CHEMICAL ENGINEERING TRANSACTIONS

VOL. 69, 2018

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

Guest Editors: Elisabetta Brunazzi, Eva Sorensen
Copyright © 2018, AIDIC Servizi S.r.l.
ISBN 978-88-95608-66-2; **ISSN** 2283-9216

DOI: 10.3303/CET1869148

New Conceptual Design Methodology for a Concentric Heat Integrated Distillation Column (HIDiC)

Mylène Detcheberry Marin, Michel Meyer, Benoit Mizzi*, David Rouzineau

Laboratoire de Génie Chimique, Université de Toulouse, CNRS, INPT, UPS, Toulouse, France
benoit.mizzi@ensiacet.fr

The concept of Heat Integrated Distillation column (HIDiC) was introduced by Mah et al. (1977) to improve the energy efficiency of distillation processes. The aim of this study is to propose a new conceptual design methodology for concentric HIDiC. Our methodology is based on simulation of the process performed on ProsimPlus^{TM} and found the optimised heat exchange between the two parts of the process. The optimised heat exchange is characterized by the maximum of energy transmissible between the two sections, before the column does not work properly and the simulation does not run. This paper presents the three different steps to achieve the design of the concentric HIDiC for chosen operating conditions. The design procedure and the simulation are carried out for the separation of a binary mixture cyclohexane and n-heptane. In addition to presenting the design results, the energy gain was verified compared to the simulation of a classical distillation column.

Conceptual design, Heat Integrated Distillation Column (HIDiC), heat transfer, process intensification

1. Introduction

Distillation is one of the most energy intensive consuming units in chemical process industries. This is related to the low thermodynamic efficiency of classic distillation, which occurs due to large differences between reboiler and condenser temperatures. Many configurations have been proposed in the literature to save energy, such as: dividing-wall columns (DWC), direct vapor recompression scheme column (VRC), diabatic distillation, and the internally heat-integrated-distillation column (HIDiC). All these configurations have been compared by Kiss et al., (2012) and the authors advise ranges of applicability in terms of relative volatility and pressure/temperature conditions for each technology. The concept of HIDiC was introduced by Mah et al. (1977) to improve the energy efficiency of distillation processes. Although this technology has limitations, the HIDiC are interesting in some cases, especially when the boiling temperatures of the species to be separated are close. This is why HIDiC are the subject of this study. The principle of the HIDiC is the combination of vapor recompression scheme and heat integration between the two diabatic sections of the column (see Figure 1). The rectifying section temperature is raised and it is in direct contact with the stripping section. The vapor compression at the entrance of the rectification section insures the increase of temperature. Thanks to this heat transfer from the rectifying section to the stripping section, the reboiler duty decreases. By coupling vapor recompression and diabatic column, an energetic gain between 30% and 50% could be achieved (Olujić et al., 2009). Different methodologies to simulate HIDiC processes are proposed in the literature by Gadalla, (2009). Other methodologies are proposed to design HIDiC process (Suphanit, 2010) but they are all based on the economic evaluation to assist the structural optimisation of the process. In the current study, a new approach based on the maximal heat transfer between both column sections is proposed. So the optimal design is determined with the best performances accessible with the maximum amount of energy that may be transferred, independent of the pressure gap chosen and without any economical consideration. Thus, this method can be very useful for process revamping operation. The method is composed of three steps; first step consists in the pre-design and simulation of a classical distillation column, second step is to determine on one hand the pressure gap between the two sections of the HIDiC column and on the other hand the maximum amount of heat exchanged, and third step, an iterative procedure is used in order to derive the best heat exchange profile with respect to hydrodynamic and heat transfer constraints.

Please cite this article as: Detcheberry Marin M., Meyer M., Mizzi B., Rouzineau D., 2018, New conceptual design methodology for a concentric heat integrated distillation column (hidic), Chemical Engineering Transactions, 69, 883-888 DOI: 10.3303/CET1869148

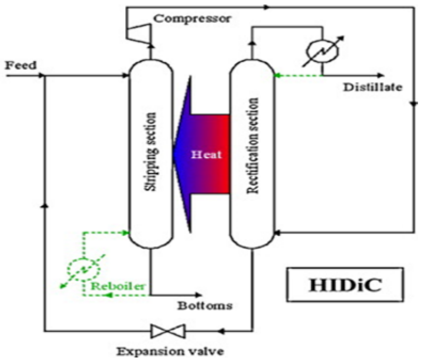

Figure 1: Scheme of the HIDiC configuration (Bruinsma et al., 2012).

2. Heat Integrated Distillation Column conception and Results, case study

The separation of a binary mixture with cyclohexane and n-heptane is studied for this case study. The activity coefficient thermodynamic model NRTL is chosen for the simulation and the liquid phase, steam is considered as ideal gas. The feed composition is 50/50 of the two compounds with a 20 kg/h global feed flowrate. The Table 1 resumes the specifications of the feed flowrate. Action variables to reach the fixed separation specifications (residue purity $x_{nC7,res}$ and distillate purity $x_{C6,dis}$) are the distillate flowrate in the stripping section and the reflux of the rectification section.

Table 1: Specification of the treated feed for the case study.

Mass composition (-)		Global Flowrate (kg/h)	Pressure (atm)	Temperature (°C)
Cyclohexane 0.5	n-Heptane 0.5	20	1	(Bubble temperature) 88.20

2.1 Basic design of HIDiC column

The Figure 2 presents the simulation scheme of HIDiC. The stripping section (external colum) is simulated as a column with a reboiler and without condenser. The rectification section (inner column) is simulated as a column without reboiler and with a condenser. The residue and the distillate come from respectively of the external column and of the inner column. The pressure gap between the two sections, to ensure a temperature difference between the two sections, is simulated as a compressor with an isentropic factor of 0.75. An isenthalpic expansion valve insures the depression of the rectification section liquid to the stripping section.

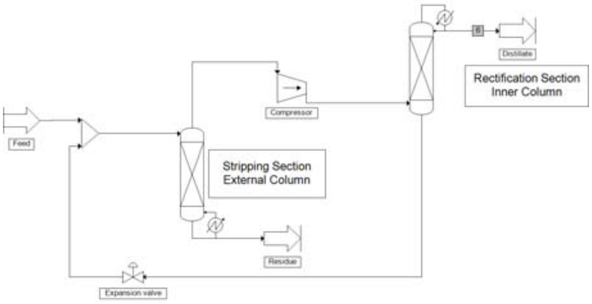

Figure 2: Scheme of the simulated HIDiC (ProsimPlus^{TM}).

2.2 Design methodology of HIDiC

This section presents the design methodology of HIDiC. It is composed of three classified steps where the results of a step are useful for the next step to ensure a good result, the design of HIDiC. The Figure 3 presents the flow diagram of the design procedure.

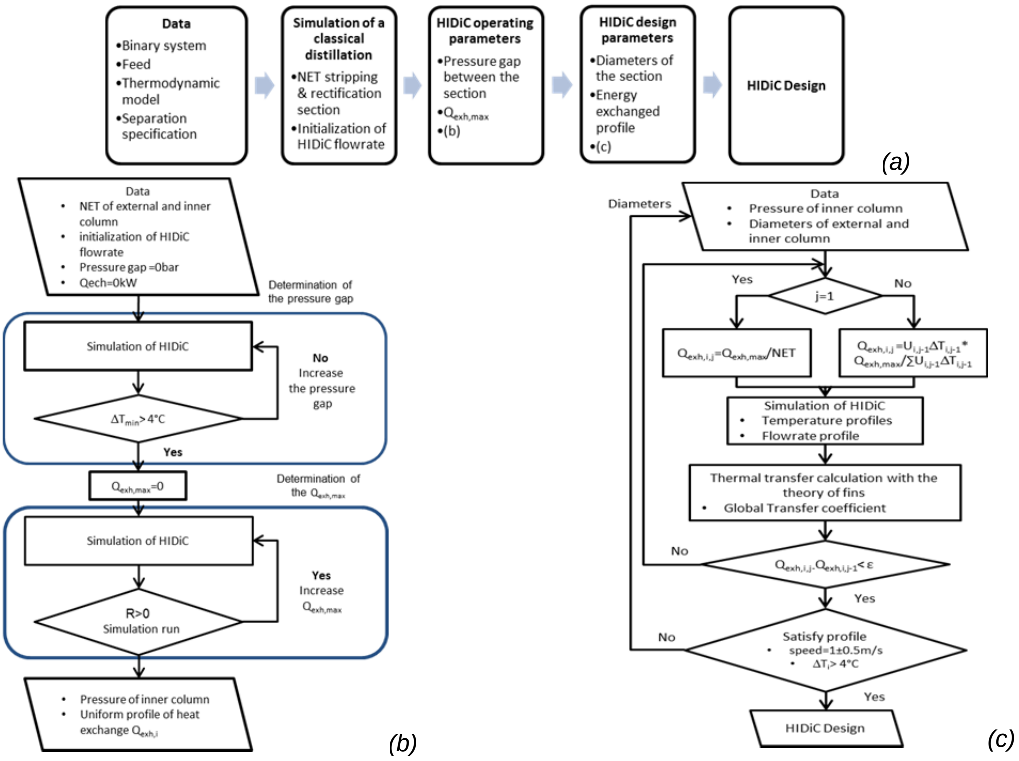

Figure 3: flow diagram of HIDiC design procedure

The aim of the first step is to simulate a classical distillation column and determined initialization parameters of HIDiC. Second step is the determination operating parameters of HIDiC as the pressure gap and the maximum amount of heat exchange. Finaly the third step simulate HIDiC where the hydrodynamic and thermal transfer is taken into account with the theory of fins adapted to the packing technologies used in HIDiC. The aim of this step is to define the geometrical parameters of the column.

Step I: first design parameter, Number of Theoretical Stage

The initialization of the HIDiC design methodology is based on the performance of a conventional distillation column to which the same operating conditions and specifications are applied. The parameters of this first column were determined using the shortcut method (Fenske-Underwood-Gilliland, Kirkbride). The results obtained are as follows and summarize in the Table 2.

Table 2: Results of the shortcut method of the case study

Reflux ratio R	Theoretical plate	Save energy to the condenser	Use energy at the boiler
3.107	36 plates (Boiler and condenser included) 20 stripping plates (condenser included) 16 rectifications plates (boiler included)	4.05 kW	4.84 kW

The operating parameters for the simulation of the classical distillation column are fixed with the results of the shortcut simulation (Table 2). The following results resume in Table 3 of the classical distillation column are use to initialize the simulation of the HIDiC column. The separation specifications are the mass composition of cyclohexane and n-heptane respectively at the distillate and the residue. The action variables are the distillate flowrate ant the reflux ratio. The results of the classical distillation simulation form an initialization point for the HIDiC simulation. The chosen initialization parameters are resumed in the Table 4. With the simulation scheme of HIDiC and with the determined initialization point, the second step can be performed to determine the operating parameters of HIDiC.

Table 3: Operating parameters of the classical distillation

Reflux ratio R	Theoretical plate	Save energy to the condenser	Use energy at the boiler
2.96	40 (Boiler and condenser included) 20 stripping plates (condenser included) 20 rectifications plates (boiler included)	3.92 kW	4.71 kW

Table 4: Initialization point of the HIDiC simulation

Theoretical plate	Parameters of residue flowrate of rectification section	Distillate flow rate of rectification section	Distillate flowrate of stripping section
20 stripping plates (external column) (condenser included) 20 rectifications plates (inner column) (boiler included)	Flowrate=0.65kmol/h* $x_{mass,c6}$=0.61	T=86.34 10kg/h	0.45kmol/h*

**Some of the flowrate are given in different units (kmol/h), because they must be used in this special unit.*

Step II: operating parameters of the HIDiC, pressure gap and maximum amount of heat exchanged

The aim of this step is to determine two operating parameters of HIDiC. They are the pressure gap and the maximum amount of heat exchange between the two sections. On the one hand, the pressure gap is determined to ensure a minimum temperature difference of at least 4°C. This ensures proper operation of the column. The simulation is run with different compressor pressure and the temperature difference between the two sections is computed. The chosen pressure gap is 1.6bar as one can see on Table 5 with the minimum maximum and mean temperature difference.

Table 5: Difference temperature between inner and external column according to the pressure gap evolution

Pressure gap (bar)	ΔT_{min} (°C)	ΔT_{max} (°C)	ΔT_{avg} (°C)
1.1	-8.30	-2.95	-5.75
1.2	-8.37	0.31	-5.45
1.3	-5.53	3.07	-2.64
1.4	0.04	5.45	2.58
1.5	2.56	7.96	5.14
1.6	4.93	10.30	7.46
1.7	7.14	12.49	9.57

On the other hand, the maximum amount of energy exchange is determined to have the order of magnitude of the amount of energy exchanged between the two columns. At the pressure gap determined, the simulation is run with increasing and uniformly distributed amount of energy exchange. By increasing the energy exchange, liquid is boiling more and more in the stripping section, and in the rectification section the steam condense. At the maximum amount of heat exchange all the steam in the rectification section is condense at the column head. On the simulation results, the reflux is nul, the convergence objective increase and/or the simulation does not run. Figure 3(b) presents the algorithm of the procedure for determining the column operating parameters. The following Figures 4 and 5 resumes the results of the different iterations of the determination $Q_{éch,max}$.

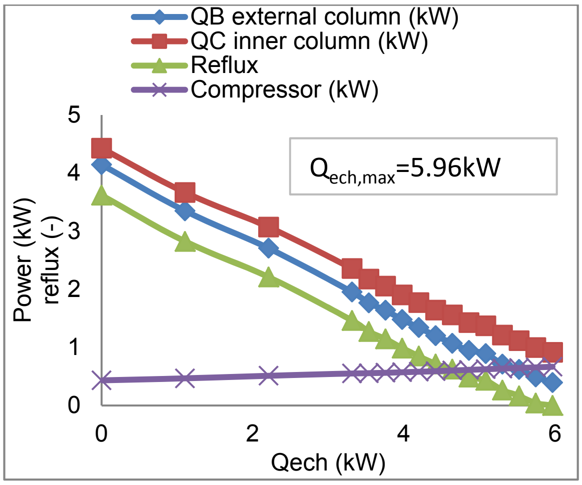

Figure 4: Evolution of HIDiC operating parameters according to the heat exchange

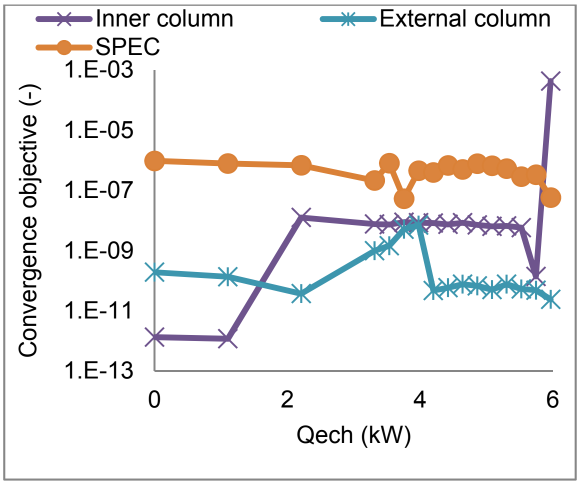

Figure 5: convergence objective simulation unit according to the heat exchange

Step III: Optimization of heat distribution and last geometric design parameters

The third step consists of the simulation of HIDiC with the distribution of heat exchange and the determination of the geometrical parameters of the column, inner and external diameters. The heat exchange is calculated by applying the basic overall heat-transfer equation (1) for the heat exchange:

$$Q_{éch,i} = U_i \Delta T_i \frac{Q_{éch,max}}{\sum U_i \Delta T_i} \qquad (1)$$

Where, U is the overall heat transfer coefficient (J.m^{-2}.s^{-1}.°C^{-1}) and ΔT is the temperature difference between the two section. The exchange area is considered constant, so it is assumed that the liquid and the gas are evenly distributed over the packing throughout the column. The heat exchange calculated is implemented in the module (external and inner column) and simulated to reach the separation objectives. The results of the two sections are useful to calculate the overall heat transfer coefficient U by using the fins theory adapted to the packing used in HIDiC. The liquid entering the external column is evaporated along the column and the vapor formed is introduced into the internal column where it condenses. We consider three thermal transfer phenomena along the column:

- the convective transfer by condensation of the vapor inside the column, characterized by the transfer coefficient h_{cond}
- the convective transfer by evaporation of the liquid outside the column, characterized by the transfer coefficient h_{evap}
- the conduction in the fins, characterized by the transfer coefficient λ_m

The overall transfer coefficient in the column is calculated taking into account the three phenomena. The results of each iteration are compared to the previous iteration and the calculation method is repeated until the results converge. The temperature and steam speed profiles must satisfy the hydrodynamic and heat transfer constraints, steam speed 1±0.5m/s and difference temperature between the two sections is more than 4°C. If the profiles respect the constraints, the geometrical design is good, if the profiles are not satisfying, the diameters are adjusted and a new simulation is performed until the heat transfer and hydrodynamics constraints are respected. Figure 3 presents the algorithm of the procedure for determining the column diameters. The numerical values of the initial and final geometrical data of the column and the foam are recalled in the following table

Table 6: Geometrical parameters of HIDiC

Parameters	initialization value	design value
D_{int} (m)	0.08	0.06
D_{ext} (m)	0.15	0.08

The Figure 6 to 8 present the heat transfer and the hydrodynamic condition with the determined geometrical parameters resume in the Table 6.

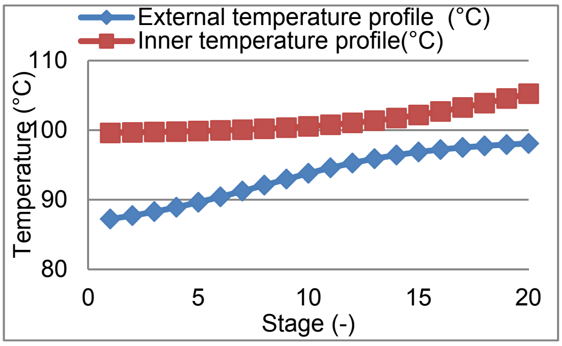

Figure 6: Temperature profile in the columns

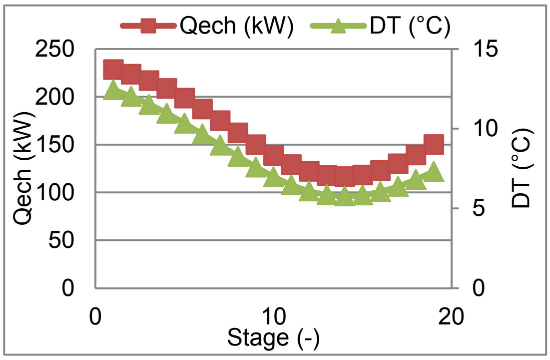

Figure 7: Heat and temperature difference profile

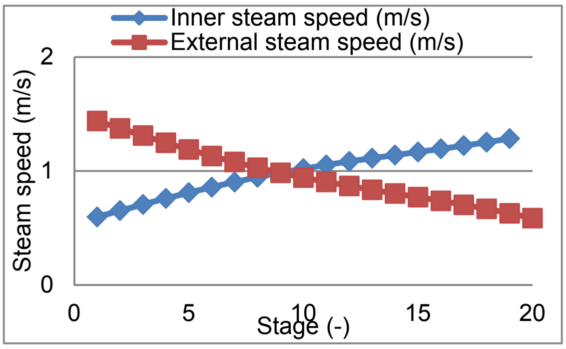

Figure 8: Steam speed in the columns

3. Conclusion

A new design method for HIDiC columns is presented in this study. It takes into account the constraints of optimal distribution of heat exchanged and hydrodynamic constraints. Iterative procedure are set up to determine the operating parameters, pressure drop between the two sections and maximum amount of heat exchange, and the geometrical parameters, inner and external column diameters, of the column to respect hydrodynamic and thermal constraints (steam speed around 1±0.5m/s and temperature difference between section of 4°C). The hydrodynamic constraints are respected but a velocity profile along the column is established because of the cylindrical column. The conical column study is therefore possible to have a constant speed along the column. However, this generates more complex and difficult to size columns. An economic study can also be taken into account in the design of these columns as for the works of Yala & al., 2017.

References

Gadalla, M.A., 2009. Internal heat integrated distillation columns (iHIDiCs)—New systematic design methodology. Chemical Engineering Research and Design 87, 1658–1666. https://doi.org/10.1016/j.cherd.2009.06.005

Kiss, A.A., Flores Landaeta, S.J., Infante Ferreira, C.A., 2012. Towards energy efficient distillation technologies – Making the right choice. Energy, Asia-Pacific Forum on Renewable Energy 2011 47, 531–542. https://doi.org/10.1016/j.energy.2012.09.038

Mah, R.S.H., J. J. Nicholas Jr., R. B. Wodnik, 1977. Distillation with secondary reflux and vaporization: A comparative evaluation. AIChE Journal 23, 651–658. https://doi.org/10.1002/aic.690230505

Olujić, Ž., Sun, L., de Rijke, A., Jansens, P.J., 2006. Conceptual design of an internally heat integrated propylene-propane splitter. Energy, ECOS 2004 - 17th International Conference on Efficiency, Costs, Optimization, Simulation, and Environmental Impact of Energy on Process Systems 31, 3083–3096. https://doi.org/10.1016/j.energy.2006.03.030

Suphanit, B., 2010. Design of internally heat-integrated distillation column (HIDiC): Uniform heat transfer area versus uniform heat distribution. Energy 35, 1505–1514. https://doi.org/10.1016/j.energy.2009.12.008

Yalla, O., Rouzineau, D., Thery-Hetreux, R., Meyer, M., Design and optimization of Heat Integrated Distillation Column “HIDiC”. Proceedings of the 27th European Symposium on Computer Aided Process Engineering, ESCAPE 27. October 1st - 5th, 2017, Barcelona, Spain © 2017 Elsevier B.V.