CHEMICAL ENGINEERING TRANSACTIONS Volume 21, 2010
Editor J. J. Klemeš, H. L. Lam, P. S. Varbanov
Copyright © 2010, AIDIC Servizi S.r.l., ISBN 978-88-95608-05-1 ISSN 1974-9791
DOI: 10.3303/CET1021047

Energy integration of multiple effect evaporators in sugar process production

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Heat demand in sugar plants occurs in juice heating, evaporation and crystallization operations. Although all the operations mentioned are necessary for the production process, evaporation is emphasized in the energetic integration aspect, not only due to the largest energy consumption, but also, due to the possibility of using the vapor generated in that operation, as heating source to the remaining of the process.

The way for solving the energy integration problem, simultaneously designing the configuration of the multiple effect evaporator (MEE), must be through the decomposition of the thermal system, assuming the existence of two interactive sub-systems: MEE and the remaining of the process. To reduce the energy consumption, the evaporator subsystem and the process heating subsystem should be retrofitted to make improved heat recovery possible. Process integration can help to choose the best configuration of MEE in order to achieve a more efficient process in the sense of energy use.

In this study the multiple effect evaporation stage in an actual sugar plant was simulated in ASPENPLUS. The problem can be solved iteratively by combining pinch analysis algorithms using ASPENPINCH and simulation of the evaporation step. Since there are several effects, heat flows must be classified as utility, and equipment configuration should be defined according to the thermal demand of the process.

The study focuses on a typical sugar cane factory, processing 150 t of cane/h. The properties of the feed steam flows were given by the outlet conditions of streamlines located between the boilers and the preflash unit. The individual thermal loads of the streams were calculated, by using temperature and flow rate data for the juice streams.

For MEE configuration analyzed, the simulations were accomplished and compared with the actual process in order to validate de adequacy of models choose. Energy curves were plotted for determining minimum energy consumption of the global process. MEE simulations were accomplished, to make the thermal analyses easier.

This approach allows the elaboration of an algorithm that systematizes the use of pinch analysis in sugar plants through process modelling and simulation.

Please cite this article as: Gonzalez Cortes M., Verelst H. and Gonzales E., (2010), Energy integration of multiple effect evaporators in sugar process production, Chemical Engineering Transactions, 21, 277-282 DOI: 10.3303/CET1021047

1. Introduction

A few years ago, no systematic methods for energy system retrofit in sugar factories had been widely accepted. Research carried out in the 1970s on the application of mathematical modelling and non-linear programming methods (Morar and Serban, 2010), turned out to be premature because with the computer technology available at that time, these methods were too difficult to implement in practical design. Early applications of pinch based techniques to energy improvements in British and other European sugar factories could only confirm that conventional design methods were sufficiently effective (Linnhoff and Polley, 1988; Christodoulou, 1992). Methodological problems limiting the efficiency of pinch based techniques in their applications to sugar factories were also identified. Taking advantage of the accumulated experience, these methods are now being implemented in retrofit design of energy systems in sugar factories. (Smith et al. 2010; Prin-Levasseur et al. 2008). In a recent study, a pinch based approach served the purpose of describing and comparing the energy efficiency of various design options rather then directly augmenting the decision making. The most energy intensive steps of the sugar manufacturing process are: (i) extraction of juice from raw matter; (ii) Juice purification to reduce its content of non-sugars; (iii) Evaporation to remove excess water and concentrate the juice; (iv) Evaporating crystallization of sugar from concentrated juice.

In each of these steps, heating is required as either temperatures of process streams must be increased, or water must be evaporated. The energy system can be divided into three subsystems: power plant, multiple-effect evaporator and process heating subsystem.

The evaporator step is the aim in this paper and can be regarded as a subsystem generating vapors and condensates at various temperature levels corresponding to the individual evaporation stages. Vapors and condensates are the carriers of medium temperature heat to be used for process heating. A retrofit strategy that is of particular interest to sugar factory operators assumes reducing energy consumption by retrofitting the subsystems of evaporation and process heating so as to make improved heat recovery possible. This may create an opportunity to increase the sugar output while avoiding costly investments in the utility systems.Using vapor extraction to the process is relevant for reducing the energy consumption in sugar plants. Previous papers, (Miranda and Simpson, 2005); (Bikash and Khanam, 2007); (Ensinas and Nebra, 2007) and (Higa and Freitas, 2009), showed that in multiple effect evaporators, thermal recovery is usually larger when vapor extractions occur from the last effects of that operation. Considering that problem, an appropriate method for optimization of process integration and choosing the best configuration of MEE is necessary. In previous papers, pinch analysis as been used effectively to evaluate industries processing beet and sugarcane (Urbaniec, 2000) and (Lewis et al. 2010); however, the fact of not understanding some difficulties has been limiting its application in the sector. The aim of this study was to simulate the evaporation step in a sugar factory and evaluate the possibilities of energy integration in it.

2. Simulation of evaporation step in sugar process production.

The process simulation was carried out in ASPEN PLUS 11.1. First the data was introducing in the software:

1. Components definition: The main constituents of the sugar cane are water, fibre and soluble solids (sugars especially). For the simulation of the evaporation stage are considered water and sucrose and dextrose concentrations like main components of the sugar inside the soluble solids.
2. Method of estimate of the properties. The thermodynamic pattern NRTL was that better adjustment reported for the data. It is applicable to binary systems (liquid - vapour), the method was developed by Renon and Prausnitz (1969), which doesn't not accept the - randomness of the molecules distribution in a solution, this model is based on the pattern of Wilson, (Carlson, 1996).

In the case of study, the evaporation system consists of two pre - evaporators that work like one alone and 4 evaporator effects. From the first pre-evaporator is extracted vapour for the first effect of the multiple and spam and to the second effect of the multiple effects is extracted vapour for the secondary heater. For the simulation of MEE the pattern Flash2 was selected and the extraction in the pre-evaporators and second effect was simulated with a separator (SPLIT). In the Tab 1 and 2 appear some data used in the simulation. In the Fig 1 is showed the flowsheet simulated in Aspen plus.

Table 1. Data for the simulation

Stream Name	Flow, kg/s	Temperature, °C
Juice Flow that enters pre-evaporator	39.64	114
Vapor that enters pre-evaporator	10.58	120

Table 2. Specifications for Multiple Effect Evaporators

Equipment	Stream name	Pressure, atm	Temperature, °C
Pre-evaporator	PREFLA	1.69	115
First Effect	FL1	1.30	107
Second Effect	FL2	0.83	94
Third Effect	FL3	0.34	83
Fourth Effect	FL4	0.15	54

Table 3. Variation coefficient between Aspen results and actual process.

	COND1	COND2	COND3	COND4	COND5	CONDP
Flow	3.6E-03	1.8E-03	1.5E-04	4.9E-03	8.7E-03	3.2E-04
Temp.	2.7E-06	2.8E-04	1.3E-03	6.7E-04	5.0E-03	-1.3E-04
Pressure	0	0	0	0	-1.3E-03	-2.5E-01
	FEED	FEED1	FEED2	FEED3	FEED4	MEL
Flow	0	1.2 E-03	1.6 E-03	2.77 E-03	1.7 E-03	3.8 E-03
Temperature	0	5.5 E-03	7.8 E-03	1.3 E-02	2.3 E-02	6.5 E-02
Pressure	0.14	0	0	0	0	1.33E-03
	EP1	FPAM	HFIRST	SPVAPFL3	STEIN	
Flow	2.4 E-03	3.4E-03	2.5E-03	1.5E-04	0.00	
Temperature	5.5 E-03	5.55 E-03	1.3E-03	1.3E-02	-1.3 E-04	
Pressure	0	0	0	0	-0.2	
	VAP1	VAP2	VAP3	VAP4	VAPP	
Flow	1.8 E-03	1.4 E-03	4.9 E-03	8.7 E-03	3.5 E-03	
Temperature	-7.8 E-03	-1.3E-02	-2.3E-02	-6.5 E-03	-5.5 E-03	
Pressure	0	0	0	-1.3 E-03	0	

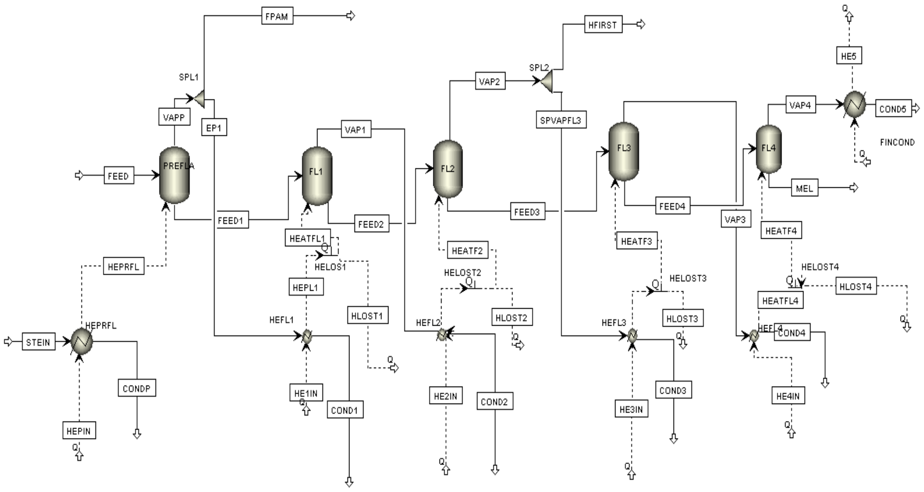

Figure 1: Flow sheet of the evaporation stage modelled in Aspen Plus.

The analysis of variation coefficient, see Table 3, results in that the proposed pattern is adequacy for the simulation of the evaporation stage.

3. Energy integration of multiple effect evaporator

The analysis Pinch was carried out in order to see in an efficient way the true requirements of energy of the evaporation stage. The energy integration was carried out in the ASPEN PINCH through the direct introduction of the hot and cold currents that are included in the evaporation scheme and that were previously simulated in ASPEN PLUS. A total of 14 hot currents and 5 cold currents were analyzed with possibilities of exchanging thermal energy. In each effect the included currents were the feed, the evaporations, the entrances of vapour to each effect and the condensed flows. The identification of possible opportunities of thermal integration can be visualized through the hot and cold composite curves (CCs), Fig 2, which are combinations of the thermal streams of total process, in terms of their heat contents over each temperature level (Temperature_Enthalpy). Hot and cold CCs represent the energetic availability and the requirement of the global process, their overlapping indicates the maximum heat recovery of process, whereas the overshoots determine the minimum hot and cold utility requirements of the process (targets). The minimum temperature difference (ΔT_{min}), imposed by the project, with regard to capital cost, is the limit for the approximation between the curves and establishes the pinch-point. For the analysis the data were evaluated different Δ_{Tmin} (6, 8, 10 °C), for each one the minimum requirements of utilities was estimated. The Grand Composite Curve (GCC) is another tool also used in pinch analysis. That combines hot and cold CCs in a single curve, also through the sum of their heat content in each temperature level. For zero value of the enthalpy horizontal axis, the temperature of that point coincides with the pinch-point. Using GCC it is easier to observe that, in the temperature levels above the pinch, the process just needs hot utility, whereas below the pinch the demand is for cold utility. In addition, the dark areas indicate where the process can supply its own demand.

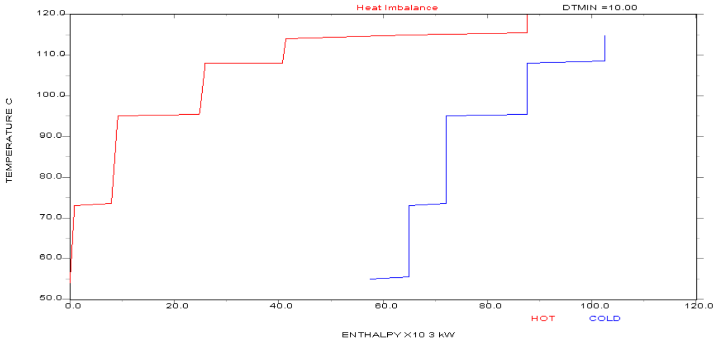

Figure 2: Hot and Cold Composite Curves.

In case of many utilities (multiple level utilities), it is possible to choose one of them, based on the closer temperature level to the demand, minimizing the heat transfer irreversibility. In the Figure 3 the Grand Composite Curve can be appreciated for the case in study, being been able to identify each one of the effects.

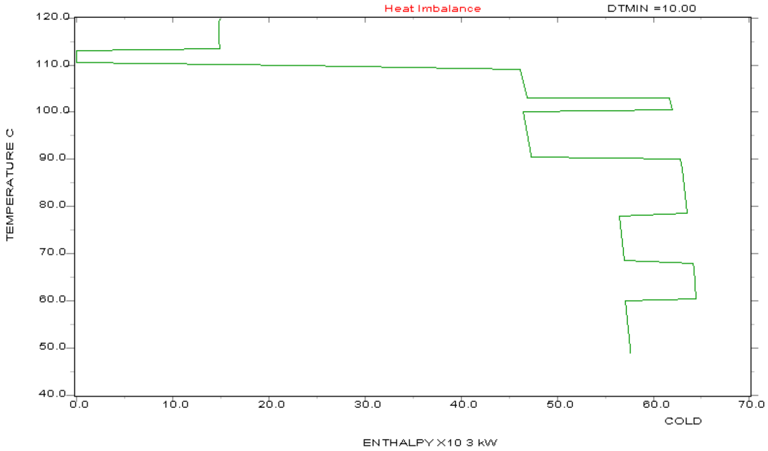

Figure 3: Grand Composite Curve

In the Table 4 the minimum requirements are shown. From the energy balance in the process was obtained that the requirement of hot utilities is of 23814.52 kW, however as a result of the integration it is obtained that the minimum requirement of utilities in this process is 14973.6 kW, what evidences that there is a consumption of exhausted vapor in excess in the process that can be replaced perfectly by the currents of utilities of the evaporation stage.

Table 4. Minimum requirements of utilities results from ASPEN PINCH.

	Minimum hot utility, kW	Minimum cold utility, kW
ΔT_{min} 10 °C, Pinch 113 °C ΔT 11.0 °C, 110.5 °C ΔT 20.0 °C	14973.6	57583.6

4. Conclusions

Process simulation and integration can help to choose the best configuration of MEE in order to achieve a more efficient process in the sense of energy use. The way for solving the energy integration problem, simultaneously designing the configuration of the multiple effect evaporator (MEE), must be through the decomposition of the thermal system, assuming the existence of two interactive sub-systems: MEE and the remaining of the process. For MEE configuration analyzed, the simulations were accomplished and the comparison with the actual process shown adequacy in the models selected. Aspen PINCH found the minimum requirements of utilities for the studied process. The fact of not understanding some difficulties in this approach has limited its application in the sector.

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