

Simulation and performance analysis of a plate fin heat exchanger in Unisim Design

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Abstract. This paper presents a simulation of a plate fin heat exchanger with the aim of choosing optimized geometry and design parameters among given set of parameters using Unisim Design software. The simulation includes an analysis of the effects of varying exchanger parameters on the total annual cost of the plate fin heat exchanger. Results from the simulation indicate that Unisim Design can be used to design different variants of plate-fin heat exchanger with further optimization on cost, heat load or any other parameters. This work provides useful insights into the simulation of plate fin heat exchangers in Unisim Design and can be used to develop more efficient designs.

1 Introduction

Oxygen, nitrogen, and argon are extensively utilized gases in the steel and metal industry. In steelmaking, oxygen plays a crucial role in the basic oxygen process (BOP), which occurs within a basic oxygen furnace (BOF). This method entails injecting high purity oxygen into a furnace containing molten iron and other scraps to convert them into steel.

Nitrogen finds common application in the metalworking process known as annealing. Nitrogen annealing involves subjecting metals to heat treatment to enhance ductility and reduce hardness.

Argon, in conjunction with oxygen, is employed in the steelmaking procedure called argon oxygen decarburization (AOD). This process is carried out subsequent to melting the metals into a liquid state.

Throughout the metallurgy industry, these gases find utility in various stages of metal production, spanning from initial processing to the final stages (<https://air-source.com>).

Mentioned gases are core components of ambient air and are separated in Air Separation Units (ASU). Nowadays mostly cryogenic air separation technology is used in this industry which includes compression and expansion of air during which cryogenic temperatures are reached and air components are liquified. One of the most important parts of ASU is multi-stream heat exchanger, often it is plate-fin heat exchanger (PFHE) with big heat exchange areas for each of the streams. General arrangement of mentioned PFHE is given in Figure 1.

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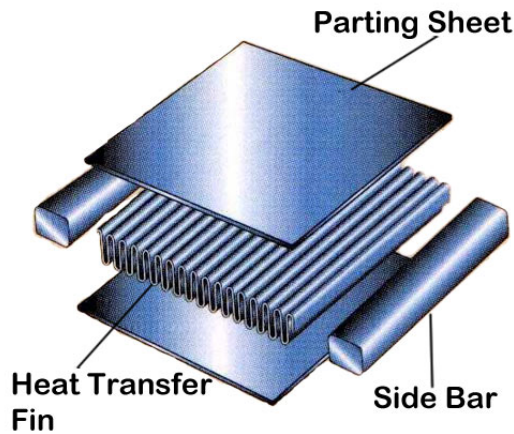


Fig. 1. General structure of one layer of PFHE.

A plate-fin heat exchanger is a specific design of heat exchanger that employs plates and finned chambers to facilitate heat transfer between fluids, typically gases. This type of heat exchanger is recognized for its compactness, emphasizing the relatively large surface area available for heat transfer in proportion to its volume. It finds widespread use across various industries, particularly in cryogenics, where its ability to facilitate efficient heat transfer even with small temperature differences is highly valuable.

Specifically, aluminum alloy plate fin heat exchangers, also known as Brazed Aluminum Heat Exchangers, were introduced to the cryogenic air separation industry during the second World War. Soon after, they were adopted in cryogenic processes within chemical plants, such as those involved in Natural Gas Processing (https://en.wikipedia.org/wiki/Plate-fin_heat_exchanger).

Modern simulation software makes it possible to design or at least check some design parameters of PFHE with decent accuracy. One of the most recent and leading simulators in industry today is UniSim Design environment, development of Honeywell Company [1-4]. The Unisim Design Suite, developed by Honeywell, serves as a simulation module for technological objects and processes. This comprehensive software package enables users to simulate various production and field oil and gas processes, as well as refining and petrochemical processes [5-7]. Using before mentioned software we can simulate Plate-fin heat exchangers (PFHE) also. There are two options of PFHE simulation using Unisim Design: a) Use the special Unisim Plate fin exchanger modeler software; b) Use the PFE Engine inside Unisim Design. For current work the latter one was chosen. Embedded PFE engine also allows to simulate the PFE in conjunction with field equipment and instrumentation like valves, manometers, thermocouples, vessels, other heat exchangers, etc.

2 Methodology

In current work will be used Unisim Design R480 edition. Set up for research is as follows: we used LNG Exchanger unit operation inside Unisim Design software and Plate Fin Exchanger (PFE) engine inside it, our heat exchanger has two streams (Cold and Hot), streams inlet conditions are reflected in Table 1.

This paper aims to give some basic insights on implementation of PFHE in Unisim Design, its parameters and tabs. We are going to set up PFHE with sample parameters shown in Table 3 (Base case), change some of them (Cases from A to F in Table 4), get results after changing, make cost calculations and compare results of different cases.

In Unisim Design we created a case with Peng-Robinson fluid package and components: Nitrogen, Oxygen, Argon as we used Air as heat exchanging streams in PFHE. Set up worksheet as in Figure 2: LNG heat exchanger, two inlet and two outlet streams.

Table 1. Parameters of inlet streams in Unisim Design.

	Cold inlet	Hot inlet
Temperature	30°C	3°C
Pressure	5 bar_g	5 bar_g
Mass flow	300 tonne/h	300 tonne/h
Composition	Air	Air

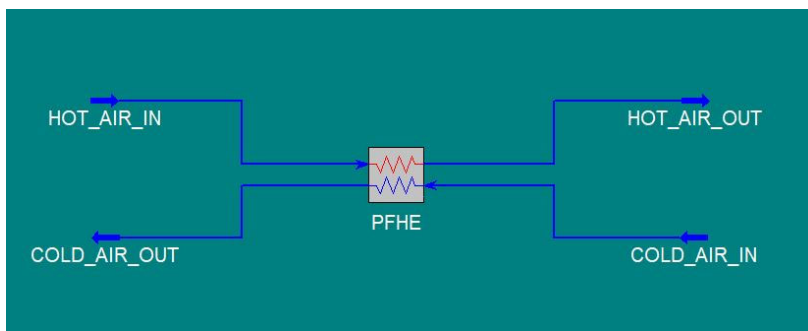


Fig. 2. Unisim Design worksheet overview.

2.1 Unisim PFE settings

In LNG heat exchanger unit operation we used Unisim PFE tab. In further steps each tab inside Unisim PFE is studied with regards to which of them are changed in this work.

In Exchanger tab we choose inlet streams, set flow direction for them inside PFE: in our case we have counter flow exchanger, set number of layers for each stream: 10 in Base case, distance to start of main fin: 50mm for all cases, orientation: 1 for all cases, exchangers in parallel: 1 for all cases, effective width: 500mm for Base case, exchanger metal: aluminium for all cases.

Process tab lets us to set estimated values mainly for pressure and temperature, it is recommended to do in some complicated PFE cases when we want to “help” Unisim to start calculations with values that are near to ones that should be. In our case none of parameters inside are changed.

Distributors tab is designed to set inlet, outlet and intermediate distributors parameters, types and dimensions which makes Unisim PFE model as near to real PFE as possible. None of parameters in this tab is set in current work.

In Layer patterns tab we can set different non-uniform layer patterns for PFE. It is especially important during design of heat exchangers with many layers. None of parameters in this tab is set in current work.

In Fins tab fins geometry such as fin height, thickness and frequency can be set, we also can choose their types from the list of Plain, Perforated, Serrated and Wavy fins. For base case fin height is 50mm, thickness is 0.5mm and fin frequency is 500 1/m.

Next tab to be changed is Stream Details, where for the Base case we choose Fin number (1) for each stream in heat exchanger and set the length of first Main Fin (500mm). Other parameters are not changed in current work.

Methods tab we are leaving as it is.

In Full results and Profiles tabs we can check summarized report on process parameters inside PFE and view the temperature profile as a plot. It is very convenient when comparing different PFE designs.

2.2 Thermal-economic calculations

For thermal-economic calculations we the heat exchanger’s total annual cost (TAC). The TAC is the summation of investment cost (C_{cp}) and operating cost (C_{op}). C_{cp} includes the unit area’s construction cost, heat exchanger surface area, and annual coefficient factor, where C_{op} contains the compressor electricity price as defined below [3]:

$$TAC = C_{cp} + C_{op} \tag{1}$$

$$C_{cp} = A_{cf} C_A A^e \tag{2}$$

$$C_{op} = [\zeta \tau \frac{\Delta P \dot{m}}{\eta \rho}]_h + [\zeta \tau \frac{\Delta P \dot{m}}{\eta \rho}]_c \tag{3}$$

where C_A , e , ζ , τ , and η presents the cost per unit surface area, exponent of nonlinear increase with area, electricity price of the compressor, operation time, and compressor effectivity in order. A_{cf} indicates the annual coefficient factor as below:

$$A_{cf} = \frac{r}{1 - (1+r)^{-y}} \tag{4}$$

The heat exchanger surface area for both hot and cold sides, A ($= A_h + A_c$), can be calculated in equations:

$$A_h = L_h L_c N_h [1 + 2n(H - t_f)] \tag{5}$$

$$A_c = L_h L_c N_c [1 + 2n(H - t_f)] \tag{6}$$

L_h, L_c – fins length of hot and cold sides of exchanger respectively

N_h, N_c – Number of fin layers of hot and cold sides of exchanger respectively

H, n, t_f – fin height, fin frequency and exchanger thickness respectively

Table 2. Constants of thermal-economic parameters.

Constants	Value
Cost per Unit Area, C_A (\$/m ²)	90
Electricity Price, ζ (\$/MWh)	20
Operation Hours, τ (hr)	5000
Exponent of Nonlinear Increase with area, e	0.6
Depreciation Time, y (yr)	10
Compressor Efficiency, η (%)	60
Interest Rate, r	0.1

3 Results

After process streams are set up as per Table 1 and PFE is set up as per Base case parameters in Table 3 we calculated Total Annual Cost (TAC) for Base case. After that we started changing PFE parameters as per Table 3.

Table 4 explanation: We have overall 6 cases in Table 4 (Case A – Case F). For example, For Case A we changed Number of layers, Case A as well as all other cases, has 3 subcases where for subcase 1 we have parameter value of 60% of Base case, for subcase 2 we have 140% of Base case and for subcase 3 we have 200% of Base case. In such manner we have some base case parameters, case with less value and more value of parameter comparing to the Base case. In Table 4 also included TAC for every subcase.

Table 3. Base case parameters.

Base Case	Stream name	Number of layers	Width	Fin height	Fin thickness	Fin frequency	Fin type	Length
	HOT_STRM	10	500	50	0.5	500	Plain	500
	COLD_STRM	10	500	50	0.5	500	Plain	500

4 Conclusion

As we can see from the results of our work each PFE design parameter affects the total annual cost of the exchanger. TAC was chosen as a parameter for comparing all subcases and finding the minimum among them. All PFE parameters are abstract ones and economical constants for calculating TAC are taken from [8]. TAC is calculated with regards to pressure drop through PFE thus we are choosing the most energy saving case and outlet temperatures of streams are not taken into account. Among all cases covered in the current work subcase 3 of Case B has minimal TAC of 1096 \$/year.

In current work, as it was stated in the beginning, were given only basic insights of implementation of Plate-fin heat exchanger in Unisim Design, was used two-stream set up and Total Annual Cost was calculated for different cases. This work can be expanded in several ways: more than 2 streams can be used, PFE parameters can be more complicated (more layers, different layer patterns, mixing of streams, etc.), optimization can be done not only by calculating TAC but also considering heat load, outlet temperature or any other target parameter using different optimization algorithms.

Table 4. PFE parameters.

Case name	Subcase	Number of layers	Width	Fin height	Fin thickness	Fin frequency	Fin type	Length	TAC
Case A	1	5	500	50	0.5	500	Plain	500	8615.7
	2	15	500	50	0.5	500	Plain	500	1675.0
	3	20	500	50	0.5	500	Plain	500	1305.8
Case B	1	10	300	50	0.5	500	Plain	500	6418.9
	2	10	700	50	0.5	500	Plain	500	1715.3
	3	10	1000	50	0.5	500	Plain	500	1095.9
Case C	1	10	500	30	0.5	500	Plain	500	6484.2
	2	10	500	70	0.5	500	Plain	500	NA
	3	10	500	100	0.5	500	Plain	500	NA
Case D	1	10	500	50	0.3	500	Plain	500	2046.8

	2	10	500	50	0.7	500	Plain	500	4104.9
	3	10	500	50	1	500	Plain	500	8582.5
Case E	1	10	500	50	0.5	300	Plain	500	1212.5
	2	10	500	50	0.5	700	Plain	500	5960.9
	3	10	500	50	0.5	1000	Plain	500	18918.8
Case F	1	10	500	50	0.5	500	Plain	300	1658.7
	2	10	500	50	0.5	500	Plain	700	3965.4
	3	10	500	50	0.5	500	Plain	1000	5729.2

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