Application of CHP Gas Engine Plant for a Detergent Factory: Energy and Environmental Aspects

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Abstract: In Middle East countries like Iran, energy intensity is higher than the other regions due to low energy prices. One of the good motives towards energy efficiency is energy prices and because of this fact Iranian government wants increase the energy prices. One of the best technologies in energy efficiency is combined production of heat and power (CHP). In this paper the feasibility study of utilizing a CHP unit in an Iranian detergent factory has been described. The thermal and electrical energy uses in the factory has been measured According to the energy consumptions. The CHP system has been selected based on reciprocating gas engines. The feasibility study for the CHP system has been performed with different energy prices and environmental effect like reduction in CO2 emission has been analyzed. The CHP system can save 6,500 tons of CO2 per annum. In the feasibility studies rate of return method has been utilized. According to the energy prices scenarios, the rate of return would vary between 13% and 33%.

Keywords: *CHP, Gas engine, Energy efficiency, Carbon dioxide emission, Feasibility study*

Nomenclature

AEL annual saving of electricity bill................ €
ANG annual fuel cost .... €
i rate of return
AO&M annual operation/maintenance cost..... €
ARH recoverable heat from intercooler/oil... kW
CHP combined heat and power
CI capital investment..................................... €
ASNG annual saving of natural gas bill........... €
EUF energy utilization factor........................... €
E30 30,000th hour maintenance cost.................€
E60 60,000th hour overhaul cost.......................€
ELEC present worth of saving electricity production ....€
NGC natural gas consumption.................. $m^3 \cdot h^{-1}$
MRH recoverable heat from water jacket..... kW
L percent of electrical full load

1. Introduction

After the first energy crisis in 1970s, OECD Countries decided to change their energy policies in order to reduce their dependence on imported energy from the Middle East. They utilized energy efficiency as an effective way to reach that goal. The best way to comprehend the presence of energy efficiency in a country or a region is to take a short look at its energy intensity curve. By utilizing energy efficiency in energy programming, the energy intensity will decrease every year (Fig.1).

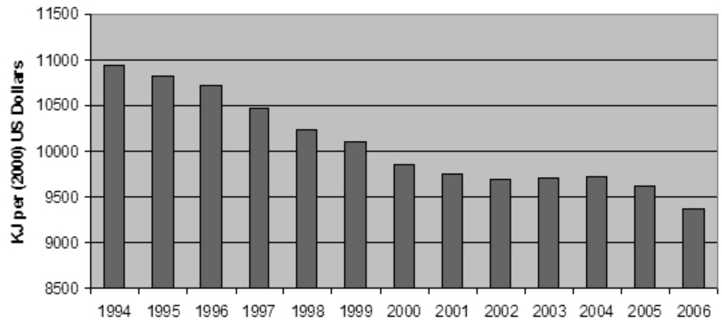

Fig. 1. World energy intensity [1].

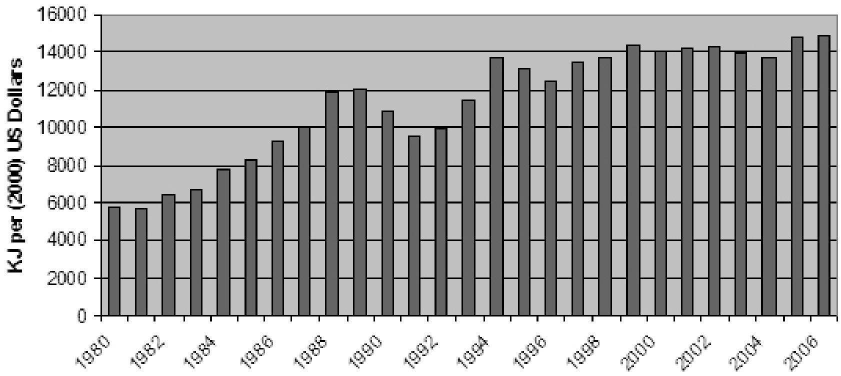

Fig. 2. Iran energy intensity [1].

On the other hand, Middle East Countries like Iran, which have rich energy resources, delayed utilizing the energy efficiency (Fig.2). In such countries, there is a huge obstacle on the path to reach an ideal energy efficiency, which is obviously the "low energy price". Low energy price always turns a profitable energy efficiency project to a lowly-lucrative one. In order to remove this obstruction, the Iranian government has planned policies to increase energy price in the near future. This project has sparked so many controversies amongst politicians because of its influential effect on the rate of inflation. However, because of the above-mentioned debates, it has not been enacted yet. Such an increase in energy prices is a nightmare for Iranian industries who are accustomed to low energy prices. The only way the industries may be able to come up with is by changing this threat to an opportunity through energy efficiency programs. One of the good practices in energy efficiency, which has been achieved since 1970s, is combined production of heat and power (CHP). In addition, distributed CHP systems in industries will result in reduction of electrical grid losses. The average thermal efficiency of thermal power plants in Iran is 36% and the loss in high and medium voltage electrical network is 4% [2]. Most of factories in Iran receive their electrical power by medium voltage network. Therefore, if the industries produce their own electrical demand by a CHP system, the grid losses, the fuel consumption and carbon dioxide emission will be lower. In this paper, application of a CHP system in a detergent factory in Iran is studied and discussed about the ratio between natural gas (as a fuel) and electricity prices and feasibility of the project. This factory is one of the largest detergent producers in the Middle East and produces over 132,500 tons of detergents per annum. The process of this factory requires electrical and thermal energy simultaneously. Therefore, CHP system is a perfect way to utilize energy efficiency in the factory, reducing energy bills and carbon dioxide emission.

2. Methodology

In the following section the energy demands of the factory, utilization of gas engines CHP system and economical analysis are described.

2.1. Energy demands of the factory

By installing a power logger in the main electrical feeder of the factory, electrical demand of the factory was measured. The electrical power demand of the factory is 3600 kilowatts and the annual consumption of electrical energy is 28,400,000 kilowatt-hours.

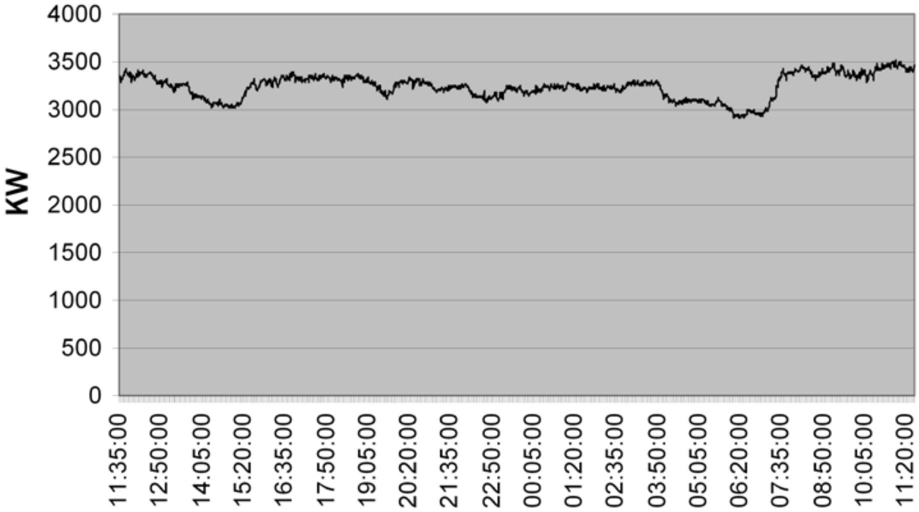

Fig. 3. Electrical demand of the detergent factory in a typical day.

The factory process consumes 244,931,438 kWh of thermal energy annually. Thermal energy source of the factory process is 45 tons per hour saturated steam at 1 MPa by 5 fire tube steam generator. The boiler's fuel is natural gas. The feed water enters the steam plant at $15^\circ C$ and it is heated by pegging steam in heat exchangers to $60^\circ C$. It enters the dearator to be heated to $95^\circ C$ in order to remove incondensable gases from feed water. For preheating the feed water in the steam plant, the factory needs 4.6 tons of steam per hour. All the produced steam is consumed within the process and there is no pipeline to return the condensate and recycle it as boiler feed water.

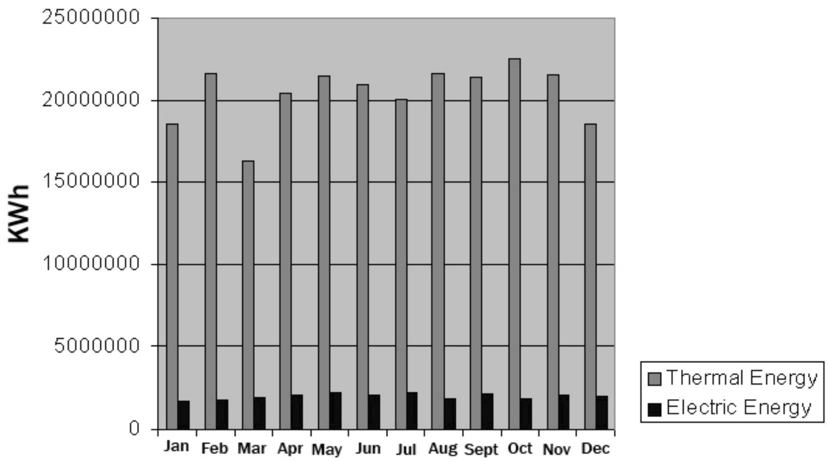

Fig. 4. Electrical and thermal energy usage in the detergent factory.

2.2. The choice of gas engine CHP system

In this case study, the authors selected a CHP system with 4 gas engine generating sets to cover the electrical demand. The nominal power of each gas engine is 952 kW therefore the overall nominal power of the plant is 3808 kW. The plant altitude is 1100 meters above the see level and in this site conditions the gas engines derate and actual power would be 4% and 3655 kW respectively [3]. For heat recovery of the system 2 plate heat exchangers are allocated for each gas engine. One of the plate heat exchangers recovers the waste heat from intercooler and engine oil and the other dedicates for waste heat of engine water jacket. The temperature of the intercooler/oil and water jacket are $60^\circ C$ and $95^\circ C$ respectively. The waste heat of intercooler/oil is 844 kW (4 gas engines) and it can heat the feed water from $15^\circ C$ to $31^\circ C$ [3]. After preheating in intercooler/oil heat exchanger, the feed water enters the water jacket heat exchanger and gains 2520 kW thermal power and reaches to $80^\circ C$. Utilizing the waste heat of the gas engines will saves up to 3.8 tons per hour of steam in heat exchangers and dearator in steam plant. The electrical and thermal efficiency in full power at actual site conditions are 38% and 35%. Therefore the EUF of the plant is 73% at full power. However, the EUF, thermal and electrical efficiencies would vary with different electrical power output.

2.3. Energy analysis

According to Fig.3 the hourly electrical demand of the factory is fluctuating and the gas engines have to follow these fluctuations. With changing the electrical load of a gas engine, its waste heat will be different. Less electrical output of a gas engine means less amount of heat to be recovered. However, the variation in amount of recoverable heat is not linear with electrical output power. The electrical demand of the factory has been measured with the sampling time of 1 minute for 24 hours. To calculate the amount of recoverable heat from intercooler/oil and water jacket, the demand is divided between 4 gas engine generators. In Table 1 the thermal data sheet of the gas engine is mentioned. By interpolation between columns of Table 1, the correlations between the amount of recoverable heat from intercooler/oil and water jacket versus electrical output power have been developed. To reach this goal authors fitted a polynomial order 3 curves between the electrical output power versus the amount of recoverable heat from main and auxiliary water circuits.

$$MRH = 5 + 1216 \times L - 1112 \times L^2 + 520 \times L^3 \qquad (1)$$

$$ARH = 76 - 81 \times L + 300 \times L^2 - 84 \times L^3 \qquad (2)$$

$$NGC = 12 + 302.5 \times L - 125 \times L^2 + 62.5 \times L^3 \qquad (3)$$

$$EUF = \frac{Electrical \quad Power + Heat \quad Power}{Inputed \quad Heat \quad by \quad Fuel} \qquad (4)$$

Where L is the ratio between electrical load on each generator and maximum net actual power on the given site conditions for one gas engine generator. Using Eqs. (1) and (2), the amount of recoverable heat from intercooler/oil and water jacket is calculated every minute for 24 hours. In order to estimate the consumption of natural gas of the gas engines versus load, a correlation has been developed (Equation 3). Table 1 shows fuel consumption of the engines. In this table, fuel consumption is mentioned as heat power in kilo Watt. To transfer the heat power to flow rate of natural gas, the net heating value of natural gas is needed [4]. Energy utilization factor (EUF) for a CHP system is the amount of electrical power plus useful recovered heat from the system divided by the amount of heat input from the fuel (natural gas) to the system. Table 2 shows the amount of recovered heat from auxiliary and main circuits, natural gas consumption for 24 hours period of a typical day and a year. Table 2 reveals that the total recovered heat per year is 26,760,340 kWh, which is equivalent to 2,804,554 m^3 of natural gas per year. In addition, the total heat input to the CHP system per year is 76,428,645 kWh. Therefore, the EUF of the CHP system is 72.14%.

Table 1. The gas engine thermal datasheet [3].

Power rating		Full	Partial load		
load	%	100	80	60	40
Electrical power	KW	952	761	571	380
Fuel consumption	KW	2386	1952	1538	1105
Water jacket waste heat	KW	630	533	447	347
Intercooler/oil waste heat	KW	211	160	117	86
Heat in exhaust gases (120 C)	KW	388	328	268	194

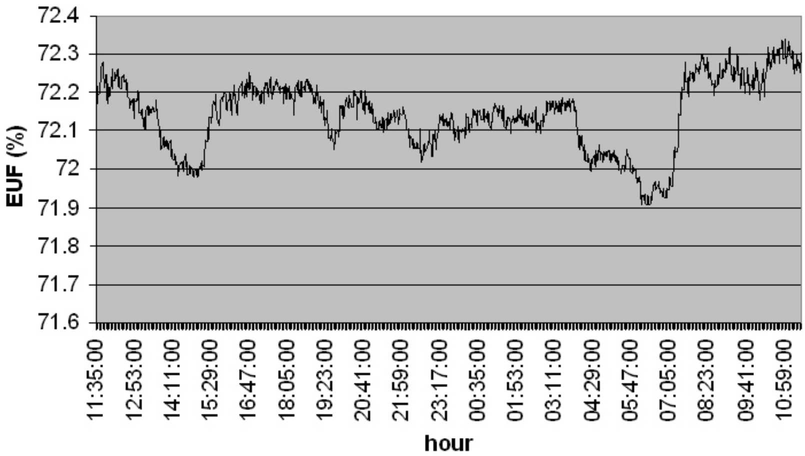

Fig. 5. Energy utilization factor of CHP System in a typical day.

Table 2. Energy parameters of CHP system.

	Unit	Per day	Per year
Natural gas consumption	m^3	21,945	8,009,925
Electrical energy production	kWh	77,754	28,380,210
Auxiliary circuit	kWh	17,743	6,476,195
Main circuit	kWh	55,573	20,284,145
Total heat recovery	kWh	73,316	26,760,340

2.4. Economical analysis

First step towards the economical analysis of a combined production of heat and power in the detergent factory is to determine the costs and benefits of the project. The costs of the project include the capital investment (which is 1.440.000 Euro), annual fuel cost, annual operation and maintenance (O&M) cost, and the 30,000th-hour maintenance and 60,000th-hour overhaul costs. The maintenance period of the selected gas engine is 60,000 hours, which includes 30,000th-hour maintenance and 60,000th-hour overhaul and the same periodic maintenance will be carried out quite regularly. The benefits of the project include saving the electricity bill and saving the natural gas bill as the result of recovering heat from the engines for preheating the boilers feed water instead of using pegging steam. The lifetime of the gas engine for continuous operation assumed to be 20 years. As it is discussed, the current energy price in Iran is low (natural gas: 0.011 Euro/m^3, Electricity: 0.014 Euro/kWh) and Iranian government is planning to increase it rapidly (natural gas: 0.0695 Euro/m^3, electricity: 0.0348 Euro/kWh) in the near future. Therefore, the benefits of the project need to be calculated with two different energy price references accordingly. Economical analysis carried out with rate of return method. Rate of return method is based on time value of money. In this method, the net present worth of costs including capital investments, are placed to be equal to net present worth of benefits with a variable rate of interest (Equation 5). This variable rate of interest is called the rate of return.

$$AEL\times\left(\frac{(1+i)^{20}-1}{i\cdot(1+i)^{20}}\right)+ASNG\times\left(\frac{(1+i)^{20}-1}{i\cdot(1+i)^{20}}\right)=CI+ANG.\times\left(\frac{(1+i)^{20}-1}{i\cdot(1+i)^{20}}\right)$$
$$+AO\&M\times\left(\frac{(1+i)^{20}-1}{i\cdot(1+i)^{20}}\right)+E30\times\left[\frac{1}{(1+i)^{4}}+\frac{1}{(1+i)^{12}}\right]+E60\times\left[\frac{1}{(1+i)^{8}}+\frac{1}{(1+i)^{16}}\right] \quad (5)$$

3. Results

In this section reduction in carbon dioxide emission, costs and benefits of project, economical analysis based on rate of return method are discussed.

3.1. Environmental analysis

As mentioned before, the average efficiency of Iranian national thermal power plants are 36% and energy losses in high and medium voltage grid is 4%. Currently the factory receives 28,380,210 KWh of electrical energy per annum from medium voltage grid, which means that the national power plants have to generate 29,562,935 kWh annually to overcome the energy losses. For generation of 29,562,935 kWh of electrical energy, a typical Iranian thermal power plant consumes 8,606,316 m^3 of natural gas. On the other hand for producing the same amount of electrical energy in the factory, the specified CHP unit consumes 8,009,925 m^3 of natural gas with 26,760,340 kWh of useful recovered heat energy, which is equivalent to 2,804,554 m^3 of natural gas. Therefore, CHP unit saves 596,391 m^3 of natural gas as the result of reducing grid losses and improving the electrical energy efficiency and 2,804,554 m^3 of natural gas as the result of recovering the wasted heat from the engines, which are totally 3,400,945 m^3. Burning each cubic meter of natural gas produces 1.91407 Kg of carbon dioxide [4]. Therefore, an annual saving of 3,400,945 cubic meters of natural gas means saving 6,509 tons of carbon dioxide emission per annum.

3.2. Economical analysis

By solving the Equation 5, rate of return of the project is revealed. In table 3, the feasibility study result of the project for two different energy prices has been discussed.

Table.3. Annual costs and benefits of the CHP system

Item	Amount	Current price (€)	Price in near future (€)
Natural gas	8,009,925 m^3	88,999	556,244
O&M	-	77,250 [5]	
Maintenance at 30,000 hour	-	140,000 [5]	
Overhaul at 60,000 hour	-	160,000 [5]	
Saving the electricity bill	28,380,210 kWh	394,169	985,423
Saving the natural gas bill	2,804,554 m^3	31,161	194,760
Rate of return	-	12.6 %	33.3 %

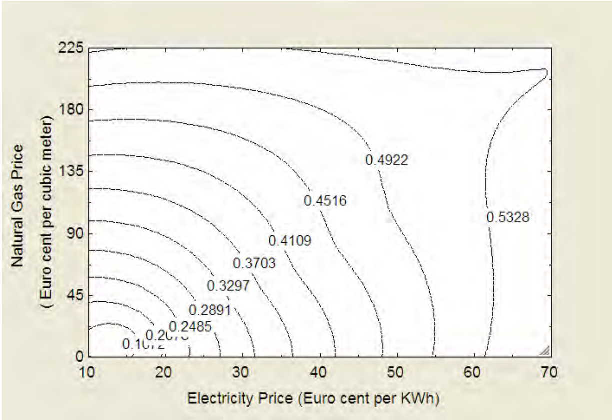

Fig.6. The sensitivity of energy prices versus rate of return.

Feasibility of the project is highly dependant to the energy prices. In the Fig.6, the effect of natural gas and electricity prices on the rate of return has been shown.

4. Conclusion

Application of a CHP system in the detergent factory was discussed from technical, economical and environmental point of views. Such a system can save 2,804,554 m^3 of natural gas and 6,509 tons of carbon dioxide annually without interrupting in the factory processes. The factory needs steam for its processes and the only way for direct steam generation with gas engines is utilizing heat from exhaust gases. The exhaust gases can produce only 2 ton of steam per hour but by utilizing low temperature heat from intercooler/oil and water jacket in order to preheat the feed water of boilers, 3.8 tons of steam per hour will be saved. This method of heat recovery is more efficient, simple and cheap. The feasibility of the project strongly depends on the fuel and electricity prices. Government should increase the energy prices in a conducted way to encourage the industries to utilize CHP system. Finally this study encouraged the owners of the detergent factory to install gas engines CHP plant and now the system is under operation.

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