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Flexible Operation of Cooling System for Reducing Energy Consumption

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A Process Integration has made possible to reduce operation and input costs in the industrial field. Generally, processes are subject to modifications that lead to further modifications throughout the operation of the industrial process itself. Such is the case we study in this paper: once the operation of a cooling system is modified by changing the heat exchange network and managing to reduce the heat exchange area and water consumption, the pumping system is also modified, achieving lower energy consumption. That is to say, by altering a system (the heat exchange network in this case) the possibility to modify other systems arises as well (in this case, the pumping system), and that way the costs of operation for the cooling process are further reduced.
Throughout this paper, a series of steps are provided to reduce the energy consumption once modifications have been made to the heat exchange network for a cooling system in a particular given case study.
The results shown in the case study serve as guidelines to continue developing heuristic technologies for the integration of processes wherein different study disciplines can be involved in order to achieve global savings in the cost of inputs for industrial processes.

1. Introduction.

The implementation of different techniques and methodologies on industrial processes has opened path for the concept of Process Integration (Manenti et al., 2013). Particularly, the application of this concept has taken place in the case of cooling networks implemented into different industrial fields (Panjeshahi et al., 2009). Water is used for cooling purposes in some industrial processes where temperature plays an important role, and such is the case presented in this article. The interactions of the heat exchange network and the pumping system represent two systems that are essential in the case study of this paper (Figure 1).
There are methodologies that manage to reduce thermal energy consumption in cooling systems by means of Process Integration (Gogolo and Majozi, 2010) and (Picon-Núñez et al., 2011) even presenting to us the integration of heating, water and power systems in a case that has been studied in the field of paper industry (Martinez-Patiño et al., 2010).
Emphasizing the actual purpose of a cooling system, related to the inlet and outlet temperature of a heat exchange network, a reduction in water consumption is aimed by making a flexible modification in the operation of the heat exchange network, that way modifying the operating conditions of the pumping system in order finally achieve reducing energy consumption.
It should be mentioned that many studies are only focused on reducing water. Other studies focus on reducing temperatures and the heat exchange area (Boldyryev et al., 2013), whereas other publications achieve presenting methodologies that help reducing water and temperature jointly; all of them for cooling systems. But all of these studies have failed in complementing those achievements with the saving of

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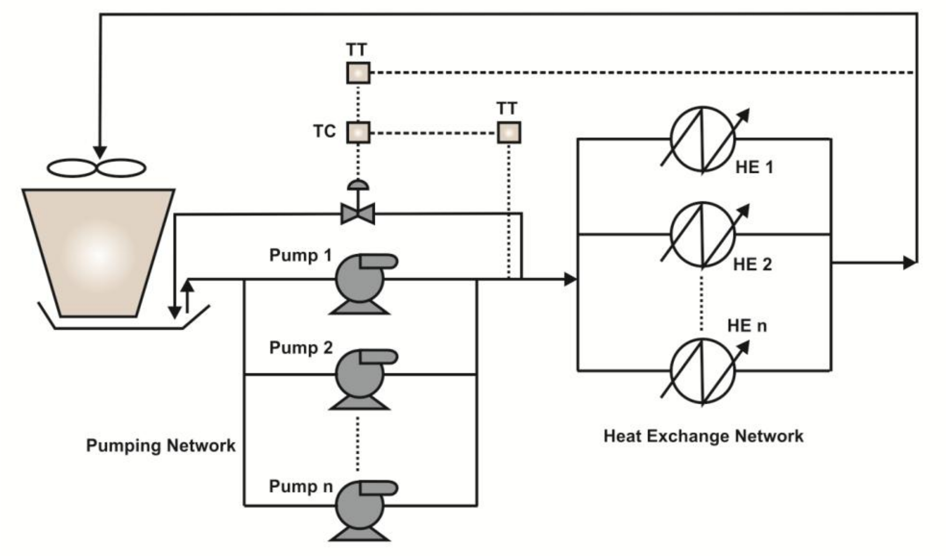

Figure 1: Cooling water system electric energy that can also be achieved in direct correlation with the changes implemented to a cooling system

2. Cooling System

As shown in Figure 1, a cooling system is for the most part composed by three main elements: the cooling tower, the heat exchange network, and the pumping system. It also incorporates measuring and control equipment. There are different settings available for heat exchange networks, depending on the design type of the cooling system itself (Čuček et al., 2013). These settings can be serial, parallel, or mixed; there are even more complex settings that can be implemented through different methodologies El-Halwagi, (2006) and more recently Klemešs et al. (2013)

Some of the most relevant pieces of information in the operation of a cooling system are the inlet and outlet temperature of the cooling network, because, altogether with the cooling tower, they regulate the temperature required for the industrial process. Therein resides the importance of the heat exchange network setting, as the efficiency in heat exchange helps modifying the temperatures of the whole process, which directly relates to the costs of operation.

There are different mathematical models that demonstrate the analysis of water flux in cooling towers and systems, such as the Fisenko et al. (2004) and in another paper, Soylemez (2001) presented a thermo-hydraulic performance optimization analysis of counter flow cooling towers. For this case study, the model presented by Fisenko will be used, from Eq(1).

$$\varepsilon_{Tower} = \frac{\left(T_{w1} - T_{w2}\right)}{\left(T_{w1} - T_{wb}\right)} \tag{1}$$

From Eq(1) we can obtain the efficiency levels of the cooling tower (tower), which is correlation with the inlet and outlet temperature (T_{w1} and T_{w2}) and where T_{wb} is the wet bulb temperature. In order to achieve a system flexible in its operation, and for this particular case, the wet bulb temperature is modified; with this variation (δ_{wb}), the new bulb temperature would result this way:

$$T^{N}_{wb} = T_{wb} + \delta_{wb} \tag{2}$$

With the inlet and outlet temperature data for the cooling tower, it becomes possible to theorize changes in the heat exchange network.

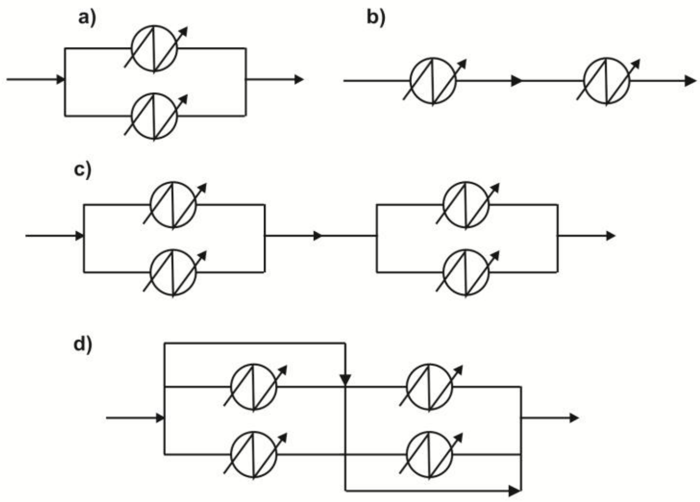

Figure 2: Various cooling network arrangements. a) Parallel, b)Series, c) Series- Parallel, d) With water re-use

3. Reduction to the heat and water exchange area

There are different settings for the heat exchange network employed for cooling systems; Figure 2 shows four different settings: serial, parallel, serial-parallel and with water reuse.
Castro et al. (2000) and recently Castro et al. (2013) present a methodology to reduce costs in a cooling system; he modified the heat exchange network, keeping the serial setting. Picon et al. (2007) presented a methodology that determines the temperature obtained with the different settings of a heat exchange network for a particular case study. Meanwhile, Kim and Smith present with their paper a setting including water reuse in its water pinch methodology in which the setting of the heat exchange network is far more complex than the usual serial or parallel setting. Panjeshahi et al. (2009) presents a mathematical model for the design of the heat exchange network; even when it also takes into account water reduction, Panjeshahi's model focuses on reducing costs globally, having as a goal the reduction of the heat exchange area and water usage for the cooling process.
The mentioned articles and papers all particularly focus on settings for heat exchange networks in cooling systems.
As for the case of the retrofit applied to a cooling system, analysis should be previously conducted on the heat exchange network design with the purpose of applying that methodology that would help reducing costs of operation and would likewise allow flexibility in the operation of its pumping system. Flexibility is very important for this part of the design, as, generally, flexibility in operations is used to increase or decrease production levels, for equipment maintenance, and so on. Because of it, it is necessary to know the operation conditions of the industrial process throughout different periods in time, and to know the modifications applied to the systems partaking of the cooling system.

4. Reduction in energy consumption for the pumping system

As it is known, there are different kinds of water flux controls for pumping systems (Europump and Hydraulic Institute, 2004a), each of them with a set of pros and cons concerning costs and electric energy consumption. In the case of retrofit in cooling systems, the pumping system must be carefully checked in order to achieve important savings in the consumption of electric energy by applying new technologies (Martínez-Patiño et al., 2010) or through modifications in its operation.
Once the re-designing of the heat exchange network has been achieved, it follows the re-design of the pumping network, too. It is necessary to analyze the amount of water needed for the functioning of the heat exchange network. In Figure 3, two modification options for the water flux in pumping systems are shown: by-passing and VSD (variable speed drivers) control. Martínez-Patiño et al. (2010) presented a case study wherein the use of variable speed drives was implemented to reduce the consumption of electric energy in a pumping system; that paper is limited to the consumption thermal, water and electric energy. On the other hand, Sun et al. (2014) presented a case study in which the amount of energy

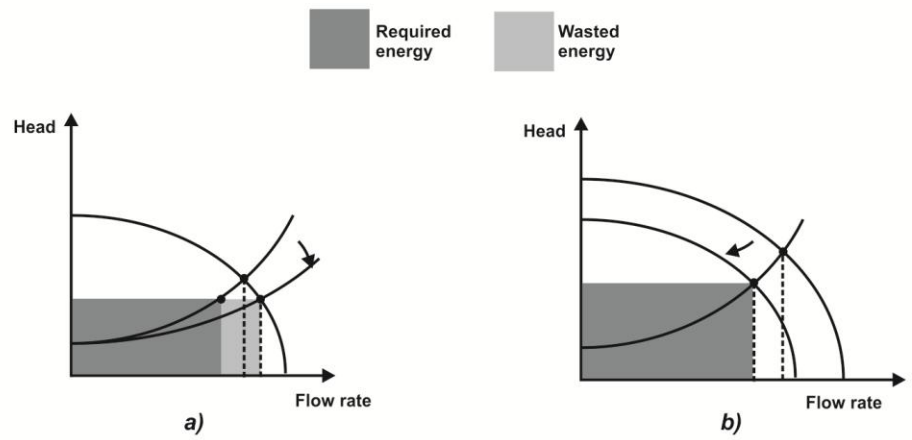

Figure 3: Power consumptions of different process control method: a) bypassing and b) VSD control

consumption and the operation costs for the whole cooling system are reduced; for such, Sun employed a mathematical model to reduce the costs of a superstructure that modified the heat exchange network, the cooling tower and the pumping system: that study focuses on recirculation and in modifying the valves of the pumping system within the frame of the modifications to the superstructure.
Because of this paper primacy to flexibility in the operation of the pumping system; it studies the control on water flux by means of variable speed drivers installed in each pump or through the usage of bypass. It is necessary to be aware of the pump's working life, and if they have the capacity to support the installation of VSD to control the water flux in the pumping system: if the engines of the pumps already have a long working life, then it is likely that it will be required to update to high-efficiency engines that can support the variable speed drivers.

5. Case study

The data for this case study (Table 1) is taken from literature (Kim and Smith, 2001) wherein four fluxes with different temperatures are involved. It is necessary to highlight that other articles previously published focus on cooling systems and do not take into account the reduction in electric energy consumption in their methodologies, and rather remain within the range of thermal and water energy saving.
In this particular case, flexibility is provided by the water pumping system; this flexibility is aided by the water flux control in its operation. In the study represented in Table 1, two options for electric energy saving were analyzed, which can be applied once the modification to the heat exchange network has been made.
Once the water flux reduction has been achieved through the corresponding modification to the heat exchange network, the first option hereby presented for the reduction of electric energy consumption resides in elimination one of the water pumps and put the other four pumps to full function, that way the fifth pump would only be put into function if for any given case greater water flux was required. This first option is not the best as it provides rather little flexibility margin in the operation of the cooling system. Besides that, the reduction in energy consumption is not extensive.
Now, the second option to reduce energy consumption is to install variable speed drivers in the water pumps; in this case study, two pieces of VSD equipment were analyzed to assess the benefits of their installation. The installation of VSDs allow greater flexibility in the operation of water pumps, managing to reduce energy consumption levels, and would also involve the five pumps in its operation, which provides greater flexibility margin in the operation of the cooling system.
Table 2 shows the results in the comparative assessment of the two presented options, and there we can evidently notice the ample reduction in electric energy consumption achieved by the use of VSDs: a reduction of 4,121.59 MW in power is achieved. Besides that, the VSD option has the advantage of providing greater flexibility in the operation and control of water fluxes.

Table 1: Case study. Process data for network cooling design

Stream	T_{in} (°C)	T_{out} (°C)	M*Cp (kW / °C)	Q (kW)
1	50	30	20	400
2	50	40	100	1,000
3	85	40	40	1,800
4	85	65	10	200

Table 2: Alternatives pumping system for the case study

Options	Power consumptions (Annual)	Annual Cost (Dls)
4 pumps (100 % operation)	11,775.99 MW	959,172
5 pumps with Variable Speed Control (80 % operation)	7,654.40 MW	623,463

6. Conclusiones

The flexibility in the operation of industrial processes is or relevance when carrying out maintenance, implementing production increase or decrease, calculating holiday periods, etc. This flexibility involves different systems that must support modifications in their operation. This paper has presented the operating flexibility of a cooling system wherein energy consumption levels are reduced; such flexibility is sustained by the use of variable speed drivers in the water pumps. It also reduces the water consumption and the heat exchange area of the cooling system.

The stages to achieve the reduction in water consumption, the heat exchange area (reducing heat exchangers) and electric energy can be summarized in two: first, the implementation of the water pinch to reduce water consumption and the heat exchange area, which implies a new setting for the heat exchange network. In the second stage, an analysis of the different options available for the flux variation in the pumping system is carried out; this modification to the pumping system is directly dependent of the flux changes of the first stage.

Firsthand, an analysis of the VSDs installation is recommended, in order for the system to achieve further reduction in the consumption of electric energy and also have the flexibility in its operation.

The most important contribution of this article mainly resides in that, once a cooling system is modified either in its cooling tower or in its heat exchange network, it provides the means through which the electric energy consumption of a pumping system can be reduced.

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