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Sustainable Reverse Osmosis application for wastewater treatment in the steel industry

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ABSTRACT

The research work presented in this paper is related to water reuse and facility management concepts for the main circuits in different steel plants through the salt elimination techniques. In particular the study concerned two water circuits belonging to two integrated steelworks where high salts concentrations caused relevant problems. In the first circuit, the high chloride and carbonate concentration in the cooling water of the hot strip mill can affect the quality of the strips, due to the salt depositions on the strip surfaces, and causes corrosion of equipment. In the second circuit, the high content of chlorides and fluorides in the process waters of a Blast Furnace gas cleaning system causes corrosion of various components.

In both cases tests were carried out to assess the possibility to apply Reverse Osmosis implementation and to evaluate the stability of its qualitative performance to the brackish water. The tests showed that pre-treatments are actually needed for colloids removal, and, consequently, to protect Reverse Osmosis membranes: in the first circuit, ultrafiltration, and in the second circuit conventional coagulation-flocculation-sedimentation system followed by sand filtration have been implemented.

Results showed that, through Reverse Osmosis system, most salts, such as chlorides, fluorides, calcium, sulphates, etc. can be removed and other parameters, such as electrical conductivity, alkalinity and Total Dissolved Solids dramatically decreased. Accordingly significant results have been achieved, such as fresh water consumption and water discharged decrease, and the pipe service life improvement, due to the reduction of corrosion problems. The economic viability at industrial scale was also evaluated and their implementation resulted feasible.

1. Introduction

In order to improve sustainability of its production cycle, steel industry is committed to reduce its environmental impact (to air, water and soil), the natural resources exploitation, the waste production, as well as to save energy, to minimise the use of raw materials and to increase the materials recycling (World Steel Association, 2014). On this subject recently important results have been achieved. For example, through the IS it is possible to achieve environmental and economic benefits simultaneously (Dong et al., 2013). Furthermore, a recent study on the water footprint assessment methodology has been developed. This indicator has been implemented for the iron and steel industry instead of conventional indicators, such as FWC per tonne of steel and WC per tonne of steel. This can lead to the improvement of water

Abbreviations: AME, Arcelor Mittal Espana; BF, Blast Furnace; BMF, Back-Washable Microfiltration; BOD, Biochemical Oxygen Demand; BOF, Basic Oxygen Furnace; BW, Brackish Water; CMF, Continuous Microfiltration; COD, Chemical Oxygen Demand; EC, Electric Conductivity; ED, Electro-Dialysis; EDR, Electro-Dialysis Reversal; FWC, Fresh Water Consumption; HSM, Hot Strip Mill; IS, Industrial Symbiosis; IX, Ion Exchange; N, Nitrogen; P, Phosphorus; PBP, Pay Back Period; RO, Reverse Osmosis; SDI, Silt Density Index; SS, Suspended Solids; TDS, Total Dissolved Solids; TSS, Total Suspended Solids; UF, Ultra-Filtration; VCR, Volume Concentration Reduction; WC, Water Consumption.

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efficiency, and, consequently, to a lower environmental impact of the production (Gu et al., 2015).

The steel sector is one of the largest energy-intensive and water-intensive process industries. Water is mainly used for cooling facilities, process and environmental-technical applications, such as the wet gas cleaning, and sanitary applications, particularly in the integrated route, which produces steel from iron ore and fossils. Wastewaters resulting from different processes have specific characteristics, and water management variability is mainly due to the differences of local conditions, in particular plant configuration, water availability, water quality and legislation. For this reason the steel industry pays attention on the water resources in order to minimise the water consumption per ton of steel. Furthermore, as the quality of wastewater resulting from some processes might not be high enough for further usage, it is important to develop advanced treatments to enable its reuse and increase the water recycling rate. On this subject considerable efforts have been and are being spent to improve the water management efficiency (Suvio et al., 2010) and the environmental performances of this sector in order to reduce fresh water consumption (Hird, 2006) as well as to meet legal compliance and to save natural resources. Improvements of effluent treatments have been carried out not only related to the traditional ones, but also regarding advanced treatments, aiming at achieving high-quality water and high efficiency of water recycling (Water, 2009). They are represented by basic chemical sedimentation/clarification combined with flocculant treatment. They produce sludge by-product formation, which needs to be further handled and treated. Some projects have produced a reduction of wastewater discharge as well as a decrease of pollutants in wastewaters. The improvement of water management in the steelworks concerned not only the performances of process in the existing infrastructures but also the reduction of water used and discharged (Mortier et al., 2007). Through the implementation of a recycling system, wastewater was treated and consequently reused. The decrease of water use per ton of liquid steel produced has led to an efficient recycling system which has reduced the extraction of non-phreatic groundwater (Van Caneghem et al., 2010). Another study concerns the integration of all water-use processes into a system and the application of the substance flow analysis in order to build up an optimization model and an evaluation index system for the water-use network of a steelworks. Results analyses and evaluation have led to important results. Actually, after the optimization, both the water consumption and the wastewater discharged could be significantly reduced, by producing important achievement in water savings (Gao et al., 2011). Furthermore in a recent study, in order to achieve potential freshwater saving, the integration of two approaches (water network optimal operations with fixed design and water pinch technology) through the simulation of a water network, has been carried out (Porzio et al., 2014).

RO represents a good technology for treating wastewater with high conductivity, such as iron and steel wastewater. It consists of a water purification process which separates the solvent and the solutes through the application of pressure difference. This is produced by retention effect on the membrane which allows the water molecules transit. The RO process is generally used, on one hand, to remove water pollutants, such as phosphorus, organic matter, etc., and, on the other hand, in the desalination processes, in order to remove, for example, Na^+ and Cl^- (Malaeb and Ayoub, 2011).

In this regard the steel sector presents specific issues and special features. In effect process waters with high salts concentration can affect environment and equipments (e.g. cooling system). In particular, for instance, phosphate can lead to eutrophication and consequently to the pollution of water system; chloride can produce the metal corrosion, causing problems for the cooling systems; carbonate can cause the scale formation in the pipes, producing the increase of energy consumption. Therefore the steel industry, such as other process industries, aims to selectively reduce salts from process waters as well as to increase the reuse of process waters, leading also to reduce fresh water costs and wastewater discharge costs.

Although RO is an energy intensive process, its energy demand is lower if compared to thermal technologies. Nevertheless the high electricity demand of the RO process is currently supplied mainly by fossil fuels, and, consequently, it results in increased CO_2 emissions.

The use of RO for removing monovalent and divalent ions dissolved in wastewater coming from the steelmaking processes can be efficient when it is combined with an effective pre-treatment, such as BMF. Results of this work showed that RO effectively removed both monovalent and divalent ions (that cannot be removed by conventional physicochemical treatment) dissolved in wastewater. However, although the efficiency was nearly 100%, pre-treatment (such as BMF) was often necessary, due to the wastewater nature (Lee et al., 2006). The application of RO treatment allows the reduction of dissolved salts but shows some problems in organics removal. A study concluded that cyanide and ammonium are not easily removed in a single step from industrial wastewater, but through different separation steps at different pH values (Bodalo-Santoyo et al., 2003).

As far as the electroplating industry is concerned, the application of RO technology has produced significant improvements, particularly in metals removing in the permeate as well as in the recycling of the plating bath. The experimental procedure has included some pre-treatments, such as cyanides oxidation, filtration of solids, pH adjustment. The permeate obtained showed the quality as deionised water and it could be used into production processes, thanks to its physical and chemical properties, by achieving the recycling percentage of about 75–95% (Benito and Ruiz, 2002).

During the RO process one of the main issues can be the membrane fouling, which is usually caused by pollutants as well as by microorganisms, colloidal materials and salts. These deposits can lead to the decrease of flux through the membrane and consequently to the efficiency reduction. Nevertheless, thanks to the improvement of the problems due to the membrane fouling, RO has become a good application for reducing salt concentration in the brackish surface water used in the industrial processes.

Usually the membrane fouling can be prevented by applying pre-treatments, such as disinfection, acidification, addition of coagulant and/or flocculant, media filtration and cartridge filtration. Nevertheless the traditional pre-treatment processes cannot be effective to remove the fine colloidal suspended solids organic matter, and microorganisms. Due to this reason, along with traditional pre-treatments, microfiltration and UF are often used. This can bring to the improvement of water quality and to the cost reduction, although during these processes some membrane contamination can occur and consequently some further pre-treatments are necessary (Huang et al., 2011). Furthermore the application of constructed wetlands represent an important technology for SS, COD, N, P, and other pollutants removal from wastewater. In a recent study this has produced the RO membrane fouling prevention as well as important achievements in wastewater treatment and recovery rate (Huang et al., 2011). Moreover, over the past few years, due to the characteristics of industrial wastewater (such as high EC), the use of membrane processes for effluent treatment, such as UF, RO, ED and EDR, has increased (World Steel Association, 2011). Desalination technologies for wastewater allows to produce high quality water for industrial