CHEMICAL ENGINEERING TRANSACTIONS
VOL. 39, 2014
A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet
Guest Editors: Petar Sabev Varbanov, Jiří Jaromír Klemeš, Peng Yen Liew, Jun Yow Yong

ISBN 978-88-95608-30-3; **ISSN** 2283-9216
DOI:10.3303/CET1439067

Mechanical Vapour Recompression Incorporated to the Ethanol Production from Sugarcane and Thermal Integration to the Overall Process Applying Pinch Analysis

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Vapour recompression is a means of upgrading energy by the compressing of a lower pressure vapour up to a higher pressure, thus making the energy more available to do useful work. There are two types of vapour recompression: thermo-compression and mechanical recompression. Thermo-compression uses high pressure steam through a nozzle to compress a lower pressure vapour to an intermediate pressure. On the other hand, in mechanical recompression "mechanical" means that the compression task is done through the expenditure of mechanical energy for instance a steam turbine driven a compressor. Other means of driving could be also include an electric motor or an internal combustion engine. In both of cases the main advantage of vapour recompression is that it is not necessary to supply the latent heat of vaporization to the vapour being compressed. The aim of this study is to evaluate the possibilities of the incorporation of mechanical vapour recompression in the ethanol production process from the energy point of view. Thus mechanical vapour recompression is integrated to the juice evaporation system which is composed by a multiple effect evaporator. Simulations in Aspen Plus were accomplished to perform the mass and energy balances. Results showed that the introduction of vapour recompression promoted a reduction in steam consumption of approximately 10 % in evaporation system and 4% in overall process. In order to further reduce the steam consumption of the plant, Pinch Analysis was applied to integrate the vapour recompression process coupled to evaporation system to all available streams in ethanol production process.

1. Introduction

Vapour recompression can help improve the steam efficiency of a sugar mill substantially in the right conditions (Rein, 2007). This may be achieved either by vapour recompression, using high pressure steam through a steam nozzle (thermo-compressor) to compress a lower pressure vapour to an intermediate pressure, or through mechanical vapour recompression using centrifugal compressors to do the recompression. The requirements of thermo-compression is the availability of surplus high pressure steam, on the other hand, mechanical vapour recompression is advantageous when there is surplus power available (Boggild and Andersen, 1989). In sugarcane plants vapour recompression is frequently coupled to evaporation system of juice, however it can be applied to distillation process (Kiss et al., 2012). Mechanical vapour recompression has been used with success in the sugar industry according to Baloh (1984); principles of selection of vapour compression circuits best suited to practical requirements and conditions are discussed by Baloh (1991) cited by Van der Poel et al. (1998). Thus, the aim of this study is to evaluate the possibilities of the incorporation of mechanical vapour recompression to the ethanol production process. Simulations in Aspen Plus were accomplished to integrate the vapour recompression

Please cite this article as: Palacios-Bereche R., Ensinas A.V., Modesto M., Nebra S.A., 2014, Mechanical vapour recompression incorporated to the ethanol production from sugarcane and thermal integration to the overall process applying pinch analysis, Chemical Engineering Transactions, 39, 397-402 DOI:10.3303/CET1439067

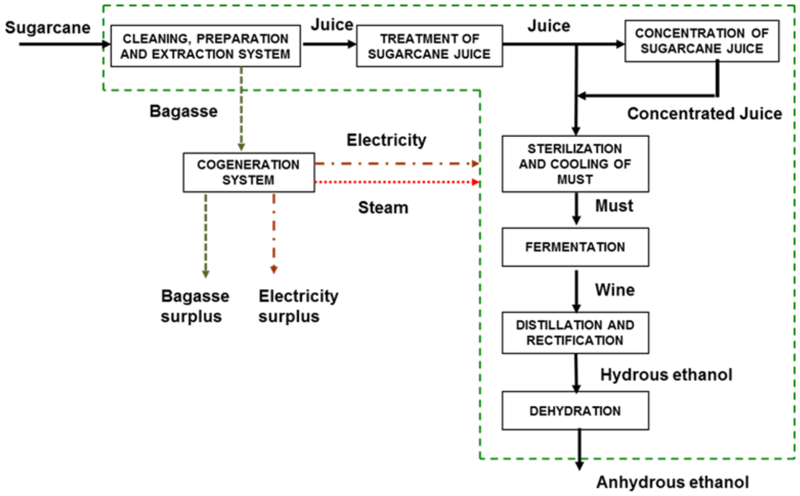

Figure 1: Scheme of the ethanol production process from sugarcane

in evaporation system as well as to perform the mass and energy balances, and, in this way, evaluate the impacts and consequences of this integration in overall production process. In order to further reduce the steam consumption of the plant, Pinch Analysis was applied to integrate the vapour recompression process coupled to evaporation system to all available streams in ethanol production process.

2. Conventional ethanol production process

The simulation of the conventional production process was accomplished according to Palacios Bereche et al. (2013). Figure 1 shows the scheme of the conventional ethanol production process, which begins with the cleaning operation. After that sugarcane goes to the extraction system where juice and the bagasse are separated. Raw juice goes to the physical-chemical treatment while the bagasse is used as fuel in cogeneration system. The juice concentration of treated juice takes place in a multiple-effect evaporation system in order to achieve a juice sugar concentration adequate to fermentation. A five effect evaporation system was assumed. The pressure adopted in each effect was 1.69 bar, 1.31 bar; 0.93 bar; 0.54 bar and 0.16 bar.

Must sterilization is carried out by an HTST-type treatment (High Temperature Short Time) and fermentation was based on the Melle- Boinot process (cell-recycle batch fermentation). A conventional distillation system with distillation and rectification columns was simulated. For ethanol dehydration, a process of extractive distillation with MEG (monoethylene glycol) was simulated. The cogeneration system adopted in the simulation consists of a steam cycle with backpressure steam turbines, and live steam parameters of 100 bar and 530 °C

3. Mechanical vapour recompression incorporated to the evaporation system

The vapour recompression was integrated with the multiple effect evaporation system to compress lower pressure vapour to a higher level. Two vapour compression circuits were evaluated in this work, which are presented in Figure 2 and 3.

3.1 Configuration A: Recompression of 5th effect to 1st effect

Figure 2 present the vapour recompression of 5th effect (vapour VV5 at 58.6°C and 0.16 bar) to 1st vapour (vapour VV5-1 at 2 bar). In conventional process, vapour bleeding of 1st effect (vapour SVV1) is used to cover heat demands in juice treatment stage. The recompression is done in the block RE-COMP using centrifugal compressors. According to the literature data (GEA, 2014), the pressure ratio selected was 1.86. For this reason it was necessary to use 4 single stage compressors in series with intercooling. An additional heat exchanger was inserted in flow sheet (EVA1X in Figure 2); in order to avoid the mixing of recompressed vapour with the turbine exhaust vapour (EXH-ST1). The isentropic efficiency of compressors was assumed at 80% while the mechanical efficiency at 98 %.

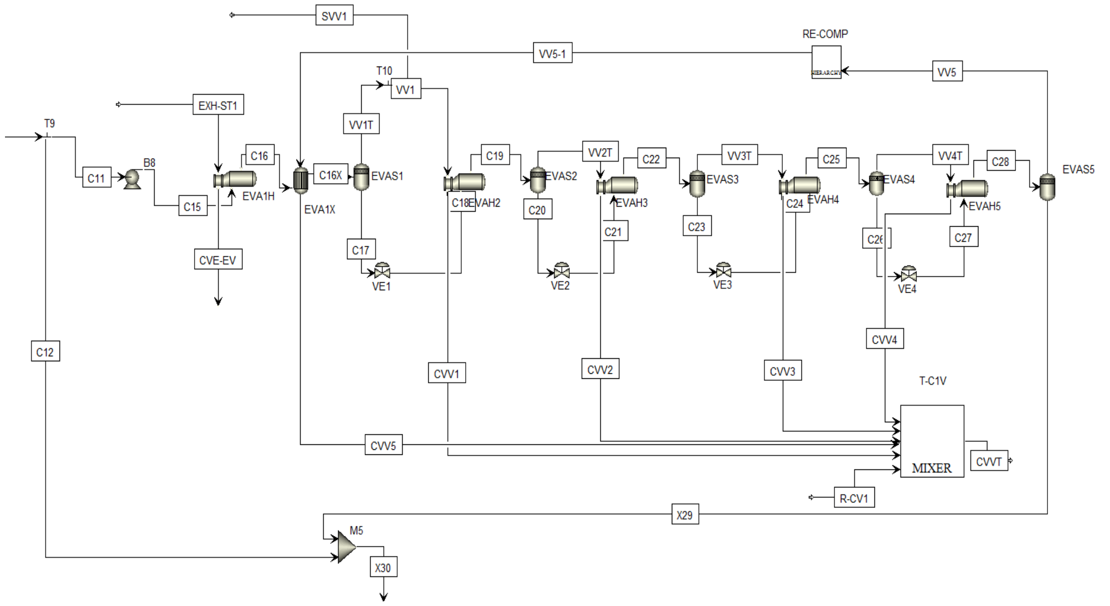

Figure 2: Flow sheet of the vapour recompression integrated to the evaporation system in Aspen Plus ®-Recompression of 5th effect to 1st effect

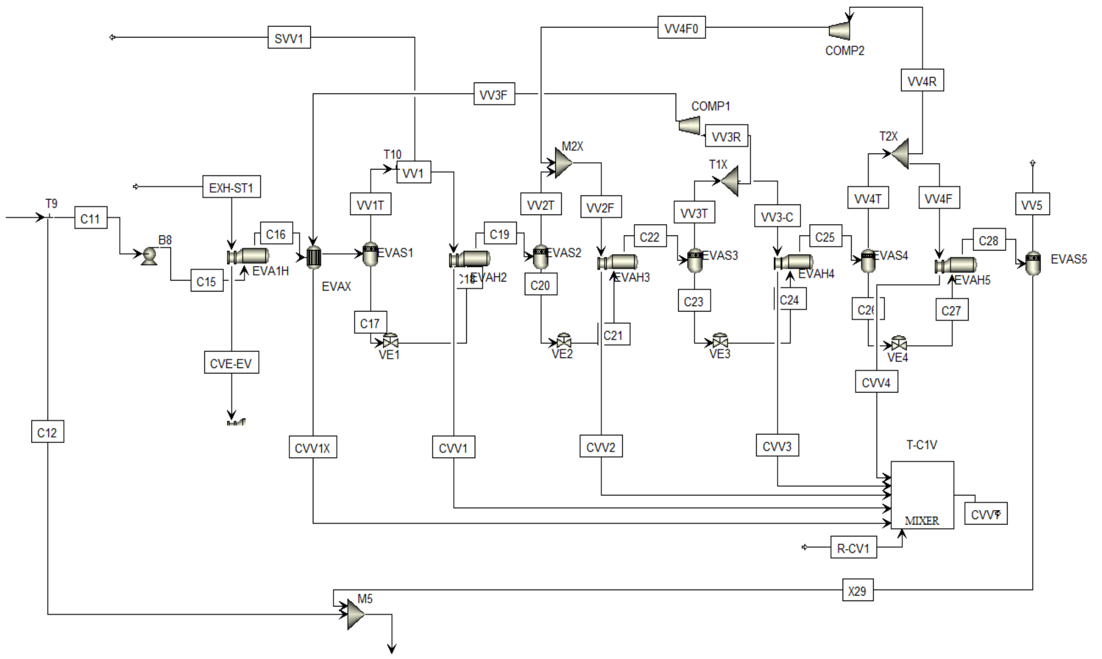

Figure 3: Flow sheet of the vapour recompression integrated to the evaporation system in Aspen ® - Recompression of 3rd to 1st effect and 4th to 3rd

3.2 Configuration B: Recompression of 3rd effect to the 1st effect and of the 4th to the 3rd effect

Configuration A shows a pressure change relatively high, between the 5th and 1st stage; for this reason, it was necessary to adopt 4 compressors in series, which presented elevated power consumption in compression. Thus, configuration B adopts vapour recompression of the 3rd effect to 1st effect and of the 4th to the 3rd effect. Figure 3 shows the flow sheet of configuration B in Aspen Plus ® simulator. In this figure it can be observed that unit block COMP1 compresses the vapour VV3 to be used in the first stage (block EVAX) and unit block COMP2 compresses the vapour VV4 to be used in the 3rd stage. In this case, the pressure increase in the compressors was smaller compared to the previous case with the purpose of reducing the size of the equipment (compressors) and decreasing the necessary compression power.

3.3 Evaluated cases

In this study, the following cases were evaluated:

1) Base: Conventional distillery
2) RE-VA: Conventional distillery with vapour recompression – Configuration A
3) RE-VA: Conventional distillery with vapour recompression – Configuration B
4) RE-VTI: Conventional distillery with vapour recompression and thermal integration of the process streams.

Regarding the cogeneration system, for each of the cases evaluated, two configurations for cogeneration system were simulated:

i) Configuration I: Vapour cycle with back-pressure steam turbines
ii) Configuration II: Vapour cycle with extraction-condensing steam turbines

4. Thermal integration applying Pinch Analysis

The thermal integration of the process streams was done following the procedure described in Palacios-Bereche et al. (2011) and further information in Dias et al. (2011). Table 1 shows the adopted streams for the thermal integration procedure without the evaporation system streams. The optimal bleedings of each stage of the evaporation system are determined from this procedure. After this, the evaporation system is inserted including the vapour recompression. The minimum approach difference of temperature (ΔT) adopted was 10 °C for process streams and 4 °C for the evaporation system streams.

Figure 4 presents the steps of the graphical method for thermal integration. Figure 4 (a) represents the preliminary Grand Composite Curve - GCC without the evaporation system streams. Horizontal bars represents each one of the effects of the evaporation system. This diagram allows to identify possibilities of integration of the evaporation system, as well as the appropriate bleeding of vapour in each stage of the system. Figure 4 (b) shows the vapour recompression of 5th to 1st effect and the use of bleeding vapour only in the first effect (dashed line). For this case the bleed was 42.9 t/h and the vapour recompressed (VV5) was 15.2 t/h.

Since it is necessary to introduce the work of the compressor, the recompression system operates similarly to a heat pump operating through the Pinch point.

5. Results and discussion

In the case RE-VA, the simulation results show that it is possible to recompress 9.1 t/h of vapour V5 (5th effect) to be used in the first effect at a pressure of 2 bar, maintaining the vapour bleed V1 (at 1.69 bar) of 71,6 t/h in the first effect (this bleed is equal to the one adopted in the Base Case). The necessary mass flow of the exhaust steam at 2.5 bar (hot utility) in evaporation system was 72.4 t/h.

Table 1: Adopted streams for thermal integration

Hot streams	Ti (°C)	Tf (°C)	ΔH (MW)	Cold streams	Ti (°C)	Tf (°C)	ΔH (MW)
Sterilized juice	130	32	40.9	Imbibition water	25	50	4.4
Wine	32	28	12.2	Juice treatment	34	105	44.1
Phlegmasse	103.9	35	2.9	Juice pre-heating	98.1	115	2.6
Vinasse	109.3	35	37.2	Juice for sterilization	95.5	130	14.8
Anhydrous ethanol	78.3	35	8.6	Final wine	31.2	90	34.3
Vapour condensates	111.9	35	9.3	Reboiler - column A	109.3	109.3	44.6
Condenser - column D	84.9	35	19.8	Reboiler - column B	103.8	103.8	21.7
Condenser - column B	81.7	81.7	25.9	Reboiler – extractive column	134.5	134.5	7.2
Condenser - extractive column	78.3	78.3	7.4	Reboiler - recovery column	149.6	149.6	2.5

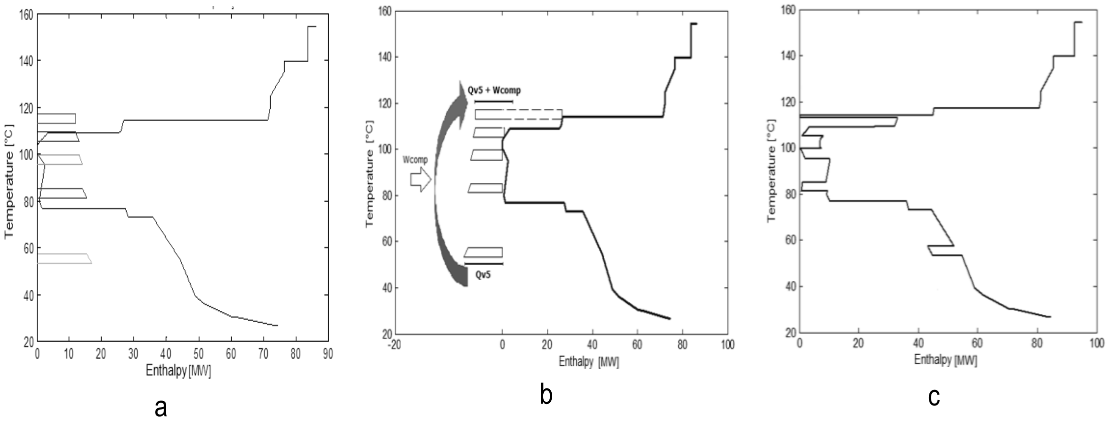

Figure 4: a) Preliminary GCC and evaporation system, b) Preliminary GCC and evaporation system with vapour bleeding at 1st effect and with vapour recompression of 5th effect, c) Final GCC

Table2: Steam consumption (hot utility) in each of the operations in the process (kg/t of cane)

	Base	RE-VA	RE-VB	RE-VTI
Steam at 6 bar	84.4	84.4	84.4	48.8
Pre-heating of juice (2.5 bar)	--	--	--	3,6
Evaporation system (2.5 bar)	164.3	144.8	148.3	84.1
Distillation column A (2.5 bar)	147.1	147.1	147.1	147.2
Distillation column B (2.5 bar)	71.7	71.7	71.7	--
TOTAL	**467.5**	**448.1**	**451.6**	**283.6**
Reduction in evaporation system, (%)		**11.8**	**9.7**	**46.7**
Reduction in total steam consumption, (%)		**4.2**	**3.4**	**39.3**

In the case RE-VB case, 6.8 t/h of vapour V3 (3rd effect) was recompressed to be used as hot stream in the 1st effect at 2 bar, and 7.8 t/h of vapour V4 (4th effect) to be used in the 3rd effect. These mass flows were adopted taking the same vapour mass flows produced in the 3rd and 4th effects in the Base Case. For this case, the necessary mass flow of the exhaust steam in evaporation system was 74.2 t/h.

Table 2 presents the steam consumption in each operation of the process (hot utility).

About the power consumption in recompression it was observed that it represents 8.5%, 4.9% and 13.5% of the total power consumption for the RE-VA, RE-VB and RE-VTI cases, respectively. It is interesting to notice that in the RE-VB Case, the power consumption in the compressors is significantly smaller (43.9%) in comparison with the RE-VA Case, due to the adopted configuration. Figure 5 presents the electricity and bagasse surplus for all the cases.

It would be interesting to apply this study in an ethanol and sugar production plant, since in this plant a larger amount of water must be removed in the concentration process, and a greater amount of vapour is available for recompression. In this case, the arising impacts of the introduction of vapour recompression should be more significant.

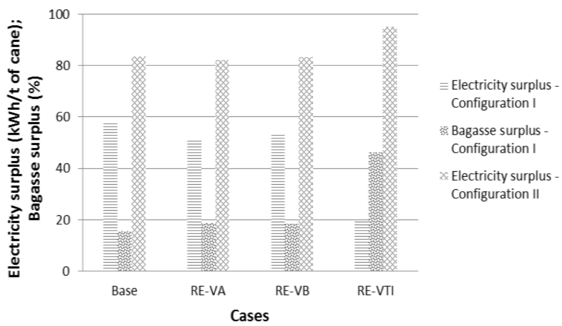

Figure 5: Electricity surplus and bagasse surplus for evaluated cases

Acknowledgments

The authors wish to thank to CNPq (Process PQ 304820/2009-1) for the researcher fellowship and the Research Project Grant (Process 470481/2012-9), and FAPESP for the Post PhD fellowship (Process 2011/05718-1) and the Research Project Grant (Process 2011/51902-9).

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