2012 International Conference on Environment, Energy and Biotechnology
IPCBEE vol.33 (2012) © (2012) IACSIT Press, Singapore

Technical-Economical and Environmental Feasibility Study of Combined Heat and Power Systems in Pulp and Paper Industry

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Abstract. In this study, technical-economical and environmental feasibility study of utilizing Combined Heat and Power (CHP) Systems in Pars Pulp and Paper Industry has been carried out by Thermo flow and COMFAR EXPERT III software's within two scenarios. In the first scenario, application of a back pressure steam turbine to generate the electricity and supply the factory's steam demand at three pressure levels was investigated, while in the second scenario, application of a gas turbine along with Heat Recovery Steam Generator System (HRGS) to supply part of the steam demand of the steam turbine designed in the factory was examined. The results reveal in the first scenario, the factory will be able to supply 9 MW of its power requirements. In this scenario, natural gas saving would be 18,585,974 m^3/yr, savings in external costs would be US$ 348,850/yr and normal pay back period would be 0.9 year. In the second scenario, the factory will be able to supply its entire power requirements and annual natural gas saving would be 32,599,209 m^3, savings in external costs would be US$ 611,893/yr and normal pay back period would be 1.21 year. Both scenarios are economically and financially feasible. However, the second scenario is preferred as it supplies the factory's total power requirement, leads to high saving in natural gas consumption and reduces more GHG emissions.

Keywords: Combined Heat and Power Systems, Steam Turbine, Gas Turbine, Greenhouse Gas, Pulp and Paper Industry

1. Introduction

Combined Heat and Power (CHP) was initially commenced at the United States and Europe in the late 1980s. During the early 20th century, most of the industries used to provide their required electricity by coal-fueled boilers and steam turbines. Generally, majority of these industries were employing the output steam of turbines to run the processes. Industrial application of CHP was triggered in 19th century in Europe and nowadays it is considered as one of the old methods of electricity generation. Growth of CHP in Spain, particularly in industrial sector, had been very fast in 1990s, though it has stopped now due to some reasons as reduction in fuel price [1]. In Canada, CHP forms about 7% of the national electricity production. Low price of energy and policies of electricity sector towards subsidiary and surplus sale legislations can account for the small share of this technology in electricity generation. Despite these obstacles, cogeneration is still common in some sectors such as paper and chemical productions [2]. CHP is an absolutely tangible concept in Japan. Following the 3rd Conference of Kyoto in 1997, Japan declared to be resolved to reduce its greenhouse gases (GHGs) emission up to 6%, from 1990 to 2010. Accordingly, CHP is an important

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measure towards reduction of GHG emissions [3]. GAS turbine is of grater interest to those industries with high demand of steam, tough it has low efficiency of electricity generation due to high rate of steam recovery. In 2008, CHP, with the capacity of 8.7 GW, accounted for 4% of the electricity generation in Japan [4].

The present work was carried out aiming at studying technical-economical and environmental feasibility of utilizing CHP in Pars Pulp and Paper Factory. Two scenarios including application of a back pressure steam turbine to generate the electricity and supply the factory's steam demand and application of a gas turbine along with Heat Recovery Steam Generator (HRSG) system to supply part of the steam demand of the steam turbine designed in the factory was examined by using Thermo flow Ver.18 COMFAR EXPERT III software's.

2. Materials and Methods

In order to improve the conditions of production and steam consumption in Pars Paper Factory and also to maximize the efficiency of the whole system, reduce the natural gas consumption and decrease the GHG emissions, two scenarios were proposed using Thermo flow Ver.18 based on CHP systems. In the first scenario, application of a back pressure steam turbine-based CHP system having three steam extractor to supply the factory's steam and part of power requirements has been outlined, and in the second scenario, application of a gas turbine-based CHP system to meet a part of the steam demand of the steam turbine applied in the first scenario and to supply the factory's entire power requirement has been designed. Moreover, the results obtained from each scenario were economically and environmentally analyzed by COMFAR EXPERT III software. Since, the major part of fossil energy consumed in paper factories is in the form of steam, the index of specific fossil energy consumption can be expressed according to steam consumption rate. Pars Paper Factory's energy requirement is 155 t/h of a 30 bar steam (at three pressure levels of about 17, 10.5 and 4.2 barg) and 15 MW electric power. Table 1 presents the nominal and operational status of boilers at Pars Paper Factory in 2005.

Table 1: Nominal and operational status of boilers at Pars Paper Factory in 2005

Status	Parameter	90-ton boiler	The recovery boiler	Pitt-burning boiler No. 1	Pitt-burning boiler No. 2	Pitt-burning boiler No. 3
Design conditions	Temperature (ºC)	350 (1)	288-320 (2)	320 (3)	320 (3)	320 (3)
	Pressure(kg/cm^2)	45 (1)	30 (2)	25 (3)	32 (3)	32 (3)
	Enthalpy (kJ/kg)	3080.4	3042.19	3067.53	3036.43	3036.43
	Entropy (kJ/kgºK)	6.5156	6.6408	6.7419	6.5863	6.5863
	Steam production rate(ton/h)	90 (1)	65 (2)	22 (3)	25 (3)	25 (3)
Operation conditions	Temperature range (º C)	260-270 (3)	330-365 (3)	280 (3)	180-240 (3)	180-240 (3)
	Normal operating Temperature (ºC)	270 (4)	350 (4)	280 (5)	220 (5)	220 (5)
	Pressure range (kg/cm^2)	20-21 (4)	25 (4)	11.5-15 (3)	12-19 (3)	12-19 (3)
	Normal operating pressure (kg/cm^2)	20 (4)	25 (4)	13 (5)	15.5 (5)	15.5 (5)
	Enthalpy in normal conditions (kJ/kg)	2950.88	3126.24	2998.29	2844.67	2844.67
	entropy in normal conditions,(kJ/kgºK)	6.6336	6.8402	6.9076	6.5378	6.5378
	The range of steam production rate (ton/h)	50-55 (4)	35-40 (4)	8-15 (3)	6-15 (3)	8-12 (3)
	Steam production rate in normal conditions (ton/h)	52 (4)	37 (4)	5.9 (6)	9.5 (6)	9.7 (6)
	Range of total steam production rate (ton/h)			135-155 (3)		

1- AHLSTROM; Description and Operating Manual
2- BABCOCK & WILCOX COPERATIONS LTD; LONDON.4862; Page 5
3- Experts' expressions in the boiler section of the factory
4 - Based on statistical analysis of information recorded from the log-sheet
5 - The average range reported by the expert of the factory
6 – The average recorded by the counter and the estimation conducted based on measured fed water rate

3. Results and Discussion

3.1. Scenario 1: CHP System based on Steam Turbine

In the first scenario, using Thermo flow software as well as considering the factory's need of various levels of steam, a back pressure steam turbine "Ural Tm6y" Model with capacity of 9 MW has been applied. To do this, the steam, with the capacity of 155 ton/hr, pressure of 30 bar and temperature of 300 °C, is generated by boilers, enters the steam turbine and leaves it by means of three extractions, in three pressure levels. The first level equals to 46.5 ton/hr, at pressure of 30 bar and temperature of 245 °C; the second level equals 15.2 ton/hr, at pressure of 17 bar and temperature of 203 °C; and the third level equals to 93.3 ton/hr, at pressure of 4.2 bar and temperature of 145 °C. in this case, the factory will be able to supply 8,925 kW of its power requirements. Fig. 1 demonstrates the steam flow of back pressure turbine with three extractions and Table 2 shows the technical specifications of the steam turbine designed for Pars Paper Factory.

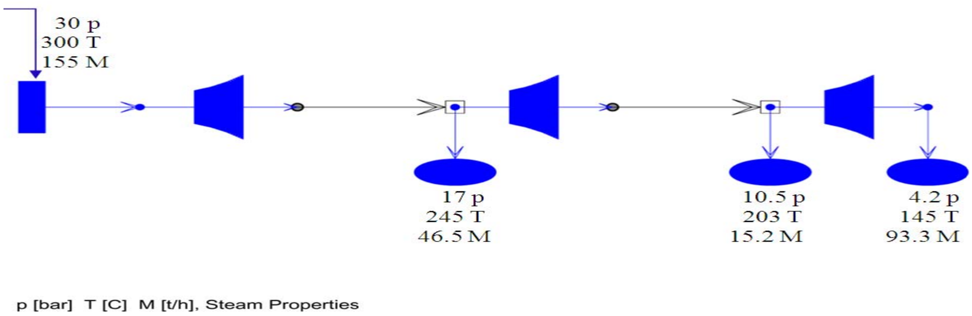

Fig. 1: Steam flow of the back pressure turbine with three extractions in the first scenario for Pars Paper Factory

Based on this scenario, the demand electricity of the factory can be obtained from the energy wasted on pressure relief valves. Thus, the factory will be able to supply only about 9 MW of its required power and provide the rest from the network.

Table 2: Technical specifications of the steam turbine designed in the first scenario for Pars Paper Factory

Steam turbine capacity (MW)	Output pressure	Steam mass flow (ton/h)	Steam pressure (bar)	Ultra saturation steam temperature (°C)	Efficiency of each extraction in steam turbine
9	Back pressure with three extractions	155	30	300	70%

3.2. Scenario 2: CHP System based on Gas Turbine

In this scenario, at the gas turbine, electricity is generated after expansion of the gases produced by natural gas combustion. Hot exhaust gases, in a HRSG system, can supply approximately 17.25 ton/h steam of 30 bar pressure with temperature of 300 °C required for the back pressure turbine designed in the factory, while the rest of steam needed for the steam turbine is provided through the boilers in the factory. The produced steam is sent to the mentioned steam turbine and a part of the steam needed for the designed steam turbine is supplied this way. In the CHP system designed to be installed in Pars Paper Factory, first, 1.76 ton/h natural gas is combusted with air in the closed combustion chamber of Kawasaki gas turbine (Model: GPB 15). Then, the exhaust gases of the gas turbine are expanded and produce 5,159 kW electricity. In the HRSG system, these gases produce a 17.25 ton/h steam, with pressure of 30 bar and temperature of 300 °C, which is sent to the steam turbine. Fig. 2 shows the flow diagram of the proposed CHP system based on gas turbine using Thermo flow software in the second scenario. Finally, 17.25 ton/h and 138 ton/h out of the entire 155 ton/h steam required for the back pressure turbine are provided by gas turbine and boilers at the factory. Thus, in the case of project implementing, two pitt-burning boilers (No. 1 and No. 2) can be removed from the factory. Table 3 illustrates the technical specifications of the selected gas turbine for CHP system in Pars Paper Factory.

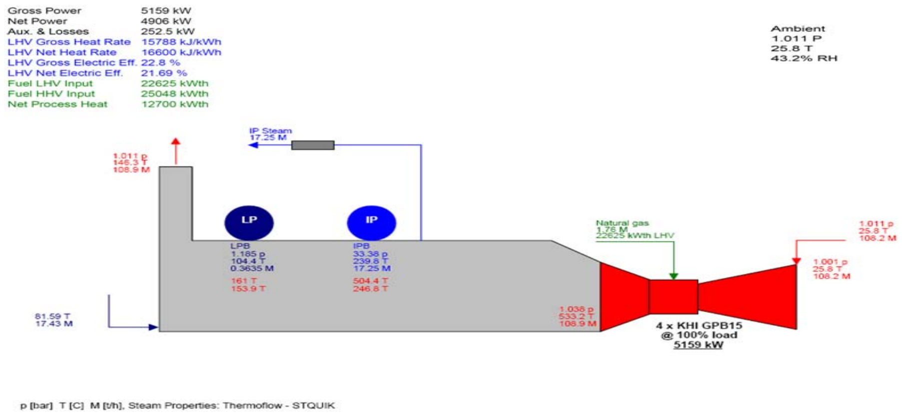

Fig. 2: Flow diagram of CHP system gas turbine proposed in the second scenario in Pars Paper Factory

Table 3: Technical specifications of the selected gas turbine for CHP system in Pars Paper Factory

Specifications of Kawasaki Gas Turbine (Model GPB 15) at ISO condition	
Nominal power (kW)	5731
Fuel Type	Natural Gas
Frequency (Hz)	50-60
Electrical efficiency (%)	23.63
Heat rate (kJ/kWh)	15234
Turbine speed (rpm)	22000
Compressor air input (ton/h)	28.70
Ratio of compressor pressure	9.4
Output gas flow (ton/h)	28.88
Output gas temperature (^{0}C)	524.6
Efficiency of HRSG system (%)	73.64
Efficiency CHP system (%)	79.31

3.3. Economical and Environmental Feasibility Study of CHP System in Scenario 1

Implementation of scenario 1 will bring about 18,585,974 m^3/yr saving in natural gas consumption. Considering the international price of natural gas (US$ 0.25/m^3), the factory's benefit from saving in gas consumption will amount to nearly US$ 4,602,241/yr. Moreover, as a result of savings in natural gas consumption, US$ 348,850/yr will be saved in external costs (US$ 1 = 10,500 Rials). Investment projects with at least 30% IRR are approved by Mine and Industry Bank of the Islamic Republic of Iran as well as the Ministry of Industry [5]. In this scenario, the project's NPV with the discount rate of 30% over 20 years will be equal to US$ 16,870,041 and the net cash flows are positive at the first year and the costs of investment return at 0.9 yr, making the project profitable (Fig. 3).

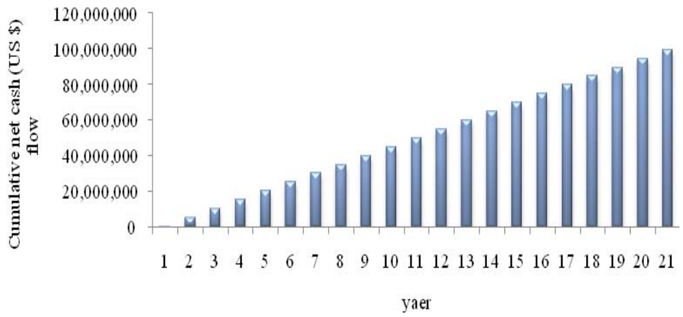

Fig. 3: Pay Back Period in the first scenario for Pars Paper Factory

3.4. Economical and Environmental Feasibility Study of CHP System in Scenario 2

Utilization of the scenario 2 will lead to 32,599,209 m^3 /yr saving in natural gas consumption. Considering the international price for natural gas (US$ 1 = 10,500 Rials), the factory's benefits from saving in natural gas consumption would be US$ 8,072,185/yr. Furthermore, the reduction of external costs would be US$ 611,893/yr. The project IRR would be 477.89% which implies that the project is economically feasible . Furthermore, the pay back period will be 1.21 year and the NPV will be US$ 26,972,388/yr. The project profit index is also 2.57, which is an acceptable value.

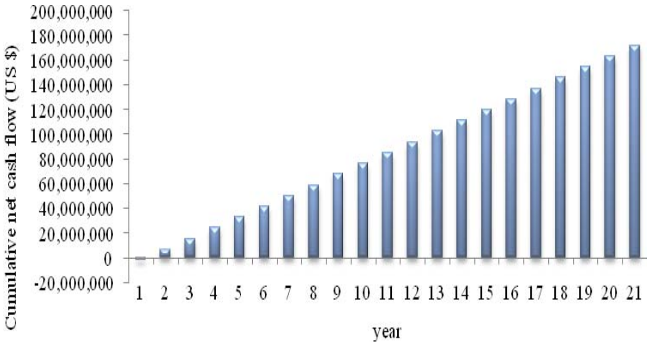

Fig. 4: Pay Back Period in scenario 2 for Pars Paper Factory

4. Conclusions

In order to perform the technical- economic and environmental feasibility study on application of CHP systems in Pars Pulp and Paper Industry, two scenarios were considered by using Thermo flow and COMFAR software's. The first scenario was proposed based on using a back pressure steam turbine with capacity of 9 MW. In this project, in addition to reducing the energy loss and supplying the required steam for the process at three pressure levels, the factory will be able to provide 9,000 kW of its required power, while the rest is supplied through the network. The initial investment cost for this project is estimated to be 4.5 million dollars and it brings about 18,585,974 m^3/yr saving in natural gas consumption. The annual income from implementation of the project is US$ 4,951,091 and the pay back period assigned to the project implementation will be 0.9 year, as well.

In the second scenario, by installing a gas turbine along with heat recovery steam generator, a part of the steam needed for the back pressure steam turbine designed in the factory is provided, while the rest of steam needed for the steam turbine is supplied by the boilers in the factory and the generated steam is sent to the mentioned steam turbine. Accordingly, two boilers of the factory can be removed from the production line. Moreover, 5,000 kW of the required power of the factory, which was taken from the network in the previous scenario, is supplied by the gas turbine. Therefore, the factory will be able to supply its entire power requirements. The initial investment cost of this project will be US$ 10,500,000. This project brings about 32,599, 209 m^3/yr saving in natural gas consumption. The annual income would be US$ 8,684,078 and the payback period would be 1.21 years. Both scenarios are economically and financially feasible. However, the second scenario is preferred as it supplies the factory's total power requirement, leads to high saving in natural gas consumption and reduces more GHG emissions.

5. Acknowledgements

Authors would like to express their gratitude toward the Managing Director, and the Head of the Research Department of "Iranian Fuel Conservation Company" (IFCO) for their support.

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