ChE 417

CHEMICAL ENGINEERING DESIGN I

Gasket type Heat Exchanger Design

Report Name

Group No: 2

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Abstract

In this report design process of gasket type plate heat exchanger for municipal water and geothermal with respective inlet, outlet temperatures, and flow rate of 372 K, 405 K, 11.95 kg/s and 419 K 383 K, 10.01 kg/s and algorithm for this design is explained and discussed on merits of overall heat transfer and cost efficiency. The design procedure suggested for a gasket type plate heat exchanger was used as a basis. Certain correlations and relations were taken from other sources[1]–[6]. Fixed cost calculations were evaluated from 3 different sources, including the Turkish Market for 2020; however, none of the methods yield reasonable results compared to real costs.

With the combinational iteration method, total of 4,008,396 possible designs was evaluated at a rate of one design per 1.5 milliseconds. Filtering the results for %0.01 of heat duty error, 436 designs were found, sorting reminder designs for total cost and with consideration of flawed cost calculation, 63rd design, with row #3891028 was chosen. Fixed cost of 16,828 TL, the operation cost of 113,883 TL, the total maintenance cost of 30,000 TL[7], and total cost of 160,711 TL was found for 20 years of operation. In addition to designing a cost-effective gasket type heat exchanger for the specific case. A user-friendly application with GUI was created. Essentially, offering a general solution or general solution basis for gasket plate heat exchanger design.

Table of Contents

Nomenclature

Symbol	Name	Unit
$A_{pro,1}$	Projected Area per plate	m^2
N_t	Total Number of Plates	
ϕ	Enlargement Factor	
N_p	Number of Pass	
U	Overall Heat Transfer Coefficient	W/m^2K
D_p	Port Diameter	mm
L_{gap} (b)	Plate Gap	mm
m_c	Mass flow rate of Cold fluid	kg/s
m_h	Mass flow rate of hot fluid	kg/s
N_e	Effective Number of Plate	
L_{eff}	Effective Flow Length	m
L_p	Projected Plate Length	m
L_w	Plate Width	m
L_v	Vertical port distance	m
$L_{thickness}$	Plate Thickness	mm
L_c	Compress plate head length	mm
p	Plate pitch	mm

A_{ch}	One channel flow area	m^2
$A_{P,T}$	Total Area	m^2
$A_{T,E}$	Total Effective Area	m^2
$A_{1,E}$	Single Effective Area	m^2
D_h	Channel Hydraulic Diameter	mm
N_{cp}	Number of Channel per pass	
m_{ch}	Mass flow rate per channel hot	kg/s
m_{cc}	Mass flow rate per channel cold	kg/s
G_{ch}	Channel mass velocity hot	kg/m^2s
G_{cc}	Channel mass velocity cold	kg/m^2s
μ_c	Viscosity Cold	Ns/m^2
μ_h	Viscosity Hot	Ns/m^2
k_c	Thermal conductivity cold	W/mK
k_h	Thermal conductivity hot	W/mK
Pr_c	Prandtl Number cold	
Pr_h	Prandtl Number hot	
ρ_h	Density hot	kg/m^3
ρ_c	Density cold	kg/m^3
$C_{p,h}$	Specific Heat Hot	kJ/kgK
$C_{p,c}$	Specific Heat Cold	kJ/kgK
Re_h	Reynolds Number Hot	
Re_c	Reynolds Number Cold	

β	Chevron angle	°
Nu_h	Nusselt number hot	
Nu_c	Nusselt number cold	
h_h	Heat Transfer Coefficient for Hot	W/m^2K
h_c	Heat Transfer Coefficient for Cold	W/m^2K
U_c	Overall Clean Heat Transfer Coefficient	W/m^2K
U_f	Overall Fouling Heat Transfer Coefficient	W/m^2K
CF	Cleanliness Factor	
Q_c	Heat load under clean condition	kW
Q_f	Heat load under fouling condition	kW
ΔT_{lm}	Log mean Temperature	K
f_h	Fanning friction factor hot	
f_c	Fanning friction factor cold	
Δp_c	Channel Pressure Drop	Pascal
Δp_p	Port Pressure Drop	Pascal
Δp_t	Total Pressure Drop	Pascal
G_p	Port mass velocity	kg/m^2s
$T_{m,c}$	Average Temperature of Cold	K
$T_{m,h}$	Average Temperature of Hot	K
$\hat{W}$	Specific Work	$(m/s)^2$
$t_{project}$	Project Lifetime	year

PLPC	Project Life Pumping Cost	TL
LF	Location Factor	
$C_{pumping}$	Pumping Cost	TL
$C_{heat\ Exchanger}$	Heat Exchanger Cost	TL
η_{pump}	Pump Efficiency	

1 INTRODUCTION

1.1 Project Specifications

The aim of the project is to design a safe and cost-efficient heat exchanger for transferring thermal energy from geothermal water to water that will be used for district heating. Properties for both streams can be found in Table 1. Temperatures were found according to the initial temperature of the fluids and heat losses during the transportation for worst weather conditions and maximum energy requirement, which implies that the heat exchanger design will be compatible with worst case scenario.

Table 1 Stream properties

Properties	**Hot Fluid**	**Cold Fluid**
Fluids	Geothermal Water	Water
Flow Rates (kg/s)	11.95	11.01
Temperature in (°C)	98.65	146.05
Temperature Out (°C)	131.85	110

1.2 Heat Exchanger Properties

In the following sections, properties of heat exchangers are thoroughly explained; for more detailed explanations, related references can be checked.

1.2.1 Flow Arrangements

“Pass” term refers to a group of heat exchanger channels in which the flow direction is the same[1]. In the PHE case, these channels are spaces between the plates. There is an infinite about of ways that the flow arrangements can be chosen. The main classification for arrangements is for flow division, parallel and series, and for the direction of the streams; co-current and counter-current. Different classifications can exist in the same design. Usually, the number of passes and channels per pass are identical for both streams.

Multi-pass systems are generally preferred when the flow rate is greater. Most of the basic operations with low-temperature drops and flow rates use single-pass systems with the counter-current flow direction.

1.2.2 Plate Material

One of the most important aspects of heat exchanger design is the material selection for thermal plates due to its effectiveness on both cost and overall heat transfer efficiency. Thermal plates are made of metal, metal alloy, or even special graphite materials, depending on the application. Stainless steel, titanium, nickel aluminum are some examples commonly found in industrial applications [8]. By looking at Table 2, the thermal conductivities of materials can be compared with each other for having a rough understanding.

Table 2 Plate materials vs. thermal conductivities [1]

Plate Materials

Material	Thermal Conductivity ($W/m^2 \cdot K$)
Stainless steel (316)	16.5
Titanium	20
Inconel 600	16
Incolay 825	12
Hastelloy C-276	10.6
Monel 400	66
Nickel 200	66
9/10 Cupro-nickel	52
70/30 Cupro-nickel	35

Another constraint for plate material selection is the flowing fluid's composition; suggestions for different compositions can be seen in Table 3.

Table 3 Material selection suggestions for fluid compositions

Materials Selection

Application	Material
Natural cooling water, cooling tower water, or demineralized water	Stainless steel 316
Sea or brackish water	Titanium
Dilute sulphuric and nitric acids up to 10% concentration, and for temperatures up to 70°C	Titanium, titanium–palladium alloy, Incoloy 825, Hastelloy
Chloride solution	
Chloride content < 200 ppm	Stainless steel
Chloride content > 200 ppm	Titanium
Caustic solutions (50–70%)	Nickel
Wet chloride, chlorinated brines, hypochlorite solutions	Titanium
Copper sulphate solution in electrolyte refining	Stainless steel
Cooling hydrogen gas saturated with water vapor and mercury carryover in electrolysis plants	Incoloy

1.2.3 Gasket Material

Leakage from the channels between the plates to the surrounding atmosphere is prevented by the gasketing around the exterior of the plate [1]. The gaskets are typically molded elastomers, selected based on their fluid compatibility and conditions of temperature and pressure. Butyl or nitrile rubbers are the materials generally used in the manufacture of gaskets [8]. In addition, gaskets are available in a wide range of elastomers, the most common being Nitrile rubber and EPDM [9]. Gasket location can be better understood by looking at Figure 1.

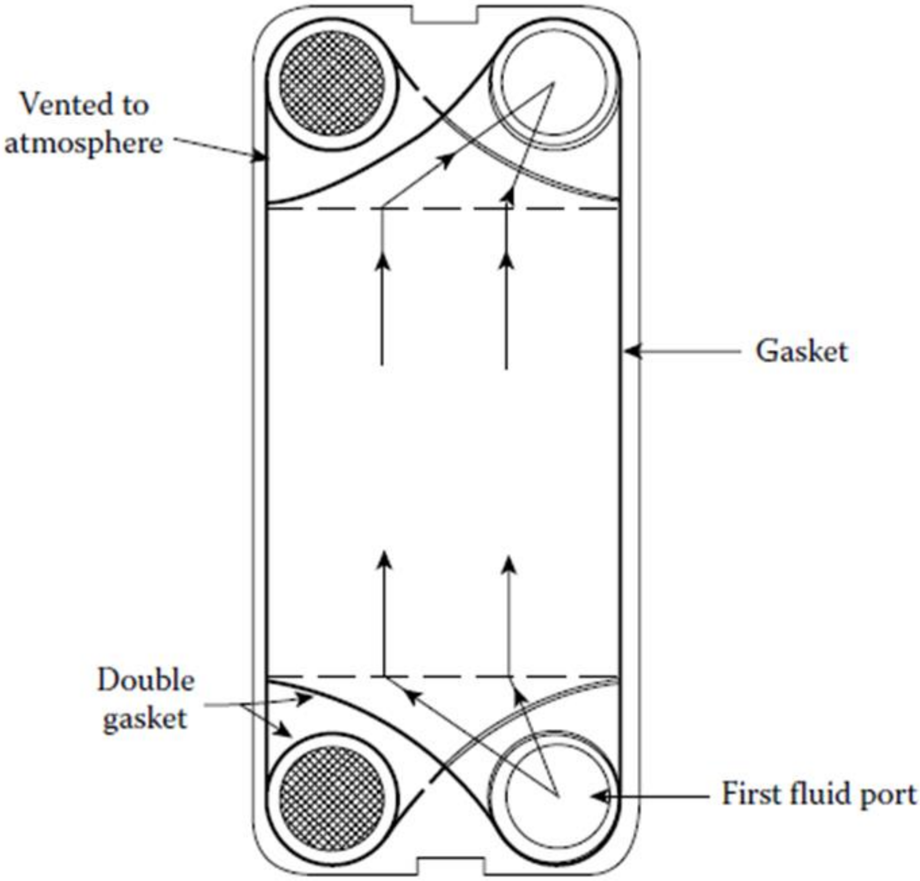
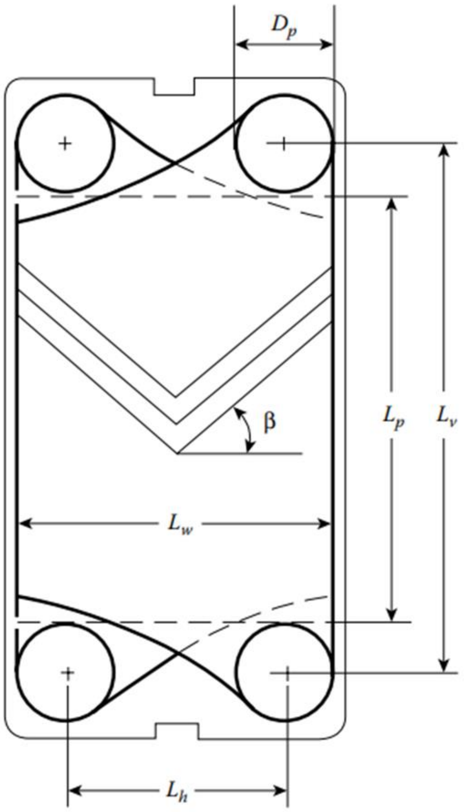


Figure 1 Gasket Model [1]

1.2.4 Plate Size

Heat transfer is provided by plates in gasketed plate heat exchangers. For this reason, the dimensions of the plates are very important in the design of plate heat exchangers. According to the limits, the heat transfer area of the plate should be in the range of 0.03 square meters to 2.2 square meters [1]. In addition, the fluid flow must be maintained evenly across the width of the entire plate. Thus, to ensure regular flow, the minimum length/width ratio should be 1.8. For a better understanding of plate and plate measurements, the reader can refer to Figure 2.

Increasing the size of the plate increases the heat exchange that will be provided in each plate, so it decreases the number of plates that need to be used, but also increases the production cost of each plate. In addition, since the pressure loss occurring in the heat exchanger also directly affects the size and number of plates, the number and size of the plates should be decided as a result of optimization calculations.



D_p: Port diameter

β: Chevron angle

L_w: Plate width

L_p: Plate length

L_v: Plate length from port center

L_h: Plate width from port center

Figure 2 Main dimensions of a chevron plate [1]

1.2.5 Enlargement Factor

Due to the corrugations in the plates, the actual surface areas of the plates differ from the projected surface areas of plates [1]. Due to this difference problem, the enlargement factor has been defined. The enlargement factor is defined as the ratio of the developed plate surface area to the flat or projected plate surface area. Illustration of developed dimension and projected dimension can be seen in Figure 3.

The enlargement factor ranges from 1.15 to 1.25. It can be assumed that 1.17 is a typical average enlargement factor.

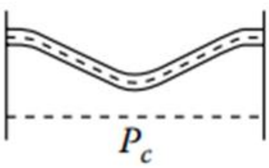


Figure 3 Projected dimension and developed dimension representation [1]

1.2.6 Plate Pattern

The plates can be flat, but in most applications, the plate pattern is different from than flat type. In the majority of modern PHEs, chevron plate pattern types are used [8].Some plate types are shown in Figure 4. The channel formed between adjacent plates imposes a swirling motion to the fluids, which is overall increasing heat transfer rate. The chevron angle is reversed in adjacent sheets so that when the plates are tightened, the corrugations provide numerous points of contact. That is, the heat transfer area is increased by the chevron angle[8]. The chevron angle varies between the extremes of about 65°C and 25°C [1].

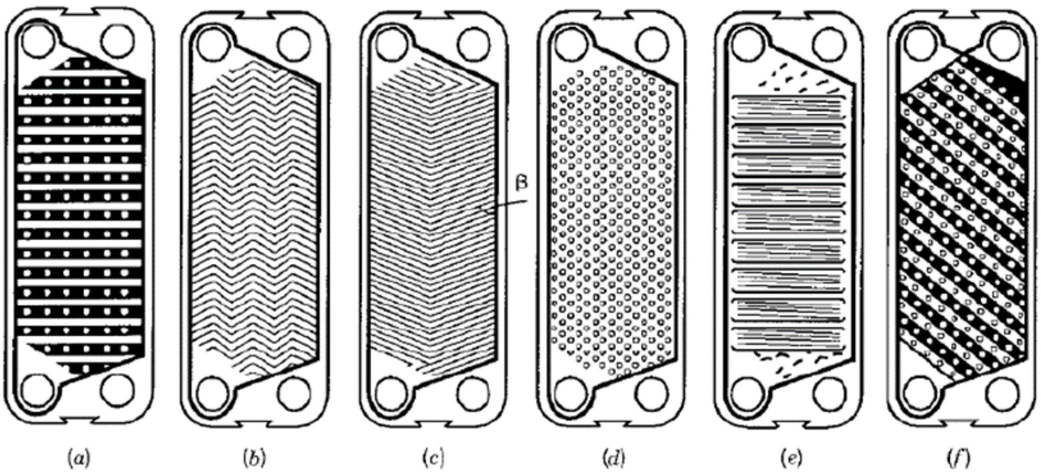


Figure 4 Typical categories of plate corrugations. (a) washboard, (b) zigzag, (c) chevron or herringbone, (d) protrusions and depressions (e) washboard with secondary corrugations(f) oblique washboard [1]

1.2.7 Plate Thickness

Plate thickness represents the thickness of the heat transfer medium between fluids in gasketed plate heat exchangers. Considering the physical strength of the plate, it is kept as low as possible in order to provide a high amount of heat flow rate. According to the literature, the plate thickness has a range of 0.5 to 1.2 mm[1].

1.2.8 Chevron Angle

Chevron angle is an angle of the corrugated pattern, as shown in Figure 2 Main dimensions of a chevron plate [1]below. Chevron angle effects of the pressure drop and heat transfer characteristics on the plate [1]. Experiments show that pressure drop, and the heat transfer coefficient increase while the chevron angle is decreased. Therefore, to achieve the optimum thermal performance of the plate heat exchanger, the chevron angle has a high effect on it.

Figure 5 shows that at the same surface roughness and water velocity, the lower chevron angle plate yields a higher heat transfer coefficient [10]. It is affected by the recirculation flow, which is inside the plate heat exchanger is mainly related to the chevron pattern and corrugation configuration. If a similar corrugation configuration is available, the recirculation flow is higher when the chevron angle plate is smaller.

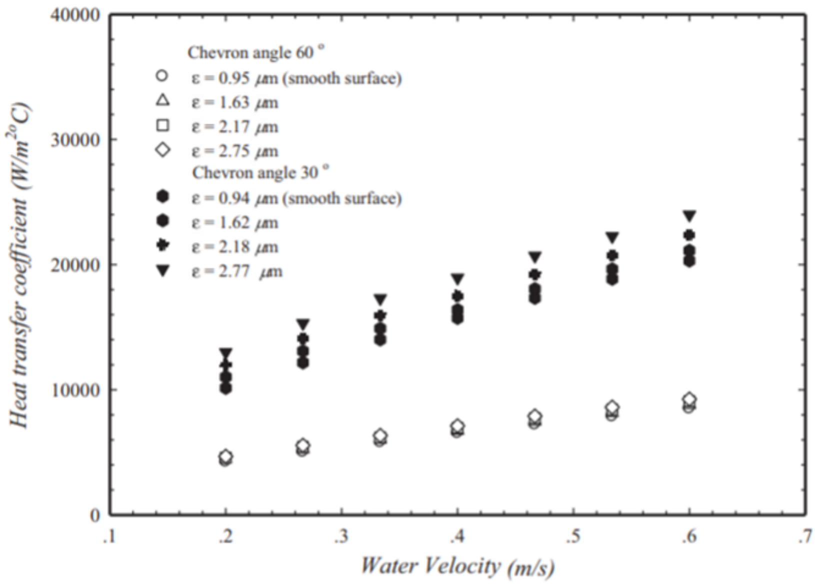


Figure 5 Chevron angle effect on heat tr coef. and water velocity [10]

1.2.9 Number of Plates

The Total number of plates has an important factor in the plate heat exchanger[11]. It is considered as if the plate number is increased, the number of transfer units (NTU) increases, and the consequent improvement in thermal performance. In addition, material cost is increasing when the total number of plates is increased; in other words, m^2 is increased. Therefore, it directly affects fixed costs. Figure 6 shows the flow distribution in many plates. For the plate heat exchanger with 300 plates, the last 100 plates do not receive any flow. So, the last 100 plates would not have any role in overall thermal exchanging. Therefore, according to the design, the optimum number of plates can be subject to change.

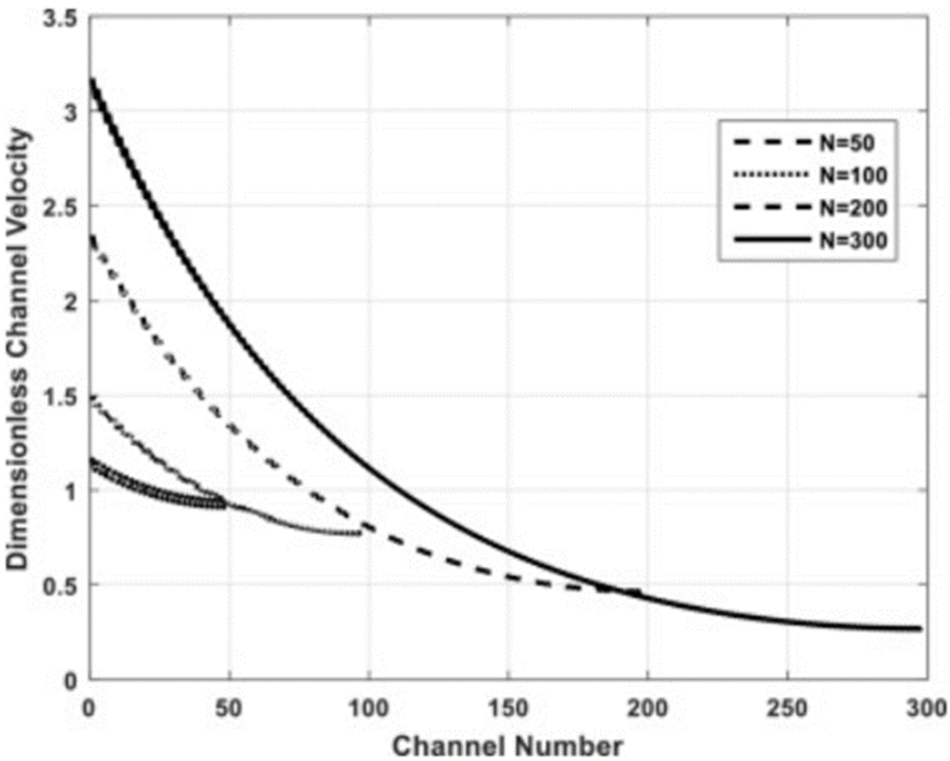


Figure 6 Channel velocity to channel number [11]

1.3 Fouling Inside the Heat Exchanger

There are a lot of microorganisms, inorganic salts, sediment, and other particles in the geothermal water, which is used in a heat exchanger. These things can be accumulated easily on the heat exchange surface during the operation process, so fouling problem could be observed. According to the investigation, more than 90% of the heat exchanger equipment has fouling problems. The fouling layer has poor thermal conductivity, and a very thin layer of fouling can produce large thermal resistance. Developed countries spend about 0.25% of their GDP on fouling treatment every year, so fouling cannot be underestimated. There are common methods for controlling fouling in plate heat exchangers, such as mechanical methods, chemical methods, and surface modification [12].

2 METHODS

2.1 Overall Design Approach

2.1.1 Main Idea of the Algorithm

All required calculations for the design are analyzed for determining independent and dependent variables affecting the design. Design initiates by designing all possible designs within the reasonable range of chosen independent variables by utilizing independent variables of design specifications. Not chosen independent variables are implemented as constants. To illustrate, the plate size is chosen as independent variable and iterated between suggested values of 3 to 200; pass count is a not chosen an independent variable, so it is chosen as one and is constant for all the designs. Essentially, the design is only optimized for chosen independent variables.

After all the designs are created, designs are filtered for heat duty specification and physical constraints such as working pressure limits, formula domain limits, etc. These considerations can be found in subsection 2.1.3. The remaining designs are sorted for overall cost, and the cheapest design is chosen after checking for possible physical limitations, such as bigger port size than plate width.

This approach generates a general solution than an individual solution for plate heat exchanger design.

2.1.2 Mathematical Calculations for Algorithm

Using chosen independent variables, dependent variables are calculated by using mathematical relations within an indicated numerical variable domain, supplied by various sources[1]–[3]. The exact relations and sample calculation for one design can be found in the appendix. Exact pathway in the appendix is tracked in the creation of every design.

2.1.3 Algorithm Assumptions and Constraints

Assumptions and constraints for the algorithm are listed below:

- The gasketed plate heat exchanger operates at steady-state conditions.
- Physical properties are constant.
- No heat generation is in the plate heat exchanger.
- Heat losses to the surroundings are negligible.
- No phase change in the plate heat exchanger. (Operating pressure is higher than cavitation pressure for both fluids)
- Wall thermal resistance are constant.
- Reynolds number is greater than 1000 for equation validity[1].
- Port velocities are within valid ranges.
- Chevron angle is from 30 to 60 for equation validity[1].
- Enlargement factor is 1.17
- Plate width is much larger than plate gap (L_w >> b).

- Pressure drop is manageable by the pump
- Heat duty is same with the project specifications

2.1.4 Algorithm Flow Chart

The overall simplified algorithm can be found in Figure 7. In the flow chart graphical user interface (GUI) part was completely removed, and the interface was oversimplified due to the scope of this report. Further information can be extracted from the code and code comments. The main property of combining all parameters and achieving individual heat exchanger design is achieved by combinationalArrayLooper function and plateHEX class. Code for these can be found in the appendix.

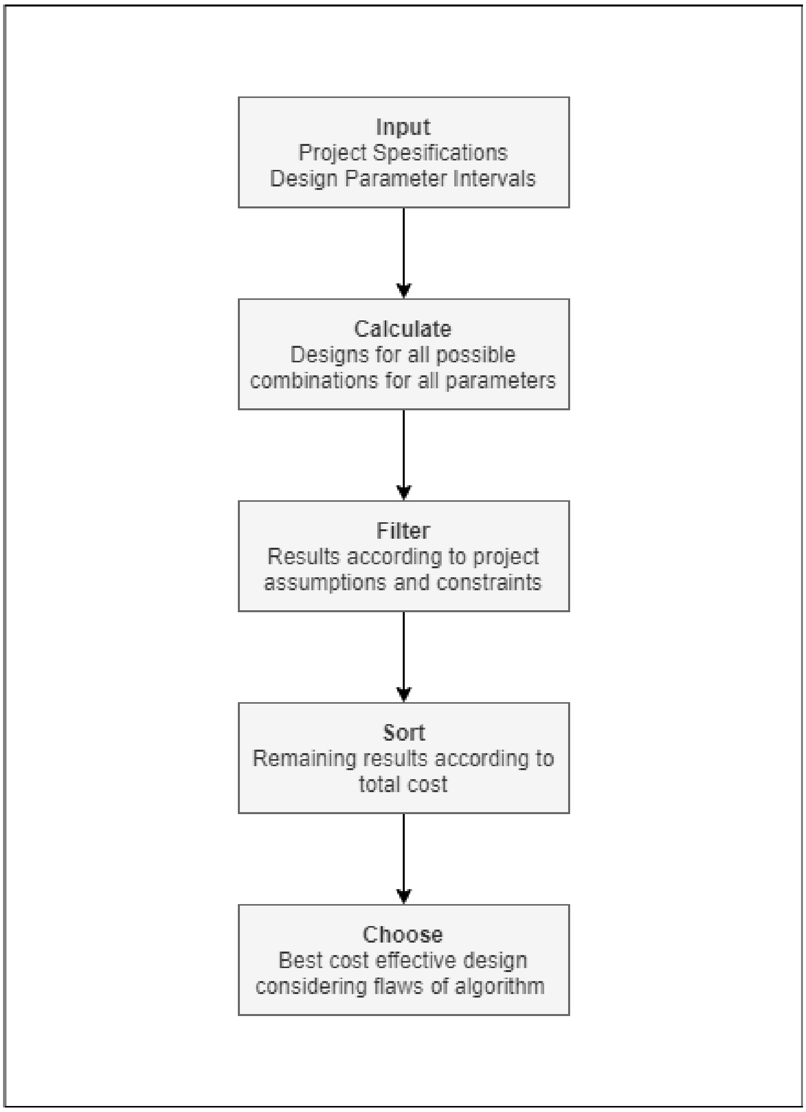


Figure 7 Simplified algorithm flow chart

2.2 Heat Exchanger Price Calculation

Price -related calculation methods are explained in the following subsections.

2.2.1 Fixed Cost Calculation

Three different fixed cost calculation methods were utilized for estimating a realistic value. In the following sub-sections, these methods are explained, sample calculation with the methods can be found in the Appendix. On top of the listed methods' results were multiplied with time index (CEPCI[5]) and location index[3].

2.2.1.1 G. Towler Chemical Engineering Design Book Calculation

In Chemical Engineering Design Book, Equation 7.9 and Table 7.2 were used for price estimation[3]. Found prices were well over the Turkish market; as a result, this correlation was not used.

2.2.1.2 Curve Fitting on Turkey (2020) Plate Heat Exchanger Prices

Different prices were quoted from a Turkish company for plate type heat exchanger with different plate sizes and numbers[7]. Total Area vs. Price was plotted, and linear curve fitting was applied to find a numerical relationship between total plate area and price. This method resulted in a really limited range for total plate area; as a result, it was not utilized in end calculations. The resulting curve fitting plot can be seen in Figure 8. Samples can be found as an excel file in the attachment.

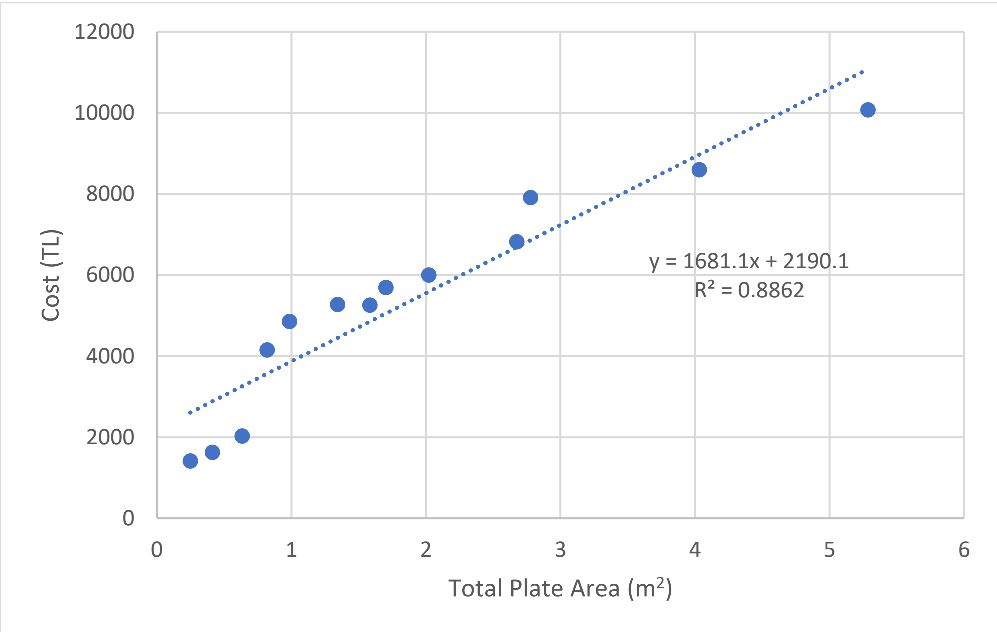


Figure 8 Total Plate Area vs. Cost for Plate Heat Exchangers, Turkey, 2020

2.2.1.3 K. D. Timmerhaus Plant Design and Economics Book Calculation

Following Figure 9, Figure 14-25 in Plant Design Book shows the different prices for different heat-transfer surface area[2]. This figure was sampled to find a linear relationship between area and purchase cost. Overall, the best estimation was made by this method. This method was utilized inside the calculations.

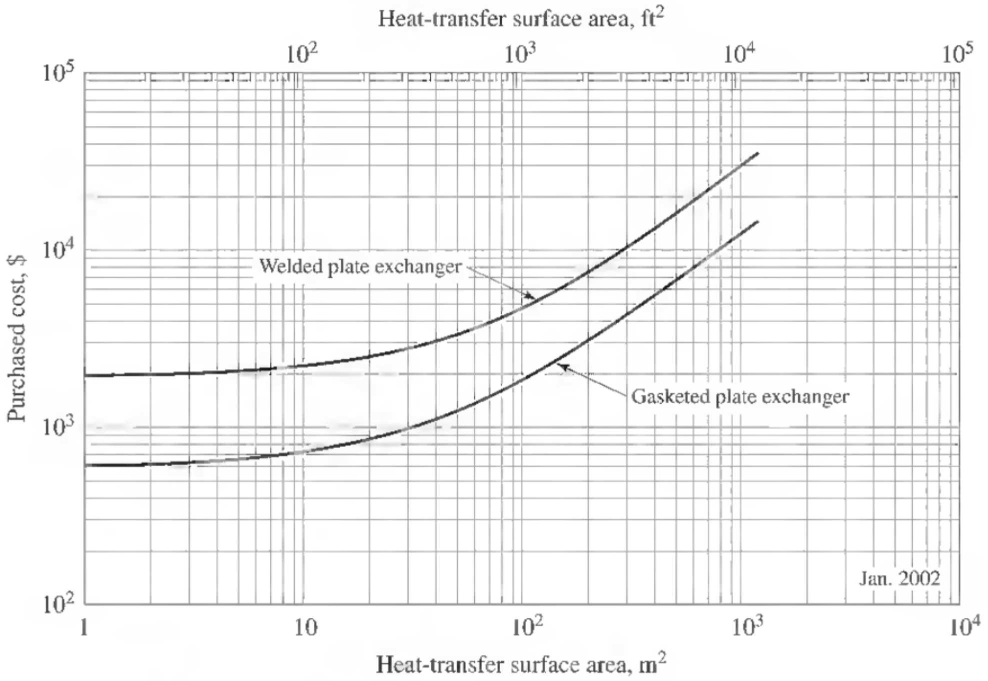


Figure 9 Purchase cost of gasketed and welded plate exchangers[2]

2.2.2 Operating Cost Calculation

For finding the operation cost, the work needed for pumping the fluid for corresponding pressure drops was calculated. For calculated work with known pump efficiencies, the total needed wattage was found. According to the specified project lifetime and electricity price, operation cost was calculated.

2.2.3 Maintenance Cost Calculation

Yearly maintenance fee was quoted for the chosen heat exchanger design as 1,500 TL and multiplied with total operation time for the overall cost of maintenance[7].

2.3 Calculation synchronization

All calculations were calculated by 2 people and the algorithm. Results were cross-checked for possible calculation, syntax, conversion errors. Verifying accuracy equation wise.

3 RESULTS

3.1 Non-Iterative Results

In the following sub-sections, noniterative results for the design are listed.

3.1.1 Plate Material

Due to the high chloride content of geothermal water and working pressure temperatures specifications of the project, stainless steel was chosen as plate material. Stainless steel also provides effective thermal conductivity and resistance to corrosion.

3.1.2 Gasket Material

In accordance with the working temperature specifications for the project, Ethylene-Propylene (EPDM) type rubber is chosen. It is suitable for working temperatures between -51°C and 149°C [13].

3.1.3 Plate Pattern

Chevron pattern type is used since it provides a much larger heat contact area than another type of pattern types[1].

3.1.4 Fouling Solution

The chemical method is preferred in this project. To avoid fouling problem on the heat exchanger equipment, hot fluid, geothermal water is treated with an inhibitor; after the treatment, fouling resistance is assumed to be the same with hard water or borehole water. With the treatment, fouling layer can be cleaned. While doing this treatment, adverse impact on the environment of this chemical is considered, according the to producer of the inhibitor product is harmless to the environment.

3.1.5 Flow arrangement

Single- pass, counterflow is utilized for both flows. Passes are made in parallel.

3.1.6 Enlargement factor

Enlargement factor is chosen as 1.17 independent of plate gap and chevron angle.

3.1.7 Plate Thickness

According to the literature data, it is determined as plate thickness has a range of 0.5 mm to 1.2 mm to obtain optimum performance on the plate heat exchanger [1].

3.1.8 Chevron Angle

Chevron angle is varying between 30° to 60° to obtain optimum thermal performance on the plate heat exchanger [1].

3.1.9 Number of Plates

Iteration can be done to determine the total number of plates from 3 to 700 plates, which are the limit values for optimum heat exchanger design [1]

3.1.10 Maintenance

The heat exchanger will be done in a one- year interval. Maintenance will consist of usage of nitric acid and broken, critical parts replacement. The yearly fee is quoted as 1,500 TL [7].

3.2 Plate Heat Exchanger Application

Algorithm was coded as a user-friendly Matlab application with GUI. Application can input project specification as discrete values, Figure 10, and design parameters as discrete values or discrete value intervals with chosen value count, Figure 11. After selection of project specification and design parameters algorithm designs all possible designs for given intervals.

All possible designs can be viewed as a labeled table and exported as excel file to application's location, Figure 12. Also prior to exportation can be filtered for heat duty or wanted property of the design.

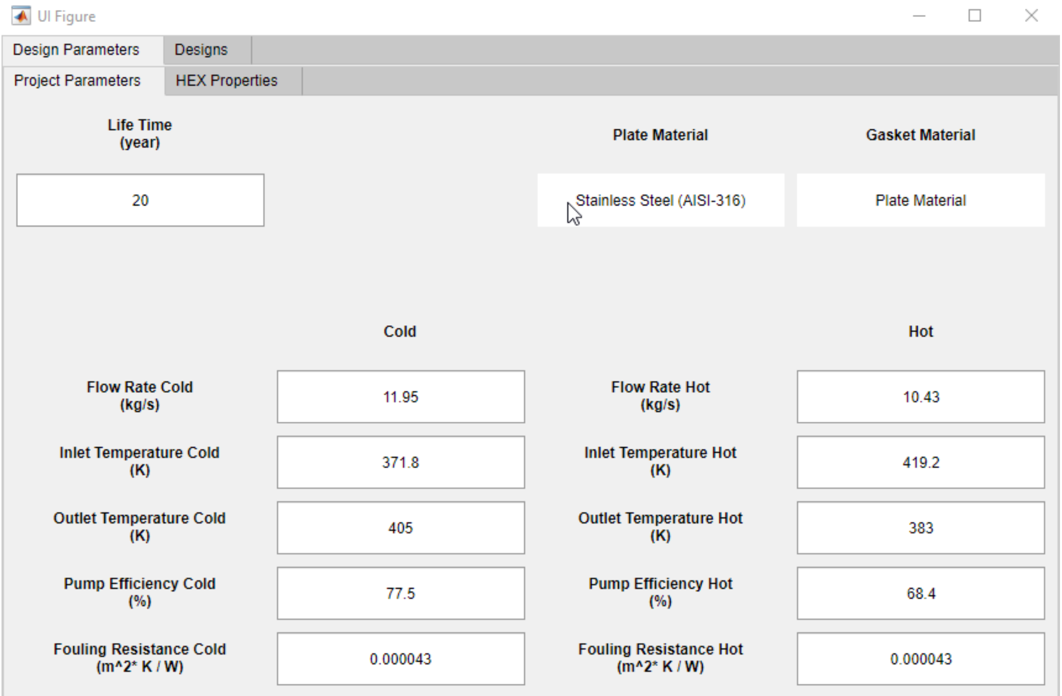


Figure 10 Application Project Spesification Input Tab

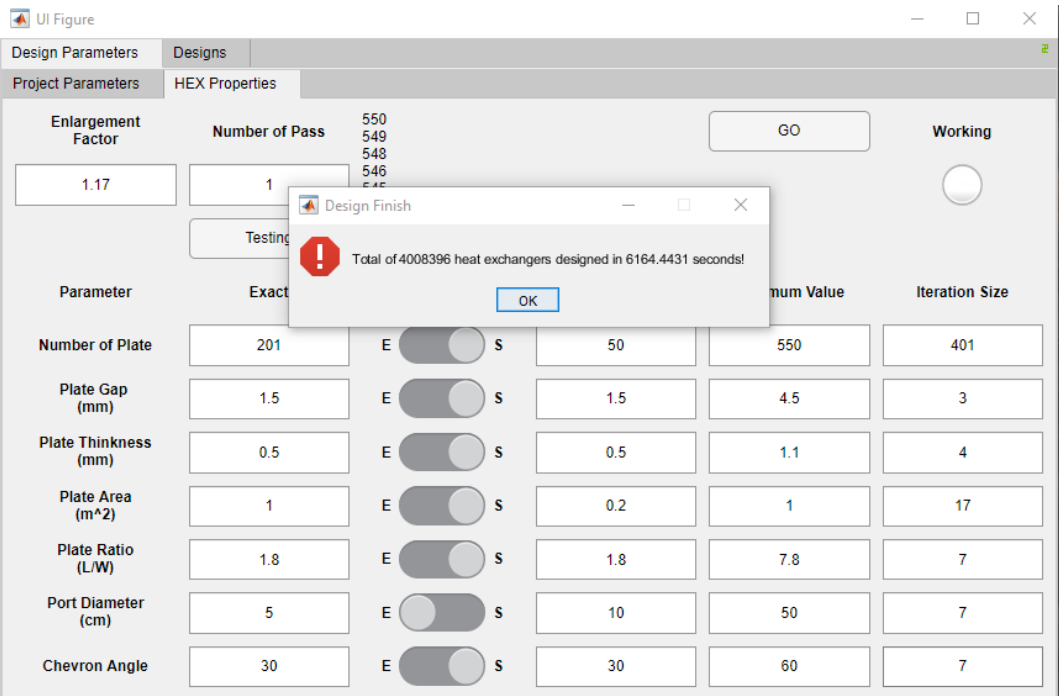


Figure 11 Design parameter input tab

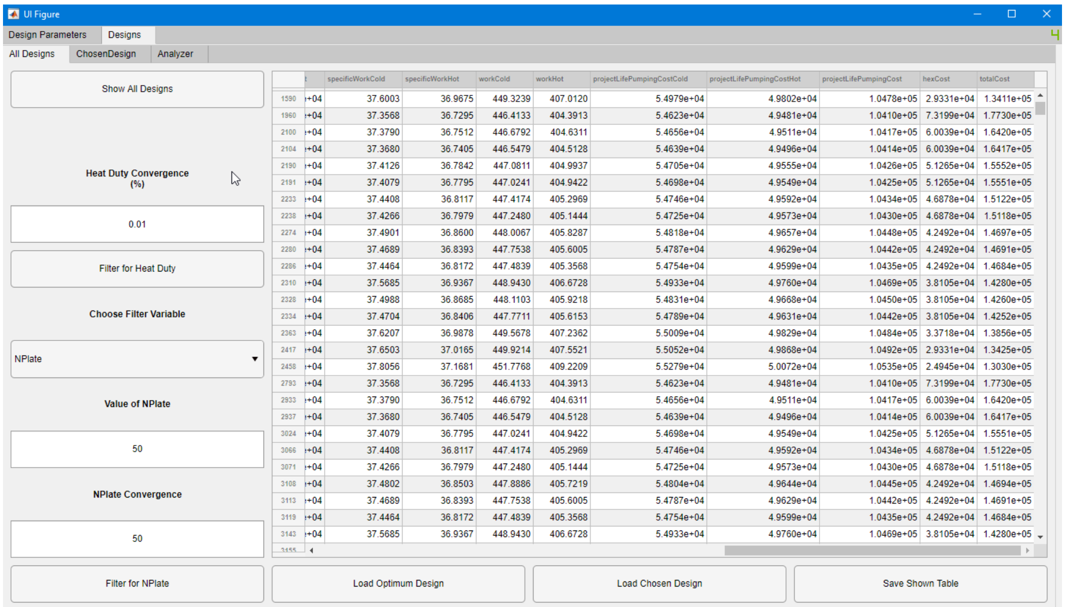


Figure 12 Created design viewing and saving tab

3.3 Results with iteration

In the following sub-sections, design results are listed. Due to memory limitations by computers, most comprehensive results include %1.5 error. Excel files for all following designs can be found in the attachment.

In creation of these results the, iteration interval and sizes indicated in Table 4 were used. The overall total of 4,008,396 heat exchanger was designed in 1 hour, 42 minutes, and

44 seconds with the mean heat exchangers design rate of 650 designs per second. A design is being calculated every 1.5 milliseconds.

Table 4 Iteration Interval and Size for Iterated Variables

Parameter	Minimum Value	Maximum Value	Iteration Size
Number of Plates	50	550	401
Plate Gap (mm)	1.5	4.5	3
Plate Thickness (mm)	0.5	1.1	4
Plate Area (m^2)	0.2	1	17
Plate Ratio (L/W)	1.8	7.8	7
Chevron Angle	30	60	7

3.3.1 Summary of Designs

In Table 5, summary of all designs can be found for heat duty error percentage of 1.5, 1, 0.1, 0.01. Higher error percentages were included in the table since results could not be embedded in excel format. This embedding limitation is caused by a high amount of memory demand by the application. A number of designs indicates a number of designs covered by the corresponding error percentage.

Table 5 Summary for designs filtered for different heat duty error percentage

Heat Duty Error Percentage	Number of Designs	Cost Type	Cost (₺)	
			Best	Worst
1.5	63293	Operating	107,895	2,574,283
		Fixed	18,765	10,472
		Total	126,660	2,584,754
1	42220	Operating	107,800	2,574,283
		Fixed	18,925	10,472
		Total	126,724	2,584,754
0.1	4221	Operating	107,620	2,574,283
		Fixed	19,245	10,472
		Total	126,865	2,584,754
0.01	436	Operating	107,316	2,092,658
		Fixed	19,845	10,536
		Total	127,162	2,103,194

3.3.2 Chosen Design

The design was chosen from %0.01 margin of error for heat duty, with consideration of flaws utilized by the algorithm. Specification sheet for the chosen design.

GASKETED PLATE HEAT EXCHANGER		Date :	12.01.2021

DATA OF FLUIDS

		Hot Fluid	Cold Fluid
Fluid		Geothermal Water	Municipal Water
Total fluid flow	kg/s	11.01	11.95
Inlet temperature	°C	146.2	98.8
Outlet temperature	ºC	110	132
Average temperature	ºC	128.1	115.4
Density	kg/m^3	936.2	946.6
Dynamic viscosity	$N.s/m^2$	$2.15*10^{-4}$	$2.41*10^{-4}$
Specific heat capacity	kJ/kg.K	4.26	4.24
Thermal conductivity	W/m.K	0.69	0.68
Heat duty	kW	1681	1681
Pressure loss from channels	kPa	2.22	2.60
Pressure loss from ports	kPa	23.51	27.39
Total pressure loss	kPa	25.72	29.99
Number of passes		1	1
Fouling coefficient	$W/m^2.K$	0.000043	0.000043

PROPERTIES OF HEAT EXCHANGER

Plate type		Stainless steel
Gasket type		EPDM
Flow type		Counter flow
Number of plates		64
Plate thickness	mm	0.5
Plate area	m^2	0.95
Plate length (L_p)	cm	163.1
Plate with (L_w)	cm	58.2
Plate gap	mm	4.5
Port diameter (D_p)	mm	50
Chevron angle (β)	°	60
Life time	years	20
Operation temprature limits	ºC	-45 - 155
Operation pressure limits	mPa	0.1-1.5
Fixed cost	₺	16828
Total maintanance cost	₺	30000
Pumping cost	₺	113883
Total cost	₺	160711

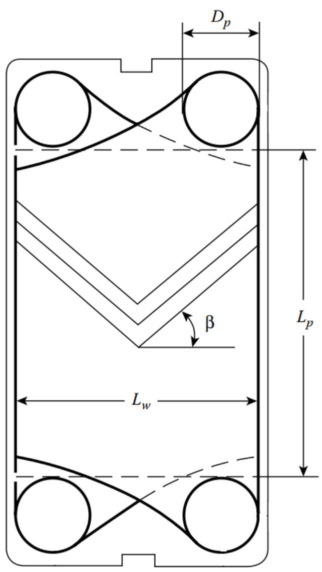


Figure 13 Specification sheet for chosen design

4 DISCUSSION

4.1 Pressure Drop

Pressure drop is one of the important result data for heat exchangers due to its effect on operating cost, highest cost for the overall design. This is due to the needed work being increased with increased pressure drop.

The pressure drop in the heat exchanger is positively related to the number of passes, plate width, plate length, and negatively related to port diameter, the plate gap, number of plates. As a result of these correlations chosen design expect to have minimal pass count, length, width, and maximum port diameter, and plate gap.

In the design results, it is observed that neither minimum area (length, width) or number of plates are chosen. This is due to heat duty filtering. With inclusion of filtering, it is hard to indicate an ideal value as “maximum”, “minimum” because of the interconnected nature of correlations that include plate area and the number of plates. These relations must be tested with the Ceteris Paribus method. However, it is uncertain that the result of findings by the usage of Ceteris Paribus can be used for real design since only design parameters are not the number of plates and plate area.

Chosen, the best design has maximum possible plate gap (0.0045 mm) is chosen, which was guessed earlier, this situation caused by increasing pressure drop consecutively increasing total operating costs with decreasing plate gap. The algorithm should be tested with a higher maximum value for the plate gap to conclude at better designs. However, width >> gap assumption should be considered when setting the maximum limit.

4.2 Correlation Constraints

Reynold’s number calculation was made using correlation from Kakaç’s book[1], for the case of per channel, the Reynolds number is higher than 1000. This assumption has been a limiting factor for us to see all possible results in heat exchanger design. However, the used correlation includes all turbulent flows that have a Reynolds number greater than 2300. As turbulent flows are generally used in heat exchanger design, a wide range of possible heat exchanger design outcomes are obtained from the heat exchanger design. Therefore, the use of this correlation is appropriate for finding the optimum design.

4.3 Effects of Viscosity Assumption

Dynamic viscosity evaluated at the bulk means temperature, μ_b, and dynamic viscosity evaluated at the wall temperature, μ_w, was assumed the same because of the small temperature difference. For this reason, It is used as $\mu_b/\mu_w \approx 1$ in the calculations. However, in the real case, the hot fluid bulk temperature is higher than the wall temperature, so the viscosity of bulk temperature is lower than the viscosity of wall temperature, $\mu_b/\mu_w < 1$. It negatively affects Nusselt numbers by equation 11.12 from Kakaç’s book and heat transfer convection by equation 11.16 from Kakaç’s book. Also, channel pressure drop would increase for hot fluid, as shown in equation 11.20 from Kakaç’s book[1]. For cold fluid, $\mu_b/\mu_w > 1$; Nusselt number and heat transfer convection would increase; channel pressure drop would decrease. Because conditions are opposite for cold and hot fluids, these differences could cancel each other out. Therefore, the results could not change much, as assumed. However, this equality symmetry could shift to any side with considerable difference between fluid flow rates.

4.4 Fouling Factor Effects

Minerals of the municipal and geothermal waters will cause the fouling, so the heat transfer is negatively affected due to the fouling. The gap between the plates will decrease when fouling occurs between the surface of plates. With the decreasing gap value, the velocity between plates would increase. As a result of this, the pressure drop in the plate heat exchanger increases due to the decreasing of the plate gap. However, in the used correlation, 11.26, which is taken from Kakaç's book[1], decreasing the gap distance is not considered. Thus, in the calculation of pressure drop, there might be an error due to fouling.

4.5 Blind Spots

In the following section blind spots for the design algorithm is discussed at length.

4.5.1 Fixed Cost Estimation

Even though fixed cost estimation was done with 3 different correlations, when compared to real cost values was found inaccurate. This is probably due to outdated location factors, a small interval for plate area interval. Fixed cost is critical for design selection since with increasing fixed cost, operation cost decreases (This relationship can be directly observed in results). An inaccuracy in fixed estimation essentially means inaccuracy in overall design selection. With these inaccuracies in fixed cost calculations, the results of this report can only be thought of as an indicator rather than an exact answer. Improvements over cost calculation methods are further discussed in the recommendations part. Overall, found fixed cost for project, 16,828 TL, was significantly lower than quoted cost for similar heat exchanger, 20,000 TL.

4.5.2 Enlargement Factor

The value of the enlargement factor is a function of the corrugation pitch and the corrugation gap or plate gap. Depending on these variables, the enlargement factor directly changes the Nusselt numbers and friction factors of the fluids in the heat exchanger. According to the literature, an average expansion factor of 1.17 is acceptable for a typical plate heat exchanger [1].Therefore, in our calculations, we assumed that the enlargement factor was 1.17. However, this assumption had a direct effect on our design as it directly affected the total heat transfer rate. Since the enlargement factor is considered constant, a specific corrugation pitch converges a corresponding plate gap value. As a result, corrugation pitches become a dependent variable, consecutively non optimizable.

4.5.3 Different Flow Arrangements

All designs were made for one pass heat exchangers, which is accurate for common heat exchanger designs: however, inaccurate for specific cases such as small temperature differences, high flow rates. Since project's case was matching with common cases, one pass selection is accurate, but the algorithm cannot be used for the evaluation of specific other cases.

4.5.4 Gasket, Material Selection

While doing cost correlation, the equation taken from the Design book considers stainless steel as a material type. Therefore, cost calculations cannot be used with other material types like titanium. If the equation considers other material types, prices would be different from stainless steel.

Gasket material type does not affect the cost estimation in current calculations, which is not problematic for cost optimization since gasket material cost is negligible compared to the overall cost.

4.6 Design Method Evaluation

The current design algorithm creates designs that would not be utilized in the final design selection. These "extra" designs slow down the overall calculation process. An alternative would be to center around exact solutions, which would lead to only designs that are a solution to the project specifications. In return, this approach lowers the total degree of freedom by keeping a calculated, dependent variable, heat duty constant. This approach clearly seems more elegant and easier to processing limitations.

However, fixing a dependent variable, especially a dependent variable that is one of the last variables in the calculation order, means that a drastic change in calculation correlations is necessary. Essentially, complicating relations, reversing cause, and effect. For example, making plate area a function of heat duty, chevron angle, etc. This process decreases overall stability due to being more prone to calculation, assumption errors.

Emerging correlations likely to be partial, non-linear equations that will need initial guess, iteration methods to be solved, lowering time per heat exchanger design.

4.7 Uniformly Distributed Heat Duty Phenomena

This phenomenon can be observed by investigating Table 5 and comparing filtered design result count to exact percentage of total designs. For example, for %1.5 with filtering found design count is 63,293, %1.5 of 4,008,396 is 60,126. This indicates a uniform distribution on heat duty domain. This is highly unexpected since independent variables are not chosen in basis of creating this kind of distribution. This phenomena's consistency can be investigated by taking different percentage heat duty sample and comparing with exact percentage of total designs.

5 CONCLUSIONS

Gasketed-type heat exchanger design was optimized for project specifications and independent design variables; the number of plates, plate gap, plate thickness, plate area, plate ratio, and chevron angle. Independent design variables were investigated with uniformly sampled, discrete samples with limited value intervals. Interval limitations, relations, and correlation were obtained from several sources[1]–[6]. For fixed capital cost estimation, three different correlations were used, two from established design books, and one was created by directly sampling the local market. All fixed cost estimation correlations found to be inconsistent with the real prices quoted from suppliers, indicating algorithms must be used with caution. The maintenance cost for the found design was quoted as 1,500 TL per year[7].

With intervals and discrete sample sizes indicated in the results section, a total of 4,008,396 heat exchangers were designed in 1 hour, 42 minutes, and 44 seconds at a rate of 650 designs per second or design per 15 milliseconds. Maximum %1.5 of the results were exportable due to memory limitations. Nonetheless, results are totally reproducible with the same intervals.

With filtering of results for %0.01 heat duty error, 436 designs were found. By sorting these designs for decreasing total cost and considering inadequate fixed cost correlations, the 63rd design, with row #3891028 was chosen. Specification related to the chosen design can be found in both results and attachments. The main properties for the design are stainless steel plates, EPDM gaskets, single pass, 64 plates, 0.95 m2 plate area, 60 chevron angle, fixed cost of 16,828 TL, the operation cost of 113,883 TL, the total maintenance cost of 30,000 TL, and total cost of 160,711 TL.

In addition to designing cost effective gasket type heat exchangers for the specific case. A user-friendly application with GUI was coded. The application can be used to design gasket type heat exchangers for future projects with similar properties to the project investigated in this report. Essentially, offering a general solution or general solution basis for gasket plate heat exchanger design.

6 RECOMMENDATIONS

6.1 Multi-Variable Fixed Cost Calculations

Until now, fixed cost is estimation is done on one variable, total plate area, which fails to embrace costs occurring due to the increasing number of plates and area of an individual plate. To illustrate, a heat exchanger with a plate area 1 m^2 individual plate area and 10 plates can have the same cost as a heat exchanger with a plate area 2 m^2 individual plate area and 5 plates. However, in reality, these prices diverge due to fabrication, installment, transport costs.

A multi-variable fixed cost calculation correlation can be found by sampling heat exchanger prices with 2 variable bases. Essentially, in 3 dimensions; plate area, number of plates, and cost. By formation of this relation, it is possible to have more accurate fixed cost estimations with the algorithm.

6.2 Enlargement Factor

The enlargement factor was considered as constant. The enlargement factor varies depending on the corrugation pitch and plate gap. Since the enlargement factor directly affects the heat transfer rate, the enlargement factor function can be found for Chevron type plates. By usage of this correlation, a more precise calculation on the enlargement factor can be made. As a result, the corrugation pitch can be an independent variable that can be optimized by adding the algorithm. By this addition, exact results can be obtained for the wanted corrugation pitch, consequently corresponding enlargement factor.

6.3 Maintenance

After obtaining a price for maintenance from a heat exchanger firm[7] gasket type plate heat exchanger firm, it was observed that the price was too high compared to the price of the heat exchanger. The firm uses nitric acid while cleaning the plates and nitric acid usage while cleaning the heat exchanger plates. This method is considered an expensive method due to used cleaning material. Maintenance cost might be decreased by quoting other firms that use other techniques for cleaning[9].

6.4 Location Factor in Cost Analysis

While doing cost analysis, the location factor, which has a value from the year 2002 was used. Instead of using this location factor, the current location factor could be searched. Overall, making fixed cost estimation more accurate. According to the current value of location factor, total costs might be much more expensive than 2002 since countries' economic path heavily diverged. As can be seen from exchange rates corresponding to 2002 and 2020[6].

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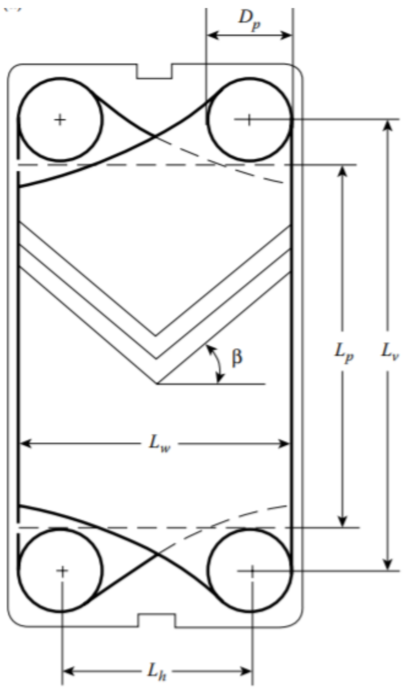
8 APPENDIX

Appendix A Sample Calculations

Plate Thickness ($L_{thickness}$)	0.5mm
Chevron Angle(β)	30°
Total Number of Plates N_t	201
Enlargement Factor (ϕ)	1.17
Number of pass (N_p)	1
Overall Heat Transfer Coeff (U)	-
Projected Area ($A_{pro,1}$)	1 m^2
Length/ Width (Ratio)	3.5
All port diameter (D_p)	300 mm
Plate gap (b, L_{gap})	1.9 mm
Mass flow rate of cold (m_c)	11.95 kg/s
Mass flow rate of hot (m_h)	10.01 kg/s



First, the mean temperature difference was calculated with known values;

$$\Delta T_1 = T_{h,in} - T_{c,out}$$

$$\Delta T_2 = T_{h,out} - T_{c,in}$$

$$T_{h,in} = 419.2\ K$$

$$T_{h,out} = 383.0\ K$$

$$T_{c,in} = 371.8\ K$$

$$T_{c,out} = 405.0\ K$$

$$\Delta T_1 = 14.2\ K$$

$$\Delta T_2 = 11.2\ K$$

Therefore,

$$\Delta T_{lm,cf} = \frac{\Delta T_1 - \Delta T_2}{ln\frac{\Delta T_1}{\Delta T_2}}$$

$$\Delta T_{lm,cf} = 12.64\ K$$

And, mean temperature for cold and hot fluids calculated as;

$$T_{m,c} = \frac{371.8\ K + 405\ K}{2}$$

$$T_{m,c} = 388.4\ K$$

$$T_{m,h} = \frac{419.2\ K + 383\ K}{2}$$

$$T_{m,h} = 401.1\ K$$

The effective number of plates (N_e) is,

$$N_e = N_t - 2$$

$$N_e = 201 - 2$$

$$N_e = 199$$

Effective Flow Length of the fluid flow path, L_{eff}, is between inlet ports and outlet ports and it is considered as the vertical port distance. Therefore,

$$L_{eff} = L_v$$

Vertical port distance can be found by adding the port diameter to the port distance.

$$L_v = L_p + D$$

The projected area approximation is done with multiplying port distance to the width distance

$$A_{pro,1} = L_p * L_w$$

The minimum length over width gives the ratio,

$$L_p = L_w * Ratio$$

Therefore, while combining these two equations the result is;

$$L_w = \sqrt{\frac{A_{pro,1}}{Ratio}}$$

$$L_w = \sqrt{\frac{1m^2}{3.5}}$$

$$L_w = 0.535m$$

$$L_p = 0.535m * 3.5$$

$$L_p = 1.87m$$

$$L_v = 1.87m + 0.3m$$

$$L_v = 2.17m$$

$$L_{eff} = 2.17m$$

Compress plate head length (Lc), between the head plates, can be calculated as,

$$L_c = N_t * (L_{gap} + L_{thickness})$$

$$L_c = 201 * (1.9\,mm + 0.5mm)$$

$$L_c = 482.4mm$$

Plate pitch or the corrugated plate's outside depth was calculated as adding to gap length to plate thickness,

$$p = L_{gap} + L_{thickness}$$

$$p = 1.9\,mm + 0.5mm$$

$$p = 2.4mm$$

One channel flow area (Ach) was calculated as using channel spacing, b, and width length,

$$A_{ch} = b * L_w$$

$$A_{ch} = 1.9mm * 535mm$$

$$A_{ch} = 0.00102m^2$$

The total projected area was calculated as,

$$A_{P,T} = A_{Pro,1} * N_e$$

$$A_{P,T} = 1m^2 * 199$$

$$A_{P,T} = 199\, m^2$$

The total effective area can be calculated by multiplying the total projected area with enlargement factor,

$$A_{T,E} = A_{P,T} * \phi$$

$$A_{T,E} = 199m^2 * 1.17$$

$$A_{T,E} = 232.8m^2$$

The single effective area is,

$$A_{1,E} = \frac{A_{T,E}}{N_e}$$

$$A_{1,E} = \frac{232.8m^2}{199}$$

$$A_{1,E} = 1.17\, m^2$$

The channel hydraulic/equivalent diameter was calculated with an assumption that is b<<L_W

$$D_h = \frac{2 * b}{\phi}$$

$$D_h = \frac{2 * 1.9mm}{1.17}$$

$$D_h = 3.25\ mm$$

The number of channel per pass is found from,

$$N_{cp} = \frac{N_t - 1}{2N_p}$$

$$N_{cp} = \frac{201 - 1}{2 * 1}$$

So, the number of channel per pass is,

$$N_{cp} = 100$$

The mass flow rate per channel hot fluid is,

$$\dot{m_{ch}} = \frac{\dot{m}_h}{N_{cp}}$$

$$\dot{m_{ch}} = \frac{10.01\ kg/s}{100}$$

$$\dot{m_{ch}} = 0.100\ kg/s$$

The mass flow rate per channel cold fluid is,

$$\dot{m_{cc}} = \frac{\dot{m}_c}{N_{cp}}$$

$$\dot{m_{cc}} = \frac{11.95\ kg/s}{100}$$

$$\dot{m}_{cc} = 0.120\ kg/s$$

The channel mass velocity for hot fluid is,

$$G_{ch} = \frac{\dot{m}_{ch}}{A_{ch}}$$

$$G_{ch} = \frac{0.100\ kg/s}{0.00102\ m^2}$$

$$G_{ch} = 98.04\ \frac{kg}{m^2 * s}$$

The channel mass velocity for cold fluid is,

$$G_{cc} = \frac{\dot{m}_{cc}}{A_{ch}}$$

$$G_{cc} = \frac{0.120\ kg/s}{0.00102\ m^2}$$

$$G_{cc} = 117.65 \frac{kg}{m^2 * s}$$

Constants taken by the Heat book, from table A.6

Viscosity of cold fluid is,

$$\mu_c = \mu_c(\,T_{m,c})$$

$\mu_c(388.4\ K) = 2.41 * 10^{-4}\ N * \frac{s}{m^2}$

Thermal conductivity of cold fluid is,

$$k_c = k_c(T_{m,c})$$

$$k_c(388.4\ K) = 0.685 \frac{W}{m * K}$$

Prandtl Number of cold fluid is,

$$Pr_c = Pr_c(T_{m,c})$$

$$Pr_c(388.4\ K) = 1.489$$

Density of cold fluid is,

$$\rho_c = \rho_c(T_{m,c})$$

$$\rho_c(388.4\ K) = 946.6\ kg/m^3$$

Specific heat for cold fluid is,

$$C_{p,c} = C_{p,c}(T_{m,c})$$

$$C_{p,c}(388.4K) = 4.237 kJ/kgK$$

Viscosity of hot fluid is,

$$\mu_h = \mu_h(\ T_{m,h})$$

$$\mu_h(\ 401.1\ K) = 2.15 * 10^{-4} N * \frac{s}{m^2}$$

Thermal conductivity of hot fluid is,

$$k_h = k_h(T_{m,h})$$

$$k_h(401.1\ K) = 0.688 \frac{W}{m * K}$$

Prandtl Number of hot fluid is,

$$Pr_h = Pr_h(T_{m,h})$$

$$Pr_h(401.1\ K) = 1.33$$

Density of hot fluid is,

$$\rho_h = \rho_h(T_{m,h})$$

$$\rho_h(401.1\ K) = 936.24\ kg/m^3$$

Specific heat for hot fluid is,

$$C_{p,h} = C_{p,h}(T_{m,h})$$

$$C_{p,h}(401.1K) = 4.258\ kJ/kg\ K$$

Reynolds for the hot fluid was calculated based on channel mass velocity, and the hydraulic diameter is,

$$Re_h = \frac{G_{ch} * D_h}{\mu_h}$$

$$Re_h = \frac{98.04\ \frac{kg}{m^2 s} * 3.25mm}{2.15 * 10^{-4}\ \ N\frac{s}{m^2}}$$

$$Re_h = 1488.03$$

Reynolds for the cold fluid was calculated same as hot fluid,

$$Re_c = \frac{G_{cc} * D_h}{\mu_c}$$

$$Re_c = \frac{117.65\frac{kg}{m^2 s} * 3.25mm}{2.41 * 10^{-4}\ \ N\frac{s}{m^2}}$$

$$Re_c = 1586.57$$

Since Re > 1000, Chevron Angle ; 30 ° ≤ β ≤ 60°, and enlargement factor is ; 1 ≤ ϕ ≤ 1.5

Nusselt number for hot and cold fluid was calculated from Equation 11.12 from Kakaç's book with an assumption $\mu_b = \mu_w$

Nusselt number fort the hot fluid is,

Where,

$$\beta = 30°\ (\ chevron\ angle)$$
$$\phi = 1.17 (enlargement\ factor)$$

$$Nu_h = [\ 0.2668 - 0.006967\beta + 7.244 * 10^{-5}\beta^2] * [\ 20.78 - 50.94\phi\ + 41.1\ \phi^2 - 10.51\phi^3] * Re_h^{\left[0.728+0.0543 sinsin\left\{\left(\frac{\pi\beta}{45}\right)+3.7\right\}\right]} Pr_h^{\frac{1}{3}} \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

$$Nu_h = [\ 0.2668 - 0.006967 * 30 + 7.244 * 10^{-5} * 30^2] * [\ 20.78 - 50.94 * 1.17\ + 41.1 *\ 1.17^2 - 10.51 * 1.17^3] * 1488.03^{\left[0.728+0.0543 sinsin\left\{\left(\frac{\pi*30}{45}\right)+3.7\right\}\right]} * 1.33^{\frac{1}{3}} * (1)^{0.14}$$

$$Nu_h = 13.95$$

The heat transfer coefficient for hot fluid is,

$$h_h = \frac{Nu_h * k_h}{D_h}$$

$$h_h = \frac{13.95 * \frac{0.688W}{mK}}{3.25mm}$$

$$h_h = 2954.1 \frac{W}{m^2K}$$

Nusselt number fort the cold fluid is,

$$Nu_c = [\ 0.2668 - 0.006967\beta + 7.244 * 10^{-5}\beta^2] * [\ 20.78 - 50.94\phi\ + 41.1\ \phi^2 - 10.51\phi^3] * Re_c^{\left[0.728+0.0543 sinsin\left\{\left(\frac{\pi\beta}{45}\right)+3.7\right\}\right]} Pr_c^{\frac{1}{3}} \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

$$Nu_c = [\ 0.2668 - 0.006967 * 30 + 7.244 * 10^{-5} * 30^2] * [\ 20.78 - 50.94 * 1.17\ + 41.1 *\ 1.17^2 - 10.51 * 1.17^3] * 1586.57^{\left[0.728+0.0543 sinsin\left\{\left(\frac{\pi*30}{45}\right)+3.7\right\}\right]} * 1.489^{\frac{1}{3}} * (1)^{0.14}$$

$$Nu_c = 15.17$$

The heat transfer coefficient for cold fluid is,

$$h_c = \frac{Nu_c * k_c}{D_h}$$

$$h_c = \frac{15.17 * \frac{0.685W}{mK}}{3.25mm}$$

$$h_c = 3202.23 \frac{W}{m^2K}$$

The clean overall heat transfer coefficient, (U_c) is,

$$U_c = \left(\frac{1}{h_c} + \frac{1}{h_h} + \frac{L_{thickness}}{K_{material}}\right)^{-1}$$

Where,

$K_{material}$ taken by the thermal conductivity Table 11.1 as Stainless Steel (316) from Kakaç's book as K=16.5 W/m^{2}K

$$U_c = \left(\frac{1}{3202.23 \frac{W}{m^2K}} + \frac{1}{2954.1 \frac{W}{m^2K}} + \frac{0.5mm}{16.5\ W/m^2K}\right)^{-1}$$

$$U_c = 1468.23 \frac{W}{m^2K}$$

Overall fouling heat transfer coefficient, (U_f) is,

$$U_f = \left(\frac{1}{U_c} + Fouling\ Factor\right)^{-1}$$

$$Fouling\ Factor\ Overall = Fouling\ factor\ of\ Hot + Fouling\ factor\ of\ Cold$$

Fouling factor values taken from Table 9.1 (L.Wang) as,

River, canal, borehole	0.000043 m^2K/W
Towns (hard) heating	0.000043 m^2K/W

Therefore,

$$Fouling\ Factor\ Overall = 0.000086\,\frac{m^2K}{W}$$

$$U_f = \left(\frac{1}{1468.23\ W/m^2K} + \frac{0.000086 m^2K}{W}\right)^{-1}$$

$$U_f = 1303.63\ W/m^2K$$

The corresponding cleanliness factor is,

$$CF = \frac{U_f}{U_c}$$

$$CF = \frac{1303.63\ \ W/m^2K}{1468.23\ \ W/m^2K}$$

$$CF = 0.88$$

The actual heat duties for clean and fouled surfaces are,

$$Q_c = U_c * A_{T,E} * \Delta T_{lm}$$

$$Q_f = U_f * A_{T,E} * \Delta T_{lm}$$

$$Q_c = 1468.23 \ \frac{W}{m^2K} * 232.8m * 12.64K$$

$$Q_c = 4320.40 \ kW$$

$$Q_f = 1303.63 \ \frac{W}{m^2K} * 232.8m * 12.64K$$

$$Q_f = 3834.20 \ kW$$

Pressure Drop Analysis

Channel pressure drop equation taken from equation 11.20 from Kakaç's book as,

$$\Delta p_c = 4 * f * \frac{L_{eff} * N_p}{D_h} \frac{G_c^2}{2\rho} \left(\frac{\mu_b}{\mu_w}\right)^{-0.17}$$

Friction factors for the hot fluid and cold fluid equations taken from equation 11.13 Kakaç's book,

Since Re > 1000, Chevron Angle ; 30 ° ≤ β ≤ 60°, and enlargement factor is ; 1 ≤ φ ≤ 1.5

with an assumption $\mu_b = \mu_w$,

$$\beta = 30° \, , chevron \ angle$$

$$\phi = 1.17 \, , enlargement \ factor$$

Friction factors for the hot fluid is,

$$f_h = [\, 2.917 - 0.1277\beta + 2.016 * 10^{-3}\beta^2] * [\, 5.474 - 19.02\phi + 18.93\,\phi^2 - 5.341\phi^3] * Re_h^{-\left[0.2+0.0577 sinsin\left\{\left(\frac{\pi\beta}{45}\right)\right\}+2.1\right]}$$

$$f_h = [\,2.917 - 0.1277 * 30 + 2.016 * 10^{-3} * 30^2] * [\,5.474 - 19.02 * 1.17\ + 18.93 *\ 1.17^2 - 5.341 * 1.17^3] * 1488.03^{-\left[0.2+0.0577 sinsin\left\{\left(\frac{\pi*30}{45}\right)\right\}+2.1\right]}$$

$$f_h = 0.1746$$

Friction factors for the cold fluid is,

$$f_c = [\,2.917 - 0.1277\beta + 2.016 * 10^{-3}\beta^2] * [\,5.474 - 19.02\phi\ + 18.93\ \phi^2 - 5.341\phi^3] * {Re_c}^{-\left[0.2+0.0577 sinsin\left\{\left(\frac{\pi\beta}{45}\right)\right\}+2.1\right]}$$

$$f_c = [\,2.917 - 0.1277 * 30 + 2.016 * 10^{-3} * 30^2] * [\,5.474 - 19.02 * 1.17\ + 18.93 *\ 1.17^2 - 5.341 * 1.17^3] * 1586.57^{-\left[0.2+0.0577 sinsin\left\{\left(\frac{\pi*30}{45}\right)\right\}+2.1\right]}$$

$$f_c = 0.1729$$

The frictional pressure drop for hot fluid is with an assumption $\mu_b = \mu_w$,

$$(\Delta p_c)_h = 4 * f_h * \frac{L_{eff} * N_p}{D_h} \frac{G_{ch}^2}{2\rho_h} \left(\frac{\mu_b}{\mu_w}\right)^{-0.17}$$

$$(\Delta p_c)_h = 4 * 0.1746 * \frac{2.17m * 1}{3.25\ mm} \frac{(\frac{98.04\ kg}{m^2 s})^2}{2 * \frac{936.24kg}{m^3}} * (1)^{-0.17}$$

$$(\Delta p_c)_h = 2422.30\ Pa$$

The frictional pressure drop for cold fluid is with an assumption $\mu_b = \mu_w$,

$$(\Delta p_c)_c = 4 * f_c * \frac{L_{eff} * N_p}{D_h} \frac{G_{cc}^2}{2\rho_c} \left(\frac{\mu_b}{\mu_w}\right)^{-0.17}$$

$$(\Delta p_c)_c = 4 * 0.1729 * \frac{2.17m * 1}{3.25\ mm} * \frac{\left(117.65 \frac{kg}{m^2 s}\right)^2}{2 * 946.6 kg/m^3} * (1)^{-0.17}$$

$$(\Delta p_c)_c = 3380.99\ Pa$$

Port pressure drop was calculated according to equation 11.22 from Kakaç,

$$\Delta p_p = 1.4 N_p * \frac{G_p^2}{2\rho}$$

Where G_p is the port mass velocity,

$$G_p = \frac{\dot{m}}{\frac{\pi D_p^2}{4}}$$

The total pressure drop is,

$$\Delta p_t = \Delta p_c + \Delta p_p$$

G_p for the hot fluid is,

$$G_{p,h} = \frac{\dot{m}_h}{\frac{\pi D_p^2}{4}}$$

$$G_{p,h} = \frac{10.0\dot{1}\ kg/s}{\frac{\pi * (300mm)^2}{4}}$$

$$G_{p,h} = 141.61 kg/m^2 s$$

G_p for the cold fluid is,

$$G_{p,c} = \frac{\dot{m}_c}{\frac{\pi D_p^2}{4}}$$

$$G_{p,c} = \frac{11.95\ kg/s}{\frac{\pi * (300mm)^2}{4}}$$

$$G_{p,c} = 169.06\ kg/m^2 s$$

Port pressure drop for hot fluid is,

$$\Delta p_{p,h} = 1.4N_p * \frac{G_{p,h}^2}{2\rho_h}$$

$$\Delta p_{p,h} = 1.4 * 1 * \frac{\left(\frac{141.61\ kg}{m^2 s}\right)^2}{2 * 936.24\ kg/m^3}$$

$$\Delta p_{p,h} = 14.99\ Pa$$

Port pressure drop for cold fluid is,

$$\Delta p_{p,c} = 1.4N_p * \frac{G_{p,c}^2}{2\rho_c}$$

$$\Delta p_{p,c} = 1.4 * 1 * \frac{\left(\frac{169.06kg}{m^2 s}\right)^2}{2 * 946.6kg/m^3}$$

$$\Delta p_{p,c} = 21.13\ Pa$$

The total pressure drop for hot fluid,

$$\Delta p_{t,h} = \Delta p_{c,h} + \Delta p_{p,h}$$

$$\Delta p_{t,h} = 2422.30\ \ Pa + 14.99\ Pa$$

$$\Delta p_{t,h} = 2437.29\ Pa$$

The total pressure drop for cold fluid,

$$\Delta p_{t,c} = \Delta p_{c,c} + \Delta p_{p,c}$$

$$\Delta p_{t,c} = 3380.99\ Pa + 21.13\ Pa$$

$$\Delta p_{t,c} = 3402.13\ Pa$$

Cost Analysis

In order to obtain cost analysis, specific work calculation is done as;

$$Specific\ Work, \widehat{W} = \frac{\Delta P_{total}}{\rho * \eta_{pump}}$$

Specific work for cold fluid,

$$\widehat{W}_{cold} = \frac{\Delta P_{total,cold}}{\rho_{cold} * \eta_{pump,cold}}$$

$$\widehat{W}_{cold} = \frac{3402.13\ \ Pa}{946.6\ kg/m^3 * 75.5}$$

$$\widehat{W}_{cold} = 4.64\frac{m^2}{s^2}$$

Therefore, cold fluid work is,

$$W_{cold} = \ \widehat{W}cold * \ \ \dot{m}_{\ c}$$

$$W_{cold} = \ 4.64\frac{m^2}{s^2} * \ \ 11.95\frac{kg}{s}$$

$$W_{cold} = 55.42\ kW$$

Specific work for hot fluid is,

$$\widehat{W}_{hot} = \frac{\Delta P_{total,hot}}{\rho_{hot} * \eta_{pump,hot}}$$

$$\widehat{W}_{hot} = \frac{2437.29\ \ Pa}{936.24\frac{kg}{m^3} * 68.4}$$

$$\widehat{W}_{hot} = 3.80\frac{m^2}{s^2}$$

Therefore, hot fluid work is,

$$W_{hot} = \widehat{W}_{hot} * \dot{m}_h$$

$$W_{hot} = \frac{3.80\ m^2}{s^2} * \frac{10.01\ kg}{s}$$

$$W_{hot} = 38.10\ kW$$

Project Lifetime Pumping Cost (PLPC) for cold fluid calculated as a result of multiplying work of cold fluid with the lifetime of the project and electricity cost which is found from EPDK.

$$PLPC_{cold} = W_{cold} * t_{project} * C_{electricity}$$

$$t_{project} = 20\ years = 175200\ hour$$

$$PLPC_{cold} = 0.275\ kW * 20\ years * 0.70 \frac{TL}{kWh}$$

$$PLPC_{cold} = 33{,}726.0\ TL$$

Project Lifetime Pumping Cost for hot fluid calculated same as $PLPC_{cold}$,

$$PLPC_{hot} = W_{hot} * t_{project} * C_{electricity}$$

$$PLPC_{hot} = 0.209\ kW * 20\ years * 0.70 \frac{TL}{kWh}$$

$$PLPC_{hot} = 25{,}631.8\ TL$$

Therefore, Project Lifetime Pumping Cost Total is,

$$PLPC_{total} = PLPC_{hot} + PLPC_{cold}$$

$$PLPC_{total} = 25{,}631.8\ TL + 33{,}726.0\ TL$$

$$PLPC_{total} = 59{,}357.8\ TL$$

Heat Exchanger Price Index

Maintenance Cost

From Ekin Endüstriyel price,
1500TL per year is offered for yearly maintenance,
Therefore,

$$C_{maintenance} = Maintenance\ Cost\ per\ year\ *\ Lifetime$$

$$C_{maintenance} = 1500\ TL * 20$$

$$C_{maintenance} = 30{,}000\ TL$$

According to Design Book,

Heat Exchanger Price USA in 2010 is,

$$C_{2010} = a + b * s^n$$

From Design Book where,

a = 1600

b= 210

n= 0.95

s = total projected area, $A_{P,T}$

$$C_{2010} = a + b * s^n$$

$$C_{2010} = 1600 + 210 * (199m^2)^{0.95}$$

Heat exchanger price in 2010 is,

$$C_{2010} = \$\ 33{,}672.3$$

CEPCI Index

CEPCI 2010 is found from design book for USA, and for CEPCI 2020, the values from 2019 are used by assuming no change between 2019 and 2020 values[5],

$$C_{2020} = C_{2010} * \frac{CEPCI\ 2020}{CEPCI\ 2010}$$

$$C_{2020} = \$\,33{,}672.3 * \frac{607.5}{532.9}$$

Heat exchanger price in 2020 is,

$$C_{2020} = \$\,38{,}386.04$$

Location Factor

To obtain price values in Turkey, location factor was used as,

$$C_{TR} = C_{USA} * LF$$

Location Factor, LF, from design book for 2003 is 1.07

$$C_{TR,2020} = \$\,38{,}386.04 * 1.07$$

$$C_{TR,2020} = \$\,41{,}073.07$$

To change prices from \$ to ₺ exchange rate was used as,

$$C_{TL,2020} = C_{\$,2020} * Exchange\ Rate$$

$$C_{TL,2020} = \$\,41{,}073.07 * 7.38\frac{TL}{\$}$$

$$C_{TL,2020} = 303{,}119.2\ TL$$

Total Cost

Total cost was found from adding pumping cost to heat exchanger cost,

$$C_{TOTAL} = C_{Pumping} + C_{Heat\ Exchanger} + C_{maintenance}$$

$$C_{TOTAL} = 11{,}442.34\ TL + 303{,}119.2\ TL + 30{,}000.00\ TL$$

Total cost is,

$$C_{TOTAL} = 344{,}561.5\ TL$$

According to Timber House Book, 2002

According to equation, where x is the total plate area (Timber house book,2002)

$$y = 13.261 * x + 610.67$$

Our total projected plate area is 199m^2

Heat Exchanger Price USA in 2002 is,

$$y = 13.261 * 199m^{2} + 610.67$$

$$C_{2002} = \$\ 3249.6$$

CEPCI Index is 1.534 (from Timber house book). Then,

$$C_{2020} = C_{2002} * \frac{CEPCI\ 2020}{CEPCI\ 2002}$$

$$C_{2020} = \$\ 3249.6 * 1.534$$

Cost of plate heat exchanger in 2020 is,

$$C_{2020} = \$\ 4984.9$$

Location Factor,

$$C_{TR} = C_{USA} * LF$$

$$C_{TR} = \$\ 4984.9 * 1.07$$

$$C_{TR} = \$\ 5333.8$$

Exchange Rate,

$$C_{TL,2020} = C_{\$,2020} * Exchange\ Rate$$

$$C_{TL,2020} = \$\ 5333.8 * 7.38$$

$$C_{TL,2020} = 39{,}363.7\ TL$$

Total Cost

Total cost was found from adding pumping cost to heat exchanger cost,

$$C_{TOTAL} = C_{Pumping} + C_{Heat\ Exchanger} + C_{maintenance}$$

$$C_{TOTAL} = 11{,}442.34\ TL + 39{,}257.61\ TL + 30{,}000.00\ TL$$

Total cost is,

$$C_{TOTAL} = 80{,}699.96\ TL$$

According to Dogus's Method,

Heat Exchanger price in 2020 is according to (dogusun method) , below equation is obtained by v prices of 2020 heat exchangers.

Total plate area is 199m^2

$$y = 1681.1 * x + 2190.1$$

Heat Exchanger Price Turkey in 2020 is,

$$y = 1681.1 * 199m^2 + 2190.1$$

$$C_{2020} = 336{,}729.0\ TL$$

Since prices are obtained in 2020, there are no CEPCI Index, location factor and exchange rate. Then,

Cost of plate heat exchanger in 2020 is,

$$C_{2020} = 336{,}729.0\ TL$$

Total Cost

Total cost was found from adding pumping cost to heat exchanger cost,

$$C_{TOTAL} = C_{Pumping} + C_{Heat\ Exchanger} + C_{maintenance}$$

$$C_{TOTAL} = 11{,}442.34\ TL + 336{,}729.0\ TL + 30{,}000.00\ TL$$

Total cost is,

$$C_{TOTAL} = 378{,}171.34\ TL$$

Appendix B Application Codes

B.1 combinationalArrayLooper.m

```
function resultArrayOut = combinationalArrayLooper(arrays,
theFunction)

persistent loopTracker;
if isempty(loopTracker)
   loopTracker = 0;
end

persistent resultArray;
if isempty(resultArray)
    resultArray = {};
end

persistent functionInputRelay;
if isempty(functionInputRelay)
    functionInputRelay = {};
end

persistent arraysPersistent;
if isempty(arraysPersistent)
    arraysPersistent = arrays;
    arraysPersistent{end + 1} = [];
end

persistent functionPersistent;
if isempty(functionPersistent)
    functionPersistent = theFunction;
end


loopTracker = loopTracker + 1;

if length(arraysPersistent) == loopTracker
    resultArray{end + 1} = functionPersistent(functionInputRelay);
end

for currentArrayIndex = 1:length(arraysPersistent{loopTracker})
    functionInputRelay{loopTracker} =
arraysPersistent{loopTracker}(currentArrayIndex);
    combinationalArrayLooper();
end

loopTracker = loopTracker - 1;

if loopTracker == 0
   resultArrayOut = resultArray;
   resultArray = {};
   functionInputRelay = {};
```

```
    arraysPersistent = {};
    functionPersistent = {};
end
```

B.2 KF.m (Constants and functions)

```
classdef KF
    % Constants and formulas are determined in this class file

    properties (Constant)
        IPValues =
struct("heatCapacity",[4217,4211,4198,4189,4184,4181,4179,4178,4178,
4179,4180,4182,4184,4186,4188,4191,4195,4199,4203,4209,4214,4217,422
0,4226,4232,4239,4256,4278,4302,4331],...

"density",[1000,1000,1000,1000,999,998,997.010000000000,995.02000000
0000,993.050000000000,991.080000000000,989.120000000000,987.17000000
0000,984.250000000000,982.320000000000,979.430000000000,976.56000000
0000,973.710000000000,970.870000000000,967.120000000000,963.39000000
0000,960.610000000000,957.850000000000,956.940000000000,953.29000000
0000,949.670000000000,945.180000000000,937.210000000000,928.51000000
0000,919.120000000000,909.920000000000],...

"viscosity",[0.00175000000000000,0.00175000000000000,0.0014220000000
0000,0.00122500000000000,0.00108000000000000,0.000959000000000000,0.
000855000000000000,0.000769000000000000,0.000695000000000000,0.00063
1000000000000,0.000577000000000000,0.000528000000000000,0.0004890000
00000000,0.000453000000000000,0.000420000000000000,0.000389000000000
000,0.000365000000000000,0.000343000000000000,0.000324000000000000,0
.000306000000000000,0.000289000000000000,0.000279000000000000,0.0002
74000000000000,0.000260000000000000,0.000248000000000000,0.000237000
000000000,0.000217000000000000,0.000200000000000000,0.00018500000000
0000,0.000173000000000000],...

"thermalConductivity",[0.569000000000000,0.574000000000000,0.5820000
00000000,0.590000000000000,0.598000000000000,0.606000000000000,0.613
000000000000,0.620000000000000,0.628000000000000,0.634000000000000,0
.640000000000000,0.645000000000000,0.650000000000000,0.6560000000000
00,0.660000000000000,0.664000000000000,0.668000000000000,0.671000000
000000,0.674000000000000,0.677000000000000,0.679000000000000,0.68000
0000000000,0.681000000000000,0.683000000000000,0.685000000000000,0.6
86000000000000,0.688000000000000,0.688000000000000,0.688000000000000
,0.685000000000000],...

"prandtlNumber",[12.9900000000000,12.2200000000000,10.2600000000000,
8.81000000000000,7.56000000000000,6.62000000000000,5.83000000000000,
5.20000000000000,4.62000000000000,4.16000000000000,3.77000000000000,
3.42000000000000,3.15000000000000,2.88000000000000,2.66000000000000,
2.45000000000000,2.29000000000000,2.14000000000000,2.02000000000000,
1.91000000000000,1.80000000000000,1.76000000000000,1.70000000000000,
1.61000000000000,1.53000000000000,1.47000000000000,1.34000000000000,
1.24000000000000,1.16000000000000,1.09000000000000],...
```

```
"temperature",[273.150000000000,275,280,285,290,295,300,305,310,315,
320,325,330,335,340,345,350,355,360,365,370,373.150000000000,375,380
,385,390,400,410,420,430])
        stainlessSteel = struct("thermalConductivity",16.5);

        priceData = 
struct("CEPCI",struct("CEPCI2010",532.9,"CEPCI2020",607.5,"CEPCI2002
",396,"CEPCI2020_2010",1.14,"CEPCI2020_2002",1.534090909)...

,"locationFactor",struct("USA",1,"Turkey",1.07,"Turkey_USA",1.07)...
            ,"electricityPrice",0.000000194...
            ,"Dollar2TL",7.38);
    end

    methods (Static)
        function value = waterValues(valueType, temperature)

            yValuesAll = KF.IPValues;
            temperatures = yValuesAll.temperature;

            switch valueType
                case {"heatCapacity", "hc","spesificHeat","sh","cp"}
                    yValues = yValuesAll.heatCapacity;
                case {"density", "d"}
                    yValues = yValuesAll.density;
                case {"viscosity", "v"}
                    yValues = yValuesAll.viscosity;
                case {"thermalConductivity", "tc"}
                    yValues = yValuesAll.thermalConductivity;
                case {"prandtlNumber", "pn"}
                    yValues = yValuesAll.prandtlNumber;
                case {"temperature", "t"}
                    yValues = yValuesAll.temperature;
            end

            value = interp1(temperatures, yValues, temperature);
        end

        function [price] = plateArea2Price2002(plateArea)
           price = 13.216 * plateArea + 610.67;
        end


        function [tableR] = objectArray2Table(objArray)

            firstObj = objArray{1};
            objProperties = convertCharsToStrings( properties(
firstObj ) );
            rowSize = length(objArray);
            % Add + 1 for indexing???
            columnSize = length(objProperties);
            resultMatrix = zeros([rowSize,columnSize],"double");
```

```
            for row = 1:rowSize
                obj = objArray{row};
                objValues = transpose(cellfun(@(name) obj.(name),
objProperties));
                resultMatrix(row,:) = objValues;
            end

            tableR = array2table(resultMatrix);

            tableR.Properties.VariableNames = objProperties;
            tableR.Properties.RowNames =
string(linspace(1,rowSize,rowSize));
        end

        function [dateTimeStr] = getDateTimeStrWOSpace()
            dt = datestr(datetime);
            dateTimeStr = regexprep(regexprep(dt, ' ', '-'),':','-
');
        end

        function filteredTable = filterTable(...

tableUnfiltered,variableName,wantedValue,rangePercentage)
            condition = @(value) wantedValue*(1-rangePercentage/100)
>= value |...
                value >= wantedValue*(1+rangePercentage/100);
            values = tableUnfiltered.(variableName);

            logicalArray = arrayfun(condition,values);

            tableUnfiltered(logicalArray,:) = [];

            filteredTable = tableUnfiltered;
        end


    end
end
```

B.3 plateHEX.m (Class)

```
classdef plateHEX < handle
    %UNTITLED Summary of this class goes here
    %   Detailed explanation goes here
    %% Initial Properties
    properties
        flowRateCold % kg/s
        flowRateHot % kg/s
        TColdIn % K
        TColdOut % K
```

```
    THotIn % K
    THotOut % K

    % Plate properties
    NPlate
    plateGap
    plateThickness
    plateArea
    plateRatio
    diameterPort
    enlargementFactor
    NPass
    chevronAngle
    foilingFactorCold
    foilingFactorHot

    lifeTime
    efficiencyCold
    efficiencyHot
end
%% Calculated Properties
properties
    heatDuty % j/s - W
    TAvgCold
    TAvgHot
    TDifferenceCold
    TDifferenceHot
    LMTD % Log mean temperature

    NEPlate
    compressPlateHeadLength
    platePitch
    oneChannelFlowArea
    plateWidth % Total
    plateLength % Under ports
    plateLengthFromPortCenter
    plateAreaTotal
    plateAreaEffectiveTotal
    plateAreaEffective
    channelHydraulicDiameter
    NChannelsPerPass

    flowColdPC % per Channel
    flowHotPC % per Channel
    massVelocityColdPC
    massVelocityHotPC
    visocityCold
    visocityHot
    reynoldsColdPC
    reynoldsHotPC
    nusseltNumberCold
    nusseltNumberHot
    frictionFactorCold
    frictionFactorHot
```

```
        heatTransferCoefCold
        heatTransferCoefHot
        foilingFactor
        overallHeatTransferCoef
        overallHeatTransferCoefWithFoiling
        cleanlinessFactor
        heatDutyCalculated
        heatDutyCalculatedWithFoiling
%         safetyFactor

        pressureLossChannelCold
        pressureLossChannelHot
        portMassVelocityCold
        portMassVelocityHot
        pressureLossPortCold
        pressureLossPortHot
        pressureLossTotalCold
        pressureLossTotalHot

        specificWorkCold
        specificWorkHot
        workCold
        workHot
        projectLifePumpingCostCold
        projectLifePumpingCostHot
        projectLifePumpingCost
        hexCost
        totalCost




    end
    %% Construtor, calculator functions
    methods
        function self = plateHEX2(flowRateCold,flowRateHot,...
                TColdIn,TColdOut,THotIn,THotOut,...

NPlate,plateGap,plateThickness,plateArea,plateRatio,...
                diameterPort,enlargementFactor, NPass, chevronAngle,
foilingFactorCold, foilingFactorHot,...
                lifeTime,efficiencyCold,efficiencyHot)

            self.flowRateCold = flowRateCold;
            self.flowRateHot = flowRateHot;
            self.TColdIn = TColdIn;
            self.TColdOut = TColdOut;
            self.THotIn = THotIn;
            self.THotOut = THotOut;

            self.NPlate = NPlate;
            self.plateGap = plateGap/1000;
            self.plateThickness = plateThickness/1000;
            self.plateArea = plateArea;
```

```
            self.plateRatio = plateRatio;
            self.diameterPort = diameterPort/100;
            self.enlargementFactor = enlargementFactor;
            self.NPass = NPass;
            self.chevronAngle = chevronAngle;
            self.foilingFactorCold = foilingFactorCold;
            self.foilingFactorHot = foilingFactorHot;

            self.lifeTime = lifeTime * 365 * 24 * 60 * 60;
            self.efficiencyCold = efficiencyCold/100;
            self.efficiencyHot = efficiencyHot/100;

            self.calculator();
        end

        function self = plateHEX(theArray)

            self.flowRateCold = theArray{1};
            self.flowRateHot = theArray{2};
            self.TColdIn = theArray{3};
            self.TColdOut = theArray{4};
            self.THotIn = theArray{5};
            self.THotOut = theArray{6};

            self.NPlate = theArray{7};
            self.plateGap = theArray{8}/1000;
            self.plateThickness = theArray{9}/1000;
            self.plateArea = theArray{10};
            self.plateRatio = theArray{11};
            self.diameterPort = theArray{12}/100;
            self.enlargementFactor = theArray{13};
            self.NPass = theArray{14};
            self.chevronAngle = theArray{15};
            self.foilingFactorCold = theArray{16};
            self.foilingFactorHot = theArray{17};

            self.lifeTime = theArray{18} * 365 * 24 * 60 * 60;
            self.efficiencyCold = theArray{19}/100;
            self.efficiencyHot = theArray{20}/100;

            self.calculator();
        end
        function calculator(self)
            self.TemperatureCalculations();
            self.HeatDuty();
            self.physicalPlateCalculations();
            self.flowRelatedCalculation();
            self.pressureLossCalculation();
            self.costCalculation();
        end
    end
    %%
    methods
        function TemperatureCalculations(self)
```

```
            self.TDifferenceCold = abs(self.TColdOut -
self.TColdIn);
            self.TDifferenceHot = abs(self.THotOut - self.THotIn);

            self.TAvgCold = (self.TColdOut + self.TColdIn) / 2;
            self.TAvgHot = (self.THotOut + self.THotIn) / 2;

            deltaT1 = self.THotIn - self.TColdOut;
            deltaT2 = self.THotOut - self.TColdIn;
            self.LMTD = (deltaT2 - deltaT1) / log(deltaT2 /
deltaT1);
        end
        function HeatDuty(self)
            self.heatDuty = self.flowRateCold * self.TDifferenceCold
* KF.waterValues("cp",self.TAvgCold);
        end
        function physicalPlateCalculations(self)

            self.NEPlate = self.NPlate - 2;

            self.compressPlateHeadLength = self.NPlate * (
self.plateGap + self.plateThickness);

            self.platePitch = self.plateGap + self.plateThickness;

            % Plate with length and width calculation
            self.plateWidth = sqrt(self.plateArea /
self.plateRatio);
            self.plateLength = self.plateWidth * self.plateRatio;

            self.oneChannelFlowArea = self.plateGap *
self.plateWidth;

            self.plateLengthFromPortCenter = self.plateLength +
self.diameterPort;

            self.plateAreaTotal = self.plateArea * self.NEPlate;

            %%%%
            % Calculate enlargement maybe???????
            %%%%
            self.plateAreaEffectiveTotal = self.plateAreaTotal *
self.enlargementFactor;

            self.plateAreaEffective = self.plateAreaEffectiveTotal /
self.NEPlate;

            self.channelHydraulicDiameter = 2 * self.plateGap /
self.enlargementFactor;

            self.NChannelsPerPass = (self.NPlate - 1)/(2 *
self.NPass);
```

```
        end
        function flowRelatedCalculation(self)
            self.flowColdPC = self.flowRateCold /
self.NChannelsPerPass;
            self.flowHotPC = self.flowRateHot /
self.NChannelsPerPass;

            self.massVelocityColdPC = self.flowColdPC /
self.oneChannelFlowArea;
            self.massVelocityHotPC = self.flowHotPC /
self.oneChannelFlowArea;

            self.visocityCold = KF.waterValues("v",self.TAvgCold);
            self.visocityHot = KF.waterValues("v",self.TAvgHot);

            self.reynoldsColdPC = self.massVelocityColdPC *
self.channelHydraulicDiameter / self.visocityCold;
            self.reynoldsHotPC = self.massVelocityHotPC *
self.channelHydraulicDiameter / self.visocityHot;

            self.nusseltNumberFrictionFactorCalculation();

            self.heatTransferCoefCold = self.nusseltNumberCold *
KF.waterValues("tc",self.TAvgCold) / self.channelHydraulicDiameter;
            self.heatTransferCoefHot = self.nusseltNumberHot *
KF.waterValues("tc",self.TAvgHot) / self.channelHydraulicDiameter;

            % Add material selection maybe?
            self.foilingFactor = self.foilingFactorCold +
self.foilingFactorHot;

            self.overallHeatTransferCoef = (1 /
self.heatTransferCoefCold + ...
                1 / self.heatTransferCoefHot + self.plateThickness /
KF.stainlessSteel.thermalConductivity)^-1;
            self.overallHeatTransferCoefWithFoiling = (1 /
self.overallHeatTransferCoef + self.foilingFactor)^-1;

            self.cleanlinessFactor =
self.overallHeatTransferCoefWithFoiling...
                / self.overallHeatTransferCoef;

            self.heatDutyCalculated = self.overallHeatTransferCoef *
self.plateAreaEffectiveTotal * self.LMTD;
            self.heatDutyCalculatedWithFoiling =
self.overallHeatTransferCoefWithFoiling *
self.plateAreaEffectiveTotal * self.LMTD;

%             self.safetyFactor =
self.heatDutyCalculatedWithFoiling...
%                 /self.heatDutyCalculated;
```

```
        end
        function pressureLossCalculation(self)

            % Losses in channels
            f = self.frictionFactorCold;
            g = self.massVelocityColdPC;
            d = KF.waterValues("d",self.TAvgCold);

            self.pressureLossChannelCold = 4 * f * ...
                self.plateLengthFromPortCenter * self.NPass /
self.channelHydraulicDiameter ...
                * g^2 / (2 * d);

            f = self.frictionFactorHot;
            g = self.massVelocityHotPC;
            d = KF.waterValues("d",self.TAvgHot);

            self.pressureLossChannelHot = 4 * f * ...
                self.plateLengthFromPortCenter * self.NPass /
self.channelHydraulicDiameter ...
                * g^2 / (2 * d);

            % Losses in ports
            self.portMassVelocityCold = self.flowRateCold / (pi *
(self.diameterPort)^2 / 4);
            self.portMassVelocityHot = self.flowRateHot / (pi *
(self.diameterPort)^2 / 4);

            self.pressureLossPortCold  = 1.4 * self.NPass * ...
                self.portMassVelocityCold^2 / (2 *
KF.waterValues("d",self.TAvgCold));
            self.pressureLossPortHot  = 1.4 * self.NPass * ...
                self.portMassVelocityHot^2 / (2 *
KF.waterValues("d",self.TAvgHot));

            % Losses total
            self.pressureLossTotalCold =
self.pressureLossChannelCold + self.pressureLossPortCold;
            self.pressureLossTotalHot = self.pressureLossChannelHot
+ self.pressureLossPortHot;

        end
        function costCalculation(self)
            % Operating Cost
            self.specificWorkCold =  self.pressureLossTotalCold /
...
                KF.waterValues("d",self.TAvgCold) /
self.efficiencyCold;
            self.specificWorkHot =  self.pressureLossTotalHot / ...
                KF.waterValues("d",self.TAvgHot) /
self.efficiencyHot;

            self.workCold = self.specificWorkCold *
self.flowRateCold;
```

```
            self.workHot = self.specificWorkHot * self.flowRateHot;

            self.projectLifePumpingCostCold = self.workCold *
self.lifeTime * KF.priceData.electricityPrice;
            self.projectLifePumpingCostHot = self.workHot *
self.lifeTime * KF.priceData.electricityPrice;

            self.projectLifePumpingCost =
self.projectLifePumpingCostCold...
                + self.projectLifePumpingCostHot;

            % Fixed Cost
%             a = 1600;
%             b = 210;
%             n = 0.95;
%
%             purchasePrice2010USA = a + b *
(self.plateAreaTotal)^n;

            purchasePrice2002USA =
KF.plateArea2Price2002(self.plateAreaTotal);
            purchasePrice2020USA = purchasePrice2002USA *
KF.priceData.CEPCI.CEPCI2020_2002;
            purchasePrice2020Turkey = purchasePrice2020USA *
KF.priceData.locationFactor.Turkey_USA;
            purchasePrice2020TurkeyTL = purchasePrice2020Turkey *
KF.priceData.Dollar2TL;

            self.hexCost = purchasePrice2020TurkeyTL;

            % Total Cost
            self.totalCost = self.hexCost +
self.projectLifePumpingCost;
        end
        function nusseltNumberFrictionFactorCalculation(self)
            % For cold
            c = self.chevronAngle;
            r = self.reynoldsColdPC;
            e = self.enlargementFactor;
            p = KF.waterValues("pn", self.TAvgCold);

            self.nusseltNumberCold = (0.2668 - 0.006967 * c + 7.244
* 10^-5 * c^2) * ...
                (20.78 - 50.94 * e + 41.1 * e^2 - 10.51 * e^3) * ...
                r^(0.728 + 0.0543 * sin((pi * c / 45 + 3.7))) *
p^(1/3);

            self.frictionFactorCold = (2.917 - 0.1277 * c + 2.016 *
10^-3 * c^2)*...
                (5.474 - 19.02 * e + 18.93 * e^2 - 5.341 * e^3)*...
                r^(-(0.2 + 0.0577 * sin(pi * c / 45 + 2.1)));

            % For hot
            r = self.reynoldsHotPC;
```

```
            p = KF.waterValues("pn", self.TAvgHot);

            self.nusseltNumberHot = (0.2668 - 0.006967 * c + 7.244 *
10^-5 * c^2) * ...
                (20.78 - 50.94 * e + 41.1 * e^2 - 10.51 * e^3) * ...
                r^(0.728 + 0.0543 * sin((pi * c / 45) + 3.7)) *
p^(1/3);

            self.frictionFactorHot = (2.917 - 0.1277 * c + 2.016 *
10^-3 * c^2)*...
                (5.474 - 19.02 * e + 18.93 * e^2 - 5.341 * e^3)*...
                r^(-(0.2 + 0.0577 * sin((pi * c / 45) + 2.1)));
        end
    end
end
```

B.4 HEXDesignerApp.mlapp (Application GUI)

```
classdef HEXDesignerApp < matlab.apps.AppBase

    % Properties that correspond to app components
    properties (Access = public)
        UIFigure                        matlab.ui.Figure
        TabGroup                        matlab.ui.container.TabGroup
        DesignParametersTab             matlab.ui.container.Tab
        TabGroup3                       matlab.ui.container.TabGroup
        ProjectParametersTab            matlab.ui.container.Tab
        GridLayout_2                    matlab.ui.container.GridLayout
        ColdLabel                       matlab.ui.control.Label
        HotLabel                        matlab.ui.control.Label
        FlowRateHotkgsEditFieldLabel    matlab.ui.control.Label
        FlowRateHotkgsEditField         matlab.ui.control.NumericEditField
        InletTemperatureHotKEditFieldLabel  matlab.ui.control.Label
        InletTemperatureHotKEditField   matlab.ui.control.NumericEditField
        OutletTemperatureHotKEditFieldLabel  matlab.ui.control.Label
        OutletTemperatureHotKEditField  matlab.ui.control.NumericEditField
        PumpEfficiencyHotEditFieldLabel  matlab.ui.control.Label
        PumpEfficiencyHotEditField      matlab.ui.control.NumericEditField
        FlowRateColdkgsEditFieldLabel   matlab.ui.control.Label
        FlowRateColdkgsEditField        matlab.ui.control.NumericEditField
        InletTemperatureColdKEditFieldLabel  matlab.ui.control.Label
        InletTemperatureColdKEditField  matlab.ui.control.NumericEditField
        OutletTemperatureColdKEditFieldLabel  matlab.ui.control.Label
        OutletTemperatureColdKEditField  matlab.ui.control.NumericEditField
        PumpEfficiencyColdEditFieldLabel  matlab.ui.control.Label
        PumpEfficiencyColdEditField     matlab.ui.control.NumericEditField
        LifeTimeyearEditFieldLabel      matlab.ui.control.Label
        LifeTimeyearEditField           matlab.ui.control.NumericEditField
```

```
PlateMaterialLabel                   matlab.ui.control.Label
GasketMaterialLabel                  matlab.ui.control.Label
StainlessSteelAISI316Label           matlab.ui.control.Label
PlateMaterialLabel_3                 matlab.ui.control.Label
FoulingResistanceColdm2KWEditFieldLabel  matlab.ui.control.Label
FoulingResistanceColdm2KWEditField  matlab.ui.control.NumericEditField
FoulingResistanceHotm2KWEditFieldLabel  matlab.ui.control.Label
FoulingResistanceHotm2KWEditField  matlab.ui.control.NumericEditField
HEXPropertiesTab                     matlab.ui.container.Tab
GridLayout                           matlab.ui.container.GridLayout
MinimumValueLabel                    matlab.ui.control.Label
MaximumValueLabel                    matlab.ui.control.Label
IterationSizeLabel                   matlab.ui.control.Label
ExactLabel                           matlab.ui.control.Label
ParameterLabel                       matlab.ui.control.Label
PlateThinknessmmLabel                matlab.ui.control.Label
PlateAream2Label                     matlab.ui.control.Label
PlateRatioLWLabel                    matlab.ui.control.Label
PortDiametercmLabel                  matlab.ui.control.Label
NumberofPlateLabel                   matlab.ui.control.Label
PlateGapmmLabel                      matlab.ui.control.Label
ChevronAngleLabel                    matlab.ui.control.Label
numberOfPlateEx                      matlab.ui.control.NumericEditField
numberOfPlateMin                     matlab.ui.control.NumericEditField
numberOfPlateMax                     matlab.ui.control.NumericEditField
numberOfPlateStep                    matlab.ui.control.NumericEditField
plateGapEx                           matlab.ui.control.NumericEditField
plateGapMin                          matlab.ui.control.NumericEditField
plateGapMax                          matlab.ui.control.NumericEditField
plateGapStep                         matlab.ui.control.NumericEditField
plateThicknessMax                    matlab.ui.control.NumericEditField
plateThicknessMin                    matlab.ui.control.NumericEditField
plateThicknessStep                   matlab.ui.control.NumericEditField
plateThicknessEx                     matlab.ui.control.NumericEditField
plateAreaMin                         matlab.ui.control.NumericEditField
plateAreaMax                         matlab.ui.control.NumericEditField
plateAreaStep                        matlab.ui.control.NumericEditField
plateRatioEx                         matlab.ui.control.NumericEditField
plateAreaEx                          matlab.ui.control.NumericEditField
portDiameterEx                       matlab.ui.control.NumericEditField
plateRatioStep                       matlab.ui.control.NumericEditField
plateRatioMax                        matlab.ui.control.NumericEditField
plateRatioMin                        matlab.ui.control.NumericEditField
chevronEx                            matlab.ui.control.NumericEditField
portDiameterMin                      matlab.ui.control.NumericEditField
chevronMax                           matlab.ui.control.NumericEditField
portDiameterStep                     matlab.ui.control.NumericEditField
chevronStep                          matlab.ui.control.NumericEditField
chevronMin                           matlab.ui.control.NumericEditField
portDiameterMax                      matlab.ui.control.NumericEditField
ExactStepLabel                       matlab.ui.control.Label
Switch                               matlab.ui.control.Switch
```

```
        TestingButton                  matlab.ui.control.Button
        TestingLabel                   matlab.ui.control.Label
        GOButton                       matlab.ui.control.Button
        Switch_2                       matlab.ui.control.Switch
        Switch_3                       matlab.ui.control.Switch
        Switch_4                       matlab.ui.control.Switch
        Switch_5                       matlab.ui.control.Switch
        Switch_6                       matlab.ui.control.Switch
        Switch_7                       matlab.ui.control.Switch
        EnlargementFactorEditFieldLabel  matlab.ui.control.Label
        EnlargementFactorEditField     matlab.ui.control.NumericEditField
        NumberofPassEditFieldLabel     matlab.ui.control.Label
        NumberofPassEditField          matlab.ui.control.NumericEditField
        WorkingLampLabel               matlab.ui.control.Label
        WorkingLamp                    matlab.ui.control.Lamp
        DesignsTab                     matlab.ui.container.Tab
        TabGroup2                      matlab.ui.container.TabGroup
        AllDesignsTab                  matlab.ui.container.Tab
        GridLayout2                    matlab.ui.container.GridLayout
        LoadChosenDesignButton         matlab.ui.control.Button
        resultHEXsTable                matlab.ui.control.Table
        HeatDutyConvergenceEditFieldLabel  matlab.ui.control.Label
        HeatDutyConvergenceEditField   matlab.ui.control.NumericEditField
        FilterforHeatDutyButton        matlab.ui.control.Button
        ShowAllDesignsButton           matlab.ui.control.Button
        LoadOptimumDesignButton        matlab.ui.control.Button
        SaveShownTableButton           matlab.ui.control.Button
        ValueConvergenceEditFieldLabel matlab.ui.control.Label
        ValueConvergenceEditField      matlab.ui.control.NumericEditField
        ChooseFilterVariableDropDownLabel  matlab.ui.control.Label
        ChooseFilterVariableDropDown   matlab.ui.control.DropDown
        FilterforButton                matlab.ui.control.Button
        ValueforEditFieldLabel         matlab.ui.control.Label
        ValueforEditField              matlab.ui.control.NumericEditField
        ChosenDesignTab_2              matlab.ui.container.Tab
        chosenDesignTable              matlab.ui.control.Table
        AnalyzerTab                    matlab.ui.container.Tab
        GridLayout3                    matlab.ui.container.GridLayout
        UIAxes                         matlab.ui.control.UIAxes
        GraphDimensionSwitchLabel      matlab.ui.control.Label
        GraphDimensionSwitch           matlab.ui.control.ToggleSwitch
        FirstDimensionDropDownLabel    matlab.ui.control.Label
        FirstDimensionDropDown         matlab.ui.control.DropDown
        SecondDimensionDropDownLabel   matlab.ui.control.Label
        SecondDimensionDropDown        matlab.ui.control.DropDown
        ThirdDimensionDropDownLabel    matlab.ui.control.Label
        ThirdDimensionDropDown         matlab.ui.control.DropDown
    end


    properties (Access = private)
        chosenHEXDesign plateHEX % Description
```

```
        hexTableMain table % Description
        hexArray % Description
        hexTableShown table % Description
    end

    methods (Access = public)

        function populateIndividualDesignResults(app)

            HEXObject = app.chosenHEXDesign;
            HEXProperties = properties(HEXObject);
            HEXProperties = convertCharsToStrings(HEXProperties);
            Values = cellfun(@(name) HEXObject.(name), HEXProperties);


            propertyTable = table(HEXProperties,Values);
            propertyTable.Properties.RowNames = HEXProperties;

            app.chosenDesignTable.Data = propertyTable;
        end

    end

    methods (Access = private)

        function fillResultTable(app)
            app.resultHEXsTable.Data = app.hexTableShown;
            app.resultHEXsTable.ColumnName
=app.hexTableShown.Properties.VariableNames;
            app.resultHEXsTable.RowName =
app.hexTableShown.Properties.RowNames;
        end

        function populateFilterVariableList(app)
            app.ChooseFilterVariableDropDown.Items =
app.hexTableShown.Properties.VariableNames;
            app.ChooseFilterVariableDropDown.ItemsData =
app.hexTableShown.Properties.VariableNames;
        end

        function AnalyzerStartGraph(app)
            if (app.GraphDimensionSwitch == "2D")

            elseif (app.GraphDimensionSwitch == "3D")

            end
        end
    end



    % Callbacks that handle component events
    methods (Access = private)
```

```
        % Button pushed function: TestingButton
        function TestingButtonPushed(app, event)
            app.TestingLabel.Text = app.Switch.Value;
        end


        % Button pushed function: GOButton
        function GOButtonPushed(app, event)
            app.WorkingLamp.Color = [0.39,0.83,0.07];
            drawnow();
            %
            if app.Switch.Value == "E"
                NPlate = app.numberOfPlateEx.Value;
            else
                NPoints = (app.numberOfPlateMax.Value -
app.numberOfPlateMin.Value) / app.numberOfPlateStep.Value;
                NPoints = app.numberOfPlateStep.Value;
                NPlate = round(linspace(app.numberOfPlateMax.Value,
app.numberOfPlateMin.Value, NPoints));
            end
            %
            if app.Switch_2.Value == "E"
                plateGap = app.plateGapEx.Value;
            else
                NPoints = (app.plateGapMax.Value - app.plateGapMin.Value) /
app.plateGapStep.Value;
                NPoints = app.plateGapStep.Value;
                plateGap = linspace(app.plateGapMax.Value,
app.plateGapMin.Value, NPoints);
            end
            %
            if app.Switch_3.Value == "E"
                plateThickness = app.plateThicknessEx.Value;
            else
                NPoints = (app.plateThicknessMax.Value -
app.plateThicknessMin.Value) / app.plateThicknessStep.Value;
                NPoints = app.plateThicknessStep.Value;
                plateThickness = linspace(app.plateThicknessMax.Value,
app.plateThicknessMin.Value, NPoints);
            end
            %
            if app.Switch_4.Value == "E"
                plateArea = app.plateAreaEx.Value;
            else
                NPoints = (app.plateAreaMax.Value - app.plateAreaMin.Value) /
app.plateAreaStep.Value;
                NPoints = app.plateAreaStep.Value;
                plateArea = linspace(app.plateAreaMax.Value,
app.plateAreaMin.Value, NPoints);
            end
            %
```

```
            if app.Switch_5.Value == "E"
                plateRatio = app.plateRatioEx.Value;
            else
                NPoints = (app.plateRatioMax.Value - app.plateRatioMin.Value)
/ app.plateRatioStep.Value;
                NPoints = app.plateRatioStep.Value;
                plateRatio = linspace(app.plateRatioMax.Value,
app.plateRatioMin.Value, NPoints);
            end
            %
            if app.Switch_6.Value == "E"
                diameterPort  = app.portDiameterEx.Value;
            else
                NPoints = (app.portDiameterMax.Value -
app.portDiameterMin.Value) / app.portDiameterStep.Value;
                NPoints = app.portDiameterStep.Value;
                diameterPort = linspace(app.portDiameterMax.Value,
app.portDiameterMin.Value, NPoints);
            end
            %
            if app.Switch_7.Value == "E"
                chevronAngle = app.chevronEx.Value;
            else
                NPoints = (app.chevronMax.Value - app.chevronMin.Value) /
app.chevronStep.Value;
                NPoints = app.chevronStep.Value;
                chevronAngle = linspace(app.chevronMax.Value,
app.chevronMin.Value, NPoints);
            end
            %
            flowRateCold = app.FlowRateColdkgsEditField.Value;
            flowRateHot = app.FlowRateHotkgsEditField.Value;
            TColdIn = app.InletTemperatureColdKEditField.Value;
            TColdOut = app.OutletTemperatureColdKEditField.Value;
            THotIn = app.InletTemperatureHotKEditField.Value;
            THotOut = app.OutletTemperatureHotKEditField.Value;

            enlargementFactor = app.EnlargementFactorEditField.Value;
            NPass = app.NumberofPassEditField.Value;

            foilingFactorCold = app.FoulingResistanceColdm2KWEditField.Value;
            foilingFactorHot = app.FoulingResistanceHotm2KWEditField.Value;

            lifeTime = app.LifeTimeyearEditField.Value;
            efficiencyCold = app.PumpEfficiencyColdEditField.Value;
            efficiencyHot = app.PumpEfficiencyHotEditField.Value;


            parameterArrays = {flowRateCold,flowRateHot,...
                TColdIn,TColdOut,THotIn,THotOut,...
                NPlate,plateGap,plateThickness,plateArea,plateRatio,...
```

```
                diameterPort,enlargementFactor, NPass, chevronAngle, 
foilingFactorCold, foilingFactorHot,...
                lifeTime,efficiencyCold,efficiencyHot};
            tic


            app.hexArray = combinationalArrayLooper(parameterArrays, 
@plateHEX);
            app.hexTableMain = KF.objectArray2Table(app.hexArray);
            aaa = app.hexArray;

            app.TestingLabel.Text = string(NPlate);
            app.WorkingLamp.Color = [1.00,1.00,1.00];
            errordlg(append("Total of ",string(length(app.hexArray))," heat 
exchangers designed in ",string(toc)," seconds!"),"Design Finish")
        end


        % Button pushed function: LoadChosenDesignButton
        function LoadChosenDesignButtonPushed(app, event)

            app.populateIndividualDesignResults();
        end


        % Button pushed function: ShowAllDesignsButton
        function ShowAllDesignsButtonPushed(app, event)
            app.hexTableShown = app.hexTableMain;
            app.fillResultTable();
            app.populateFilterVariableList();
        end


        % Button pushed function: SaveShownTableButton
        function SaveShownTableButtonPushed(app, event)
            filename = append("All_Hex_Designs-
",append(KF.getDateTimeStrWOSpace,".xls"));
            writetable(app.hexTableShown, ...
                filename);
        end


        % Value changed function: ChooseFilterVariableDropDown
        function ChooseFilterVariableDropDownValueChanged(app, event)
            variable = app.ChooseFilterVariableDropDown.Value;
            app.FilterforButton.Text = append("Filter for ",variable);
            app.ValueConvergenceEditFieldLabel.Text = append(variable," 
Convergence");
            app.ValueforEditFieldLabel.Text = append("Value of ",variable)


        end
```

```
        % Button pushed function: FilterforHeatDutyButton
        function FilterforHeatDutyButtonPushed(app, event)
            wantedHeatDutyConvergence =
app.HeatDutyConvergenceEditField.Value;
            app.hexTableShown = KF.filterTable(app.hexTableShown,
"heatDutyCalculatedWithFoiling" ...
                ,app.hexTableMain.heatDuty(1),wantedHeatDutyConvergence);
            app.fillResultTable();
        end


        % Button pushed function: FilterforButton
        function FilterforButtonPushed(app, event)
            wantedVariableConvergence = app.ValueConvergenceEditField.Value;
            variable = app.ChooseFilterVariableDropDown.Value;
            app.hexTableShown = KF.filterTable(app.hexTableShown, variable ...
                ,app.ValueforEditField.Value,wantedVariableConvergence);
            app.fillResultTable();
        end


        % Selection change function: TabGroup2
        function TabGroup2SelectionChanged(app, event)


            if "Analyzer" == app.TabGroup2.SelectedTab.Title;



                items = app.hexTableMain.Properties.Variables;

                app.FirstDimensionDropDown.Items = items;
                app.FirstDimensionDropDown.ItemsData = items;

                app.SecondDimensionDropDown.Items =  items;
                app.SecondDimensionDropDown.ItemsData = items;

                app.ThirdDimensionDropDown.Items = items;
                app.ThirdDimensionDropDown.ItemsData = items;

                app.AnalyzerStartGraph();
            end
        end


        % Value changed function: GraphDimensionSwitch
        function GraphDimensionSwitchValueChanged(app, event)
            if  "2D" == app.GraphDimensionSwitch.Value;
                app.FirstDimensionDropDown.Visible = false;
            else
                app.FirstDimensionDropDown.Visible = true;
            end
            app.AnalyzerStartGraph();
```

```
        end
    end

    % Component initialization
    methods (Access = private)

        % Create UIFigure and components
        function createComponents(app)

            % Create UIFigure and hide until all components are created
            app.UIFigure = uifigure('Visible', 'off');
            app.UIFigure.Position = [100 100 857 537];
            app.UIFigure.Name = 'UI Figure';

            % Create TabGroup
            app.TabGroup = uitabgroup(app.UIFigure);
            app.TabGroup.Position = [1 1 857 537];

            % Create DesignParametersTab
            app.DesignParametersTab = uitab(app.TabGroup);
            app.DesignParametersTab.Title = 'Design Parameters';

            % Create TabGroup3
            app.TabGroup3 = uitabgroup(app.DesignParametersTab);
            app.TabGroup3.Position = [1 0 855 512];

            % Create ProjectParametersTab
            app.ProjectParametersTab = uitab(app.TabGroup3);
            app.ProjectParametersTab.Title = 'Project Parameters';

            % Create GridLayout_2
            app.GridLayout_2 = uigridlayout(app.ProjectParametersTab);
            app.GridLayout_2.ColumnWidth = {'1x', '1x', '1x', '1x'};
            app.GridLayout_2.RowHeight = {'1x', '1x', '1x', '1x', '1x', '1x',
'1x', '1x', '1x'};

            % Create ColdLabel
            app.ColdLabel = uilabel(app.GridLayout_2);
            app.ColdLabel.HorizontalAlignment = 'center';
            app.ColdLabel.FontWeight = 'bold';
            app.ColdLabel.Layout.Row = 4;
            app.ColdLabel.Layout.Column = 2;
            app.ColdLabel.Text = 'Cold';
```

```
            % Create HotLabel
            app.HotLabel = uilabel(app.GridLayout_2);
            app.HotLabel.HorizontalAlignment = 'center';
            app.HotLabel.FontWeight = 'bold';
            app.HotLabel.Layout.Row = 4;
            app.HotLabel.Layout.Column = 4;
            app.HotLabel.Text = 'Hot';


            % Create FlowRateHotkgsEditFieldLabel
            app.FlowRateHotkgsEditFieldLabel = uilabel(app.GridLayout_2);
            app.FlowRateHotkgsEditFieldLabel.HorizontalAlignment = 'center';
            app.FlowRateHotkgsEditFieldLabel.FontWeight = 'bold';
            app.FlowRateHotkgsEditFieldLabel.Layout.Row = 5;
            app.FlowRateHotkgsEditFieldLabel.Layout.Column = 3;
            app.FlowRateHotkgsEditFieldLabel.Text = {'Flow Rate Hot';
'(kg/s)'};


            % Create FlowRateHotkgsEditField
            app.FlowRateHotkgsEditField = uieditfield(app.GridLayout_2,
'numeric');
            app.FlowRateHotkgsEditField.HorizontalAlignment = 'center';
            app.FlowRateHotkgsEditField.Layout.Row = 5;
            app.FlowRateHotkgsEditField.Layout.Column = 4;
            app.FlowRateHotkgsEditField.Value = 10.43;


            % Create InletTemperatureHotKEditFieldLabel
            app.InletTemperatureHotKEditFieldLabel =
uilabel(app.GridLayout_2);
            app.InletTemperatureHotKEditFieldLabel.HorizontalAlignment =
'center';
            app.InletTemperatureHotKEditFieldLabel.FontWeight = 'bold';
            app.InletTemperatureHotKEditFieldLabel.Layout.Row = 6;
            app.InletTemperatureHotKEditFieldLabel.Layout.Column = 3;
            app.InletTemperatureHotKEditFieldLabel.Text = {'Inlet Temperature
Hot'; '(K)'};


            % Create InletTemperatureHotKEditField
            app.InletTemperatureHotKEditField = uieditfield(app.GridLayout_2,
'numeric');
            app.InletTemperatureHotKEditField.HorizontalAlignment = 'center';
            app.InletTemperatureHotKEditField.Layout.Row = 6;
            app.InletTemperatureHotKEditField.Layout.Column = 4;
            app.InletTemperatureHotKEditField.Value = 419.2;


            % Create OutletTemperatureHotKEditFieldLabel
            app.OutletTemperatureHotKEditFieldLabel =
uilabel(app.GridLayout_2);
```

```
            app.OutletTemperatureHotKEditFieldLabel.HorizontalAlignment =
'center';
            app.OutletTemperatureHotKEditFieldLabel.FontWeight = 'bold';
            app.OutletTemperatureHotKEditFieldLabel.Layout.Row = 7;
            app.OutletTemperatureHotKEditFieldLabel.Layout.Column = 3;
            app.OutletTemperatureHotKEditFieldLabel.Text = {'Outlet
Temperature Hot'; '(K)'};

            % Create OutletTemperatureHotKEditField
            app.OutletTemperatureHotKEditField = uieditfield(app.GridLayout_2,
'numeric');
            app.OutletTemperatureHotKEditField.HorizontalAlignment = 'center';
            app.OutletTemperatureHotKEditField.Layout.Row = 7;
            app.OutletTemperatureHotKEditField.Layout.Column = 4;
            app.OutletTemperatureHotKEditField.Value = 383;

            % Create PumpEfficiencyHotEditFieldLabel
            app.PumpEfficiencyHotEditFieldLabel = uilabel(app.GridLayout_2);
            app.PumpEfficiencyHotEditFieldLabel.HorizontalAlignment =
'center';
            app.PumpEfficiencyHotEditFieldLabel.FontWeight = 'bold';
            app.PumpEfficiencyHotEditFieldLabel.Layout.Row = 8;
            app.PumpEfficiencyHotEditFieldLabel.Layout.Column = 3;
            app.PumpEfficiencyHotEditFieldLabel.Text = {'Pump Efficiency Hot';
'(%)'};

            % Create PumpEfficiencyHotEditField
            app.PumpEfficiencyHotEditField = uieditfield(app.GridLayout_2,
'numeric');
            app.PumpEfficiencyHotEditField.HorizontalAlignment = 'center';
            app.PumpEfficiencyHotEditField.Layout.Row = 8;
            app.PumpEfficiencyHotEditField.Layout.Column = 4;
            app.PumpEfficiencyHotEditField.Value = 68.4;

            % Create FlowRateColdkgsEditFieldLabel
            app.FlowRateColdkgsEditFieldLabel = uilabel(app.GridLayout_2);
            app.FlowRateColdkgsEditFieldLabel.HorizontalAlignment = 'center';
            app.FlowRateColdkgsEditFieldLabel.FontWeight = 'bold';
            app.FlowRateColdkgsEditFieldLabel.Layout.Row = 5;
            app.FlowRateColdkgsEditFieldLabel.Layout.Column = 1;
            app.FlowRateColdkgsEditFieldLabel.Text = {'Flow Rate Cold';
'(kg/s)'};

            % Create FlowRateColdkgsEditField
            app.FlowRateColdkgsEditField = uieditfield(app.GridLayout_2,
'numeric');
            app.FlowRateColdkgsEditField.HorizontalAlignment = 'center';
            app.FlowRateColdkgsEditField.Layout.Row = 5;
```

```
            app.FlowRateColdkgsEditField.Layout.Column = 2;
            app.FlowRateColdkgsEditField.Value = 11.95;

            % Create InletTemperatureColdKEditFieldLabel
            app.InletTemperatureColdKEditFieldLabel =
uilabel(app.GridLayout_2);
            app.InletTemperatureColdKEditFieldLabel.HorizontalAlignment =
'center';
            app.InletTemperatureColdKEditFieldLabel.FontWeight = 'bold';
            app.InletTemperatureColdKEditFieldLabel.Layout.Row = 6;
            app.InletTemperatureColdKEditFieldLabel.Layout.Column = 1;
            app.InletTemperatureColdKEditFieldLabel.Text = {'Inlet Temperature
Cold'; '(K)'};

            % Create InletTemperatureColdKEditField
            app.InletTemperatureColdKEditField = uieditfield(app.GridLayout_2,
'numeric');
            app.InletTemperatureColdKEditField.HorizontalAlignment = 'center';
            app.InletTemperatureColdKEditField.Layout.Row = 6;
            app.InletTemperatureColdKEditField.Layout.Column = 2;
            app.InletTemperatureColdKEditField.Value = 371.8;

            % Create OutletTemperatureColdKEditFieldLabel
            app.OutletTemperatureColdKEditFieldLabel =
uilabel(app.GridLayout_2);
            app.OutletTemperatureColdKEditFieldLabel.HorizontalAlignment =
'center';
            app.OutletTemperatureColdKEditFieldLabel.FontWeight = 'bold';
            app.OutletTemperatureColdKEditFieldLabel.Layout.Row = 7;
            app.OutletTemperatureColdKEditFieldLabel.Layout.Column = 1;
            app.OutletTemperatureColdKEditFieldLabel.Text = {'Outlet
Temperature Cold'; '(K)'};

            % Create OutletTemperatureColdKEditField
            app.OutletTemperatureColdKEditField =
uieditfield(app.GridLayout_2, 'numeric');
            app.OutletTemperatureColdKEditField.HorizontalAlignment =
'center';
            app.OutletTemperatureColdKEditField.Layout.Row = 7;
            app.OutletTemperatureColdKEditField.Layout.Column = 2;
            app.OutletTemperatureColdKEditField.Value = 405;

            % Create PumpEfficiencyColdEditFieldLabel
            app.PumpEfficiencyColdEditFieldLabel = uilabel(app.GridLayout_2);
            app.PumpEfficiencyColdEditFieldLabel.HorizontalAlignment =
'center';
            app.PumpEfficiencyColdEditFieldLabel.FontWeight = 'bold';
            app.PumpEfficiencyColdEditFieldLabel.Layout.Row = 8;
```

```
            app.PumpEfficiencyColdEditFieldLabel.Layout.Column = 1;
            app.PumpEfficiencyColdEditFieldLabel.Text = {'Pump Efficiency
Cold'; '(%)'};

            % Create PumpEfficiencyColdEditField
            app.PumpEfficiencyColdEditField = uieditfield(app.GridLayout_2,
'numeric');
            app.PumpEfficiencyColdEditField.HorizontalAlignment = 'center';
            app.PumpEfficiencyColdEditField.Layout.Row = 8;
            app.PumpEfficiencyColdEditField.Layout.Column = 2;
            app.PumpEfficiencyColdEditField.Value = 77.5;

            % Create LifeTimeyearEditFieldLabel
            app.LifeTimeyearEditFieldLabel = uilabel(app.GridLayout_2);
            app.LifeTimeyearEditFieldLabel.HorizontalAlignment = 'center';
            app.LifeTimeyearEditFieldLabel.FontWeight = 'bold';
            app.LifeTimeyearEditFieldLabel.Layout.Row = 1;
            app.LifeTimeyearEditFieldLabel.Layout.Column = 1;
            app.LifeTimeyearEditFieldLabel.Text = {'Life Time'; '(year)'};

            % Create LifeTimeyearEditField
            app.LifeTimeyearEditField = uieditfield(app.GridLayout_2,
'numeric');
            app.LifeTimeyearEditField.HorizontalAlignment = 'center';
            app.LifeTimeyearEditField.Layout.Row = 2;
            app.LifeTimeyearEditField.Layout.Column = 1;
            app.LifeTimeyearEditField.Value = 20;

            % Create PlateMaterialLabel
            app.PlateMaterialLabel = uilabel(app.GridLayout_2);
            app.PlateMaterialLabel.HorizontalAlignment = 'center';
            app.PlateMaterialLabel.FontWeight = 'bold';
            app.PlateMaterialLabel.Layout.Row = 1;
            app.PlateMaterialLabel.Layout.Column = 3;
            app.PlateMaterialLabel.Text = 'Plate Material';

            % Create GasketMaterialLabel
            app.GasketMaterialLabel = uilabel(app.GridLayout_2);
            app.GasketMaterialLabel.HorizontalAlignment = 'center';
            app.GasketMaterialLabel.FontWeight = 'bold';
            app.GasketMaterialLabel.Layout.Row = 1;
            app.GasketMaterialLabel.Layout.Column = 4;
            app.GasketMaterialLabel.Text = 'Gasket Material';

            % Create StainlessSteelAISI316Label
            app.StainlessSteelAISI316Label = uilabel(app.GridLayout_2);
            app.StainlessSteelAISI316Label.BackgroundColor = [1 1 1];
```

```
            app.StainlessSteelAISI316Label.HorizontalAlignment = 'center';
            app.StainlessSteelAISI316Label.Layout.Row = 2;
            app.StainlessSteelAISI316Label.Layout.Column = 3;
            app.StainlessSteelAISI316Label.Text = 'Stainless Steel (AISI-
316)';

            % Create PlateMaterialLabel_3
            app.PlateMaterialLabel_3 = uilabel(app.GridLayout_2);
            app.PlateMaterialLabel_3.BackgroundColor = [1 1 1];
            app.PlateMaterialLabel_3.HorizontalAlignment = 'center';
            app.PlateMaterialLabel_3.Layout.Row = 2;
            app.PlateMaterialLabel_3.Layout.Column = 4;
            app.PlateMaterialLabel_3.Text = 'Plate Material';

            % Create FoulingResistanceColdm2KWEditFieldLabel
            app.FoulingResistanceColdm2KWEditFieldLabel =
uilabel(app.GridLayout_2);
            app.FoulingResistanceColdm2KWEditFieldLabel.HorizontalAlignment =
'center';
            app.FoulingResistanceColdm2KWEditFieldLabel.FontWeight = 'bold';
            app.FoulingResistanceColdm2KWEditFieldLabel.Layout.Row = 9;
            app.FoulingResistanceColdm2KWEditFieldLabel.Layout.Column = 1;
            app.FoulingResistanceColdm2KWEditFieldLabel.Text = {'Fouling
Resistance Cold'; '(m^2* K / W)'};

            % Create FoulingResistanceColdm2KWEditField
            app.FoulingResistanceColdm2KWEditField =
uieditfield(app.GridLayout_2, 'numeric');
            app.FoulingResistanceColdm2KWEditField.ValueDisplayFormat =
'%.6f';
            app.FoulingResistanceColdm2KWEditField.HorizontalAlignment =
'center';
            app.FoulingResistanceColdm2KWEditField.Layout.Row = 9;
            app.FoulingResistanceColdm2KWEditField.Layout.Column = 2;
            app.FoulingResistanceColdm2KWEditField.Value = 4.3e-05;

            % Create FoulingResistanceHotm2KWEditFieldLabel
            app.FoulingResistanceHotm2KWEditFieldLabel =
uilabel(app.GridLayout_2);
            app.FoulingResistanceHotm2KWEditFieldLabel.HorizontalAlignment =
'center';
            app.FoulingResistanceHotm2KWEditFieldLabel.FontWeight = 'bold';
            app.FoulingResistanceHotm2KWEditFieldLabel.Layout.Row = 9;
            app.FoulingResistanceHotm2KWEditFieldLabel.Layout.Column = 3;
            app.FoulingResistanceHotm2KWEditFieldLabel.Text = {'Fouling
Resistance Hot'; '(m^2* K / W)'};

            % Create FoulingResistanceHotm2KWEditField
```

```
            app.FoulingResistanceHotm2KWEditField =
uieditfield(app.GridLayout_2, 'numeric');
            app.FoulingResistanceHotm2KWEditField.ValueDisplayFormat = '%.6f';
            app.FoulingResistanceHotm2KWEditField.HorizontalAlignment =
'center';
            app.FoulingResistanceHotm2KWEditField.Layout.Row = 9;
            app.FoulingResistanceHotm2KWEditField.Layout.Column = 4;
            app.FoulingResistanceHotm2KWEditField.Value = 4.3e-05;

            % Create HEXPropertiesTab
            app.HEXPropertiesTab = uitab(app.TabGroup3);
            app.HEXPropertiesTab.Title = 'HEX Properties';

            % Create GridLayout
            app.GridLayout = uigridlayout(app.HEXPropertiesTab);
            app.GridLayout.ColumnWidth = {'1x', '1x', '1x', '1x', '1x', '1x'};
            app.GridLayout.RowHeight = {'1x', '1x', '1x', '1x', '1x', '1x',
'1x', '1x', '1x', '1x', '1x'};

            % Create MinimumValueLabel
            app.MinimumValueLabel = uilabel(app.GridLayout);
            app.MinimumValueLabel.HorizontalAlignment = 'center';
            app.MinimumValueLabel.FontWeight = 'bold';
            app.MinimumValueLabel.Layout.Row = 4;
            app.MinimumValueLabel.Layout.Column = 4;
            app.MinimumValueLabel.Text = 'Minimum Value';

            % Create MaximumValueLabel
            app.MaximumValueLabel = uilabel(app.GridLayout);
            app.MaximumValueLabel.HorizontalAlignment = 'center';
            app.MaximumValueLabel.FontWeight = 'bold';
            app.MaximumValueLabel.Layout.Row = 4;
            app.MaximumValueLabel.Layout.Column = 5;
            app.MaximumValueLabel.Text = 'Maximum Value';

            % Create IterationSizeLabel
            app.IterationSizeLabel = uilabel(app.GridLayout);
            app.IterationSizeLabel.HorizontalAlignment = 'center';
            app.IterationSizeLabel.FontWeight = 'bold';
            app.IterationSizeLabel.Layout.Row = 4;
            app.IterationSizeLabel.Layout.Column = 6;
            app.IterationSizeLabel.Text = 'Iteration Size';

            % Create ExactLabel
            app.ExactLabel = uilabel(app.GridLayout);
            app.ExactLabel.HorizontalAlignment = 'center';
            app.ExactLabel.FontWeight = 'bold';
```

```
app.ExactLabel.Layout.Row = 4;
app.ExactLabel.Layout.Column = 2;
app.ExactLabel.Text = 'Exact';


% Create ParameterLabel
app.ParameterLabel = uilabel(app.GridLayout);
app.ParameterLabel.HorizontalAlignment = 'center';
app.ParameterLabel.FontWeight = 'bold';
app.ParameterLabel.Layout.Row = 4;
app.ParameterLabel.Layout.Column = 1;
app.ParameterLabel.Text = 'Parameter';


% Create PlateThinknessmmLabel
app.PlateThinknessmmLabel = uilabel(app.GridLayout);
app.PlateThinknessmmLabel.HorizontalAlignment = 'center';
app.PlateThinknessmmLabel.FontWeight = 'bold';
app.PlateThinknessmmLabel.Layout.Row = 7;
app.PlateThinknessmmLabel.Layout.Column = 1;
app.PlateThinknessmmLabel.Text = {'Plate Thinkness'; '(mm)'};


% Create PlateAream2Label
app.PlateAream2Label = uilabel(app.GridLayout);
app.PlateAream2Label.HorizontalAlignment = 'center';
app.PlateAream2Label.FontWeight = 'bold';
app.PlateAream2Label.Layout.Row = 8;
app.PlateAream2Label.Layout.Column = 1;
app.PlateAream2Label.Text = {'Plate Area'; '(m^2)'};


% Create PlateRatioLWLabel
app.PlateRatioLWLabel = uilabel(app.GridLayout);
app.PlateRatioLWLabel.HorizontalAlignment = 'center';
app.PlateRatioLWLabel.FontWeight = 'bold';
app.PlateRatioLWLabel.Layout.Row = 9;
app.PlateRatioLWLabel.Layout.Column = 1;
app.PlateRatioLWLabel.Text = {'Plate Ratio'; '(L/W)'};


% Create PortDiametercmLabel
app.PortDiametercmLabel = uilabel(app.GridLayout);
app.PortDiametercmLabel.HorizontalAlignment = 'center';
app.PortDiametercmLabel.FontWeight = 'bold';
app.PortDiametercmLabel.Layout.Row = 10;
app.PortDiametercmLabel.Layout.Column = 1;
app.PortDiametercmLabel.Text = {'Port Diameter'; '(cm)'};


% Create NumberofPlateLabel
app.NumberofPlateLabel = uilabel(app.GridLayout);
app.NumberofPlateLabel.HorizontalAlignment = 'center';
```

```
app.NumberofPlateLabel.FontWeight = 'bold';
app.NumberofPlateLabel.Layout.Row = 5;
app.NumberofPlateLabel.Layout.Column = 1;
app.NumberofPlateLabel.Text = 'Number of Plate';


% Create PlateGapmmLabel
app.PlateGapmmLabel = uilabel(app.GridLayout);
app.PlateGapmmLabel.HorizontalAlignment = 'center';
app.PlateGapmmLabel.FontWeight = 'bold';
app.PlateGapmmLabel.Layout.Row = 6;
app.PlateGapmmLabel.Layout.Column = 1;
app.PlateGapmmLabel.Text = {'Plate Gap '; '(mm)'};


% Create ChevronAngleLabel
app.ChevronAngleLabel = uilabel(app.GridLayout);
app.ChevronAngleLabel.HorizontalAlignment = 'center';
app.ChevronAngleLabel.FontWeight = 'bold';
app.ChevronAngleLabel.Layout.Row = 11;
app.ChevronAngleLabel.Layout.Column = 1;
app.ChevronAngleLabel.Text = 'Chevron Angle';


% Create numberOfPlateEx
app.numberOfPlateEx = uieditfield(app.GridLayout, 'numeric');
app.numberOfPlateEx.HorizontalAlignment = 'center';
app.numberOfPlateEx.Layout.Row = 5;
app.numberOfPlateEx.Layout.Column = 2;
app.numberOfPlateEx.Value = 201;


% Create numberOfPlateMin
app.numberOfPlateMin = uieditfield(app.GridLayout, 'numeric');
app.numberOfPlateMin.HorizontalAlignment = 'center';
app.numberOfPlateMin.Layout.Row = 5;
app.numberOfPlateMin.Layout.Column = 4;
app.numberOfPlateMin.Value = 3;


% Create numberOfPlateMax
app.numberOfPlateMax = uieditfield(app.GridLayout, 'numeric');
app.numberOfPlateMax.HorizontalAlignment = 'center';
app.numberOfPlateMax.Layout.Row = 5;
app.numberOfPlateMax.Layout.Column = 5;
app.numberOfPlateMax.Value = 50;


% Create numberOfPlateStep
app.numberOfPlateStep = uieditfield(app.GridLayout, 'numeric');
app.numberOfPlateStep.HorizontalAlignment = 'center';
app.numberOfPlateStep.Layout.Row = 5;
app.numberOfPlateStep.Layout.Column = 6;
```

```
app.numberOfPlateStep.Value = 48;


% Create plateGapEx
app.plateGapEx = uieditfield(app.GridLayout, 'numeric');
app.plateGapEx.HorizontalAlignment = 'center';
app.plateGapEx.Layout.Row = 6;
app.plateGapEx.Layout.Column = 2;
app.plateGapEx.Value = 1.9;


% Create plateGapMin
app.plateGapMin = uieditfield(app.GridLayout, 'numeric');
app.plateGapMin.HorizontalAlignment = 'center';
app.plateGapMin.Layout.Row = 6;
app.plateGapMin.Layout.Column = 4;
app.plateGapMin.Value = 1.5;


% Create plateGapMax
app.plateGapMax = uieditfield(app.GridLayout, 'numeric');
app.plateGapMax.HorizontalAlignment = 'center';
app.plateGapMax.Layout.Row = 6;
app.plateGapMax.Layout.Column = 5;
app.plateGapMax.Value = 4.5;


% Create plateGapStep
app.plateGapStep = uieditfield(app.GridLayout, 'numeric');
app.plateGapStep.HorizontalAlignment = 'center';
app.plateGapStep.Layout.Row = 6;
app.plateGapStep.Layout.Column = 6;
app.plateGapStep.Value = 3;


% Create plateThicknessMax
app.plateThicknessMax = uieditfield(app.GridLayout, 'numeric');
app.plateThicknessMax.HorizontalAlignment = 'center';
app.plateThicknessMax.Layout.Row = 7;
app.plateThicknessMax.Layout.Column = 5;
app.plateThicknessMax.Value = 1.2;


% Create plateThicknessMin
app.plateThicknessMin = uieditfield(app.GridLayout, 'numeric');
app.plateThicknessMin.HorizontalAlignment = 'center';
app.plateThicknessMin.Layout.Row = 7;
app.plateThicknessMin.Layout.Column = 4;
app.plateThicknessMin.Value = 0.5;


% Create plateThicknessStep
app.plateThicknessStep = uieditfield(app.GridLayout, 'numeric');
```

```
app.plateThicknessStep.HorizontalAlignment = 'center';
app.plateThicknessStep.Layout.Row = 7;
app.plateThicknessStep.Layout.Column = 6;
app.plateThicknessStep.Value = 5;


% Create plateThicknessEx
app.plateThicknessEx = uieditfield(app.GridLayout, 'numeric');
app.plateThicknessEx.HorizontalAlignment = 'center';
app.plateThicknessEx.Layout.Row = 7;
app.plateThicknessEx.Layout.Column = 2;
app.plateThicknessEx.Value = 0.5;


% Create plateAreaMin
app.plateAreaMin = uieditfield(app.GridLayout, 'numeric');
app.plateAreaMin.HorizontalAlignment = 'center';
app.plateAreaMin.Layout.Row = 8;
app.plateAreaMin.Layout.Column = 4;
app.plateAreaMin.Value = 0.2;


% Create plateAreaMax
app.plateAreaMax = uieditfield(app.GridLayout, 'numeric');
app.plateAreaMax.HorizontalAlignment = 'center';
app.plateAreaMax.Layout.Row = 8;
app.plateAreaMax.Layout.Column = 5;
app.plateAreaMax.Value = 2.2;


% Create plateAreaStep
app.plateAreaStep = uieditfield(app.GridLayout, 'numeric');
app.plateAreaStep.HorizontalAlignment = 'center';
app.plateAreaStep.Layout.Row = 8;
app.plateAreaStep.Layout.Column = 6;
app.plateAreaStep.Value = 21;


% Create plateRatioEx
app.plateRatioEx = uieditfield(app.GridLayout, 'numeric');
app.plateRatioEx.HorizontalAlignment = 'center';
app.plateRatioEx.Layout.Row = 9;
app.plateRatioEx.Layout.Column = 2;
app.plateRatioEx.Value = 3.5;


% Create plateAreaEx
app.plateAreaEx = uieditfield(app.GridLayout, 'numeric');
app.plateAreaEx.HorizontalAlignment = 'center';
app.plateAreaEx.Layout.Row = 8;
app.plateAreaEx.Layout.Column = 2;
app.plateAreaEx.Value = 1;
```

```
% Create portDiameterEx
app.portDiameterEx = uieditfield(app.GridLayout, 'numeric');
app.portDiameterEx.HorizontalAlignment = 'center';
app.portDiameterEx.Layout.Row = 10;
app.portDiameterEx.Layout.Column = 2;
app.portDiameterEx.Value = 20;


% Create plateRatioStep
app.plateRatioStep = uieditfield(app.GridLayout, 'numeric');
app.plateRatioStep.HorizontalAlignment = 'center';
app.plateRatioStep.Layout.Row = 9;
app.plateRatioStep.Layout.Column = 6;
app.plateRatioStep.Value = 7;


% Create plateRatioMax
app.plateRatioMax = uieditfield(app.GridLayout, 'numeric');
app.plateRatioMax.HorizontalAlignment = 'center';
app.plateRatioMax.Layout.Row = 9;
app.plateRatioMax.Layout.Column = 5;
app.plateRatioMax.Value = 7.8;


% Create plateRatioMin
app.plateRatioMin = uieditfield(app.GridLayout, 'numeric');
app.plateRatioMin.HorizontalAlignment = 'center';
app.plateRatioMin.Layout.Row = 9;
app.plateRatioMin.Layout.Column = 4;
app.plateRatioMin.Value = 1.8;


% Create chevronEx
app.chevronEx = uieditfield(app.GridLayout, 'numeric');
app.chevronEx.HorizontalAlignment = 'center';
app.chevronEx.Layout.Row = 11;
app.chevronEx.Layout.Column = 2;
app.chevronEx.Value = 30;


% Create portDiameterMin
app.portDiameterMin = uieditfield(app.GridLayout, 'numeric');
app.portDiameterMin.HorizontalAlignment = 'center';
app.portDiameterMin.Layout.Row = 10;
app.portDiameterMin.Layout.Column = 4;
app.portDiameterMin.Value = 10;


% Create chevronMax
app.chevronMax = uieditfield(app.GridLayout, 'numeric');
app.chevronMax.HorizontalAlignment = 'center';
app.chevronMax.Layout.Row = 11;
app.chevronMax.Layout.Column = 5;
```

```
app.chevronMax.Value = 60;


% Create portDiameterStep
app.portDiameterStep = uieditfield(app.GridLayout, 'numeric');
app.portDiameterStep.HorizontalAlignment = 'center';
app.portDiameterStep.Layout.Row = 10;
app.portDiameterStep.Layout.Column = 6;
app.portDiameterStep.Value = 7;


% Create chevronStep
app.chevronStep = uieditfield(app.GridLayout, 'numeric');
app.chevronStep.HorizontalAlignment = 'center';
app.chevronStep.Layout.Row = 11;
app.chevronStep.Layout.Column = 6;
app.chevronStep.Value = 7;


% Create chevronMin
app.chevronMin = uieditfield(app.GridLayout, 'numeric');
app.chevronMin.HorizontalAlignment = 'center';
app.chevronMin.Layout.Row = 11;
app.chevronMin.Layout.Column = 4;
app.chevronMin.Value = 30;


% Create portDiameterMax
app.portDiameterMax = uieditfield(app.GridLayout, 'numeric');
app.portDiameterMax.HorizontalAlignment = 'center';
app.portDiameterMax.Layout.Row = 10;
app.portDiameterMax.Layout.Column = 5;
app.portDiameterMax.Value = 50;


% Create ExactStepLabel
app.ExactStepLabel = uilabel(app.GridLayout);
app.ExactStepLabel.HorizontalAlignment = 'center';
app.ExactStepLabel.FontWeight = 'bold';
app.ExactStepLabel.Layout.Row = 4;
app.ExactStepLabel.Layout.Column = 3;
app.ExactStepLabel.Text = 'Exact / Step';


% Create Switch
app.Switch = uiswitch(app.GridLayout, 'slider');
app.Switch.Items = {'E', 'S'};
app.Switch.ItemsData = {'E', 'S'};
app.Switch.FontWeight = 'bold';
app.Switch.Layout.Row = 5;
app.Switch.Layout.Column = 3;
app.Switch.Value = 'S';
```

```
            % Create TestingButton
            app.TestingButton = uibutton(app.GridLayout, 'push');
            app.TestingButton.ButtonPushedFcn = createCallbackFcn(app,
@TestingButtonPushed, true);
            app.TestingButton.Layout.Row = 3;
            app.TestingButton.Layout.Column = 2;
            app.TestingButton.Text = 'Testing';

            % Create TestingLabel
            app.TestingLabel = uilabel(app.GridLayout);
            app.TestingLabel.Layout.Row = [1 3];
            app.TestingLabel.Layout.Column = 3;

            % Create GOButton
            app.GOButton = uibutton(app.GridLayout, 'push');
            app.GOButton.ButtonPushedFcn = createCallbackFcn(app,
@GOButtonPushed, true);
            app.GOButton.Layout.Row = 1;
            app.GOButton.Layout.Column = 5;
            app.GOButton.Text = 'GO';

            % Create Switch_2
            app.Switch_2 = uiswitch(app.GridLayout, 'slider');
            app.Switch_2.Items = {'E', 'S'};
            app.Switch_2.ItemsData = {'E', 'S'};
            app.Switch_2.FontWeight = 'bold';
            app.Switch_2.Layout.Row = 6;
            app.Switch_2.Layout.Column = 3;
            app.Switch_2.Value = 'S';

            % Create Switch_3
            app.Switch_3 = uiswitch(app.GridLayout, 'slider');
            app.Switch_3.Items = {'E', 'S'};
            app.Switch_3.ItemsData = {'E', 'S'};
            app.Switch_3.FontWeight = 'bold';
            app.Switch_3.Layout.Row = 7;
            app.Switch_3.Layout.Column = 3;
            app.Switch_3.Value = 'S';

            % Create Switch_4
            app.Switch_4 = uiswitch(app.GridLayout, 'slider');
            app.Switch_4.Items = {'E', 'S'};
            app.Switch_4.ItemsData = {'E', 'S'};
            app.Switch_4.FontWeight = 'bold';
            app.Switch_4.Layout.Row = 8;
            app.Switch_4.Layout.Column = 3;
            app.Switch_4.Value = 'S';
```

```
        % Create Switch_5
        app.Switch_5 = uiswitch(app.GridLayout, 'slider');
        app.Switch_5.Items = {'E', 'S'};
        app.Switch_5.ItemsData = {'E', 'S'};
        app.Switch_5.FontWeight = 'bold';
        app.Switch_5.Layout.Row = 9;
        app.Switch_5.Layout.Column = 3;
        app.Switch_5.Value = 'S';

        % Create Switch_6
        app.Switch_6 = uiswitch(app.GridLayout, 'slider');
        app.Switch_6.Items = {'E', 'S'};
        app.Switch_6.ItemsData = {'E', 'S'};
        app.Switch_6.FontWeight = 'bold';
        app.Switch_6.Layout.Row = 10;
        app.Switch_6.Layout.Column = 3;
        app.Switch_6.Value = 'E';

        % Create Switch_7
        app.Switch_7 = uiswitch(app.GridLayout, 'slider');
        app.Switch_7.Items = {'E', 'S'};
        app.Switch_7.ItemsData = {'E', 'S'};
        app.Switch_7.FontWeight = 'bold';
        app.Switch_7.Layout.Row = 11;
        app.Switch_7.Layout.Column = 3;
        app.Switch_7.Value = 'S';

        % Create EnlargementFactorEditFieldLabel
        app.EnlargementFactorEditFieldLabel = uilabel(app.GridLayout);
        app.EnlargementFactorEditFieldLabel.HorizontalAlignment =
'center';
        app.EnlargementFactorEditFieldLabel.FontWeight = 'bold';
        app.EnlargementFactorEditFieldLabel.Layout.Row = 1;
        app.EnlargementFactorEditFieldLabel.Layout.Column = 1;
        app.EnlargementFactorEditFieldLabel.Text = {'Enlargement';
'Factor'};

        % Create EnlargementFactorEditField
        app.EnlargementFactorEditField = uieditfield(app.GridLayout,
'numeric');
        app.EnlargementFactorEditField.HorizontalAlignment = 'center';
        app.EnlargementFactorEditField.Layout.Row = 2;
        app.EnlargementFactorEditField.Layout.Column = 1;
        app.EnlargementFactorEditField.Value = 1.17;

        % Create NumberofPassEditFieldLabel
        app.NumberofPassEditFieldLabel = uilabel(app.GridLayout);
        app.NumberofPassEditFieldLabel.HorizontalAlignment = 'center';
```

```
            app.NumberofPassEditFieldLabel.FontWeight = 'bold';
            app.NumberofPassEditFieldLabel.Layout.Row = 1;
            app.NumberofPassEditFieldLabel.Layout.Column = 2;
            app.NumberofPassEditFieldLabel.Text = 'Number of Pass';


            % Create NumberofPassEditField
            app.NumberofPassEditField = uieditfield(app.GridLayout,
'numeric');
            app.NumberofPassEditField.HorizontalAlignment = 'center';
            app.NumberofPassEditField.Layout.Row = 2;
            app.NumberofPassEditField.Layout.Column = 2;
            app.NumberofPassEditField.Value = 1;


            % Create WorkingLampLabel
            app.WorkingLampLabel = uilabel(app.GridLayout);
            app.WorkingLampLabel.HorizontalAlignment = 'center';
            app.WorkingLampLabel.FontWeight = 'bold';
            app.WorkingLampLabel.Layout.Row = 1;
            app.WorkingLampLabel.Layout.Column = 6;
            app.WorkingLampLabel.Text = 'Working';


            % Create WorkingLamp
            app.WorkingLamp = uilamp(app.GridLayout);
            app.WorkingLamp.Layout.Row = 2;
            app.WorkingLamp.Layout.Column = 6;
            app.WorkingLamp.Color = [1 1 1];


            % Create DesignsTab
            app.DesignsTab = uitab(app.TabGroup);
            app.DesignsTab.Title = 'Designs';


            % Create TabGroup2
            app.TabGroup2 = uitabgroup(app.DesignsTab);
            app.TabGroup2.SelectionChangedFcn = createCallbackFcn(app,
@TabGroup2SelectionChanged, true);
            app.TabGroup2.Position = [1 1 856 511];


            % Create AllDesignsTab
            app.AllDesignsTab = uitab(app.TabGroup2);
            app.AllDesignsTab.Title = 'All Designs';


            % Create GridLayout2
            app.GridLayout2 = uigridlayout(app.AllDesignsTab);
            app.GridLayout2.ColumnWidth = {'1x', '1x', '1x', '1x'};
            app.GridLayout2.RowHeight = {'1x', '1x', '1x', '1x', '1x', '1x',
'1x', '1x', '1x', '1x', '1x', '1x'};
```

```
            % Create LoadChosenDesignButton
            app.LoadChosenDesignButton = uibutton(app.GridLayout2, 'push');
            app.LoadChosenDesignButton.ButtonPushedFcn =
createCallbackFcn(app, @LoadChosenDesignButtonPushed, true);
            app.LoadChosenDesignButton.Layout.Row = 12;
            app.LoadChosenDesignButton.Layout.Column = 3;
            app.LoadChosenDesignButton.Text = 'Load Chosen Design';

            % Create resultHEXsTable
            app.resultHEXsTable = uitable(app.GridLayout2);
            app.resultHEXsTable.ColumnName = {'Column 1'; 'Column 2'; 'Column
3'; 'Column 4'};
            app.resultHEXsTable.RowName = {};
            app.resultHEXsTable.ColumnSortable = true;
            app.resultHEXsTable.Layout.Row = [1 11];
            app.resultHEXsTable.Layout.Column = [2 4];

            % Create HeatDutyConvergenceEditFieldLabel
            app.HeatDutyConvergenceEditFieldLabel = uilabel(app.GridLayout2);
            app.HeatDutyConvergenceEditFieldLabel.HorizontalAlignment =
'center';
            app.HeatDutyConvergenceEditFieldLabel.FontWeight = 'bold';
            app.HeatDutyConvergenceEditFieldLabel.Layout.Row = 3;
            app.HeatDutyConvergenceEditFieldLabel.Layout.Column = 1;
            app.HeatDutyConvergenceEditFieldLabel.Text = {'Heat Duty
Convergence'; '(%)'};

            % Create HeatDutyConvergenceEditField
            app.HeatDutyConvergenceEditField = uieditfield(app.GridLayout2,
'numeric');
            app.HeatDutyConvergenceEditField.HorizontalAlignment = 'center';
            app.HeatDutyConvergenceEditField.Layout.Row = 4;
            app.HeatDutyConvergenceEditField.Layout.Column = 1;

            % Create FilterforHeatDutyButton
            app.FilterforHeatDutyButton = uibutton(app.GridLayout2, 'push');
            app.FilterforHeatDutyButton.ButtonPushedFcn =
createCallbackFcn(app, @FilterforHeatDutyButtonPushed, true);
            app.FilterforHeatDutyButton.Layout.Row = 5;
            app.FilterforHeatDutyButton.Layout.Column = 1;
            app.FilterforHeatDutyButton.Text = 'Filter for Heat Duty';

            % Create ShowAllDesignsButton
            app.ShowAllDesignsButton = uibutton(app.GridLayout2, 'push');
            app.ShowAllDesignsButton.ButtonPushedFcn = createCallbackFcn(app,
@ShowAllDesignsButtonPushed, true);
```

```
            app.ShowAllDesignsButton.Layout.Row = 1;
            app.ShowAllDesignsButton.Layout.Column = 1;
            app.ShowAllDesignsButton.Text = 'Show All Designs';

            % Create LoadOptimumDesignButton
            app.LoadOptimumDesignButton = uibutton(app.GridLayout2, 'push');
            app.LoadOptimumDesignButton.Layout.Row = 12;
            app.LoadOptimumDesignButton.Layout.Column = 2;
            app.LoadOptimumDesignButton.Text = 'Load Optimum Design';

            % Create SaveShownTableButton
            app.SaveShownTableButton = uibutton(app.GridLayout2, 'push');
            app.SaveShownTableButton.ButtonPushedFcn = createCallbackFcn(app,
@SaveShownTableButtonPushed, true);
            app.SaveShownTableButton.Layout.Row = 12;
            app.SaveShownTableButton.Layout.Column = 4;
            app.SaveShownTableButton.Text = 'Save Shown Table';

            % Create ValueConvergenceEditFieldLabel
            app.ValueConvergenceEditFieldLabel = uilabel(app.GridLayout2);
            app.ValueConvergenceEditFieldLabel.HorizontalAlignment = 'center';
            app.ValueConvergenceEditFieldLabel.FontWeight = 'bold';
            app.ValueConvergenceEditFieldLabel.Layout.Row = 10;
            app.ValueConvergenceEditFieldLabel.Layout.Column = 1;
            app.ValueConvergenceEditFieldLabel.Text = {'Value Convergence';
'(%)'};

            % Create ValueConvergenceEditField
            app.ValueConvergenceEditField = uieditfield(app.GridLayout2,
'numeric');
            app.ValueConvergenceEditField.HorizontalAlignment = 'center';
            app.ValueConvergenceEditField.Layout.Row = 11;
            app.ValueConvergenceEditField.Layout.Column = 1;

            % Create ChooseFilterVariableDropDownLabel
            app.ChooseFilterVariableDropDownLabel = uilabel(app.GridLayout2);
            app.ChooseFilterVariableDropDownLabel.HorizontalAlignment =
'center';
            app.ChooseFilterVariableDropDownLabel.FontWeight = 'bold';
            app.ChooseFilterVariableDropDownLabel.Layout.Row = 6;
            app.ChooseFilterVariableDropDownLabel.Layout.Column = 1;
            app.ChooseFilterVariableDropDownLabel.Text = 'Choose Filter
Variable';

            % Create ChooseFilterVariableDropDown
            app.ChooseFilterVariableDropDown = uidropdown(app.GridLayout2);
```

```
            app.ChooseFilterVariableDropDown.ValueChangedFcn =
createCallbackFcn(app, @ChooseFilterVariableDropDownValueChanged, true);
            app.ChooseFilterVariableDropDown.Layout.Row = 7;
            app.ChooseFilterVariableDropDown.Layout.Column = 1;

            % Create FilterforButton
            app.FilterforButton = uibutton(app.GridLayout2, 'push');
            app.FilterforButton.ButtonPushedFcn = createCallbackFcn(app,
@FilterforButtonPushed, true);
            app.FilterforButton.Layout.Row = 12;
            app.FilterforButton.Layout.Column = 1;
            app.FilterforButton.Text = 'Filter for ';

            % Create ValueforEditFieldLabel
            app.ValueforEditFieldLabel = uilabel(app.GridLayout2);
            app.ValueforEditFieldLabel.HorizontalAlignment = 'center';
            app.ValueforEditFieldLabel.FontWeight = 'bold';
            app.ValueforEditFieldLabel.Layout.Row = 8;
            app.ValueforEditFieldLabel.Layout.Column = 1;
            app.ValueforEditFieldLabel.Text = 'Value for';

            % Create ValueforEditField
            app.ValueforEditField = uieditfield(app.GridLayout2, 'numeric');
            app.ValueforEditField.HorizontalAlignment = 'center';
            app.ValueforEditField.Layout.Row = 9;
            app.ValueforEditField.Layout.Column = 1;

            % Create ChosenDesignTab_2
            app.ChosenDesignTab_2 = uitab(app.TabGroup2);
            app.ChosenDesignTab_2.Title = 'ChosenDesign';

            % Create chosenDesignTable
            app.chosenDesignTable = uitable(app.ChosenDesignTab_2);
            app.chosenDesignTable.ColumnName = {'Column 1'; 'Column 2';
'Column 3'; 'Column 4'};
            app.chosenDesignTable.RowName = {};
            app.chosenDesignTable.Position = [-1 1 856 485];

            % Create AnalyzerTab
            app.AnalyzerTab = uitab(app.TabGroup2);
            app.AnalyzerTab.Title = 'Analyzer';

            % Create GridLayout3
            app.GridLayout3 = uigridlayout(app.AnalyzerTab);
            app.GridLayout3.ColumnWidth = {'1x', '1x', '1x', '1x'};
```

```
            app.GridLayout3.RowHeight = {'1x', '1x', '1x', '1x', '1x', '1x',
'1x', '1x', '1x', '1x'};

            % Create UIAxes
            app.UIAxes = uiaxes(app.GridLayout3);
            title(app.UIAxes, 'Title')
            xlabel(app.UIAxes, 'X')
            ylabel(app.UIAxes, 'Y')
            app.UIAxes.Layout.Row = [1 8];
            app.UIAxes.Layout.Column = [2 4];

            % Create GraphDimensionSwitchLabel
            app.GraphDimensionSwitchLabel = uilabel(app.GridLayout3);
            app.GraphDimensionSwitchLabel.HorizontalAlignment = 'center';
            app.GraphDimensionSwitchLabel.FontWeight = 'bold';
            app.GraphDimensionSwitchLabel.Layout.Row = 3;
            app.GraphDimensionSwitchLabel.Layout.Column = 1;
            app.GraphDimensionSwitchLabel.Text = 'Graph Dimension';

            % Create GraphDimensionSwitch
            app.GraphDimensionSwitch = uiswitch(app.GridLayout3, 'toggle');
            app.GraphDimensionSwitch.Items = {'3D', '2D'};
            app.GraphDimensionSwitch.ValueChangedFcn = createCallbackFcn(app,
@GraphDimensionSwitchValueChanged, true);
            app.GraphDimensionSwitch.Layout.Row = [4 5];
            app.GraphDimensionSwitch.Layout.Column = 1;
            app.GraphDimensionSwitch.Value = '3D';

            % Create FirstDimensionDropDownLabel
            app.FirstDimensionDropDownLabel = uilabel(app.GridLayout3);
            app.FirstDimensionDropDownLabel.HorizontalAlignment = 'center';
            app.FirstDimensionDropDownLabel.FontWeight = 'bold';
            app.FirstDimensionDropDownLabel.Layout.Row = 9;
            app.FirstDimensionDropDownLabel.Layout.Column = 2;
            app.FirstDimensionDropDownLabel.Text = 'First Dimension';

            % Create FirstDimensionDropDown
            app.FirstDimensionDropDown = uidropdown(app.GridLayout3);
            app.FirstDimensionDropDown.Layout.Row = 10;
            app.FirstDimensionDropDown.Layout.Column = 2;

            % Create SecondDimensionDropDownLabel
            app.SecondDimensionDropDownLabel = uilabel(app.GridLayout3);
            app.SecondDimensionDropDownLabel.HorizontalAlignment = 'center';
            app.SecondDimensionDropDownLabel.FontWeight = 'bold';
            app.SecondDimensionDropDownLabel.Layout.Row = 9;
            app.SecondDimensionDropDownLabel.Layout.Column = 3;
```

```
            app.SecondDimensionDropDownLabel.Text = 'Second Dimension';

            % Create SecondDimensionDropDown
            app.SecondDimensionDropDown = uidropdown(app.GridLayout3);
            app.SecondDimensionDropDown.Layout.Row = 10;
            app.SecondDimensionDropDown.Layout.Column = 3;

            % Create ThirdDimensionDropDownLabel
            app.ThirdDimensionDropDownLabel = uilabel(app.GridLayout3);
            app.ThirdDimensionDropDownLabel.HorizontalAlignment = 'center';
            app.ThirdDimensionDropDownLabel.FontWeight = 'bold';
            app.ThirdDimensionDropDownLabel.Layout.Row = 9;
            app.ThirdDimensionDropDownLabel.Layout.Column = 4;
            app.ThirdDimensionDropDownLabel.Text = 'Third Dimension';

            % Create ThirdDimensionDropDown
            app.ThirdDimensionDropDown = uidropdown(app.GridLayout3);
            app.ThirdDimensionDropDown.Layout.Row = 10;
            app.ThirdDimensionDropDown.Layout.Column = 4;

            % Show the figure after all components are created
            app.UIFigure.Visible = 'on';
        end
    end

    % App creation and deletion
    methods (Access = public)

        % Construct app
        function app = HEXDesignerApp

            % Create UIFigure and components
            createComponents(app)

            % Register the app with App Designer
            registerApp(app, app.UIFigure)

            if nargout == 0
                clear app
            end
        end

        % Code that executes before app deletion
```

```
        function delete(app)

            % Delete UIFigure when app is deleted
            delete(app.UIFigure)
        end
    end
end
```

Appendix C Property Data for Water

Temperature, T (K)	Pressure, p (bar)[b]	Specific Volume (m^3/kg) $v_f \cdot 10^3$	v_g	Specific Heat ($kJ/kg \cdot K$) $c_{p,f}$	$c_{p,g}$	Viscosity ($N \cdot s/m^2$) $\mu_f \cdot 10^6$	$\mu_g \cdot 10^6$	Thermal Conductivity ($W/m \cdot K$) $k_f \cdot 10^3$	$k_g \cdot 10^3$	Prandtl Number Pr_f	Pr_g
273.15	0.00611	1.000	206.3	4.217	1.854	1750	8.02	569	18.2	12.99	0.815
275	0.00697	1.000	181.7	4.211	1.855	1652	8.09	574	18.3	12.22	0.817
280	0.00990	1.000	130.4	4.198	1.858	1422	8.29	582	18.6	10.26	0.825
285	0.01387	1.000	99.4	4.189	1.861	1225	8.49	590	18.9	8.81	0.833
290	0.01917	1.001	69.7	4.184	1.864	1080	8.69	598	19.3	7.56	0.841
295	0.02617	1.002	51.94	4.181	1.868	959	8.89	606	19.5	6.62	0.849
300	0.03531	1.003	39.13	4.179	1.872	855	9.09	613	19.6	5.83	0.857
305	0.04712	1.005	29.74	4.178	1.877	769	9.29	620	20.1	5.20	0.865
310	0.06221	1.007	22.93	4.178	1.882	695	9.49	628	20.4	4.62	0.873
315	0.08132	1.009	17.82	4.179	1.888	631	9.69	634	20.7	4.16	0.883
320	0.1053	1.011	13.98	4.180	1.895	577	9.89	640	21.0	3.77	0.894
325	0.1351	1.013	11.06	4.182	1.903	528	10.09	645	21.3	3.42	0.901
330	0.1719	1.016	8.82	4.184	1.911	489	10.29	650	21.7	3.15	0.908
335	0.2167	1.018	7.09	4.186	1.920	453	10.49	656	22.0	2.88	0.916
340	0.2713	1.021	5.74	4.188	1.930	420	10.69	660	22.3	2.66	0.925
345	0.3372	1.024	4.683	4.191	1.941	389	10.89	664	22.6	2.45	0.933
350	0.4163	1.027	3.846	4.195	1.954	365	11.09	668	23.0	2.29	0.942
355	0.5100	1.030	3.180	4.199	1.968	343	11.29	671	23.3	2.14	0.951
360	0.6209	1.034	2.645	4.203	1.983	324	11.49	674	23.7	2.02	0.960
365	0.7514	1.038	2.212	4.209	1.999	306	11.69	677	24.1	1.91	0.969
370	0.9040	1.041	1.861	4.214	2.017	289	11.89	679	24.5	1.80	0.978
373.15	1.0133	1.044	1.679	4.217	2.029	279	12.02	680	24.8	1.76	0.984
375	1.0815	1.045	1.574	4.220	2.036	274	12.09	681	24.9	1.70	0.987
380	1.2869	1.049	1.337	4.226	2.057	260	12.29	683	25.4	1.61	0.999
385	1.5233	1.053	1.142	4.232	2.080	248	12.49	685	25.8	1.53	1.004
390	1.794	1.058	0.980	4.239	2.104	237	12.69	686	26.3	1.47	1.013
400	2.455	1.067	0.731	4.256	2.158	217	13.05	688	27.2	1.34	1.033
410	3.302	1.077	0.553	4.278	2.221	200	13.42	688	28.2	1.24	1.054
420	4.370	1.088	0.425	4.302	2.291	185	13.79	688	29.8	1.16	1.075
430	5.699	1.099	0.331	4.331	2.369	173	14.14	685	30.4	1.09	1.10

Figure 14 Water properties