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Exploiting inherent process flexibility for the reduction of water and energy consumption. Application to the pulp and paper industry

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This work presents a procedure for the reduction of energy and water consumption in existing processes. In this approach, a protocol of action for the analysis of existing processes is proposed. The retrofit approach presented here is developed for the case of pulp and paper processes. The strategy consists of three main stages, namely: 1.- Identify the interactions between equipment design and water consumption in order to undertake the necessary modification that result in effective reductions and viable implementations; 2.- Undertake a water pinch analysis seeking to minimize the consumption of fresh water, and 3.- Undertake an energy integration study seeking opportunities for energy reduction. The case of the bleaching section of a Kraft process is considered; analysis of the reaction section and its relation with water consumption is shown.

1. Introduction

At industrial level and particularly in real pulp and paper processes, methodologies and techniques to reduce independently water consumption as well as energy consumption have been implemented. As an example, Pinch technology (Linnhoff et al. 1982) began its application to this kind of industry in the early 90's (Calloway et at. 1990, Berglin et al. 1997, Koufus et al. 2001, Rouzinuo et al. 2003, Savulescu et al. 2005 and Towers, 2007) with good results in terms of the reduction of energy and water.

The concept of reduction of energy through the reduction of water in the pulp and paper industry has been applied by Wising et al. (2005). With the same concept and in the same type of industry, Nordman et al. (2006) presented a design for the water and energy systems by reducing thermal energy consumption as a consequence of the reduction of water consumption). Parthasarathy et al. (2001) reduced exclusively the water consumption in a Kraft pulp production process applying mass integration techniques for the reuse of effluents.. In the same way Lovelady et. al (2007) reduced

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the water consumption in this type of industry optimizing the effluent discharged and the reuse of water.
In this work, a hierarchical order for process retrofit is considered. First, water reductions are analyzed and in a second stage energy reductions are considered.

2. Overall (hierarchical) retrofit approach for the reduction of water and energy in pulp and paper processes

The guidelines set by Westerberg et al. (1979), also referred to in the so-called strategy of the onion (Linnhoff et al. 1982), (Shenoy, 1995) and the heuristic approach (Douglas, 1988), are examples of procedures for the design based on the decomposition of the process in stages. The philosophy behind each of these works, is the basis for implementing the necessary strategies for the minimization of water and energy in a real process of pulp production. The approach is demonstrated in the case of the retrofit of an actual process for the reduction of water and energy consumption. The procedure starts with a profound knowledge of the process; continues with the extraction of information and then the implementation of the heuristic rules and methodologies for analysis. A graphical diagram of the hierarchical approach is shown in Figure 1 by means of an "onion diagram".

1.- Reaction:
   a. Analysis of chemical reaction route
   b. Reaction system (reactors)
2.- Water use system
3.- Water regeneration for reuse
4.- Heat recovery system

2.1 Reaction

The layer of reaction is subdivided into two levels: one is related to the analysis of the route of reaction and the other one is related to the system of reactors. In this stage, the type of chemical reaction, the kinetics and the reactor design are analyzed in detail.

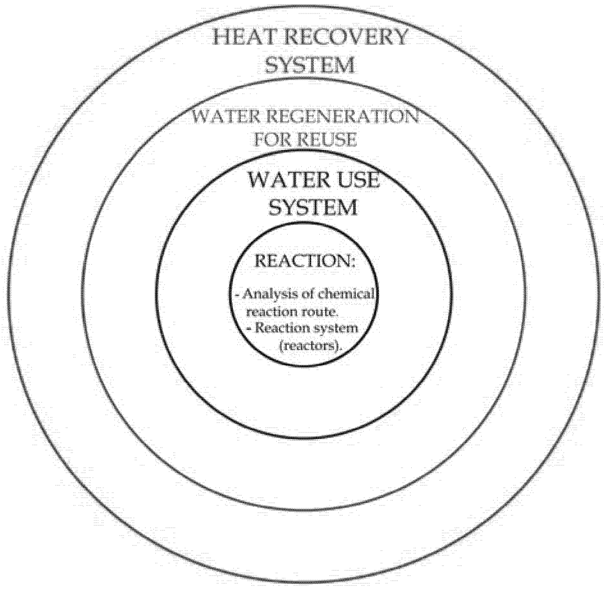

Figure 1.- "Onion Diagram ", ranking of stages for the reduction of water and energy in pulp for paper.

2.1.1. Analysis of chemical reaction route

The stage of bleaching is a section of the process for pulp production where chemical reactions take place. The purpose of the bleaching process is to withdraw the maximum amount of lignin contained within the pulp.

In this stage, the type of reaction that is carried out in each of the different stages of the bleaching process is analyzed. The chemical compounds that are used in the bleaching stages are identified. In the case of an existing plant, the analysis of the route of reaction may trigger a series of actions allowing the implementation of technologies with greater reaction conversion while reducing the water consumption.

2.1.2. Reaction system (reactors)

Once the route of chemical transformation of the process is known, the reactor systems design is then considered. This involves the examination of a three way trade-off between equipment, level of conversion and reduction in water consumption. In the case of the bleaching process, it appears that the lower is the amount of solids (mass of pulp) at the outlet of the reactor; the lower is the amount of water that is needed to reach the required concentration in the filtering stage, as it is shown in the Figure 2. Equation 1 (Walas, 1988) shows the relationship between mass flow rate, F, the volume of the reactor, V, the final conversion, x_e, the initial conversion, x_F, and conversion rate, r_e.

In this way, if we know the characteristics of the bleaching reaction and we know the volume of the reactor, we can determine the actual reaction rate. This information is then used to determine what is the new reaction volume needed in order for more lignin to react and the required investment. The flow diagram of Figure 2, shows the way the fresh water consumption is linked to the level of lignin conversion in the reactor. Since fresh water is used to dilute the reactor outlet stream for it to be filtered downstream, the more the lignin reacts, the lower the amount of solids at the reactor outlet. This condition results in less fresh water being needed for dilution and therefore water savings are obtained. In addition, warm water is added into the filter for furthering the removal of impurities from the cellulose.

$$\frac{V}{F} = \frac{x_e - x_F}{r_e} \qquad (1)$$

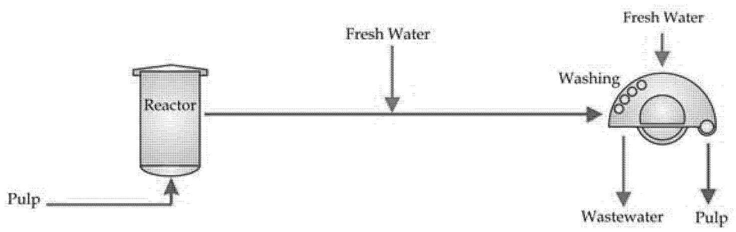

Figure 2.- Area of chemical reaction and filtering in the stage of bleaching

2.2 Water use system

At this stage a water pinch analysis is carried out. For instance, the washing section of the process, that consists of a series of physical separations for the removal of impurities from the pulp coming out from the digester. This pulp receives the name of raw flesh because it has not been bleached yet. At this stage, a large amount of water is used. It is therefore important the implementation of techniques that lead to the reduction of water. The large amounts of water used and the physical nature of the process are conducive for the implementation of the Water Pinch Analysis (WPS) technique which seeks to minimize the consumption of water. These conditions are also appropriate to pose an optimization problem by means of mathematical programming, seeking to reduce the total operation costs. Both techniques are effective for the analysis, synthesis and improvement of the water networks. Furthermore, they take into account the concepts of reuse and regeneration of water that have an impact on the generation of wastewater or effluents while minimizing the water consumption.

2.3 Water regeneration for reuse

Once exploited and completed all the options for the reduction of water consumption through the measures implemented in the first two layers of the onion diagram, the next stage consists in the application of water regeneration techniques. At this level, different techniques for feasible decentralized regeneration of the effluents for water reuse should be evaluated. Among the typical regeneration technologies are those of physical, chemical and biological nature. The selection of the regeneration system should be based on a series of considerations such as: equipment cost, operating costs, ease of implementation, availability, etc.

2.4 Heat recovery system

The last stage in the hierarchical level is to identify the options for reducing energy consumption through the maximization of the heat recovery and the quantification of direct savings generated by the simple reduction of the water consumption. In some cases, when the economic scenario is favorable, the savings of steam can be channeled to the production of electrical power in cases where the process plant is integrated with a cogeneration system.

3. Case study

In the Kraft process for the production of pulp for paper, the stage of bleaching consists of a reaction system based on the oxidation of lignin in order to facilitate its separation from cellulose. The base case conditions indicate a lignin conversion of 71 %. Water is added to the reactor effluent to reach a solid concentration of 1.2% that is required by the filtering equipment. As explained earlier, the greater the conversion of lignin the lower is the water consumption. In ideal conditions, the upper limit for the elimination of lignin is 100% conversion. This would require the installation of a reactor of infinite dimensions. The question that arises is: How much should reactor volume be increased so that the reduction in water consumption justifies the investment? The answer to this question is related to the level of investment and the pay back period accepted by the company. The results from this case study applied to real plant data resulted in water savings of 92088 m^3 per year and energy savings of 8 483.04 GJ per year (as a result of less warm water being needed). These results together with the capital investment for the additional reactor volume lead to a pay back period of approximately 3 years (Martinez-Patiño J. 2008).
The next hierarchical level consists in the application of the water pinch analysis (WPA) techniques to determine the minimum water flow rate. In a practical application, this target serves the purpose of establishing a minimum thermodynamic limit that could be achieved; however, reaching this target is always subjected to various things: the practical operation of the pieces of equipment involved and the level of investment required. On the other hand, this target motivates the deep analysis of the various unit operations and as a result, some improvements were identified. In addition, a water saving of 582.62 ton/hr was achieved and a direct energy saving of 5504 kW (Martinez-Patiño J, 2008).

4. Conclusions

A new hierarchical approach for the retrofit of existing processes has been introduced. The approach looks at the reduction in water and energy consumption in processes for the production of pulp for paper. This new approach shows how the operating conditions affect the requirements of water and energy and failure to deal with opportunities for water and energy reduction at this level may result in less than maximum benefits. The approach presented is graphically represented by means of an onion diagram that shows the hierarchical stages that should be conducted in a retrofit study.

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