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Simultaneous Energy and Water Minimization Applied to Sugar Process Production

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In this work, a procedure that can simultaneously minimize the fresh water consumption and heat usage in a process plant is proposed. This method begins with the application of mass integration followed by heat integration to target and design a network with minimum usage of fresh water and heat utility usage.

During the past decade, considerable design techniques have been developed to minimize the heat and mass (mainly focused on water) consumption simultaneously. Focusing on reducing the two resources separately may result in extra energy and heat exchanger being designed unnecessarily. Due to this reason, various academic and industrial studies had been carried out to respond to this need, and process integration techniques have been successfully applied to minimize heat and mass consumption.

The water streams are resources that often are subjected to not only the constraints of concentration levels, but also the temperature levels.

When a water-using process requires hot water for the operation, water stream of the operation involves the changes of concentration levels through the mass transfer between process stream(s) and water stream(s), as well as the changes of temperature levels resulting from heat transfer within the process. Under these circumstances, both contaminant and temperature conditions need to be considered simultaneously, if any attempts for minimising water or energy consumptions for the site are made.

On the other hand, the synthesis of heat recovery systems maximises potential recovery from waste heat, and identify the amount of energy to be exchanged between hot and cold water streams, and their network configuration. Therefore, design tasks in the study of simultaneous water and energy minimisation are to identify targets for the design, freshwater usage, energy consumption and wastewater generation, as well as a network design to achieve the targets, water reuse network and heat exchanger network.

The developed design method aims to exploit water reuse potentials between water-using operations, and simultaneously to minimise any potential lost of energy resulted from water disposal. Systematic approach was developed and tested with the water minimization project in a sugar plant.

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1. Introduction

Water is widely used in the food industries as a utility (e.g. steam, cooling water, etc.), mass transfer agent (e.g. washing, extraction, etc.) or as a raw material. Strict requirements for the quality of products and the associated safety issues in manufacturing contribute to large amounts of high-quality water being consumed by the food processing industry. In order to minimize water consumption, various measures can be considered: reducing inherent water demand through process changes; or implementing water reuse between operations if water (with/ without dilution with fresh water or other streams) from an operation can be accepted for use in another operation.

A water network design that includes strategic and system-wide reuse of water is a very effective approach to reducing overall water consumption. However, in some cases it is not straightforward to implement water reuse between water using operations because of temperature constraints.

In these situations, both the temperature and contaminant levels of the water are key factors and need to be considered simultaneously. As temperature requirements for unit operations using water are not the same, a certain degree of cooling or heating for water streams or effluents is necessary. When water reuse between operations is considered, a water network should be designed not only to satisfy concentration requirements, but also to supply the water at the desired temperature.

It is often observed that the problems of energy minimization and water minimization have been addressed as independent studies. However, attempting to find solutions for water saving projects without considering energy implications inevitably leads to non-optimal solutions, as simultaneous interactions between water systems and energy systems are not fully screened or investigated.

From the energy perspective, reducing water consumption in the utility system may be achieved by minimizing energy demands (e.g. steam, cooling water and refrigeration) from the processes, for example, by using heat integration techniques (Kemp, 2007; Kim, 2009).

2. Materials and Methods

In this paper the methodology exposed by Savulescu, (Savulescu et al., 2005 a, b) was considered. Its approach combines the concepts of thermal pinch together with the water pinch analysis. Preliminary water targeting is considered in the first step. It has to be stressed that the distribution of water streams is relevant for overall energy consumption; consequently, a two-dimensional grid diagram was proposed to exploit different options for the configuration of the water system and to enable reduced complexity of the energy and water networks.

If the water reduction analysis is performed only from the contaminant content perspective, several water distribution networks might be defined for the same water reduction target (Alva-Argáez and Savulescu, 2009). Thermal information about stream data should be extracted from the process and water distribution network to enable the construction of energy composite curves and allow the identification of minimum energy consumption targets (Polley and Picon-Nunez, 2009; Poplewski and Jezowski, 2009; Matijaševic et al., 2010 and Martínez-Patiño, 2010).

An energy project could reduce the utility consumption and, consequently, lower the water required for boiler feed water makeup and cooling water makeup, respectively. However, the project also implies changes in the design configuration which, from the water perspective, might restrict the potential of new water reduction solutions; these changes, however, could also facilitate the implementation of particular water management strategies. These tradeoffs must be clearly understood when making design decisions (Klemeš, et al, 2010).

Using less fresh water is reflected in the heating load of the process. A water reduction might affect the energy system in different ways depending on the quantity and quality of energy displaced by the eliminated water stream(s). Often, in a food processing plant, when a fresh water stream with high thermal quality requirement is replaced, there is good potential to reduce the overall steam consumption. This is the context of streams above the thermal pinch point. However, when the replaced water stream has a low thermal condition, the process waste heat could increase and consequently also the cooling water requirements. This corresponds to a below pinch stream context.

A detailed study to the papers published by (Klemeš, et al. 2007; Urbaniec et al. 2000), permitted identify the main steps of the water energy-based assessment. These are the followings:

1. Energy streams and water data gathering/extraction, Table1 and Table 2.
2. Construction of the energy composite curves using the water stream data. Figure 2. (González et al, 2010).
3. Analysis of the energy composite curves.
4. Scoping analysis – water energy-based targeting.
5. Evaluation of energy impacts due to water savings.

The case of study is base on the circuit of process water in a sugar process production from sugar cane. Figure 2 shows the main circuit, in this can be identify the principal consumers of water and wastewater generators. The consumer equipments are called sink(s) and the equipments in where water with certain quality degree to be recycled are generated is called source(s). From the process analysis were identify 13 source streams with opportunities to be recycled and 6 sinks, these can be seen in Table 1 and Table 2 respectively.

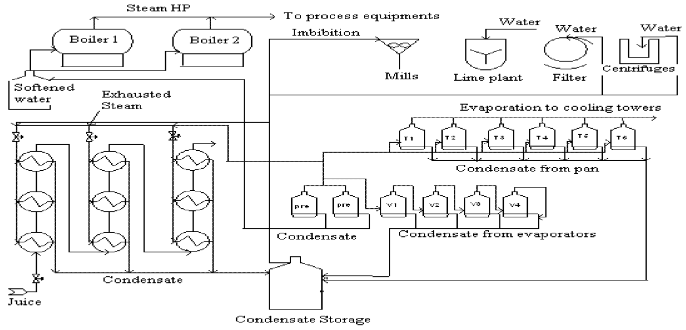

Figure 1: Circuit of water entering and leavig a sugar mill.

Table 1: Results from water balances for sources

Source	Flow (kg/s)	Composition (mg sugar/kg water)	Temperature (°C)
Condensate from heater 2	1.37	55	120
Condensate from heater 3	1.10	60	110
Condensate pre-evaporators	7.30	0	120
Condensate V1	3.30	23	112
Condensate V2	2.64	42	105
Condensate V3	6.50	48	94
Condensate V4	2.74	54	78
Condensate Pan 1	0.91	0	105
Condensate Pan 2	0.90	0	105
Condensate Pan 3	1.21	0	105
Condensate Pan 4	0.62	0	105
Condensate Pan 5	0.92	0	105
Condensate Pan 6	0.62	0	105
Total source streams	30.13		

Table 2: Results from water balances for sinks

Sinks	Flow (kg/s)	Composition in (mg sugar/kg water)	Composition out (mg sugar/kg water)	Temperature in (°C)	Temperature out (°C)
Mills (Imbibition)	6.91	0	80	45	45
Boiler	12.53	0	10	105	105
Lime make up water	0.14	0	40	30	30
Filter wash	1.06	0	80	70	70
Centrifuges	0.29	0	80	80	80
First heater	1.29	0	40	102	102
Total water	22.22				

Temperature of fresh water source: T_{in}= 25 °C
Temperature of discharge wastewater: T_{out}= 35 °C
Quality data with respect to contaminant contents and thermal conditions for all these streams were used to build and understand the total water plant profile.

Depending on the level of constraints for process and utility water, each system was considered in isolation or simultaneously for the application of energy-based water minimization methodologies. Any water reduction opportunity was checked with the energy composite curves to ensure that the modifications are energy-efficient. In the figure 2 shows the energy composite curve for the base case, through this was determined that the minimum requirement of heat for this process is 14973.6 kW.

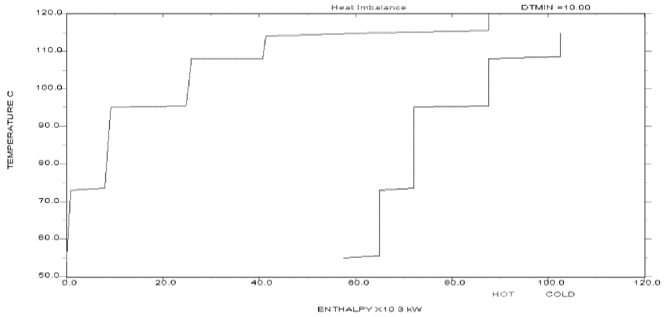

Figure 2: Energy composite curve for base case.

The input of fresh water to the process operations determined through the mass balances was 22.2 kg/s. In order to know the minimum consumption of water, Water Pinch software was used, obtained that in this kind of process there are a surplus of water with quality to be recycled and for that reason is possible to achieve a minimum water consumption near to zero value, thus the consumption of water in the process will vary in the range in which the process can be self-sufficient until the actual consumption of water.

From the Table 1 and 2, it is possible to know the temperature of fresh water source: T_{in}= 25°C and the Temperature of discharge wastewater: T_{out} = 35 °C obtaining with this the ΔT_{min}= 10°C. Using ASPEN Pinch was possible to determined the minimal consumption of heat in the system, and knowing the minimum consumption of fresh water as was mentioned above, the simultaneous heat and mass transfer system is designed, to integer the heat and the water. Due to the modification to the water and wastewater circuit the water consumption can be reduced. Also, retrofitting the water and wastewater circuit, no big changes in the existing water equipment would be required because the circuit performance could be improved through low-cost investments restricted to new piping connections. With the redesign of the flow network, it is possible to obtain water savings for 87 % and energy 65 %.

3. Conclusions

The idea of water targeting from an energy-based perspective provides valuable insights to understand the implications of water reduction strategies for the energy targets and to highlight relevant tradeoffs between process water, cooling water, steam demands and water treatment. Evaluating the energy system independent of the water network ignores from the start the interactions between them. With the redesign of the flow network considering from the beginning the interaction between water and energy resources, it is possible to obtain water savings for 87 % and energy 65 %.

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