Technical and Economic survey on power generation by use of flaring purge gas

Mohammad Heydari, Mohammad Amin Abdollahi, Abtin Ataei and Mohammad Hoseini Rahdar

Abstract— Regarding to costs, environmental effects and waste of energy by gas flaring in refineries, the necessity of reduction of this gases is obvious. Two approaches could be followed to achieve this aim, the first is to reduce the flare gases by improving the processes and the second is reusing the flare gases. This study is aimed to find a solution for applying the second approach. After reviewing features of a flare gas system in a sample plant, the electrical power generation by use of flaring purge gas is described in two scenarios. The first scenario is a simulation of power generation by gas turbine working in a simple Bryton cycle. In the second scenario, Fog method is added to the cycle to improve the efficiency of the gas turbine. These scenarios are compared together from both technical and economical point of view. The results indicate that, although the extractable power has a better situation in the second scenario, but the first one is more economically justified. The extractable powers in the first and second scenario are 38.5MW and 40.25MW respectively, while payback periods are 3.32 and 3.48 years.

Keywords— Flare Gas Recovery, Gas turbine, FOG, Payback period

I. Introduction

FLARING or venting directly to atmosphere of natural gas is one of the basic resource of greenhouse gases [1]. Global Bank estimates that 100 Billion cubic meters of natural gas, equal to annual consumption of gas for Germany and France, is flared or vented in air each year [2]. One of the reasons for flaring gas in industries and preferring it against ventilating is its lower greenhouse gas effect. The global warming potential of methane when compared to carbon dioxide usually suggests that flaring is a more environmentally attractive. One pound of methane vented to the atmosphere has a GWP of 25. If instead, this amount of methane (one pound) was burned, 2.75 lbs of CO2 would be produced. This amount of CO2 has a GWP of 2.75. In this comparison, flaring methane instead of venting it reduces the global warming impact of the emission by a factor of 9. Although Flare systems are considered as a tool for controlling air pollution but it should be considered that flaring has natural and economical wasting itself [3]. Hence, at first it is needed to reduce the volume of flaring by improving the processes and then to look for finding ways of flare gas recovery [4]. After processing, the gas can be utilized in a number of ways. It can be included in the natural gas distribution network, used for on-site electricity generation, reinjected for enhancing oil recovery, or used as feedstock for the petrochemical industry [5]. Power generation seems more attractive noticing that most of the governments have opened up competition in the generation market with the creation of qualifying facilities and they have removed some constraints on ownership of electric generation facilities and encouraged increased competition in the wholesale electric power business [6]. So flare gas from refinery could be a good candidate as a primary source of fuel for Gas turbines. Attention to flare gas as a fuel for electricity generation is cited in few papers, however, many discussed about the political, economic and environmental impacts of flare gas and the necessity to decrease the amount of gas flaring. Regarding to electricity generation, there are many books on gas turbine theory, performance and gas turbine cycles notably by Walsh and Fletcher [7], Horlock [8], Hodge [9], Cohen et al. [10] and Kerrebrock [11] but literature show that there are many works to do in order to use appropriate turbines for generating power from flare gases.

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II. Material and Methods

A. Review

Flare gases are purified and compressed with special equipment in order to be used as a feed for process units. Flares have the added consideration of a flame always being present, even when there is a very low flow rate. Purge gas is injected into the relief header at the upstream end and at the major branches to maintain a hydrocarbon-rich atmosphere in each branch, into the off-plot relief system, and into the flare stack. According to control philosophy, in normal recovery condition, the FOV (fast opening valve) locating on the pipeline of transferring gases to the burner, is fully closed, and also a bursting disc is installed in parallel to the FOV, so that if the pressure increases in the flare line and the FOV doesn't actuate thoroughly, it will conduct the gases to the burner. In the case that the flare flow rate is greater than the recovery unit, gas will be conducted to the flare. Figure 1 depicts the control philosophy of this system.

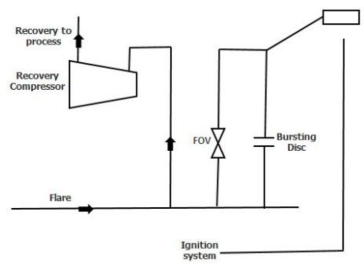

Fig. 1. General flare gas recovery system

In this study, the purge gas used for flare network in a sample plant is studied. According to calculations, 4.5 lb/s of this gas with a pressure of 6 bar, is required for the whole flare network purging. In other words, a minimum of 4.5lb/s flow rate of this gas is continuously wasting. The composition of this gas is reported in table 1. Based on the composition, the lower heating value of the gas is 19738 BTU/lb. According to the temperature and humidity profile of the flare location, the average temperature and relative humidity are 76.8 ^{0}F and 62% respectively.

TABLE I
THE FLARE PURGE GAS COMPOSITION

Gas compound	% of total gas
Nitrogen	3.81
Carbon monoxide	0
Carbon dioxide	0.68
Methane	93.43
Ethane	2.01
Propane	0.058
n-butane	0.00395
n-pentane	0.000115

B. *Technical aspects*

Based on the temperature, pressure and flow rate of the mentioned gas and also required characteristics of fuel to enter to the combustion chamber, different gas turbines data sheets have been verified and then the turbine model of Siemens W251 B10A is selected. Since the flare gas may be added to the Purge gas in some situations, the usage of 4.5 lb/s of flare gas in the gas turbine should not occur in the 100% load and turn down ratio should be considered. Table 2 indicates the main specification of the selected turbine. As it could be seen, the flow rate for the full load of turbine is 5.93 lb/s which has a 32% margin from minimum flow rate and so the turn down ratio will be 32%.

TABLEII
. SELECTED TURBINE SPECIFICATION

stream	Temp. (F)	Pressure (psi)	Flow rate (lb/s)
Inlet Air	77	14.69	331.64
Fuel	247	344.33	5.93

Based on the above information two scenarios are considered.

Scenario 1: Simple Cycle of the Gas Turbine
A turbine converts the kinetic energy of a moving fluid (liquid or gas) to mechanical energy. Gas turbines are commonly used when power utility usage is at a high demand.[13] Gas turbines can be burned to produce hot combustion gases that pass directly through a turbine, spinning the blades of the turbine to generate power. The electric power industry evolved from a highly regulated, monopolistic industry with traditionally structured electric utilities to a less regulated, competitive industry [14]. The Brayton cycle is one of the most efficient cycles for conversion of gas fuels to mechanical power or electricity. In this scenario, a simple gas turbine is modeled according to the inputs given in table 2. It should be also mentioned that, in order to increase the fuel pressure from 6 bar to 23.7 bar, a compressor with an efficiency of 90% is used. The power consumption of this compressor is calculated by equation 1 and then deducted from the power generated by turbine.

$$W_{COMP} = P_1 Q_1 \frac{K}{K-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} - 1\right] \quad (1)$$

Where P_1 and P_2 are inlet and outlet pressure of the compressor, K is the exponential coefficient in adiabatic compression and for this fuel gas is equal to 1.28 and Q1 is the volumetric flow rate of gas at suction condition in cubic meters per second. A schematic of this approach is depicted in figure 2.

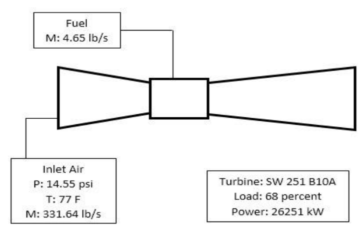

Fig 2. Schematic of the first scenario model

Scenario 2: Cooling inlet air of a simple cycle of gas turbine by Fog method:

Gas turbines are used in very wide ranges of services due to their fuel flexibility, reliability and life. The thermal efficiency of the gas turbine is a function of the pressure ratio, inlet air temperature, turbine inlet temperature, the efficiency of the compressor and the turbine elements [16].The operation of gas turbine is highly dependent to the environmental conditions. At high inlet air temperatures, both the power and efficiency are decreased [17]. Cooling inlet air to compressor enhances both power and engine efficiency by increasing the air density, so raising the specific mass flow rate through the engine. A method for cooling the inlet air is injection of small water droplets as like a fog in the upstream of air flow to the compressor [18] .This system is called Fog. In fog system, by increasing the surface of water touching with air and by water evaporation, input air of compressor is cooled. Water is sprayed through nozzles into inlet of the compressor channel in the form of fine particles with a diameter less than 20 microns [19]. In this scenario, Fog method is considered for enhancing the power generation and the inlet temperature of air to compressor is reduced to 67 ^{0}F. The required water for this change in the inlet air temperature is 0.74 lb/s. A noticeable issue is that by lowering the temperature of input air to compressor and so increasing the density of air, the maximum flow rate of the fuel and as a result the turn down ratio will increase. It should be also noticed that in this paper only the average temperature and pressure are used in models. In fog system, whatever the air temperature is warmer and the relative humidity is lower, the efficiency of cooling is higher. Therefore, the fog method is used mainly in warm and dry days of the year [20]. A schematic of this approach is depicted in figure 3.

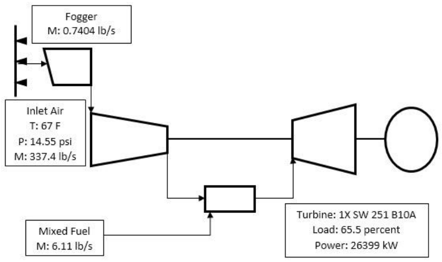

Fig 3. Schematic of the second scenario model

C. Economic aspects

In order to consider economic aspects, first the assumptions of the project including costs of investments, costs of production, annual sales rate and others should be provided as input and then economic parameters for cost-benefit analysis should be calculated [21]. The base year is 2014 then 15 years of operation has been considered based on the equipment's lifetime. In tables 3, main fixed costs for both scenarios are reported. The costs are provided according to producer's data.

TABLE III
MAIN FIXED COSTS

Description	First scenario (Million USD)	second scenario (Million USD)
Civil Works and Construction	0.56	0.6
Gas Turbine	11.5	11.57
Fuel Compressor	1.51	1.51
Voltage convert equipment	0.7	0.7
Voltage producing equipment	1.25	1.25
Oil Pump and other equipment	2.1	2.9
Cabling and electrical works	2.9	2.9
Piping and mechanical works	0.9	1
Contracting costs	3.7	3.8
Total fixed costs	18.03	18.72

In the next step, the costs of wage, repairs and maintenance and also the costs of pre-production such as engineering were added. It should be mentioned that fuel fees (flare system gases) for both scenarios are equal to zero, however in the second scenario, the costs of water consumption is considered in the analysis. The capacity factor for calculating annual incomes is considered as 7900 hour/year including 860 hour/year emergency shutdown. The price water consumption and each KWh selling are considered from Iran's situation and 800 Rials [22] (0.026 USD) per cubic meters and 870 Rials (0.029 USD) per KWH [23].

The outputs of economic analysis provide good and comprehensive criteria for economic decisions. In Net Present Value (NPV) method, costs and benefits which occur in different periods, are discounted and all of them will be described in a common method and at a specific time. In this paper, the NPV is calculated with the discount rate of 18%.Payback period is the time needed for achieving the primary investment of the project from the source of income. The criterion of accepting one plan from other plans is based on the lower payback period. According to this project the investment of investors will be paid back in a reasonable short period. Internal Rate of Return (IRR), is the discount rate which the current value of incoming cash flow is equal to current value of outgoing cash flow [24].

III. RESULTS

A. Technical results

The results of the modeling for scenarios are reported in table 3 and 4. As it could be seen, the power of 38 MW is extractable from the first scenario in full load. Regarding to turn down ratio, at 68% of full load, the power of 26.6 MW can be extracted.

TABLE III
OUTPUTS IN DIFFERENT LOADS OF FIRST SCENARIO

Load (%)	Fuel flow (lb/s)	Efficiency (%)	Turbine power (MW)
100	5.93	31.23	38
90	5.48	30.41	34.2
80	5	29.42	30.3
68	4.5	27.97	25.7

TABLE IV
OUTPUT IN DIFFERENT LOADS OF SECOND SCENARIO

Load (%)	Fuel flow (lb/s)	Efficiency (%)	Turbine power (MW)
100	6.11	31.64	40.75
90	5.64	30.86	35.7
80	5.17	29.9	31.7
68	4.62	28.46	26.9
65.5	4.5	28.12	25.9

In the second scenario fuel flow rate in full load is reached to 6.11 lb/s and the load of using 4.5 lb/s of the purge gas is 65.5%, so an improvement of 3.67% is occurred in the second scenario from this point of view. Other parametric comparisons indicate that Fog method increases the efficiency by 1.3% and the output power by 4.5%, but in minimum load the increase in efficiency will be 0.5% and for output power will be 0.7%. Hence, the benefits of using the fog system could be considerable.

B. Economical results

In figures 4 and 5, the diagram of current net value of total investment against the discount rate is presented. The point which the curve crosses the horizontal axis, defines the IRR [25].

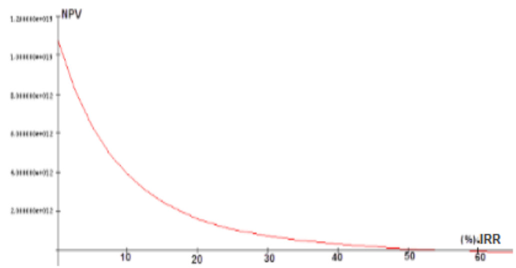

Fig. 4. Diagram of total investment NPV against discount rate, first scenario

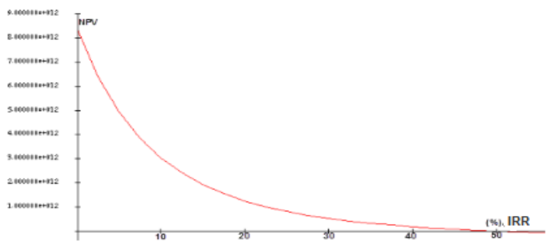

Fig. 5. Diagram of total investment NPV against discount rate, second scenario

In table 5, a summary of the most important economic parameters of both scenarios are illustrated.

TABLEV
IMPORTANT RESULTS OF ECONOMIC STUDIES

Economic Parameters	First scenario	Second scenario
Current net value in 18% discount rate	63.5 Million USD	49.6 Million USD
Internal rate of Return (IRR)	55.09%	50.02%
Payback Period	3.32 years	3.48 years

Based on the tables and figures, it can be seen that although by adding the fog system the performance and the efficiency of the whole system will be improved, but due to the costs related to fog system it is not economically justified in comparison with the system without Fog and the NPV is 16.6 Million USD lower, the IRR is 5.07% lower and the Payback Period is later. Therefore, based on this case study, the simple cycle of power generation without fog is preferred.

It is notable that regarding the consequences of using flare gas on equipment, i.e. corrosion and emissions of combustion products, currently controlled filtration packages are used for the fuel gas before entering the combustion chamber of the turbine. It is obvious that for a more realistic modeling and in precise technical/economical/environmental calculations, the cost of this package should also be considered. Also the benefits of decreasing the emissions (and therefore less environmental effects) by recovering flare gases in comparison to gas flaring should be considered as well.

IV. CONCLUSION

In this study, it has been concluded that by investing on the first scenario, within 3.32 years it would be paid back and also the 55.09% internal rate of return indicates the suitable feasibility of this investment. By this method a minimum of 25.7MW and a maximum of 38MW of electrical power generation is achievable. Regarding to the Fog system, it has been proved that the this system is one of the most effective methods for increasing the performance and efficiency of the turbine, but this it is more efficient in high temperature and low relative humidity. Hence, it can be said that one of the reasons which Fog is not practical for use in this study is the high relative humidity of the weather and as a result the enhancement of the gas turbine generated power and efficiency is not as much as the costs of water consumption and installing the fog system. Although the recovery of flare system gases in most of oil and gas fields seems to have high initial investment, but by a correct design and use of recovered gases and by considering the methods of increasing the performance and efficiency, the flare gas recovery plan could reach to economic, environmental and technical justification situation.

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