Chapter

Plate Heat Exchangers: Artificial Neural Networks for Their Design

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Abstract

Heat exchangers are installation components in which two fluids with different temperatures are separated from each other with the help of plates and these plates make heat transfer between two fluids. The biggest advantage of plate heat exchangers over other type of heat exchangers is their heat transfer efficiency. The thinness of the plates separating the two fluids compared to other material alternatives increases the amount of heat transfer and thus reduces the heat losses that may occur during heat transfer. Plate heat exchangers are not only efficient but also prevent the formation of residue and dirt that can accumulate over time in the used applications. It also protects the system against excessive pressure that may occur in the installation. In this study, some information about plate heat exchangers is given such as classification, plate geometry, pressure losses, and thermal calculations. Also, the data obtained from the experimental work were used to obtain some relativity in order to use it in plate heat exchangers and artificial neural networks (ANN) method was used for this purpose. Artificial neural network method is used in many engineering applications. The most important advantages of this method are rapid formation, simple formation and high learning capacity.

Keywords: plate heat exchanger, heat transfer, artificial neural networks, thermodynamic

1. Introduction

One of the most common and used processes in engineering practice is the heat exchange between two or more fluids at different temperatures. The devices in which these changes are made are generally called heat exchangers (HEX) and in practice they are used in power plants, chemical industries, heating, air conditioning, cooling, vehicles, electronic devices, use of alternative energy sources, can be found in many places. As can be seen from the above written, HEXs that is used in various applications in practice, can be used in different structures, capacities, sizes and types according to the intended use. HEXs are the most important heat transfer equipments of the industry and they can be seen in different kinds and capacities at almost every stage of chemistry, power plants, cooling, heating and air conditioning processes under different names such as evaporator, condenser, heater and cooler. From the point of view of machine and chemical engineering education, the HEXs are a very good application for this branch of science which contains all of the basic subjects of these engineering branches: materials, strength, thermodynamics and heat transfer science. As it can be understood, HEXs are always used in daily life. Thus, the design ought to be followed up to the best detail, and the nearest investigation results ought to be gotten by utilizing related projects, and studies ought to be directed to improve the designs. Decreasing the amount of heat transferred in the HEX causes the performance of the HEX to reduce. This implies loss of performance in the energy system utilizing HEXs. The improvement of heat transfer permits the system dimensions to be kept at the proper values, thus reducing system cost and operating costs.

In the case of plate heat exchangers (PHEX), the surfaces with the basic heat transfer are made of thin metal plates. These metal surfaces might be level or wavy. They can be examined in three groups: sealed plate, spiral plate and lamellar. Heating, cooling and ventilation applications achieve the high efficiency, affordability and compact design they require thanks to PHEXs. By replacing tubular HEXs with daytime HEXs with PHEXs, PHEXs have gained a rapidly increasing market share in the entire industry. The wide selection range of plates in various sizes and materials provides superior flexibility to PHEXs. This flexibility is a great advantage for many thermal process HEXs [1].

Some correlations can be obtained using the data obtained from experimental studies and then these correlations can be used in energy applications. Artificial neural networks (ANN) method is mostly used for this purpose in energy applications. Artificial neural networks estimate the output value corresponding to this data using, data that makes up the network. It is known that artificial intelligence methodologies are used in the analysis of PHEXs as in energy systems. However, an analysis using ANN methodology for heat transfer rate and effectiveness in PHEXs for different surface angles has been performed in a small number. This study focuses on the usability of ANN methodology for performance analysis of PHEXs.

2. Plate heat exchangers

In PHEXs, the surfaces with the basic heat transfer are made of thin metal plates. These metal surfaces might be level or wavy. They generally have a higher total heat transfer coefficient than shell-tube type HEXs. **Figure 1** shows the structure of a PHEX.

Plate heat exchangers; They can be examined in three groups as sealed plated, spiral plated and lamellar [1]:

a. Heat exchangers with sealed plates; Heat exchangers with sealed plates are made by packing the thin metal plates into a frame and packing them. On each side of each metal plate there are holes for fluid to pass through. When the plates are assembled and packed, using appropriate seals prevents the fluids from

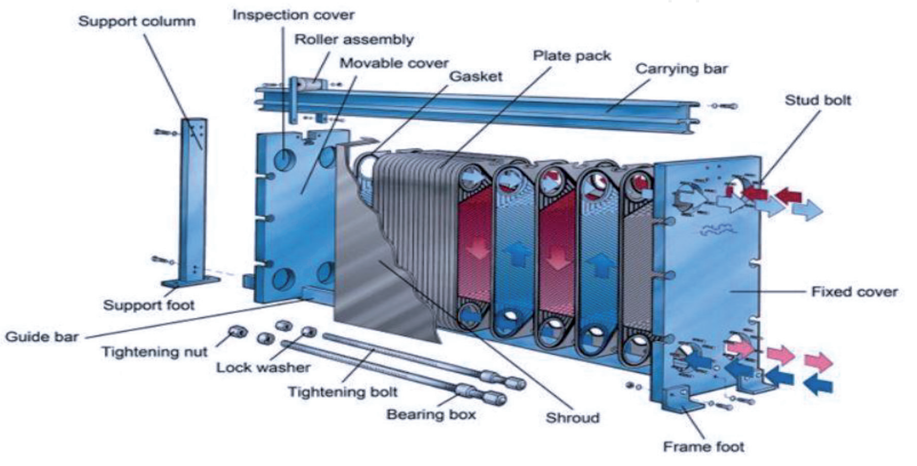

Figure 1.
The structure of the plate heat exchanger [2].

intermixing and leaking out. The hot and cold fluids flow through the spaces between the plates without mixing. The plates are made wavy to provide rigidity, to stabilize the distance between the plates and to improve heat transfer.

b. Spiral PHEXs; Plate type heat exchangers in which heat transfer surfaces are formed from plates and not formed by cylindrical pipes. Spiral plate heat exchangers are obtained by spirally wrapping two elongated thin metal plates 150–1800 mm wide each for a fluid, forming two spiral parallel edges. A uniform clearance can be maintained between the two plates. Both sides of the plates are covered with sealed covers. Various flow configurations are possible and different types of spiral heat exchangers can be manufactured depending on the flow configurations.

c. Lamellar heat exchangers; It is obtained by placing a bundle made of pipes (lamella) placed in a body. The lamella is usually held together by a point or an electric sewing source. One of the fluids flows through the lamellar tubes and flows through the other fluid lamellae. There are no surprise plates in the body. The flow is single-pass and the same direction or opposite flow arrangement can be used.

2.1 Design of plate heat exchangers

The heat exchangers are mainly regarded as pressure vessels. For this reason, the choice of design pressure, design temperature and appropriate material is crucial in the design of PHEXs. Once these criteria are established, the necessary calculations are made for the design. In the design of a PHEX, the surface A for heat transfer, the logarithmic mean temperature difference (ΔT_m) and the total heat transfer coefficient (K), pressure drop, physical size and economics are significant factors.

2.2 The importance of material used in plate heat exchangers

One of the factors that enable PHEXs to work without problems for long years in the desired thermal conditions is that the heat exchanger material is of a certain quality. In order for materials to be subjected to ISO 9001 quality testing, it is necessary to mark each item for retrospective analysis.

2.3 Plate material

It is very important to choose the plate material according to the flow rate used and the maximum desired working strength. Generally, the plate materials given in **Table 1** are used and the most commonly used material type is 1.440 / AISI 316 [2, 3].

AISI 304	NI 200/201
AISI 316	G-30
AISI 316 L	C- 4
254 SMO	INCONEL 625
654 SMO	INCONEL 825
TITANYUM	MONEL 400
Ti – PD	TANTALUM
C-276	C – 22

Table 1.
Material types of heat exchangers.

PHEXs are produced from different materials in today. These alternative materials are aluminum, carbon steel, stainless steel, nickel alloys, zirconium and titanium. For many chemical processes, Zirconium is a cost-effective material of construction in shielding process equipment systems from destructive corrosive leaks. With incredibly high resistance to corrosion, Zirconium HEXs can withstand some of the harshest situations. This translates to decreased maintenance expense, with downtime kept to a minimum. Copper has many preferred specifications for thermally efficient and durable HEXs. Above all else, copper is an perfect conductor of heat. This means that copper's high thermal conductivity allows heat to pass through it speedly. Other required specifications of copper in HEXs include its corrosion resistance, biofouling resistance, maximum allowable stress and internal pressure, creep rupture strength, fatigue strength, hardness, thermal expansion, specific heat, antimicrobial specifications, yield strength, high melting point, ease of fabrication, and ease of joining.

In chemical processes, the use of titanium HEXs has been found to be a cost-effective method of resisting leaks from corrosion on a process line. Titanium HEXs has superior corrosion resistance, high heat transfer efficiency, non-breaking property and provide an extended service life compared to other materials.

2.4 Gasket material

In plate heat exchangers it is the limit factor contour. Therefore, it is very important to choose the 'right' gasket material. Various sealing types according to application are listed below. One of the most important points that should not be forgotten is that the exchanger gaskets are produced in three qualities, normal, sulfur and peroxide. These three quality seal materials are peroxidized when compared with each other, and the material always ensures the best performance in terms of operating conditions [4, 5].

2.5 Plate geometries used in plate heat exchangers

Almost all plates used today are of the fishermen type. Traditionally, fish hatch plates are now made with two arrows, one is the "high-theta" with high resistance to flow and the other is the "low-theta" with low resistance against flow.

These two types of plates can be combined in three different ways, each with different characteristics in terms of heat transfer and pressure drop.

The symmetrical plates and the primary and secondary sides are geometrically identical and the plate deck can best be used on only one side. A later innovation is the asymmetrical plaque, these two teams have arrows, one high-theta and the other low-theta. Plates having different plate geometries are given in **Figures 2–6**

These two plates can be combined in the form of six different flow channels, each with different heat transfer characteristics. Gasket materials commonly used in plate heat exchangers are given **Table 2**.

The asymmetric plates also provide asymmetrical plate deck formation, where the geometry of the primary side is different from the geometry of the secondary side. These two aspects can be used separately in the best way, thus reducing the required heat transfer surface and providing better utilization of the existing pressure reduction.

Plates are manufactured in different thicknesses up to 8 mm by 0.4 mm in accordance with the designed pressure rating and maintenance stability. Thin plates are not used in cleaning applications and other applications where the unit needs to be opened. The most commonly used materials in geothermal applications are AISI 316, 254 SMO and commercial pure (grade 1) titanium. Other high alloy materials are also used where geothermal fluids are very corrosive.

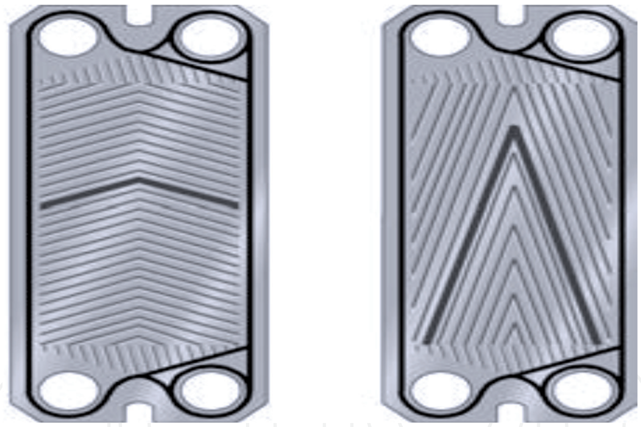

Figure 2.
Two arrowhead chevron plates.

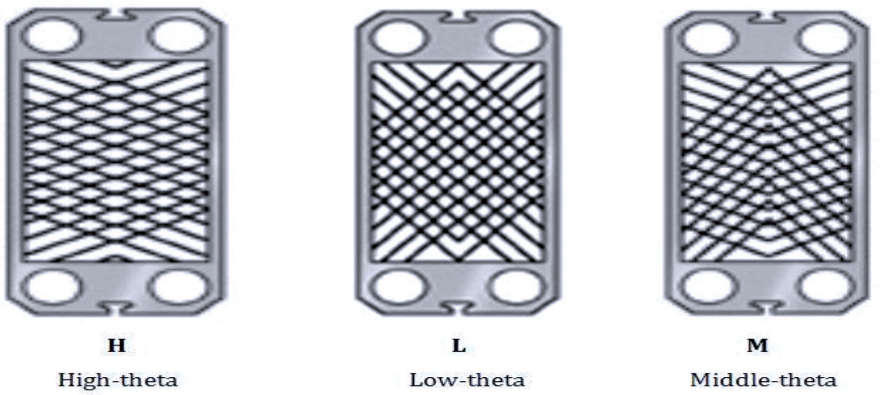

Figure 3.
Three different channels by combining two symmetrical plates.

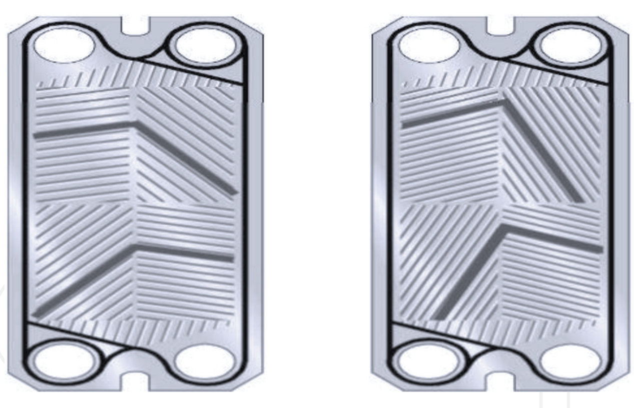

Figure 4.
Asymmetrical high and low-theta plates.

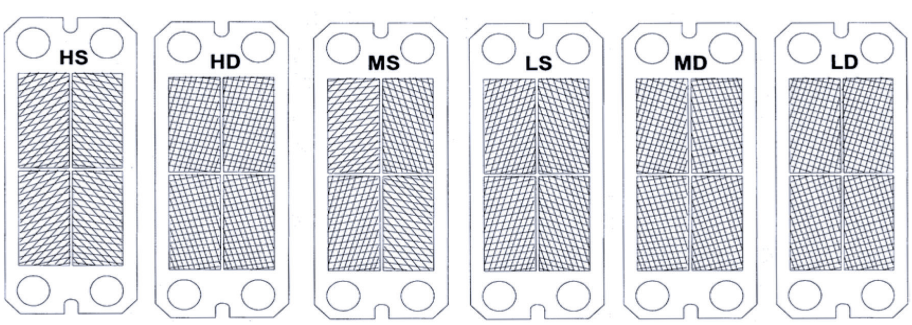

Figure 5.
Six different flow channels combined from two different platters.

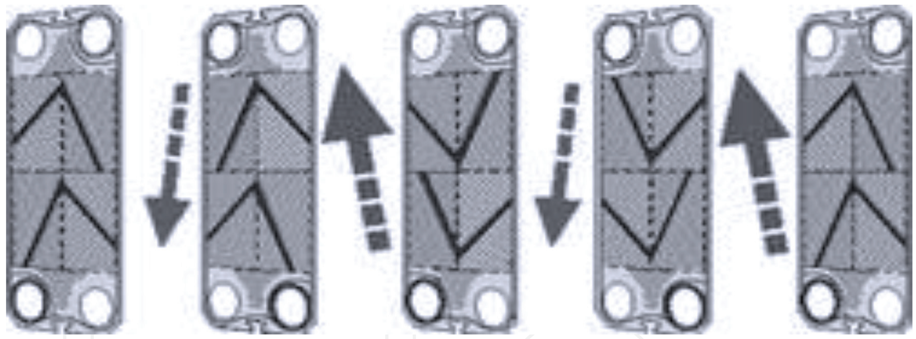

Figure 6.
Asymmetric best use at PHE.

Nitrile (Nbr)
Hnbr
Etilen Propilen (Epdm)
Florokarbon (Fpm)
Viton Gf
PTFE Encapsulated NBR

Table 2.
Gasket materials commonly used in plate heat exchangers.

3. Thermodynamic analysis of plate heat exchangers

If the heat transfer in a HEX is assumed to be only between the fluids in it and the absence of a heat loss in the center, it can be written in the PHEX with the following relation [6–9]:

$\dot{Q}$ = Heat in the HEX (W).

= Heat given by the hot fluid (W).

= Heat received by the cold fluid (W).

K = Total heat transfer coefficient ($W/m^2\,^{o}K$)

$$\dot{Q} = K\,A\,\Delta T_m \tag{1}$$

The temperatures given and received during the cooling and heating of hot and cold fluids can be found by the mass fluxes of fluids and the enthalpy of entrances and exits and can be written as [10]:

$$\dot{Q} = \dot{m}\left(h_i - h_o\right) \tag{2}$$

If the temperatures of the fluids change when the heat is taken and given, the amount of heat that passes is [10]:

$$\dot{Q} = \dot{m}_h c_{ph}\left(T_{hi} - T_{ho}\right) = \dot{m}_c\, c_{pc}\left(T_{co} - T_{ci}\right) \tag{3}$$

After a certain period of operation, particles, metal salts or various chemical elements may accumulate in the fluids on the heat exchanger surfaces. Occasionally, due to corrosive effects, an oxidation layer may form on these surfaces. All these layers are brought to an additional thermal resistance during heat transfer. This contamination resistance (or factor), as indicated by the R_f symbol, can be found as follows, in the sense that the thermal resistances of the heat transfer surfaces are dirty and clean [1]:

$$R_f = \frac{1}{K_{dirty}} - \frac{1}{K_{clean}} \tag{4}$$

Due to the roughness of the metal surfaces, there is a contact resistance between these two surfaces due to the poor contact between the two metals. The contact resistance on two surfaces causes a decrease in temperature on these surfaces. In order to take these situations into consideration, a resistance definition can be made as follows [1]:

$$\boldsymbol{R_t} = \frac{(\boldsymbol{T_A} - \boldsymbol{T_B})}{\frac{\dot{\boldsymbol{Q}}}{\boldsymbol{A}}} \tag{5}$$

Consequently, the total heat transfer coefficient at the surface of the HEX can be found by the following Eq. [1]:

$$\frac{1}{K} = \frac{1}{\alpha_1} + R_{f1} + \frac{\delta_1}{\lambda_1} + R_{t,1-2} + \frac{\delta_2}{\lambda_2} + R_{t,2-3} + \frac{\delta_3}{\lambda_3} + R_{f2} + \frac{1}{\alpha_2} \tag{6}$$

In the construction of the heat calculations of the heat exchangers, the expression of the mean logarithmic temperature difference (ΔT_m) is required if Eq. (1) is used. The mean logarithmic temperature difference value is determined by the flow rate in the heat exchanger. **Figure 7** and **Figure 8** show temperature distributions along the length of the HEX when the flow is parallel and opposite.

The mean logarithmic temperature difference (ΔTm) can be expressed as:

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}} \tag{7}$$

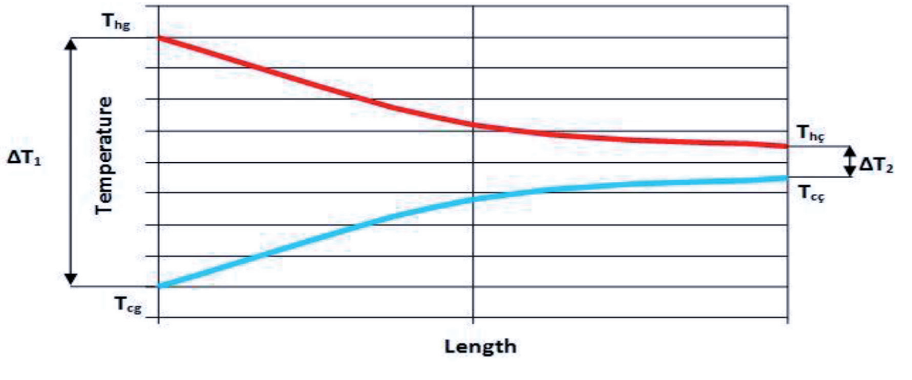

Figure 7.
Temperature distribution in a parallel flow HEX [1].

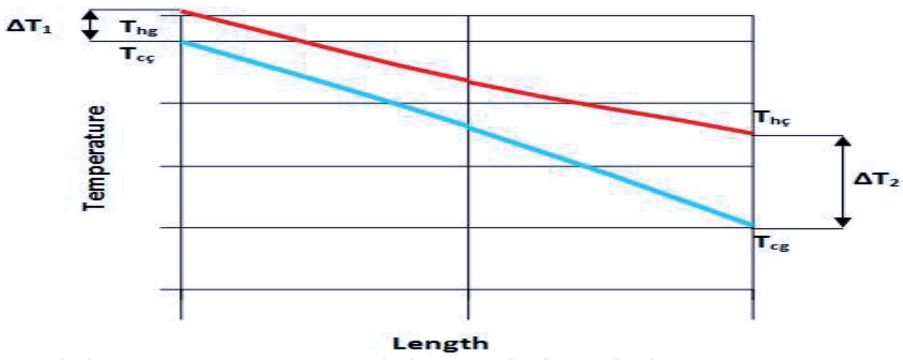

Figure 8.
Temperature distribution in the reverse flow HEX [1].

If the last equation is moved to Eq. (1):

$$\dot{Q} = \frac{KA(\Delta T_1 - \Delta T_2)}{\ln \frac{\Delta T_1}{\Delta T_2}} \tag{8}$$

expression is obtained.

The efficiency of HEXs can be calculated with the help of the following Equation [11]:

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{\max}} \tag{9}$$

$C_h = \dot{m}_h\, c_{ph}$ and $C_c = \dot{m}_c\, c_{pc}$ are the thermal capacity values of hot and cold fluids, the actual heat transfer in the HEX can be written as [12, 13]:

$$\dot{Q} = C_h\left(T_{hi} - T_{ho}\right) = C_c\left(T_{co} - T_{ci}\right) \tag{10}$$

If the Q_{max} value is defined as the maximum possible heat transition, it can be written as follows, provided that it is smaller than the C_h or C_c thermal capacity outputs [14, 15]:

$$\dot{Q}_{\max} = C_{\min}\left(T_{hi} - T_{ci}\right) \tag{11}$$

3.1 Determination of heat transfer rate and effectiveness in plate heat exchangers using alternative an approach

Artificial Neural Network (ANN) was designed for the generalizations of biological nervous systems' mathematical models. When the simplified neurons were introduced, the first steps were taken towards the neural networks, which are also known as connectionist models or parallel distributed processing. The artificial neurons are the main component of the process, and they are also known as simply neurons and nodes. In order to represent the effects of synapses in a simplified mathematical neuron model, the connection weights modulating the effects of associated input signals are utilized, while the nonlinear characteristics of neurons are represented by using the transfer function. Then, the impulse of neuron is calculated as the weighted sum of the input signals and transformed by the transfer function. The artificial neurons are provided with the capability of learning by adjusting the weights in accordance with the preferred learning algorithm.

The data obtained from the experimental work [16] were used to obtain some relativity in order to use it in PHEXs and ANN method was used for this purpose. ANN method is used in many engineering applications. The most important advantages of this method are rapid formation, simple formation and high learning capacity. Two methods are used in thermal calculations in PHEXs. These methods are mean logarithmic temperature difference and effectiveness-NTU methods. In this study, the data obtained from the experiments [16] (hot water inlet–outlet temperature, cold water inlet–outlet temperature, flow rate and plate surface angle) are quite suitable for using the mean logarithmic temperature difference method. These experimental data are the input variables of the network created for the ANN method. The effectiveness and the heat transfer rate of the PHEX are output variables. All data and calculated results obtained from experimental data can be modeled with ANN method and can be used to obtain results depending on different variables.

MATLAB Toolbox was used for ANN methodology. In the training of the data, the number of neurons in the hidden layer was changed between 3 and 12. 80% of the 227 data obtained from the experiments were randomly selected for training and 20% for testing. The generated network has 4 input variables as hot water inlet temperature (T_{hi}), cold water inlet temperature (T_{ci}), fluid flow (m) and plate surface angle (β). Effectiveness (ε) is output variable. The generated artificial neural network is shown schematically in **Figure 9**. In the created network, LOGSIG is selected as the transfer function, Forward Back Prop for the network type, and TRAINLM and TRAINSCG as the training function. The number of epochs used was 1000 values. Each network is run 10 times in order to get the best value.

To obtain the best result from ANN method, different algorithms and hidden neurons are used in different numbers. The values of root mean square error (RMSE), the coefficient of determination (R^2) and coefficient of variation (cov) obtained for heat transfer rate and effectiveness value are given in **Tables 3** and **4**. The performance evaluation criteria obtained from the ANN model are given in **Table 5**. The best R^2 value for heat transfer rate was obtained as 0.999636 for the TRAINLM-5 training function. For the best effectiveness value, R^2 value was 0.999565 for the TRAINLM-12 training function.

In determining the heat transfer rate and effectiveness of the PHEX, the equations obtained from the ANN method were used. In the above equations, E_i is the neuron summation function and F_i is the neuron activation function. In represents the input variables and bn represents the bias value. The coefficients used in the formulas represent the weight values of each neuron's summation function of the hidden layer of the training network. In the above equations, hot water inlet temperature (T_{hi}), cold water inlet temperature (T_c), fluid flow (m) and plate surface angle (β) are used in ANN as 4 input variables. The weight coefficients and bias values used for the determination of the heat transfer rate and effectiveness are given in **Tables 6** and 7 respectively.

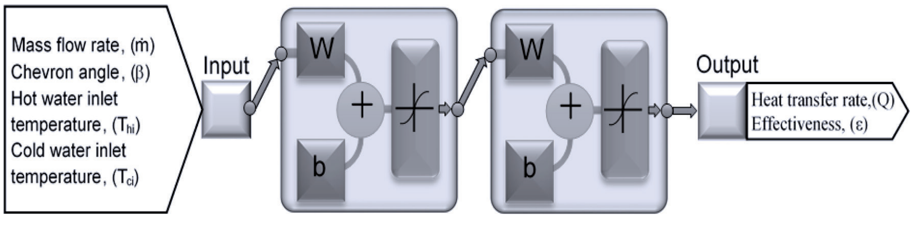

Figure 9.
Schematic representation of artificial neural network [17].

Algorithm-Neuron	RMSE	cov	R^2
Lm-3	53.5148	0.02003	0.999618
Lm-4	52.7873	0.01975	0.999628
Lm-5	**52.2255**	**0.01954**	**0.999636**
Lm-6	58.6761	0.02196	0.999540
Lm-7	54.9293	0.02056	0.999597
Lm-8	63.3763	0.02372	0.999464
Lm-9	57.5448	0.02153	0.999558
Lm-10	60.1653	0.02251	0.999517
Lm-11	58.8812	0.02203	0.999537
Lm-12	129.645	0.04852	0.997758
SCG-3	95.9341	0.03590	0.998772
SCG-4	76.4545	0.02861	0.999220
SCG-5	75.8600	0.02839	0.999232
SCG-6	61.0010	0.02283	0.999503
SCG-7	71.3101	0.02669	0.999321
SCG-8	61.6170	0.02306	0.999493
SCG-9	63.3772	0.02372	0.999464
SCG-10	54.6721	0.02046	0.999601
SCG-11	62.3508	0.02333	0.999481
SCG-12	59.8349	0.02239	0.999522

The bold values are the best values of root mean square error (RMSE), the coefficient of determination (R2) and coefficient of variation (cov) obtained from the ANN model for to estimate of heat transfer rate and effectiveness.

Table 3.
The statistical values of the network for predicting the heat transfer rate.

Heat transfer rate in the plate heat exchanger can be calculated by the following equations depending on the hot water inlet temperature (T_{hi}), cold water inlet temperature (T_c), fluid flow (m) and plate surface angle (β) [17].

$$\begin{aligned} E_6 = &-112.6039F_1 + 83.284F_2 - 89.934F_3 \\ &- 70.4233F_4 + 229.4711F_5 - 107.9219 \end{aligned} \tag{12}$$

$$\dot{Q} = \left(\frac{1}{1 + e^{-E_6}}\right)3920 \tag{13}$$

Similarly, the effectiveness in the PHEX can be calculated from the following equations depending on the hot water inlet temperature (T_{hi}), cold water inlet temperature (T_c), fluid flow (m) and plate surface angle (β) [17].

$$\begin{aligned} E_{13} = &\,21.3112F_1 - 2.7185F_2 + 21.2966F_3 + 7.2653F_4 - 0.056092F_5 \\ &- 26.4603F_6 - 19.2568F_7 - 12.4354F_8 + 3.0543F_9 - 46.6099F_{10} \\ &+ 58.215F_{11} + 0.28895F_{12} - 1.5743 \end{aligned} \tag{14}$$

$$\varepsilon = \frac{1}{1 + e^{-E_{13}}} \tag{15}$$

Algorithm-Neuron	RMSE	cov	R^2
Lm-3	0.0102575	0.022758	0.999475
Lm-4	0.0096802	0.021477	0.999532
Lm-5	0.0134191	0.029773	0.999101
Lm-6	0.0097002	0.021522	0.999530
Lm-7	0.0099292	0.022030	0.999508
Lm-8	0.0097623	0.021660	0.999524
Lm-9	0.0100210	0.022234	0.999498
Lm-10	0.0096225	0.021350	0.999538
Lm-11	0.0109986	0.024403	0.999396
Lm-12	**0.0093323**	**0.020706**	**0.999565**
SCG-3	0.0124508	0.027625	0.999226
SCG-4	0.0109349	0.024261	0.999403
SCG-5	0.0129422	0.028715	0.999164
SCG-6	0.0114423	0.025387	0.999346
SCG-7	0.0121871	0.027040	0.999258
SCG-8	0.0118729	0.026343	0.999296
SCG-9	0.0112524	0.024966	0.999368
SCG-10	0.0101688	0.022562	0.999484
SCG-11	0.0109066	0.024199	0.999406
SCG-12	0.0113416	0.025164	0.999358

The bold values are the best values of root mean square error (RMSE), the coefficient of determination (R2) and coefficient of variation (cov) obtained from the ANN model for to estimate of heat transfer rate and effectiveness.

Table 4.
The statistical values of the network for predicting the effectiveness.

Thermodynamic Values	Method	Comparison Parameters		
		R^2	RMSE	cov
Heat transfer rate	ANN	0.999636	52.2255	0.01954
Effectiveness	ANN	0.999565	0.0093323	0.020706

Table 5.
Performance evaluation criteria obtained from the ANN model.

Neuron position (w_{ni})	$I_1(T_{hi})$	$I_2(T_{ci})$	$I_3(\dot{m})$	$I_4(\beta)$	b_n
1	1.8443	10,5531	2.1624	−1.2641	18.7258
2	56.9616	−52.142	27.1211	−0.0728	−20.0211
3	−0.38653	0.42041	−2.0398	−5.9629	4.8897
4	−2.6099	2.2846	3.6669	8.8609	−7.3451
5	−40.8109	37.1115	−105.8138	33.7376	27.9695

Table 6.
The weight coefficients and bias values used for the determination of the heat transfer rate.

Neuron position (w_{ni})	$I_1(T_{hi})$	$I_2(T_{ci})$	$I_3(\dot{m})$	$I_4(\beta)$	b_n
1	11.1556	11.7598	39.362	9.2238	47.3869
2	−37.921	46.173	−7.0158	−4.478	−2.4622
3	16.3938	−38.169	−35.378	−4.640	39.5329
4	13.9183	−1.3878	−10.187	13.3089	3.5955
5	92.1152	8.6141	28.7158	−49.57	−16.817
6	31.4252	−30.344	3.3642	25.2838	−23.704
7	−14.906	11.1061	−9.057	−9.2724	10.1669
8	23.2713	−4.3873	−49.1203	20.2264	4.1424
9	68.8739	−72.556	34.7909	−44.281	13.6961
10	−0.13074	3.2502	1.8366	11.4214	−8.3915
11	−10.7511	12.7919	−3.6727	13.7598	−7.913
12	35.966	58.1377	91.3142	3.7576	−46.231

Table 7.
Weight coefficients and bias values used to determine of the effectiveness.

Temperature T_{hi}(°C)	Temperature T_{ci}(°C)	Flow rate $\dot{m}$ (kg/s)	Plate surface angle β(°)	Heat transfer rate (W)		Error (%)
				Actual values	ANN	
32.8	25	0.167	30	2167	2191	1.09
44.6	37.1	0.167	30	2167	2144	1.08
51,1	43.6	0.167	30	2167	2166	0.07
58.1	50.1	0.167	30	2377	2354	0.97
31.8	26.6	0.239	30	2195	2204	0.40
39.3	34	0.239	30	2295	2284	0.48
44.7	39.4	0.239	30	2295	2319	1.05
37.9	34.3	0.321	30	2144	2115	1.37
45.5	41.9	0.321	30	2144	2159	0.68
34.8	28.4	0.263	60	3077	3103	0.85
53.3	46.8	0.263	60	3407	3393	0.40
19.2	15.7	0.39	60	2608	2609	0.06
26.4	21.9	0.39	60	3259	3254	0.17
37.5	33.1	0.39	60	3422	3421	0.04
45.2	40.8	0.39	60	3585	3572	0.37
32.1	29	0.517	60	3023	3055	1.06
45.7	42.5	0.517	60	3455	3419	1.04

Table 8.
Comparison of the actual values of the heat transfer rate with the estimated values obtained in the ANN model.

The actual values of the heat transfer rate and the predicted values and error values obtained in the ANN model are given in **Table 8**. Eq. (16) is used in the calculation of error values [18].

$$\boldsymbol{Error} = \frac{\left|A^e - A^p\right|}{A^e} \boldsymbol{x100} \tag{16}$$

Where, A^e is the data obtained from experiments and A^p is the estimates obtained from ANN. As seen in **Table 8**, the highest error value is 1.37. It has been determined that this value is an acceptable error value.

Similarly, the actual values of the effectiveness and the predicted values and error values obtained in the ANN model are given in **Table 9**. As seen in **Table 9**, the highest error value is 1.23. This value is also determined to be an acceptable error value.

3.2 Pressure drop in heat exchangers

In all HEXs there is a close physical and economic relationship between heat transfer and pressure drop. In a heat exchanger intended to be designed for a constant heat capacity, increasing fluid velocities increases the heat transfer coefficient and allows smaller heat exchangers (compact). In this way, a smaller size or more

Temperature T_{hi}(°C)	Temperature T_{ci}(°C)	Flow rate $\dot{m}$ (kg/s)	Plate surface angle β(°)	Effectiveness		Error (%)
				Actual values	ANN	
21.2	15.4	0.167	30	0.40	0,396	0.95
44.6	37.1	0.167	30	0.41	0,409	0.22
51.1	43.6	0.167	30	0.41	0,407	0.73
31.8	26.6	0.239	30	0.42	0,423	0,71
39.3	34	0.239	30	0.43	0,435	1.23
22.4	18.9	0.321	30	0.43	0,426	0.91
29.1	25.5	0.321	30	0.42	0,423	0.69
34.8	28.4	0.263	60	0.44	0,445	1.14
41.4	34.9	0.263	60	0.45	0,453	0.62
53.3	46.8	0.263	60	0.48	0,477	0.63
26.4	21.9	0.39	60	0.44	0,439	0.20
45.2	40.8	0.39	60	0.50	0,501	0.22
21.8	19.1	0.517	60	0.44	0,443	0.77
32.1	29	0.517	60	0.45	0,452	0.40
38.8	35.7	0.517	60	0.48	0,481	0.13
45.7	42.5	0.517	60	0.50	0,505	0.90
54.3	51	0.517	60	0.52	0,521	0,21

Table 9.
Comparison of the actual values of the effectiveness with the estimated values obtained in the ANN model.

compact heat exchanger design can be achieved at the same capacity with a lower investment cost. On the other hand, increasing the velocities of the fluids causes the pressure drop in the heat exchanger to increase. This increases the investment cost of the pump due to the operating costs of the system and the growth of the pump or fan, as it increases the power of the pump or fan. Therefore, in the design of a HEX, the heat transfer and pressure drop must be considered together and the most appropriate solution for the system should be sought.

Since the flow model is very complex even in the simplest heat exchangers, approximate solutions and experimental findings are utilized in the determination of pressure drop as well as theoretical analyzes. The total pressure drop in a HEX is considered in two ways, the pressure drop in the straight pipe and the local pressure drop. The pressure drop in the straight pipe indicates the pressure drop from the rubbing in the flowing fluid in the fixed section piping or conduits. The local pressure drop is the loss of flow and direction changes in the flow. Unlike fluids at the same temperature, the natural convection caused by the temperature distribution in the heat exchangers may cause an additional pressure loss (or sometimes gambling).

The total pressure loss in a heat exchanger is summed separately from the pressure losses in each step of the exchanger.

3.3 Local losses

Cross-sectioning, rotation, separation, or coupling of fluid as it flows through a channel also causes pressure losses. These are generally called local losses. Changes in the velocity and direction of the fluid create Eddy movements (eddies) that cause energy loss. Although local losses occur at very short distances, they remain effective over a long period of time throughout the flow. These losses are generally [1];

$$\Delta P_y = \zeta \frac{\rho v^2}{2} \tag{17}$$

form. Where ζ is called the local loss coefficient and can be found from the relevant sources for various local loss factors either using formulas or diagrams.

3.4 Pressure loss caused by acceleration of the fluid and lifting force

The pressure loss during the acceleration of the fluid, in fixed cross-sections,

$$\Delta P_{iv} = \rho_o v_o^2 - \rho_i v_i^2 \tag{18}$$

Where v_g, $v_ç$ are the fluid velocity at inlet and outlet of the flow channel; ρ_g, $\rho_ç$, again indicate the density of the fluid at the inlet and outlet of the channel. The fluid is assumed to be incompressible, and in fluid fluids this value is the order of magnitude that other pressure losses can be neglected.

3.5 Pressure loss in sealed plate heat exchangers

The pressure loss in this type of heat exchanger is [19];

$$\Delta p_{gasketplate} = \lambda_{gasketplate} \frac{L_p \rho v^2}{d_h 2} \tag{19}$$

Turbulent flow;

$$\lambda_{gasketplate} = \mathbf{1{,}22}\,\mathrm{Re}^{-0{,}252} \tag{20}$$

Due to the protrusions on the plates, turbulence can pass through the Reynolds numbers, which are smaller than the values given in the flow flat exit channels. Therefore, in the case of sealed PHEXs, the flow at values such as Re > 100–400 is assumed to be turbulent.

3.6 The power required to maintain fluid motion

First, the pressure losses in the HEX and the pressure losses in the piping up to the heat exchanger are calculated. Later, the fan or pump power required to move the fluid in this system by calculating the sum of the pressure losses in the heat exchanger up to the HEX [20],

$$\boldsymbol{N} = \frac{\dot{m}\sum(\Delta \boldsymbol{P})_t}{\rho\eta} \tag{21}$$

can be found in the equation.

4. Conclusions

PHEXs are the most frequently used heat transfer equipments in energy applications and can be under various names such as evaporators and condensers in almost every stage of chemistry, petrochemical industry, power plants, cooling, heating and air conditioning process in various types and capacities. From the point of view of machine and chemical engineering education, plate heat exchangers are a very good application for this branch of science which contains all of the basic subjects of these engineering branches: materials, strength, thermodynamics and heat transfer science. As can be seen, PHEXs are a commonly used construction in our daily lives. For this reason, its design should be done in detail, analysis results should be obtained with analysis programs and studies should be done to improve the designs. Decreased the amount of heat transferred in the PHEX causes the performance of the HEX to decrease. This means loss of capacity in energy system with plate heat exchanger. The regulation of heat transfer permits the system dimensions to be kept at the proper values, thus decreasing system cost and operating costs.

In this study, some equations were obtained to use in the plate heat exchangers by using the data obtained from the experimental work. ANN methodology was used for this purpose. As a result of the equations obtained for heat transfer and efficiency values in ANN application, approximate results were obtained at the value of 1.37 which is the highest error value for the real value heat transfer value and 1.23 for the efficiency value. When we look at the literature it is seen that these values are acceptable error values.

Conflict of interest

"The authors declare no conflict of interest."

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