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Process Integration Solutions for Water Networks in Integrated Steel Making Plants

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Process Integration capabilities of promoting the internal recycling and reuse of material and energy streams allow reaching the goals of sustainable processing. Water is one of the main industrial resource which use has to be optimised to decrease freshwater intake and wastewater blowdown. Preliminary studies on the feasibility of different options are developed through Process Modelling and Simulation to predict process behaviour before plants conversion. The paper presents the approach to the problem of water reuse for an Italian integrated steelmaking plant. Application to a real case has been developed, related to reuse of continuous casting wastewater blowdown in basic oxygen steelmaking gas washing system. Process Modelling with main assumptions and results are described. The option is promising, as it involves a reduction of fresh water drawing up to 33 %, with changes in blowdown features of 2 % for pH value increase and 13 % for electrical conductivity reduction at constant global mass balance.

1. Introduction

Environmental issues and even more pressing law dispositions are nowadays the storm centre, both for industrial and social lives. From an industrial point of view, one of the main aspects to focus on is the exploitation of internal resources, in order to decrease the external intakes, together with the optimisation of process management, to produce smaller amounts of wastes. Achievement of these ambitious objectives leads on to reduced operating costs. Obviously on the basis of the application field and of the plant extension, this kind of management can turn out to be very difficult. Furthermore, the matter gets more complicated if the retrofitting of an existing plant, instead of new equipment insertion, is required. While the design stage naturally takes into account all the most updated environmental constraints and regulations, the first case demands modification on previously conceived plant, which calls for a detailed preliminary evaluation of options for the integration of existing and well established processes. In particular, the topic of water efficiency involves all fields of industrial application, as water is a primary or auxiliary resource for almost all production processes, with consequent increasingly attention toward solutions to enhance water recycle and reuse. Among a lot of possibilities, investigations need to be pursued on the exploitation of water blowdown streams to be used as feed for different processes, eventually after some intermediate treatments. In effect this solution, even though its intrinsic simplicity, can help industry to partially solve or attenuate water issues, adding value to a stream which is usually discharged. Therefore, preliminary analyses of process feasibility become fundamental to identify the most convenient option to implement, together with deeper investigation and economic evaluations. Process Modelling and Simulations are useful to carry out a representation of the Process Integration (PI) solutions, comparing foreseen results for each analysed case, taking into account equipment and plant capabilities, efficiency and quality for process streams. In the suit of commercial software for Process Modelling, Aspen Plus® V8.4 (Aspen Technology Inc., 2013) has been selected for this study, as it best matches with the characteristics of the problem, involving electrolytes chemical species and aqueous solutions. The present paper focuses on the huge reality of an Italian integrated steelwork, where also a small change in water system handling can result in relevant benefits. In particular, the presented case study investigates the

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possibility to act on water management of a sub-network of a single production area by reducing the water blowdown streams to consequently increase the environmental sustainability with respect to current operating conditions. The paper is organised as follows: Section 2 presents a brief background on PI-based approaches to wastewater minimisation, which led to the present work, Section 3 presents the main features of the proposed approach and Section 4 describes the considered industrial case study. Concluding remarks are reported in Section 5.

2. Background of PI-based solutions for water efficiency

Wastewater minimisation has been widely investigated by Wang and Smith (1994a) using Pinch Analysis, both for single and multiple contaminants in water stream. Reuse, regeneration and recycling options have been considered entirely from a conceptual point of view but a deeper insight is requested for larger scale problems, where approximations can alter physical phenomena. Within further studies, Wang and Smith (1994b) themselves exploited design rules for distributed effluent treatment system. However, in the case of more than one contaminant for water, the approach has to be repeated for each present chemical species and then merged in a final design, requiring relevant efforts. Klemeš et al. (2013) reported some recent developments of PI-based approaches, where standard methodologies like Pinch Analysis have been coupled to new ones, like Heat and Power Integration or mathematical programming. Future challenges cited representations of very complex large-scale industrial applications, also taking advantages of modelling tools. The general importance of using simulators for the study of PI solutions has been analysed by Kim (2009), assuming consolidated process knowledge, to optimise operating conditions and reduce computational costs related to engineering effort. Combination of different partial methods to consider environmental and resource targets has been attempted for several applications. Mooney et al. (2013) showed the use of this technique linked with energy consumption, providing information for decision making. The main idea for the present investigation arose from the exemplar studies of Porzio et al. (2013a, b), focusing on the problems of reducing energy consumption and CO_2 emissions in an integrated steelmaking plant; a software system generating internal reports on the current plant performances was developed, starting from an Aspen Plus® (Aspen Technology Inc., 2013) simulation of the relevant processes, which was capable to predict the plant behaviour in different scenarios. A preliminary application of this kind of approach to wastewater recycle in the steelmaking sector was presented by Porzio et al. (2014), to analyse options for optimal water network design. In this paper this methodology is deepened and validated by means of an exemplar industrial application showing its potential capacity.

3. Methodological approach

In order to obtain a general method to apply to the problem, a summary of fundamental steps is presented hereinafter. The previous overview puts into evidence the importance of a deep knowledge of the process to analyse. Therefore the following procedure assumes relevance if supported by collaboration with plant managers and process engineers, in order to avoid investigation on unfeasible solutions. A good methodological approach to reach the integration of industrial water networks can therefore be explained by the following steps: Process Analysis and Data Collection, Pinch Analysis and Constraints Observations, Process Modelling and Simulation, Process Optimisation, Design and On-line Application.

3.1 Process Analysis and Data Collection

The process has to be analysed and deeply understood starting from the use of flowsheets, Piping and Instrumentation Diagrams (P&IDs) and equipments' data sheets. Data collection is fundamental to become conscious of current operating conditions and parameters trends of the units of interest. Streams flowrates and chemical composition, equipment and pipes sizes and capabilities, treatments and processes efficiency are a small part of the relevant data to monitor. With the selected information, Process Analysis allows identifying water sources and water potential users for preliminary Pinch Analysis.

3.2 Pinch Analysis and Constraints Observation

Water Pinch Analysis is central to obtain a list of potential PI alternatives considering similarity of water properties and contamination and process constraints. In particular water contamination need to respect the limiting values for each chemical species coming from the nature of water user process. In terms of one single contaminant, it results in the limiting water profile of Pinch Analyses. In the case of multiple contaminants, some simplification are required for Pinch Analysis to be carried out but deeper investigation on the problem of interest are fundamental to elude unpredicted scenarios of non-practical feasibility arisen from such approximations. In order to avoid investigation on unfeasible solutions also water sources and potential water users' allocations need to be taken into account in this stage, together with additional intrinsic or external process constraints.

3.3 Process Modelling and Simulation

Third stage for the considered systematic approach is the Process Modelling and Simulation. Ad hoc model is developed and tuned to fit as accurately as possible the real data and phenomena. In particular, starting from theoretical process knowledge, the model has to simulate all the phases of a unit, also considering the possibility to represent a general actual operation using different sub-units, each assigned to stand for one single phenomenon. Simplifications can be necessary for huge areas, in order to obtain a scheme which is as simple as possible but taking at the same time into account all the main process stages. Thus, with a realistic representation of the actual process, sensitivity analyses of PI solutions can be carried out as a sort of virtual application. The use of specific simulation software allows in-depth analyses, which in the considered problem are related to multiple contaminants effects on the water user to fill up Pinch Analysis approximations. Changes in operating condition results in different features of the whole material flows, in this case linked with the properties of the new hypothetical water inlet to the process. The results of this stage of simulation reveal the feasibility of a solution: the option is promising if the new set of operating conditions does not strongly affect the main parameters which ensure the correct plant operation and the compliance with environmental regulation.

3.4 Process Optimisation, Design and On-line Application

Controlled On-line Applications and real experiments are the final steps to optimise and assess the simulation results before the design and eventual implementation of the analysed promising solution.

4. Example of application

Options of water reuse have been investigated in order to enhance environmental sustainability of an integrated steelwork in Italy. The size of the considered plant makes arduous the viability of a detailed water Pinch Analysis, considering all kind of constraints (i.e. average water consumption, plant layout, equipment allocation, etc.) and chemical parameters (i.e. COD, THC, Cl^-, Zn, V, Pb, Ni, Cr, Fe, Sn, SiO_2, etc.). For this reason, plant staff followed a simplified approach. Huge plant areas and water networks have been considered as single water users or sources. Only more relevant parameters have been taken into account and some of them have been grouped (e.g. TSS, metals, anions, etc.) and a set of main parameters have been considered (i.e. electrical conductivity and pH values). Equipment allocation and capability have been fixed as process constraints. In this way hypothetical PI options have been identified: Continuous Casting (CC) and pipe coating blowdown streams can be considered as water sources to be used respectively in the off-gases washing system of Basic Oxygen Furnaces (BOFs) and in the pipe mill water network (users) without turning plant down. The preliminary Pinch Analysis conducted by plant operators is not part of the proposed paper, which focuses on the evaluation of feasibility of one PI option in terms of water reuse by Process Modelling and Simulation. The selected option to represent is related to the use of CC water blowdown in BOF gas washing system.

4.1 Case study

The considered water network is the BOF off-gases washing system, currently fed by river fresh water with drawing limits due to stringent regulations for environmental protection and agriculture usage. Figure 1 shows the schematic representation of the plant area. Fresh water is fed to a supplier, which is a sort of channel where all the process water streams are collected and mixed together. The outlet from the supplier is sent to a set of clarifiers, here represented as one single unit, where pH value is adjusted by means of carbon dioxide and where wastewater coming from the water network of another plant area (i.e. the Ruhrstahl Heraeus process, RHOB) is piped. Coarse stream coming from clarification unit is the inlet of some belt filters, where it is added with polymer to enhance sludge formation. Sludge is extracted and the recovered water fraction comes back to the supplier. Overflow stream of clarifier is added with an antiscalant agent and subdivided into two fractions. The biggest portion of water serves the Venturi scrubber, where gas washing takes place and then it is separated by hydrocyclones from the iron oxides before being collected again in the supplier. The remaining part of overflow is filtered in sand filters to be discharged, while the non-filtered stream is finally sent back to supplier. The analysed PI option focuses on the total or partial replacement of fresh water with a current water blowdown stream, which comes from continuous casting area of the plant.

4.2 Application of the proposed methodology

Once ascertained a deep knowledge of the process, plant staff supported the phase of data collection and internal simplified Pinch Analyses in order to obtain a preliminary list of PI solutions.

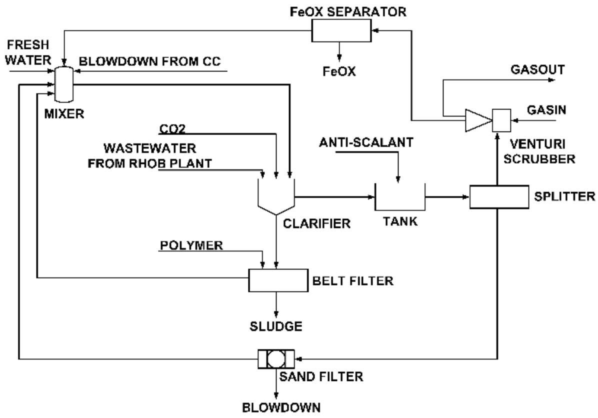

Figure 1: Simplified representation of BOF gas washing water network

Main water features for the analyses were properties such as electrical conductivity and pH value, which reveal information about contamination status. From the obtained PI list, options have been rejected due to practical constraints related to plant layout, resulting in a subset of alternatives to proceed with the application of the methodology. The presented case study is one of this subset and it has been prioritised because of the facility of implementation connected to the proximity of the two considered plant areas. Furthermore, the existing plant has pipes arrangement which allows carrying out on-line application with minimal modifications and limited investments. Nevertheless, a detailed analysis of the behaviour of the water user (BOF gas washing system) in non-conventional scenarios is quite difficult with established techniques because of the huge amount of constraints and contaminants interactions to be considered. For this reason, Aspen Plus® (Aspen Technology Inc., 2013) commercial software has been selected for Process Modelling and Simulations as the most appropriate in order to represent properties of electrolytes and aqueous solutions. According to plant data, a model of the network of the water user has been developed as shown in Figure 2. All the described unit operations have been represented, eventually composed of different sub-units, in order to consider all the physical phenomena of the process. For instance, in the case of Venturi scrubber, the representation provides the sum of an equipment for the separation of solids from gas stream, a mixing with washing water and a heat exchanger to decrease temperature value. It is important to emphasise that for each input unit and stream real data of temperature, pressure, composition, design features and/or constrains can be inserted. In order to represent realistic water solutions with multiple chemical compounds for fresh water and water coming from RHOB plant, which are input for the model, preliminary analyses of lab data for the streams have been carried out, by identifying the composition in terms of most probable salts present in solution, according to the model for simplified ionic representation of industrial water streams developed by Alcamisi et al. (2014). Taking advantages from the fact that Aspen Plus® (Aspen Technology Inc., 2013) (allows the user to customise internal blocks, electrical conductivity (EC) calculator has been implemented and compiled as a FORTRAN code within the model, such as described in Matino et al. (2014), in order to monitor this important parameter during the process. The model output is an estimate of intermediate and outgoing streams features such as EC, pH, suspended solids (SS) and also detailed water compositions. In order to obtain a realistic representation of actual conditions, some adjustments have been necessary. Obviously the higher the model accuracy, the higher computational costs. When almost all simulation results were matching with real data, model has been considered validated, as shown in Table 1 for main water streams. Thus, the analysis of the selected PI option can be performed through the validated model. Substantially, the CC blowdown water stream features have been evaluated as for fresh and RHOB water streams for the base case and, keeping constant the global mass balance, mass flowrate of fresh water can be actually reduced according to the CC blowdown availability as suggested by preliminary Pinch Analyses.

4.3 Results and discussions

Simulation results have been compared in terms of operating conditions between current and hypothetical PI solution performances. Table 2 reports the main results. As highlighted from the data, main properties of process streams (EC, pH, SS, etc.) are not significantly affected by the use of CC wastewater. The theoretical feasibility of this alternative is proved. The quality of CC wastewater is quite good, even better than the one of fresh water in terms of EC.

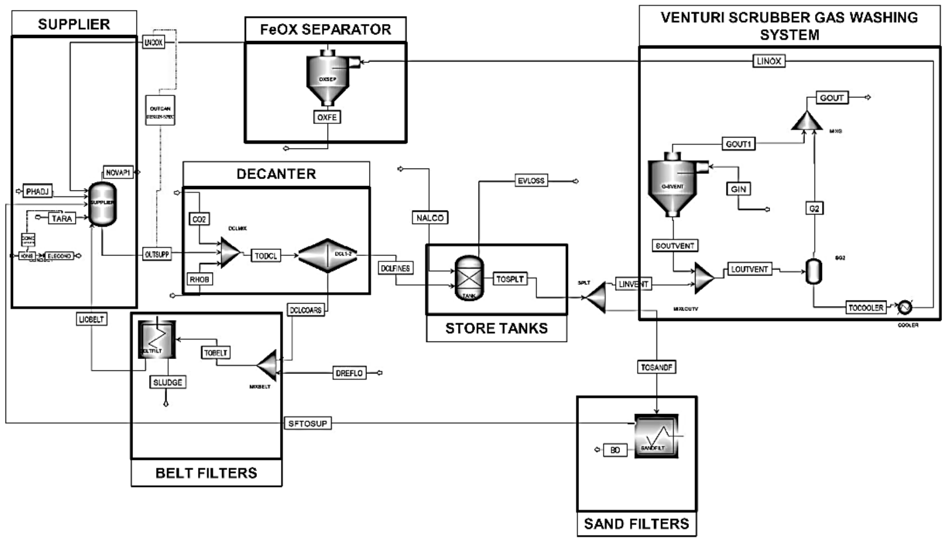

Figure 2: Aspen Plus® (Aspen Technology Inc., 2013) flowsheet of BOF gas washing system

Table 1: Comparison for main water streams of real data and simulation results at current conditions

		Fresh water		RHOB water		Clarifier overflow		Water blowdown	
Parameter	Units	Data	Simulated	Data	Simulated	Data	Simulated	Data	Simulated
Mass flow	kg/h	35,000	35,000	23,333	23,333	478,308	474,078	55,000	53,780
Temperature	°C	27	27	30	30	35	34.8	35	34.8
pH		7.9	7.9	8.5	9.3	10	10.3	11	10.3
Elect. cond.	µS/cm	3,300	3,365	4,500	4,746	< 4,800	3,764	< 6,000	3,810
Solids flow	kg/h	0.07	0.07	4.67	4.67	n. a.	3,243	n. a.	0.44

The presence and the interactions of a double content of SS and of micro-contaminants, considered by the built-in capability of Aspen Plus® (Aspen Technology Inc., 2013), seems not to affect the behaviour of the BOF gases washing system. New treatments are not required and the existing equipment appears to be suitable, according to the environmental regulations also in this new configuration. In spite of this, the CC water blowdown flowrate is not enough to completely replace the use of river water. Highlighting the main simulation results, a reduction of freshwater intake is possible up to 33 %, blowing down a stream with almost the same value of pH (increase of only 2 %) and a lower salinity as underlined by a reduction of electrical conductivity of 13 %. These results are shown in Figure 3, where modified water intake is indicated. The detailed simulation confirms the results of the simplified Pinch Analysis conducted by plant operators: this application appears to be promising for on line tests and eventual implementation, according to engineering and design computations and economical evaluations.

5. Conclusions

Industrial environmental policy is nowadays strongly committed to the reduction of impact and pollution. Particular attention is paid on the improvement of resources efficiency, both in design phase and in retrofitting of existing plants. In the second case PI alternatives need to be identified and tested. An approach to this problem has been proposed and applied for water source in industrial steelmaking. Taking advantage of process know-how of plant staff, a virtual plant has been developed using Aspen Plus® (Aspen Technology Inc., 2013) commercial software, which has been validated with real data. With a realistic simulated plant, PI options can be tested, taking information about feasibility and unit operation responses to variations. An application of reuse of wastewater blowdown coming from CC area in BOF gas washing system of an Italian steelwork has been analysed, revealing that the proposed solution can be promising for future online applications and implementation. Simulation results show the possibility to reduce freshwater intake by also improving the blowdown features in terms of salinity at constant global mass balance. All existing equipment is suitable to accept the new hypothetical operating conditions. The method provides a good solution for further studies and eventual implementation. Furthermore the proposed methodological approach and the developed model can be used to evaluate additional and also more difficult PI options.

Table 2: Comparison for main water streams of simulation results between simulated PI option (right column - PI) and current operating conditions (left column - No PI).

		Fresh water		CC wastewater		Clarifier overflow		Water blowdown	
Parameter	Units	No PI	PI	No PI	PI	No PI	PI	No PI	PI
Mass flow	kg/h	35,000	20,000	-	15,000	474,078	474,095	53,780	53,784
Temperature	°C	27	27	-	27	34.8	34.8	34.8	34.8
pH		7.9	7.9	-	8.1	10.3	10.5	10.3	10.5
Elect. cond.	µS/cm	3,365	3,365	-	1,207	3,764	3,255	3,810	3,296
Solids flow	kg/h	0.07	0.07	-	0.15	3,243	3,243	0.44	0.44

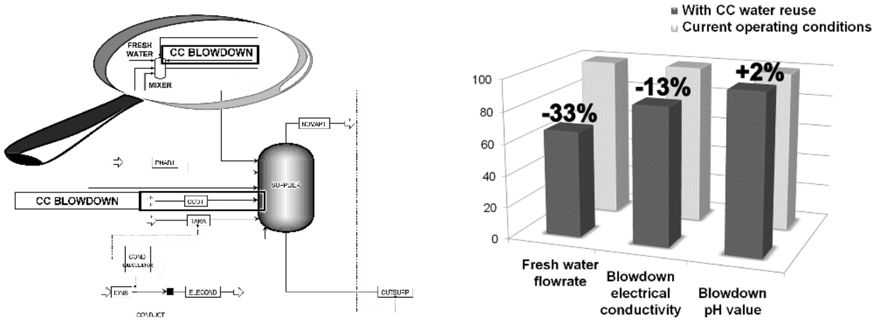

Figure 3: Modified water intake (left) and expected results of the proposed water PI solution (right).

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