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On the integration of power, heat and water in industrial processes

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The optimal use of water, heat and power is a key point for sustainability in most industries, as in the case of pulp and paper industry. These three inputs in the industries are generally handled separately in networks and systems. Recent issued works managed to integrate mass and heat systems in one single system, getting a reduction of the consumption of water and heat simultaneously.
This work presents the simultaneous integration of power, heat and mass exchange systems. It has been identified that a variation of any of the three vectors has a direct impact on the consumption of the others; therefore there is a direct relationship between the three consumptions. Knowing the relationship between the three vectors, it is possible to better control them.
It is important to emphasize that this new type of system: power, mass and heat integration (PMHI), involves different disciplines and knowledge; in addition it has important industrial applications.
This work presents a series of steps for the integration of a design in order to involve the three vectors. This new design seeks their simultaneous consumption reduction to achieve better control in their management. A case-study is presented applied to the industry of pulp and paper, in which there is a major consumption of the three inputs.

1. Introduction

Power, heat and water are the important inputs in many industries, i.e. in the pulp and paper industry. Generally, these inputs have and independent network or system, thus, the methodologies and techniques for the reduction of consumption of heat and water had been applied since 1980 in the pinch technology (Linnhoff, 1982; Kemp, 2007), in a

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combined form or independent. For the case of electrical power reduction in pumping systems, Tutterow et al. (1996) presented three cases to make this system efficient, the reduction of energy consumption was achieved. While integrating the three inputs in a direct form through the networks and compiling it into a sole system, it is possible to observe that the consumption of energy can be reduced in a simultaneous form. This work presents a series of steps in order to reduce the consumption of the three inputs in a simultaneous form using PMHI (Power, Mass and Heat Integration).

2. Power, mass and heat integration (PMHI)

In order to reduce a PMHI system, it is necessary to search the best interaction between the networks in every input (power, mass and heat), therefore it is necessary to know the minimum consumption of each of them. The next section describes the way to know the minimal input consumption.

2.1 Water and heat integration

By applying the Water Pinch Technique, for the case of water reuse, the minimal consumption of water can be known. The Water Pinch (Foo 2009; Poplewski and Jezowski, 2009) will provide the different networks of water reuse that can be employed to achieve the minimal consumption, but not all these networks of water will provide the minimal consumption of water. Now it is necessary to know the ΔT_{min} between the input temperature and the output temperature of the system, with this data, Polley and Picon-Nunez (2009) uses the equation 1 to know the minimal consumption of heat in the system.

$$Q = M \cdot c_p \cdot \left(T_{dis} - T_{\sup ply}\right) \tag{1}$$

By knowing the minimal consumption of water and heat, now it is possible to design a simultaneous heat and mass transfer system, which is conformed by the networks of heat and mass exchange. Savulescu et al. (2005 a,b), Martinez-Patiño et al. (2008) and Leewongtanawit and Kim (2008) proposed different methodologies to achieve the best integration of the networks that conform this system and succeeding in obtain the minimal consumption of water and energy in a simultaneous way. The integrations of water and energy are achieved.

2.2 Pumping System

It is important to first design the simultaneous heat and mass transfer system since this will provide the water fluxes that will be used in every operation of the process, these fluxes are supplied by the pumping system. The integrated pumping equipment reaches in relation with the highest point of efficiency of the pump for the operating volume in the process. With the help of the operation curves for a variable volume, the equation of this curve can be known and will provide the electrical energy consumption of each pump, and the electrical consumption of the system can be known.

2.3 Graphic consumption

Once the consumption of water, heat and power are known, it is possible to integer the three networks by reaching the minimal consumption in a simultaneous form, for this, the present work proposes the help of a graphic that shows the variation of the consumption thorough out and application of known techniques, such as the Pinch Analysis. The Figure 1 shows a graph with the consumption curves of heat and power related to the water variation in the process.

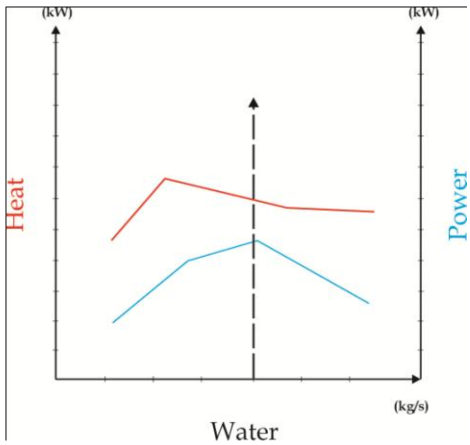

Figure 1: Heat, Water and Power consumption.

3. Case study

Two case studies are presented in this work: a case from literature, and a real case from a pulp and paper process. For the case 1, the data from Wang and Smith (1995) and Savulescu et al. (2005 a,b) are considered and presented in the Table 1.

The steps mentioned before will be used to design the PMHI system from the two case studies. It is important to mention that two situations can be presented for the design of a PMHI: one case is the retrofit for an already installed case, and other case is the totally new design of the process. For the two case studies presented in this work, the retrofit case is considered.

For the case 1, by the input of fresh water only to each of the operations of the process, the obtained total consumption of water will be of 112.5 kg/s in order to know the minimum consumption of water, the Water Pinch is used, by means of water reuse it is possible to consume 90 kg/s, thus the consumption of water in the process will vary in the range of 90 – 112.5 kg/s.

Table 1 Process data for case 1.

Operation *(No.)*	**Concentration$_{in}$** *(ppm)*	**Concentration$_{out}$** *(ppm)*	**Temperature$_{in}$** *(ºC)*	**Temperature$_{out}$** *(ºC)*	**Limiting water flowrate** *(kg/s)*	**Contaminant mass load** *(g/s)*
1	50	100	100	100	100	5
2	50	800	75	75	40	30
3	400	800	50	50	10	4
4	0	100	40	40	20	2

Temperature of fresh water source: T_{in} = 20 *ºC*
Temperature of discharge wastewater: T_{out} = 30 *ºC*

From the Table 1, it is possible to know the Temperature of fresh water source: T_{in} = 20ºC and the Temperature of discharge wastewater: T_{out} = 30 ºC obtaining with this the ΔT_{min} = 10 ºC. Using the equation 1, and knowing the minimum consumption of fresh water (90 kg/s) and the ΔT_{min}, the minimum consumption of heat can be known, which is Q = 3780 kW. After this, the Simultaneous heat and mass transfer system is designed, to integer the heat and the water. For the design of this network the methodology combination from Martinez-Patiño et al. (2008) and Leewongtanawit and Kim (2008) is used, obtaining with this the input fluxes in the operations shown in Table 1. It is important to recall that for the calculation of power consumption, the input and output fluxes from the heat and mass transfer system are considered.
Because of the PMHI system as a retrofit process, it is considered that the process is designed to achieve a water consumption of 112.5 kg/s and that the consumption for the PMHI will be of 90 kg/s, obtaining in this form, the results shown in Figure 2.

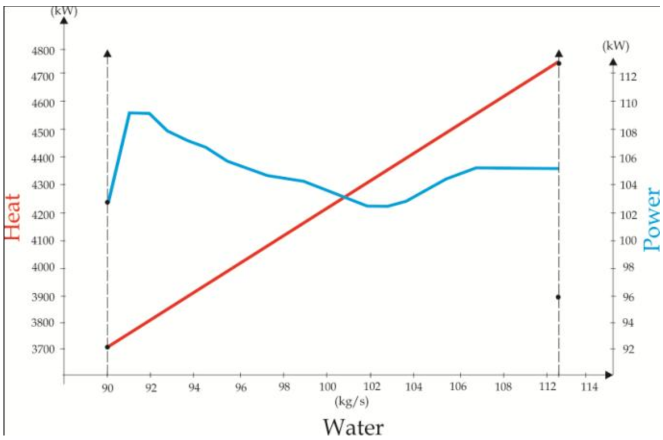

Figure 2: Heat, Water and Power consumption. Case 1.

For the Case study 2, a real process of pulp and paper is analyzed; the data from the process is shown in Table 2. As observed in the Table 2, the process contains three operations of bleaching and two washing operations, in these operations there is an interaction between heat, water and power, therefore, the presented PMHI is a real case.
The application of the WPA (Water Pinch Analysis) technique indicates the quantity of fresh water with no reuse is of 207 kg/s, and applying the reuse of fluxes the process requires 130 kg/s.
From the Table 2, the temperature of fresh water source is known: T_{in}= 20 ºC and the temperature of discharge wastewater: T_{out} = 30 ºC obtaining the ΔT_{min}= 10 ℃. With these data and applying once again the equation 1, the minimum consumption of heat is 5 460 kW. With the redesign of the flow network (PMHI system), it is possible to obtain water savings for 37 %, energy 75 % and power 34 %.

Table 2. Information for Case 2. Pulp and paper industry.

Operation *(No.)*	**Concentration$_{in}$** *(ppm)*	**Concentration$_{out}$** *(ppm)*	**Temperature$_{in}$** *(ºC)*	**Temperature$_{out}$** *(ºC)*	**Limiting water flowrate** *(kg/s)*	**Contaminant mass load** *(g/s)*
Bleaching 1	0	50	80	80	50	2.5
Bleaching 2	311	471	60	60	20	3.2
Bleaching 3	400	945	60	60	65	35.425
Washing 4	800	1500	35	35	70	49
Washing 5	0	21	20	20	80	1.69

Temperature of fresh water source: T_{in} = 20 ºC
Temperature of discharge wastewater: T_{out} = 30 ºC

4. Conclusions

Through the PMHI, it is possible to determine the variations of the three inputs of the process and the integration of these three inputs achieve a simultaneous saving between them, it is also allowable to obtain a better control of the parameter modifications and operations, this situation can be found in real cases. The application of the PMHI in a theoretical case and thereafter to a real case shows the feasibility of the reuse of this system.

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