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ECONOMIC FEASIBILITY OF AN ENERGY EFFICIENCY PROJECT FOR A STEAM DISTRIBUTION SYSTEM IN A CHEMICAL INDUSTRY

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ABSTRACT

The burning of fossil fuels majorly contributes to the increase in global warming, and it represents 93% of greenhouse gases emissions in the chemical industry. Most of the energy demand in this sector is associated with steam systems, where 1/3 of the energy efficiency opportunities are located in its distribution system. However, most of the literature focuses on the design of new systems. Those that deal with existing systems, not always use simple and available methods. Furthermore, they address energy losses of steam systems only due to thermal insulation, ignoring those due to leakages of traps. Given this context, the purpose of this paper is to determine the economic feasibility of an energy efficiency project for a steam distribution system in a chemical industry, *located in the metropolitan region of Salvador, Brazil. First, the energy lost in the steam distribution system through heat insulation and steam traps was estimated by applying thermodynamic principles, and technic consulting, respectively. Then, investments were estimated using commercial prices for new thermal insulation and steam traps. Finally, an economic evaluation of the improvement project was made, through the construction of a cash flow, and calculation of economic indicators: payback time, net present value (NPV), and internal rate of return (IRR). Economic indicators showed that the project is economically viable. The NPV and IRR reached approximately 5 million reais, and 66% per year, respectively. Additionally, this project also had social and environmental benefits, such as a reduction in greenhouse gases emissions, and increased local water availability.*

***Keywords**: economic feasibility; energy efficiency; steam distribution system.*

1. INTRODUCTION

Currently, the delivery of high quality thermal energy in large quantities is essential in many processes of manufacturing goods and services. Steam systems generally provide this thermal energy, and it is largely derived from the burning of fossil fuels (CEB; FUPAI/ EFFICENTIA, 2005a). This is worrying, as its burning is a major factor that contributes to increase in global warming.

The Intergovernmental Panel on Climate Change (IPCC) states that anthropic climate warming is unquestionable, and if current pace is maintained, irreversible environmental damages to the planet may occur (IPCC, 2014). At the 21st Conference of Parties (COP-21) of the United Nations Framework Convention on Climate Change (UNFCCC), countries agreed to restrict greenhouse gas emissions (GHG) as soon as possible, and then make major reductions by 2050, in order to limit the global temperature increase well below 2°C (UNFCCC, 2015). Analysts suggest that a reduction in emissions should be done initially by decreasing the amount of burning of fossil fuels (WYNN, 2015).

The Brazilian Chemical Industry Association (ABIQUIM) states that the theme is relevant to the sector, because chemical industries use materials rich in carbon as raw material, as well as energy sources (BRAZIL, 2010). Data from the System Study Greenhouse Gas Emissions Estimates shows the industrial sector emissions related to production processes, use of fossil fuels and treatment of effluents, totaling

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23% of Brazilian GHG emissions in 2014 (SEEG/OC, 2016). Thirteen percent of this amount came from chemical industries, whose use of fossil fuels accounted for 93% of their emissions (SEEG/OC, 2016).

According to the Ministry of Mines and Energy, about 90% of the fossil fuel used by the chemical industry is associated with steam production, which represents a consumption of more than 4 million tons of equivalent oil (BRAZIL, 2005; BRAZIL, 2015). However, about 20% of this fuel can be saved in steam systems, where one third of the energy efficiency opportunities are located in its distribution system (CEB; FUPAI/ EFFICENTIA, 2005b).

In addition to fuel, water is also an important raw material that must be taken into account in energy efficiency projects for steam systems. Brazil has a water deficit, and the northeast region, in particular, suffers increasing water stress in the semiarid region. The National Water Resources Policy establishes that in a situation of scarcity, the priority use of water resources is for human and animal consumption (BRAZIL, 1997). Therefore, industrial activities would be among the first ones to be hit by water scarcity. In this context, measures for rational use of water by industries are even more relevant.

In general, the literature on energy efficiency projects for heat distribution systems focus on the design of new systems (ÇOMAKLI; YUKSEL; ÇOMAKLI, 2004; OZTUK; KARABAY; BILGEN, 2006; CHEN; LIN, 2011; KUZNETSOV; POLOVNIKOV, 2011; DALLA ROSA; SVENDSEN, 2011; LI; SVENDSEN, 2012; SANAEI; NAKATA, 2012; KAYFECI, 2014; POLOVNIKOV; GUBINA, 2014; POLOVNIKOV; GUBANOV, 2015). Those who approach the subject in existing systems, do so with the aid of measuring devices, laboratory tests, and mathematical simulations, from which they generate data to evaluate heat loss in the operational condition of facilities (KRUCZEK, 2013; TSYGANKOVA; DMITRIENKO, 2014).

Kruczek (2013) determined the annual energy loss of a steam distribution system by measuring the external temperature of thermal insulation using a thermovision camera, as well as laboratory tests to define the emissivity coefficient of the pipe cover. Tsygankova and Dmitrienko (2014), in turn, used mathematical modeling to calculate the energy loss, considering the operating conditions of the thermal insulation and heat conductors.

http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
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Both studies focus on heat loss exclusively through thermal insulation (KRUCZEK, 2013; TSYGANKOVA; DMITRIENKO, 2014). Therefore, no studies that identify and estimate heat loss through thermal insulation and steam traps were found. This joint analysis is interesting because they can be sources of great heat loss in steam distribution systems.

Energy efficiency projects involves time and resources, which often companies do not have or have no interest in spending immediately. Thus, energy losses through thermal insulation and steam traps can be preliminarily estimated by applying the principle of energy conservation/ heat transfer by conduction on cylindrical surfaces, and by means of technical advice, respectively. Then, an economic feasibility study of the energy efficiency project can be carried out, from which a company has the elements to decide whether to carry out a more detailed study on the subject.

Nonetheless, energy efficiency is still a great challenge for Brazil. It is the second worst country in terms of energy efficiency among the 23 largest energy consumers in the world; furthermore, Brazil has a poor prognosis, because its energy efficiency has been stagnant in the last decade (ACEEE, 2016). Therefore, however simple they might be, energy efficiency projects should be encouraged and implemented in order to promote Brazil's progress in this area.

Given this context, and the interest of a chemical industry located in the metropolitan region of Salvador, Brazil, this study could be carried out. Therefore, the purpose of this paper is to determine the economic feasibility of an energy efficiency project for a steam distribution system in a chemical industry.

This paper has the following structure. It presents in section 2: main concepts studied for energy loss estimates through steam traps and thermal insulation, and techniques to carry out economic evaluation of this project. Next, the results are presented and discussed in section three, considering data of the steam distribution system of the chemical industry. Finally, conclusions and final considerations about the economic feasibility of the energy efficiency project are presented in section 4.

2. METHODOLOGY

The methodologies for heat loss estimates by thermal insulation and steam traps, as well as the techniques and indicators adopted for economic analysis, are

http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
ISSN: 2236-269X
DOI: 10.14807/ijmp.v8i4.672

described in this section. In order to refer to the chemical industry whose data were used in this study, the expression *Efficient Industry* was adopted.

2.1. Energy Loss Estimate in the Steam Distribution System

The methods for energy losses estimates by steam traps and thermal insulation are presented in this section, using ton of steam as unit.

2.1.1. Energy Loss Estimate through Steam Traps

In order to identify and quantify steam leaks, manufacturers of steam traps should be contacted as they provide services with specific instruments for this purpose (CEB; FUPAI/ EFFICENTIA, 2005a). Accordingly, the *Efficient Industry* hired Spirax Sarco Industry and Commerce (Spirax Sarco) and Techsol Industry, Commerce and Services (Techsol) to evaluate the operating conditions of its steam traps, in different moments (SPIRAX SARCO, 2006; TECHSOL, 2016).

Spirax Sarco (2006) used the ultrasonic vibration analyzer UP-100 in the inspection of steam traps. It is an electromechanical transmitter, which converts mechanical vibration into an audible small-intensity electrical signal that identifies the steam trap condition (SPIRAX SARCO, 2006). Techsol assessment, in turn, presented current data on the operating conditions of the steam traps, although it did not quantify the steam leaks (TECHSOL, 2016).

2.1.2. Energy Loss Estimate through Thermal Insulation

Depending on thermal insulation conditions, the actual heat loss may be at least 150% greater than that originally estimated (TSYGANKOVA; DMITRIENKO, 2014; KRUCZEK, 2013). The insulation of the steam distribution system of the *Efficient Industry* is about 40 years old. Therefore, it has been considered to be degraded in order to allow a 150% greater heat emission, compared to the design condition.

2.1.2.1. Saturated Steam Loss Estimate through Thermal Insulation

In saturated steam systems, when part of the steam becomes condensate (liquid), there is heat loss. In a new system where there are no steam leaks and the steam traps work well; this energy loss usually occurs through thermal insulation, because it is a cylindrical surface that conducts heat. In order to calculate the rate of heat emission, some simplifications were made: the conduction resistance of the

http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
ISSN: 2236-269X
DOI: 10.14807/ijmp.v8i4.672

tube wall and the convective resistance between the steam and the inner wall of the tube were considered negligible (KRUCZEK, 2013). Consequently, it was assumed that the temperature of the internal surface of the thermal insulation was the same as the steam temperature, allowing heat emission rate estimate through the equation:

$$Q = \frac{2 \cdot \pi \cdot k \cdot l \cdot (T_s - T_{ei})}{\ln(r_e / r_i)} \cdot 150\% \qquad (1)$$

Where:

Q – heat emission rate (kJ/h);

k – thermal conductivity of thermal insulation (kJ/m.h.°C);

l – pipeline length (m);

T_s – steam temperature (°C);

T_{ei} – external surface temperature of thermal insulation (°C);

r_e – external radius of thermal insulation (m);

r_i – internal radius of thermal insulation (m).

The amount of condensate formed due to energy loss was assumed to be equal to the amount of steam loss. Since steam operates under conditions of partial saturation in the *Efficient Industry*, its quality must be known, in order to estimate the annual steam loss through the equation:

$$M_s = \frac{Q}{h_v \cdot X} \cdot 8{,}64 \qquad (2)$$

Where:

M_s – annual steam loss amount (t);

Q – heat emission rate (kJ/h);

h_v – specific enthalpy of vaporization (kJ/kg);

X – steam quality (%).

2.1.2.2. Superheated Steam Loss Estimate through Thermal Insulation

In new superheated steam systems, where steam leaks are negligible and steam traps work well, energy loss through thermal insulation can be considered proportional to temperature variation along the pipeline. According to Cengel (2003),

http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
ISSN: 2236-269X
DOI: 10.14807/ijmp.v8i4.672

this variation can be between 1ºC and 5ºC in a standard system. In order to estimate energy loss, it was considered that a standard superheated steam system has 100m of pipeline length, and a 3ºC mean temperature variation.

In open systems with steady flow, such as that occur in the steam distribution system of the *Efficient Industry*, it is possible to estimate energy loss from the energy conservation principle (CEB; FUPAI/ EFFICENTIA, 2005a). Thus, as no work is performed, and kinetic and potential energy difference is considered negligible, heat loss rate through thermal insulation corresponds to steam enthalpy change along the pipeline. Assuming a 150% higher heat emission rate due to thermal insulation degradation, the variation of 4.5ºC / 100m was considered, using the equation:

$$Q = m_s \cdot (h_i - h_o) \cdot l/100 \quad (3)$$

Where:

Q – heat emission rate (kJ/h);

m_s – steam mass flow (kg/h);

h_i, h_o – steam specific enthalpy at the inlet and outlet operating conditions of the pipeline (kJ/kg)

l – pipeline length (m).

In the *Efficient Industry*, steam is produced in a boiler, where the water goes from an ambient condition of temperature and pressure, to become a steam at 380°C temperature and 42bar pressure. In order to estimate the equivalent steam loss amount, the energy conservation principle was used once again, considering the enthalpy change in the steam production process (CEB; FUPAI/ EFFICENTIA, 2005a). Thus, the annual amount of steam loss could be estimated through the equation:

$$M_s = \frac{Q}{(h_f - h_i)} \cdot 8,64 \quad (4)$$

Where:

M_s – annual amount of lost steam (t);

Q – heat emission rate (kJ/h);

h_i – water specific enthalpy in the initial condition (kJ/kg);

http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
ISSN: 2236-269X
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h_f – water specific enthalpy in the final condition (kJ/kg).

The mathematical expressions presented to estimate the losses of saturated and superheated steam through thermal insulation considered simplifications in the system. Only main pipelines were analyzed in this study in order to reduce the error in estimates.

2.2. Economic Evaluation of the Project

The economic feasibility study is based in the income generated from the energy saved in the steam distribution system from the implementation of the energy efficiency project. This evaluation involves problem modeling in a cash flow, from which it is possible to calculate and analyze the economic indicators.

2.2.1. Cash flow

Cash flow presents the movement of resources over time, that is, cash inflows and outflows. One of the most important aspects in the investment analysis is the estimate of the values that will make up the cash flow (ASSAF NETO, 1992). The *Efficient Industry* provided the reference data for steam production, total cost, variable cost, and fixed cost; while the amount of steam saved by the energy efficiency project was the result of the calculations presented in Section 2.1. Cash flow was calculated using the equation:

$$CF_i = T_r - Va_i - Fa_i \tag{5}$$

Where:

CF_i – Cash flow in year *i* (R$)

T_r – Total reference cost (R$/ year);

Fa_i – Fixed cost after investment, in year *i* (R$);

Va_i – Variable cost after investment, in year *i* (R$), wherein:

$$Va_i = \frac{(P_r - SS_i)}{P_r} \times V_r \tag{6}$$

Where:

P_r – Steam reference production (t/ year);

SS_i – Saving steam after project implementation in year *i* (t);

http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
ISSN: 2236-269X
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V_r – Variable reference cost (R$/ year).

2.2.2. Economic Viability Indicators

Several indicators can be used to analyze the economic viability of a project. The indicators used in this study were: payback time, net present value (NPV), and internal rate of return (IRR).

2.2.2.1. Payback time

Payback time is considered a primary economic indicator, because it does not consider the time value of money. However, it is still an indicator widely used by companies. It refers to the time required for the investment to be returned, according to equation (ASHRAE, 2007):

$$n = \frac{Investment}{Average\ Annual\ Savings} \qquad (7)$$

2.2.2.2. Net Present Value (VPL)

NPV is considered a rigorous criterion of project evaluation. It corresponds to the algebraic sum of cash flow values updated at the discount rate over time, subtracted from the investment (BRUNI; FAMÁ, 2004). Discount rate is a reference interest rate that represents the minimum amount that the investor agrees to earn when making an investment. Thus, a project will be economically feasible if it presents a positive NPV (BARROS et al. 2015). Considering that all investments are made at the beginning of the project, the NPV calculation is done using the equation:

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+i_d)^t} - I \qquad (8)$$

Where:

NPV – net presente value;

CF – cash flow;

n – total number of years;

t – analyzed year;

I – investment.

http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
ISSN: 2236-269X
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2.2.2.3. Internal Rate of Return (IRR)

The IRR of a project can be defined as the interest rate that makes the NPV equal to zero. A project is economically viable and should be implemented when its IRR is greater than the discount rate defined by the investor (BARROS et al. 2015; CEB; FUPAI/ EFFICENTIA, 2005a). The calculation of the IRR can be done using the equation:

$$0 = \sum_{t=1}^{n} \frac{CF_t}{(1+\mathrm{IRR})^t} - I \quad (9)$$

Where:

IRR – internal rate of return;

CF – cash flow;

n – total number of years;

t – analyzed year;

I – investment.

3. RESULTS AND DISCUSSION

The steam system of the *Efficient Industry* has the following steps: generation, distribution, and end use. The steam is generated in aquotubular boilers, which produce 11.5 kg of steam for each m^3 of natural gas. It exits the boilers at 380°C temperature and 42bar pressure.

Then it passes through reduction valves, which transform it into superheated steam with a pressure of 19bar and 290°C temperature, as well as saturated steam of 2.5bar pressure. Under these conditions, the steam is distributed to several areas for final use, without condensate return.

The steam distribution system mainly employs rock wool as thermal insulation; the types of steam traps used are mainly: mechanical and thermodynamic. Table 1 shows the main pipelines and its length in each operating system.

Table 1: Main steam system pipelines, according to their operating pressure.

Steam pressure (bar)	Pipeline diameter (in)	Pipeline length (m)
2,5	10	260
	12	372
	14	190
19	8	310
42	8	60
	10	20

3.1. Energy Loss Estimate in the Steam Distribution System

In the industrial sector, steam systems parameters can be considered constants throughout the year (KRUCZEK, 2013). Therefore, from data collected in the Efficient Industry, it was possible to estimate the energy losses through thermal insulation and steam traps.

3.1.1. Energy Loss Estimate through Steam Traps

The analysis performed by Techsol (2016) concluded that seven steam traps were leaking, out of 42 steam traps in the Efficient Industry. In steam systems where maintenance has not been carried out for 3 or 5 years, between 15% and 30% of steam traps may present defects, such as live steam exhaust (CEB; FUPAI/ EFFICENTIA, 2005a).

Given this context, steam traps state is reasonable, since 17% of them had steam leak. The average flow rate of steam leaks considered was 33 tons of steam per trap per month (SPIRAX SARCO, 2006). Therefore, the estimated total steam loss from the traps was approximately 3 thousand tons of steam per year.

3.1.2. Energy Loss Estimate through Thermal Insulation

3.1.2.1. Saturated Steam Loss Estimate through Thermal Insulation

Equations (1) and (2) were used to estimate the annual steam loss from heat emission through thermal insulation. The saturated steam system operates at a temperature of 139°C and a pressure of 2.5bar, with a steam quality estimated at 70%. The thermal insulation data were collected from commercial catalog: thermal conductivity (0.155 kJ/m.h.°C), internal surface temperature (28ºC) and thickness (50mm) (ISOVER, 2010). The annual amount of steam lost in the saturated steam system was about 2,800 tons.

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http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
ISSN: 2236-269X
DOI: 10.14807/ijmp.v8i4.672

3.1.2.2. Superheated Steam Loss Estimate through Thermal Insulation

Superheated steam loss through thermal insulation was estimated using equations (3) and (4). Therefore, the emitted heat rate was 592 596kJ/h for the steam system that operates at 19bar pressure, 290ºC temperature, and have a mass flow rate of approximately 18000kg/h. Considering that 3 048 kJ of energy is required for the production of a kilo of steam from water initial conditions, steam loss is about 1.7 thousand tons per year.

As for the steam system operating at 42 bar pressure, 380°C temperature, and have an approximate mass flow rate of 52200kg/h, heat loss rate resulted in 459 360 kJ/h. Considering the same previous premise for the production of steam, the steam loss resulted in approximately 1.3 thousand tons per year.

Thus, the degradation of thermal insulation and defective steam traps generated an annual steam loss of approximately 8,600 tons.

3.2. Investment Estimate

In order to remedy steam loss through steam traps leakage, new devices must be acquired to replace the defective ones. According to TECHSOL (2016), the total investment in the acquisition of steam traps should be R$ 22 thousand approximately.

Thermal insulation reduces heat emission to the environment, nevertheless, the greater the thickness, the higher the installation cost. Hence, in most cases, thicknesses consecrated by use are recommended (CEB; FUPAI/ EFFICENTIA, 2005a). Therefore, a supplier of glass wool tubes was consulted, and the investment value for the acquisition of new thermal insulation was estimated in R$ 107 thousand.

Smooth aluminum can be used for the mechanical protection of thermal insulation. Based on commercial values, this item was estimated at approximately 33 thousand reais.

The steam pipeline is located at an average height of 10 meters. In order to carry out disassembly and assembly of thermal insulation, adequate infrastructure is necessary. Despite the existence of a couple of technologies, scaffolding was chosen in order to consider the most conservative scenario. Thus, from scaffolding

http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
ISSN: 2236-269X
DOI: 10.14807/ijmp.v8i4.672

cost estimate provided by the *Efficient Industry*, this investment resulted in about 1.4 million reais.

The investment in labor, in turn, was calculated considering reference values given by the *Efficient Industry*, reaching approximately R$ 484 thousand, for disassembly/ assembly of thermal insulation, and installation of aluminum protection.

Therefore, the total investment required for the implementation of the energy efficiency project, considering the acquisition of steam traps, thermal insulation, mechanical protection, scaffolding and work force is approximately R$ 2 million.

3.3. Economic Evaluation of the Project

The economic evaluation of the project was carried out from cash flow elaboration, and calculation and analysis of economic indicators.

3.3.1. Cash Flow

The energy efficiency project shall be implemented in a real steam distribution system in the *Efficient Industry*. After the project implementation, a proportional decrease of variable expenses is estimated because the system becomes more efficient, decreasing the need of steam production. The depreciation rate for steel distribution facilities is 10% per year, thus, project lifetime is 10 years (BRAZIL, 2017).

However, technical-economic condition will not remain stable over time, making it necessary to vary some factors, such as production costs and steam economy after project implementation. In order to simulate the variation of steam production costs due to inflation, the General Price Index - Internal Availability (IGP-DI) of the last five years was adopted: 7% (FGV, 2017). Progressive loss of steam economy after project implementation was considered, due to the degradation of thermal insulation and steam traps over the lifetime of 10 years. From these considerations and equations (5) and (6), cash flow was constructed, as shown in table 2.

Table 2: Cash flow of the energy efficiency project.

Year	Cash flow (R$)
0	(2 071 868,94)
1	1 344 755,71
2	1 410 110,83
3	1 447 234,16
4	1 449 697,54

http://www.ijmp.jor.br v. 8, n. 4, October - December 2017
ISSN: 2236-269X
DOI: 10.14807/ijmp.v8i4.672

5	1 410 160,33
6	1 320 262,61
7	1 170 507,11
8	950 128,87
9	646 951,39
10	247 227,85

3.3.2. Economic Viability Indicators

Feasibility indicators of the project was calculated using equations (7) to (9), from the cash flow data. The results are presented and interpreted below.

Based on the steam loss estimate and investment, payback time resulted in 1.8 year. According to the criteria of the *Efficient Industry*, the energy efficiency project is considered economically feasible, because this indicator is less than 2 years.

The discount rate adopted by the *Efficient Industry* for economic evaluation of projects is 12% per year. From this parameter, it was possible to calculate NPV and IRR. The NPV had a positive value of about R$ 5 million. The calculated IRR resulted 66% per year, more than 5 times the discount rate considered.

All indicators pointed to the economic feasibility of the project. In addition, NPV and IRR quantified the economic benefit that the company would obtain after 10 years of implementation of the energy efficiency project.

3.4. Environmental Evaluation of the Project

Environmental evaluation of a project is extremely important, since it can result in an improvement of the company's environmental indicators. The environmental assessment of the energy efficiency project was carried out by analyzing the changes in use of main raw materials in steam production.

Natural gas is one of the main raw materials for steam production in the *Efficient Industry*. For every ton of steam produced, 87m^3 of this fuel is consumed. The use of natural gas, however, generates greenhouse gases that contribute to the increase in global warming. Thus, through the implementation of this project, it would be possible to avoid the use of about 5x10^6 m^3 of natural gas.

This represents a reduction in emission of about 11,600 tons of equivalent carbon dioxide, contributing to mitigate global warming and climate change. Furthermore, this carbon emissions reduction can generate tradable carbon credits,

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ISSN: 2236-269X
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which can be incorporated into the cash flow. However, this factor was not considered in the economic evaluation of the project, since it was not estimated the cost that this process would generate for the *Efficient Industry*.

Water is an indispensable resource in steam production. Moreover, in the *Efficient Industry*, all generated steam is consumed or discarded throughout the production process. Then, once the energy efficiency project is implemented, it will be able to reduce steam production around 57 thousand tons. In addition, the *Efficient Industry* considers 5% water waste in boilers, which would represent 3 thousand tons of water.

The production of demineralized water for steam production, in turn, uses water in the regeneration of some operational units, in the order of $0.24m^3/m^3$ of demineralized water produced. This would represent the consumption of 15 thousand tons of water. Thus, considering all the uses and consumptions of water in the steam system, 75 thousand tons of water is saved during the 10 years of the project, contributing to increase local availability of water, and consequently, decreasing water stress in the region.

Hence, we highlight some improvement in environmental indicators, which could enhance the corporate image of the *Efficient Industry*. Besides, the environmental agency could recognize the benefits of the project implementation during the renewal process of operational license.

4. CONCLUSIONS

This paper proposes to analyze the economic viability of an energy efficiency project for a steam distribution system in a chemical industry, from energy loss estimates through thermal insulation and steam traps. The objective was achieved, because:

– Energy losses of the steam distribution system were estimated at approximately 8.6 thousand tons of steam in the first year, totaling 57.4 thousand tons at the end of the 10-year project;

– The investment was estimated at approximately R$ 2 million, considering new materials and equipment, labor and scaffolding;

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– The cash flow of the project was built, and the economic indicators were calculated and analyzed: payback time, NPV and IRR. All indicated that the project is economically feasible;

– In addition, the project had environmental benefits: lower consumption of energy and water, about $5x10^6$ m^3 of natural gas and 75,000 tons, respectively, and a reduction in greenhouse gases generation of around 11,600 tons of equivalent carbon dioxide.

Therefore, the energy efficiency project is attractive economically, besides presenting socio-environmental viability. Moreover, this economic attractiveness can be improved if the following limitations are considered in future works:

– Energy loss in the distribution system could be higher, since the heat emission rate considered through thermal insulation was conservative compared to the studies conducted by Tsygankova and Dmitrienko (2014), and Kruczek (2013). Thus, on-site measurements of the operating conditions of thermal insulation should be made;

– Although thermal insulation degradation is not uniform throughout the steam distribution system, it was considered so. This prevented progressive projects of thermal insulation renewal, limiting the economic benefits of their implementation.

– The investment was probably overestimated, since among available technologies of infrastructure for disassembling / assembling thermal insulation, the most expensive one was chosen: scaffolding.

– The depreciation rate adopted for steam traps and thermal insulation has probably been underestimated. According to commercial representatives, their lifetime is at least 10 years, and around 50 years, respectively.

– Costs estimate related to registration and sale of carbon credits generated from the implementation of energy efficiency projects was not considered in the economic evaluation of the project.

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