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Consideration of Variable Physical Properties in Targeting Stage and Design of Heat Exchanger Networks with Different Type of Heat Exchangers

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Prediction of minimum required area and energy consumption (Targeting Stage) for heat recovery systems is one of the most important subjects in the synthesis of heat exchanger networks. This stage opens new insights to develop novel techniques for improving the current methods resulting in more realistic algorithms. Although, Pinch Technology contains a set of robust tools to assist designers to attain this purpose, in most current algorithms, physical properties are assumed to be constant. In this paper a new method is proposed, which takes the effect of fluid physical properties variations into account. This ability along with the pressure drop consideration forms a powerful algorithm for network area estimation ahead of design. In this method the dependency of physical properties, namely heat capacity, viscosity, density, and thermal conductivity, to temperature variation is considered. Therefore, all parameters of the Pressure Drop relationships are calculated more accurately. Having incorporated the correction factors in targeting and design of a heat exchanger network, involving gas and liquid streams, the results proved to be more accurate and reliable.

1. Introduction

Frequent application of heat exchanger networks (HENs) in miscellaneous industries, especially in chemical processes, and their considerable portion in total cost of a plant have continually motivated designers to develop new methods for prediction of investment requirement ahead of design. Proposing a novel method based on consideration of pressure drop in targeting stage, Panjeshahi (1991) resolved the deficits of previous works (Townsend and Linnhoff, 1984), which resulted in consistent results between targeting and detailed design stages. However, according to some sensitivity analyses done in different experimental works (Nellis, 2003 and van der Kraana et al., 2005), it is important to make the results more realistic while considering the variations of physical properties. Estimation of physical properties in small temperature intervals using MATLAB and HYSYS software is a method used by Ghannadi et al. (2009), which adversely makes a kind of difficulty in calculation. In contrast, Fallahi (1999)

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proposed a new method which led to reliable and accurate results in a short time. Fallahi introduced correction factors for both sides of a shell-and-tube heat exchanger, which have also an advantage to be applied in presented algorithms based on pressure drop consideration.
In this paper the correction factors for plate-and-fin heat exchangers will be derived to be implemented in targeting and design of a real industrial case study.

2. A thermo-hydraulic model for plate-and-fin heat exchangers

Heat transferred is mostly originated from frictional pressure drop across the core of a plate-and-fin exchanger (Kays and London 1984) which can be expressed by:

$$\Delta P = \frac{2 f L_p m^2}{d_h \rho A_c^2} = K_p V_T \left(\frac{h}{K_h}\right)^{\frac{3-y}{1-b}} \quad \text{or} \quad \Delta P_{eff} = \zeta K_p V_T \left(\frac{h}{K_h}\right)^{\frac{3-y}{1-b}} \tag{1}$$

Where K_p and K_h contain fin specifications, mass flow rate and physical properties.
To consider the variation of fluid physical properties the ζ parameter should be imposed, thus, the "*eff*" indices shall be considered to support the behavior of thermo-hydraulic relations.

3. Derivation of correction factors for plate-and-fin heat exchangers

Here, we have derived the ζ parameter for plate-and-fin exchangers. To indicate the behavior of Eq. (1) which includes all physical properties affecting momentum and heat transfer, the dependencies are categorized into performance parameters: ψ_{KP}, ψ_{VT} and ψ_h.

$$\Psi = \Psi_{K_P} \Psi_{V_T} \Psi_h^{\frac{3-y}{1-b}} = \rho^{\phi_1} C_p^{\phi_2} \mu^{\phi_3} \lambda^{\phi_4} \tag{2}$$

These performance parameters need to be integrated through the supply and target stream temperatures, since it is the representation of variable changes by temperature. Ultimately, for each stream a unique ζ will be obtained. For example, for stream j:

$$\zeta_j = \frac{\int_{T_{Sj}}^{T_{Tj}} \psi_j \, dT}{(T_{T_j} - T_{S_j}) \rho_{oj}^{\phi_1} C_{poj}^{\phi_2} \mu_{oj}^{\phi_3} \lambda_{oj}^{\phi_4}} \tag{3}$$

3.1 Definition of pressure drop performance parameter, ψ_{KP}

As mentioned before, K_P includes fin specifications, mass flow rate and physical properties which temperature dependency can be introduced by following manner:

$$\Psi_{K_P} = \frac{\mu^y}{\rho} \tag{4}$$

3.2 Definition of heat transfer coefficient performance parameter, ψ_h

The exhaustive parameter to illustrate the dependency of heat transfer coefficient on physical properties is defined by:

$$\Psi_h = \frac{\lambda^{\frac{2}{3}} C_p^{\frac{1}{3}}}{\mu^{\frac{2}{3}-b}} \tag{5}$$

3.3 Definition of total volume of heat exchanging performance parameter, ψ_{VT}

With regard to the role of this parameter which is an effective volume of the fluid for heat exchanging, no dependency with temperature can be found. Therefore:

$$\Psi = \Psi_{K_p} \Psi_h^{\frac{3-y}{1-b}} = \frac{\lambda^{\frac{2}{3}(\frac{3-y}{1-b})} C_p^{\frac{1}{3}(\frac{3-y}{1-b})}}{\rho \mu^{(\frac{2}{3}-b)(\frac{3-y}{1-b})-y}} \tag{6}$$

4. Case study-Refinery

Application of the correction factors would be clarified by applying it in a real case study of a refinery in Iran. The stream data and integral mean value of physical properties are presented in Table 1; also, calculated correction factors for each stream are summarized in Table 2.

Table 1: Process data for case study

Stream	T_S (°C)	T_T (°C)	m (kg/s)	ρ_o (kg/m^3)	Cp_o (J/kg°C)	μ_o (cP)	λ_o (W/m°C)	ΔP (kPa)
H_1 (l)	115	41	10.96	650	2318	0.24	0.099	20
H_2 (l)	124	38	0.91	729	2168	0.47	0.12	5
H_3 (l)	193	157	32.66	692	2653	0.27	0.12	50
H_4 (l)	265	193	9.79	642.5	2384	0.13	0.12	20
H_5 (l)	182	49	41.45	689	2763	0.26	0.135	60
H_6 (l)	251	43	8.53	756	2398	0.28	0.14	20
H_7 (l)	358	50	34.26	839.5	2576	0.21	0.155	50
C_1 (l)	25	115	65.17	830.5	2091	0.93	0.14	60
C_2 (l)	115	370	43.04	725.5	2296	1.15	0.12	60
C_3 (g)	115	370	22.13	3.18	2429	0.027	0.047	40

Table 2: Calculated correction factors for streams

Stream	H_1	H_2	H_3	H_4	H_5	H_6	H_7
ζ	1.0030	1.2668	1.3497	1.1532	1.0894	1.4526	1.1772
Stream	C_1	C_2	C_3				
ζ	1.4529	1.7124	1.7799				

Table 3: Comparison of targeting results of the new method with conventional constant physical properties method

Method	Constant physical properties	Variable physical properties
Area (m^2)	4789	4673
Area cost ($/yr)	1131983	1111736
Energy (kW)	31510	30916
Energy cost ($/yr)	2137675	2061224
Running cost* ($/yr)	115516	111146
Installation cost* ($/yr)	51898	51885
Total annual cost ($/yr)	3437072	3335991

** For Pumps and compressors*

Table 4: Detailed design of heat exchangers

Exchanger	E_1	E_2	E_3	E_4	E_5	C_1	C_2	C_3
Type	PFHE	STHE	STHE	STHE	PFHE	STHE	STHE	STHE
Area (m^2)	375.56	388	130	210	339.82	77.2	7.96	151
Exchanger	C_4	C_5	H_1	H_2	H_3			
Type	STHE	STHE	STHE	PFHE	PFHE			
Area (m^2)	74.92	645.5	575	356	410			

Table 5: Design summery based on new method

	Targeting	Synthesis	Detailed design
Area (m^2)	4673	4236	3740
Area cost ($/yr)	1111736	1001655	376992
Energy (kW)	30916	32941	48752
Energy cost ($/yr)	2061224	2306838	2807743
Running cost* ($/yr)	111146	111146	111146
Installation cost* ($/yr)	51885	51885	51885
Total annual cost ($/yr)	3335991	3471524	3347767

** For Pumps and compressors*

Table 3 compares the targeting results of the current method with presented new method considering the variable physical properties. All data is calculated using PILOT software. As indicated in Table 3, consideration of the variable physical properties caused more reliable and accurate results which show a difference in required area, energy consumption, and total annual cost of the process about 2.42%, 1.89% and

2.94 %, respectively. It should be noted that minimum temperature driving force has also changed into 17 ºC, instead of 20 ºC. Applying the new method in synthesis stage, 13 heat exchangers were laid on the streams in such a way to obtain vertical alignment (Figure 1). Our strategy is using PFHE for gas streams and STHE for liquid streams. Also, PFHE has a priority to STHE where we can apply both type of exchangers. Finally, the detailed design of all heat exchangers are calculated based on effective pressure drop (ΔP_{eff}) and integral mean value of physical properties for each stream (Table 4). In Table 5 different stages of design calculated by PILOT are summarized. The results show a good consistency between different stages.

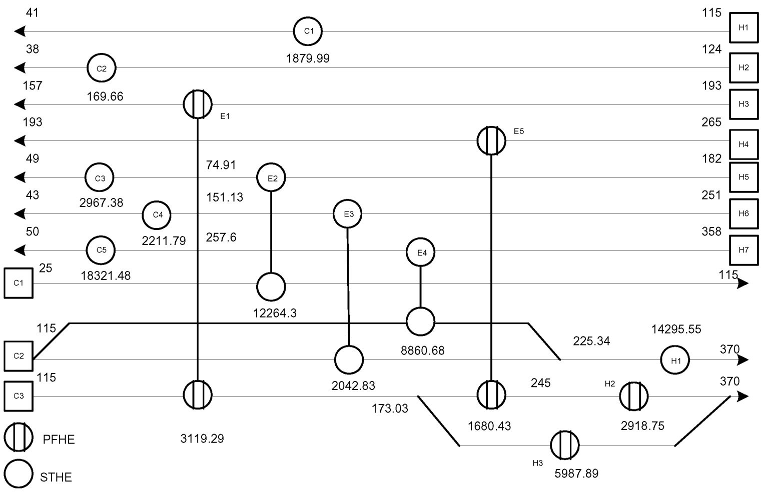

Figure 1 : Final network design @ ΔT_{min}=17 ºC

5. Conclusions

The variation of stream physical properties, especially, on those with a great difference between input and output temperatures, is considered in plate-and-fin heat exchangers. It could be more crucial for the cases in which there are a number of gases or two phase streams. Having included the correction factors in targeting and design of a heat exchanger network, the results proved to be more accurate owing to obtain relatively real heat transfer coefficients. Moreover, the proposed method is applicable in all recently proposed algorithms and easily functioned in industrial cases including a vast heat exchanger networks.

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Nomenclature

A_c free flow area, m^2
b exponent in heat transfer vs. Re correlation
C cold streams
C_p heat capacity, J/kg °C
d_h hydraulic diameter, m
f friction factor
g gas
h heat transfer coefficient, $W/m^2 °C$
H hot streams
K constant
l liquid
L_p exchanger length, m
m mass flow rate, kg/s
PFHE plate-and-fin heat exchanger
ΔP pressure drop, (kPa)
Q heat duty, kW
STHE shell-and-tube heat exchanger
T temperature, °C
T_S supply temperature, °C
T_T target temperature, °C
Ut utility
V_T total volume of heat exchanger, m^3
y exponent in friction factor vs. Re correlation

Greek letters

μ viscosity, cP
ζ correction factor
λ thermal conductivity, W/m °C
ρ density, kg/m^3
ψ performance parameter

Subscripts

eff effective
o integral mean value of each physical property
s shell
t tube

References

Fallahi H.R., 1999, Pressure Drop Optimization in Process Integration, Ph.D Thesis, University of Tehran, Iran.
Ghannadi M.M., Omidkhah M.R., Hojjati M.R., 2009, Area Targeting of HEX for Shiraz Refinery Atmospheric Distillation Unit with Variable Physical Properties of Crude Oil Consideration, The 6th International Chemical Engineering Congress & Exhibition, Kish Island, Iran.
Kays W.M. and London A.L., 1984, Compact Heat Exchangers, 3rd ed., McGraw Hill, New York.
Nellis G.F., 2003, A Heat Exchanger Model that Includes Axial Conduction, Parasitic Heat Loads, and Property Variations, Cryogenics, 43, 523–538.
Panjeshahi M.H., 1991, Pressure Drop Consideration in Process Integration, Ph.D. Thesis, UMIST, Manchester, UK.
PILOT Software, a software for targeting and design of heat exchanger networks, 2010, School of Chemical Engineering, University of Tehran, IRAN.
Townsend D.W. and Linnhoff B., 1984, Surface Area Targets for Heat Exchanger Networks, IChemE 11th Annual Research Meeting, Bath, UK.
Van der Kraana M., Peetersa M.M.W., Fernandez Cida M.V., Woerleeb G.F., Veugelersb W.J.T. and Witkampa G.J., 2005, The Influence of Variable Physical Properties and Buoyancy on Heat Exchanger Design for Near- and Supercritical Conditions, Journal of Supercritical Fluids, 34, 99–105.