: 195-202p.*
6. *LimSK. Investigation of thermal conductivity and viscosity of Al2O3/water–ethylene glycol mixture nanocoolant for cooling channel of hot-press. Int. Commun. Heat Mass Transf. 2016; 78: 182-189p.*
7. *Hwang Y. J., Ahn Y. C., Shin H. S., Lee C. G., Kim G. T., Park H. S. and Lee J. K.(2006) Investigation on characteristics of thermal conductivity enhancement of Nano fluids. Current Applied Physics. 6, 1068-1071p.*
8. *H. Arif, K. Yildiz. (2009) A review of heat pump water heating systems. Renewable Sustainable Energy Reviews ,13, 1211-1229p.*
9. *Azari A, M. Kalbasi and M. Rahimi.(2014) CFD And Experimental Investigation On The Heat Transfer Characteristics of Alumina Nano fluids Under The Laminar Flow Regime. Brazilian Journal of Chemical Engineering, Vol. 31, No. 02, 469 – 481p.*
10. *Zheng, D., Wang, J., Chen, Z., Baleta, J. and Sundén, B., "Performance analysis of a plate heat exchanger using various nanofluids. International Journal of Heat and Mass Transfer, 158, 2020, p.119993.*
11. *Gaikwad, S.N., Bandgar, R.T., Patil, M.R., Babar, A.C. and Shaikh, A.S., "Performance Analysis of Heat Exchanger Operated with Al2o3 Nanofluid by Using Copper as Tube Material." International Research Journal of Modernization in Engineering Technology and Science, 3(2), 2021.*
12. *Barmavatu Praveen & scg "CFD approach for different fluids varients in compact heat exchanger at different parametric conditions" International journal of scientific & technological research ISSN 2277-8616/vol-8/issue-12/pp:2288-2296/december2019.*
13. *Gkountas, A.A., Benos, L.T., Nikas, K.S. and Sarris, I.E., "Heat transfer improvement by an Al2O3-water nanofluid coolant in printed-circuit heat exchangers of supercritical CO2 Brayton cycle." Thermal Science and Engineering Progress, 20, 2020, p.100694.*
14. *Sözen, A., Khanları, A. and Çiftçi, E., "Heat transfer enhancement of plate heat exchanger utilizing kaolin-including working fluid." Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 233(5), 2019, pp.626-634.*
15. *Hosseini, S.M., Safaei, M.R., Estellé, P. and Jafarnia, S.H., "Heat transfer of water-based carbon nanotube nanofluids in the shell and tube cooling heat exchangers of the gasoline product of the residue fluid catalytic cracking unit." Journal of Thermal Analysis and Calorimetry, 140(1), 2020, 351-362.*
16. *Praveen Barmavatu, Mihir Kumar Das, Rathod Subhash, Banoth Sravanthi, Radhamanohar Aepuru, R Venkat reddy, Yalagandala akshay kumar "Designing an Effective Plate Fin Heat Exchanger and Prediction of Thermal Performance Operated Under Different Water Blends Using Machine Learning", Journal of Thermal Sciences and Engineering Applications, ASME Publications Apr 2023, 15(4): 041001 (22 pages) https://doi.org/10.1115/1.4055653*
17. *Barmavatu Praveen & scg "fabrication of compact heat exchanger with composite alloys" International journal of innovative technology and exploring engineering ISSN 2278-3075/vol-8/issue-6s4/pp:717-721/april 2019.*