CHEMICAL ENGINEERING TRANSACTIONS

VOL. 29, 2012

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Hon Loong Lam, Jiří Jaromír Klemeš

ISBN 978-88-95608-20-4; ISSN 1974-9791

DOI: 10.3303/CET1229037

# Design Space for the Sizing and Selection of Heat Exchangers of the Compact Type

Martín Picón-Núñez[a*], Graham Thomas Polley[a], José Manuel Riesco-Ávila[b]

[a]Departmet of Chemical Engineering, University of Guanajuato, Guanajuato, México
[b]Department of Mechanical Engineering, University of Guanajuato, Salamanca, México.
picon@ugto.mx

This paper shows the application of a graphical design tool originally developed for shell and tube heat exchangers and extended to the case of compact units. Such a graphical tool provides the design space where the available options that meet the heat duty and allowable pressure drops are displayed for the various geometrical parameters. This representation gives the designer the overall view that allows him to reconcile design specifications with the selection of the unit for the given application. The methodology is demonstrated using a design algorithm developed for the case of spiral heat exchangers. Although the design methodology is derived from the concept of full utilization of allowable pressure drop, the design space is determined considering standard exchanger by a set of set of three curves: a curve that represents the heat duty (thermal length) and two curves that represent the pressure drop on the hot and cold streams (exchanger length). The intersection of the two former lines with the heat duty curve that results in a shorter flow length represents the required exchanger dimensions.

## 1. Introduction

Design or sizing of a heat exchanger refers to the specification of the geometry through which the heat load is transferred within the limitations of allowable pressure drop. In the case of spiral heat exchangers this geometry involves: plate spacing of the two streams, plate width, inner diameter, outer diameter and passage length. In this paper, a simple approach the selection of spiral plate exchangers using a graphical representation of the design space is presented. The approach for the sizing of the spiral units used for the generation of the space design is the one developed by Picón et al. (2007, 2010).

The graphical selection approach consists of a plot where heat load and pressure drop lines are drawn for a range of design parameters such as: plate spacing for the hot and cold streams ($b_h$ and $b_c$), plate width ($W$) and plate length ($L$) (Serna et al. 2007). Other important exchanger geometrical parameters are: spiral internal diameter ($d_s$) and spiral external diameter ($D_s$) as shown in Figure 1.

The underlying thermal and hydraulic assumptions of the methodology presented in this work are: the effects of the entrance regions are not considered; the heat transfer coefficients are considered constant along the length of the exchanger; heat losses to ambient are negligible; since bolts are used to separate the thermal plates they are considered not to affect the fluid movement.

Please cite this article as: Picón-Núñez M., Polley G. T. and Riesco-Avila J. M., (2012), Design space for the sizing and selection of heat exchangers of the compact type, Chemical Engineering Transactions, 29, 217-222

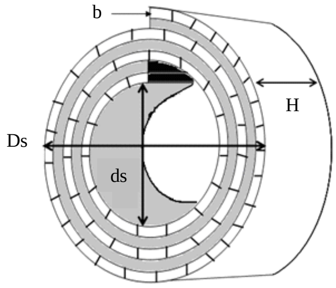


*Figure 1. Main geometrical variables of a spiral heat exchanger*

## 2. Design Methodology

The design of a spiral heat exchanger starts by specifying the following geometrical variables: plate spacing for the cold and hot stream ($b_1$ and $b_2$) and the plate width ($H$). Using this information, free flow area (Ac) and the Reynolds number are calculated from:

$$A_c = bH \tag{1}$$

$$\mathrm{Re} = \frac{d_h m}{\mu A_c} \tag{2}$$

Where $d_h$ is the hydraulic diameter and is given by:

$$d_h = \frac{2bH}{b+H} \tag{3}$$

For a Reynolds number in the range between 400 and 30,000 the heat transfer coefficient can be calculated from:

$$Nu = 0.04\,\mathrm{Re}^{0.74}\,\mathrm{Pr}^{0.4} \tag{4}$$

Where the Prandtl number is given by:

$$\mathrm{Pr} = \frac{c_p \mu}{k} \tag{5}$$

The pressure drop across the core of the exchanger is found from:

$$\Delta P = \frac{2\,fLm^2}{\rho\, d_h A_c^2} \tag{6}$$

Where $f$ is the friction factor, $L$ is the length of the stream, $m$ is the mass flow rate and $\rho$ is the density. The friction factor can be estimated for the laminar, transitional and turbulent flow from (Hesselgreaves, 2001):

$$f\ \mathrm{Re} = 24\left(1 - 1.3553\frac{b}{H} + 1.9467\left(\frac{b}{H}\right)^2 - 1.7012\left(\frac{b}{H}\right)^3 + 0.9564\left(\frac{b}{H}\right)^4 - 0.2537\left(\frac{b}{H}\right)^5\right) \tag{7}$$

$$f = 0.0054 + \frac{2.3x10^{\;8}}{Re^{-\frac{3}{2}}} \tag{8}$$

$$\frac{1}{\sqrt{f}} = 1.56\ln(Re) - 3.00 \tag{9}$$

The external diameter of the unit $D_o$, and the number of spiral turns $N_p$ can be determined form (Dongwu, 2005):

$$D_o = r_1 + r_2 \tag{10}$$

$$N_p = N + 0.5 \tag{11}$$

$$N = n + n_o \tag{12}$$

$$n + n_{odi} = \frac{-(d_1 - t/2) + \sqrt{(d_1 - t/2)^2 + 4tL/\pi}}{2t} \tag{13}$$

When $0 \le n_{odi}$ (or $n_o$) $\le 0.5$

$$L = \pi t n^2 + \pi(d_1 - t/2)n + \pi(d_1 + 2nt)n_o \tag{14}$$

$$R = \frac{d_1}{2} + nt \tag{15}$$

$$r = \sqrt{R^2 + (\frac{t}{4})^2 - \frac{Rt}{2}\cos(2n_0\pi)} \tag{16}$$

When $0.5 \le n_{odi}$ (or $n_o$) $\le 1$

$$L = \pi t n^2 + \pi(d_1 - t/2)n + \pi\left[d_1 + (2n+1)t\right]n_o \quad \pi t/2 \tag{17}$$

$$R = \frac{d_1}{2} + (n + \frac{1}{2})t \tag{18}$$

$$r = \sqrt{R^2 + (\frac{t}{4})^2 - \frac{Rt}{2}\cos\left[(2n_o - 1)\pi\right]} \tag{19}$$

The variables *t*, $d_{11}$ and $d_{f1}$ can be obtained from:

$$t = b_1 + b_2 + 2\delta \tag{20}$$

$$d_{11} = d_{21} + b_1 - b_2 \tag{21}$$

$$d_{f1} = d_{21} + b_1 + 2\delta \tag{22}$$

If *L* and *R* are known, $d_1$ can be obtained from:

$$L: \quad d_1 = d_{f1} \tag{23}$$

$$L_1: \quad d_1 = d_{11} + \delta \tag{24}$$

$$L_2: \quad d_1 = d_{21} + \delta \tag{25}$$

$$R_1: \quad d_1 = d_{11} + 2\delta \tag{26}$$

$$R_2: \quad d_1 = d_{21} + 2\delta \tag{27}$$

Standard dimensions for spiral exchangers (Picón et al., 2007) are given in Table 1 and is used to demonstrate the methodology. The design information for the case study is shown in Table 2.

*Table 1. Standard dimensions for spiral heat exchangers*

| Plate width (m) | Maximum External Diameter (m) | Internal diameter (m) |
|---|---|---|
| 0.102 | 0.813 | 0.203 |
| 0.152 | 0.813 | 0.203 |
| 0.305 | 0.813 | 0.203 |
| 0.305 | 1.473 | 0.305 |
| 0.457 | 0.813 | 0.203 |
| 0.457 | 1.473 | 0.305 |
| 0.61 | 0.813 | 0.203 |
| 0.61 | 1.473 | 0.305 |
| 0.762 | 1.473 | 0.305 |
| 0.914 | 1.473 | 0.305 |
| 1.219 | 1.473 | 0.305 |
| 1.524 | 1.473 | 0.305 |
| 1.778 | 1.473 | 0.305 |

Plate spacing [m]:$4.762 \cdot 10^{-3}$ (for a maximum plate width of 0.305 m), $6.35 \cdot 10^{-3}$ (for a maximum plate width of 1.219 m), $7.938 \cdot 10^{-3}$, $9.525 \cdot 10^{-3}$, 0.013, 0.016, 0.019 and 0.025.

Plate thickness [m]: stainless still, 14 – 3 U. S. Carbon steel, $3.175 \cdot 10^{-3}$, $4.762 \cdot 10^{-3}$, $6.35 \cdot 10^{-3}$ and $7.938 \cdot 10^{-3}$

*Table 2. Stream data for case study*

| | Hot stream | Cold stream |
|---|---|---|
| Flow rate (kg/s) | 0.783 | 0.744 |
| Inlet temperature (°C) | 200 | 60 |
| Outlet temperature (°C) | 120 | 150.4 |
| Heat capacity (J/kg °C) | 2,973 | 2,763 |
| Thermal conductivity (W/m °C) | 0.348 | 0.322 |
| Density (kg/m$^3$) | 843 | 843 |
| Pressure drop (Pa) | $6.89 \times 10^{-2}$ | $6.89 \times 10^{-2}$ |
| Viscosity (kg/m s) | $3.35 \times 10^{-3}$ | $8.0 \times 10^{-3}$ |
| Plate thickness (m) | $3.175 \times 10^{-3}$ | |
| Internal diameter (m) | 0.203 | |
| Thermal conductivity of material of construction (W/m °C) | 17.3 | |

## 3. Results

The design space is a graphical display of three curves, namely: the plate length that meets the heat duty for a given plate width (thermal length); the plate length that meets the pressure drop for the hot stream (hydraulic length) and the plate length that meets the cold stream pressure drop for a given plate width (hydraulic length). These curves are determined for a given plate spacing.

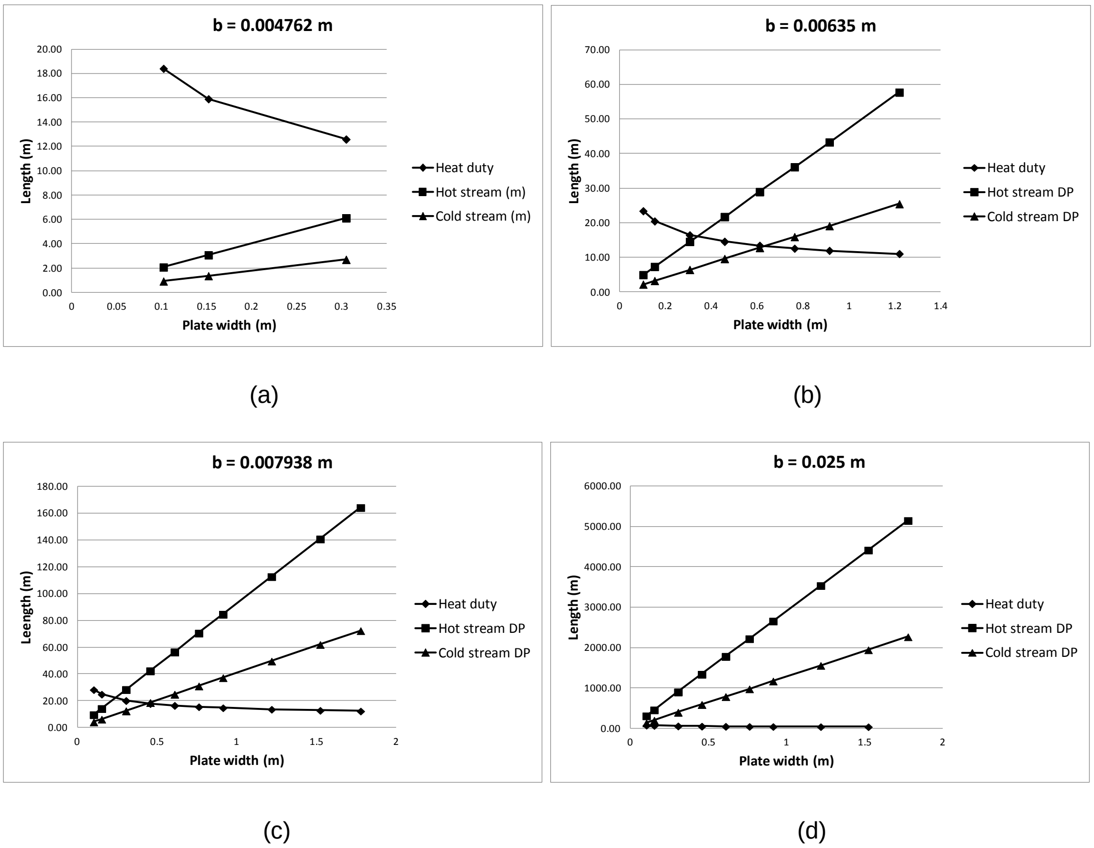


*Figure 2. Design space for the case study.*

Figure 2 shows the design space for the case study. Plots for four different plate spacing values (*b*) are displayed, namely: 0.004762 m, 0.00635 m, 0.007938 m and 0.025 m. The intersection between the curves indicates the exchanger dimensions for which the thermal length equals the hydraulic length. When the pressure drop of the two streams is different, the resulting space design is like the one shown in Figure 2. For a small place spacing value (b = 0.004762 m), a large plate width would be required to meet the process duty. The opposite occurs at large plate spacing values (b = 0.025 m) where there seems to be no plate width that meets the process duty. For values in between there are some options, for instance, for a plate spacing of b = 0.00635 m, a plate width of 0.6 m with a plate length of 12.74 m will exactly meet the process duty and the cold stream pressure drop while the pressure drop on the hot side will be lower than specified. In the case of b=0.007938 m, a plate width of 0.5 m with a plate length of 18.69 m will result in full pressure drop being absorbed on the cold stream for the required heat duty.

## 4. Conclusions

Design and specification of heat exchangers are activities that can be conducted simultaneously through the use of the concept of design space which refers to the graphical representation of the design parameters that that fulfill the process heat load and pressure drops. The design of heat exchanger allows the determination of the geometry dimensions that will meet the heat duty with the restrictions of pressure drop. On the other hand exchanger specification refers to the selection of the exchanger dimensions that will meet the heat duty within the limitations of pressure drop. This work has shown a simple way of using these plots, this is it has been assumed that the place spacing of the two streams is the same. The methodology can easily be extended to cases where the plate spacing of the streams differ from each other, giving a more complete picture of the design options available to the designer, what is more, this design methodology can readily be adapted to cover other types of exchanger technologies.

**References**

Dongwu W., 2005. Method of computing outside diameter of the SHEs, Chemical Engineering Design, 15, 4, 36-42.

Hesselgreaves J. E., 2001. Compact heat exchangers, pp. 155-200, Pergamon Press.

Picón-Núñez M., Canizalez-Dávalos, L., Martínez-Rodríguez, G., Polley, G.T., 2005. Shortcut design approach for spiral heat exchangers, Food and Bioproducts Processing, Trans IChemE, Part C, 85, 322-327.

Picón-Núñez M., Polley G.T., Jantes-Jaramillo D., 2010, Alternative design approach for plate and frame heat exchangers using parameter plots, Heat Transfer Engineering, 31, 9, 742-749.

Serna-González M., Ponce-Ortega J. M., Castro-Montoya A. J., Jiménez-Gutiérrez A., 2007. Feasible Design Space for Shell-and-Tube Heat Exchangers Using the Bell−Delaware Method Ind. Eng. Chem. Res., 46, 1, 143–155.