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Reducing water and energy consumption in chemical industry by sustainable production approach: a pilot study for polyethylene terephthalate production

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ABSTRACT

In this study, a polyethylene terephthalate manufacturing plant was subjected to environmental performance evaluation and analyses/benchmarking of water consumption. The objective was to determine processes/practices where significant water and related energy saving potential was present. Based on evaluations and analyses, a technology change was realized in heat transfer systems from water-to air-cooled process. As a result of the applications, soft cooling water consumption of the company was reduced by 46.7% which corresponds to water saving of 151,428 m^3/year. Moreover, 117,848 kWh/year of energy was saved due to electricity saving in electric motors of pumps of heat transfer systems as well as pumps/fans of cooling towers. Owing to the improved energy efficiency, total carbon emissions of the company was reduced by 69,530 kg CO_2/year. Auxiliary material consumption was also reduced since the maintenance requirements of heat transfer pumps were minimized. The total cost saving was 104,905 $/year, while the payback period was calculated as 6 months. This study was conducted to be used as a successful model to increased water and energy efficiency in manufacturing industries based on systematic environmental performance evaluations and benchmarking. Furthermore, it could serve as a building block in Turkey for the integration of cleaner and sustainable production approach into national agenda which is currently being structured by the European Union harmonization efforts of this country.

1. Introduction

Chemical industry is indispensable for the growing economy of Turkey during current shift from agricultural-to industrial-based development. In Turkey, with more than 13 billion $ of export, chemical industry has a share of 9.7% in total export of the country (MOSIT, 2012). In terms of created added-value, the chemical industry is in the 4th place among other manufacturing sectors. In addition to its export capacity and created added-value, the chemical industry is also very important when its contribution to employment (more than 230,000 employees) is taken into consideration (MOSIT, 2012). Turkish chemical industry has a product portfolio composed of variety of products including organic/inorganic chemicals, synthetic fibers, soaps/detergents, pharmaceuticals, fertilizers, essential oils, petrochemicals, paints, cosmetics and personal care products (MOE, 2013).

Although the chemical industry is of utmost importance in terms of its contribution to the national economy, its negative environmental impacts draw particular attention. According to Turkish Statistical Institute, chemical industry produces 378,341 tons of hazardous waste annually which makes it the single most hazardous waste producer industry in Turkey or 33.3% of total (TSI, 2008a). When the total solid waste production is of concern, the chemical industry is in the 4th place after basic metal, other non−metal mineral products and food industries, being responsible for 6.7% (830,039 tons/year) of total industrial solid waste generation (TSI, 2008b). Apart from hazardous and solid waste production, chemical industry is one of the major water consuming industries. In 2008, chemical industry consumed 67.5 million m^3 of water, corresponding to 5.1% of total industrial water consumption as the 4th most water consuming industry in Turkey (TSI, 2008c). Intensive energy consumption and associated greenhouse gas emissions are other important environmental issues associated with the

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chemical industry (Ulutas et al., 2012). Ministry of Science Industry and Technology – MOSIT (2012) states that chemical industry consumed 8,755,850 MWh of electricity in 2010. This figure corresponds to 11.0% of total industrial electricity consumption of Turkey.

Above discussed environmental issues seriously affect the competitiveness of the chemical industry. In Turkey it is reported that only 30% of chemical industry SMEs can comply with the environmental norms and standards set out by the European Union (EU), which is a big barrier in front of cross border trade with the EU (MOSIT, 2013, Ulutas et al., 2011). On the other hand, energy costs can be as high as 60% of total production cost in some subsectors of chemical industry (e.g. soda ash production) (SPO, 2007). High energy, water and raw material prices are listed among the major weaknesses of the chemical industry in various national strategy documents (MOSIT, 2012; SPO, 2007). Thus, Ministry of Science Industry and Technology determined that the adoption of environmentally friendly technologies, best available techniques (BATs) and emission control measures are among the actions which are targeted to be taken until 2016 (MOSIT, 2012). This strategic decision is also in line with the "Chemical Industry Roadmap" which aims to achieve high efficiency, environmentally conscious and sustainable production before the year 2023 (TUBITAK, 2003).

According to European Technology Platform for Sustainable Chemistry, chemical and refinement industries are responsible for the abstraction of 50% of all water consumed in manufacturing industry in Europe (SUSCHEM, 2012). In chemical industry it is possible to save water and energy by good-housekeeping practices and process modifications as well as technology changes that result in both increased environmental performance and profitability. The results of a study on sustainable production in chemical industry provide significant evidence of a relationship between environmental expenditures and financial performance (Wang et al., 2014). The findings suggest that firms with environmental expenditures have better efficiency and productivity. Hence, the study encourages companies in the industry to put more effort into protecting the environment that can be through practicing sustainable production to create higher benefits.

Zhang et al. (2012) stated that evaporative condenser cooling technology is applicable in chemical industry offering 50% water and 30–50% energy saving compared to conventional water cooling systems. In addition to that, near-zero emission of circulating cooling water (using desalted water as replacement for the circulating cooling system) are applicable to all kinds of ammonia producers, However only a few plants (less than 10) have applied this technology in China. By employing this technology it is possible to reduce cooling water discharge by 5–25 t/tNH_3 due to the increased degree of concentration.

According to García et al. (2013), water and chemicals can be recovered from wastewaters of chemical industry by pervaporation followed by distillation processes. The researchers reported a methodology based on pervaporation, using first hydrophobic then hydrophilic membranes for the separation of n-butanol and dichloromethane from sodium chloride containing aqueous mixtures into water, brine and a concentrate of organic solvents. The separation of organic solvents from aqueous mixtures was conducted using two membranes and was promoted by high temperatures. The dehydration was conducted using a polyvinyl alcohol and titanium dioxide membrane on a support of polyacrylonitrile and polyphenylene. The article calls for a paradigm change, to view organic solvents in wastewaters as resources to be recovered, rather than pollutants to be treated as such.

Abou-Elela et al. (2007) claims that recycling of washing water of reaction vessels (reactors) and closed circuit cooling system for the high-pressure pumps are among cleaner (sustainable) production technologies which result in water saving in chemical industry. The cooling process was an open cycle and the cooling water discharged directly to the pond via a collection channel. Analysis of this water indicated that the oil concentration was very low (maximum 4 mg/l). The study suggested to recycle the cooling water by using a chiller closed cooling system. In addition, it is possible to reuse the condensate waters in polymerization processes (Zheng et al., 2006).

In a study carried out by Cespi et al. (2014) the traditional synthesis of acrylonitrile, by propylene ammoxidation (SOHIO process), was compared with the less expensive alternative routes that use propane as the precursor, also in terms of production steps. In fact, propane production is performed with a one-step process, the distillation of petroleum, whereas propylene production involves two steps, distillation and cracking (steam or catalytic). The results revealed that starting from propane generally seem to have higher impacts especially in terms of fossil fuel depletion, and climate change categories. This outcome was mainly due to the lower activity of the commercially developed catalyst systems, entailing both larger amounts of reactants and a heavier load on the ecosystem, thus resulting in the lower sustainability of alternative processes.

Besides water saving, introducing more efficient motors, variable speed drivers and switch to the most efficient membrane electrolysis process can substantially lower energy consumption in chemical and petrochemical sectors (Saygin et al., 2011). Recovery of waste heat energy from combustion processes are among other generic energy efficiency applications (Shen et al., 2010) while in-depth studies such as selectivity improvements of reagents in chemical reactions using better catalysts in certain chemical reactions (Neelis et al., 2007) can be listed as process based energy efficiency approaches.

An industrial project was carried out to demonstrate the importance and effectiveness of exploiting the operational flexibility for energy conservation in crude oil distillation, one of the most common chemical operations (Zhang et al., 2013). The key operating variables that affect the energy efficiency are the pumparound duties in both the atmospheric and the vacuum distillation columns, which have significant effects on both product qualities and heat recovery performance. Therefore, in order to improve the energy efficiency by operation optimization of crude oil distillation processes, it is essential that distillation and heat recovery can be optimized at the same time. By applying advanced optimization technique to integrate the operation of distillation and heat recovery in a crude oil distillation unit, the energy consumption was reduced by 8% without capital expenditure.

The aim of this study was to investigate potential water saving applications in a chemical plant which could simultaneously reduce energy consumption of the company leading to a cost effective and sustainable solution to intensive resource consumption. Through this study it is expected to fill a gap in Turkish chemical sector by demonstrating a full-scale application with tangible environmental and economic benefits. The study was carried out within the framework of "National Eco-efficiency (Cleaner Production) Programme" which was coordinated by the United Nations Industrial Development Organisation (UNIDO) and implemented by Technology Development Foundation of Turkey (TTGV). The technical consultancy was provided by the Middle East Technical University. The programme was implemented as a subprogramme of the United Nations Joint Programme "MDG-F 1680: Enhancing the Capacity of Turkey to Adapt to Climate Change". Further information about the "National Eco-efficiency (Cleaner Production) Programme" can be retrieved from its web page (http://www.ecoefficiency-tr.org/).