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Research Paper

Development and analysis of two novel methods for power generation from flare gas

Mohammad Heidari [a,*], Abtin Ataei [a,b], Mohammad Hoseini Rahdar [a]

[a] Department of Energy Engineering, Graduate School of the Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Department of Mechanical and Aerospace Engineering, University of Dayton, OH, USA

HIGHLIGHTS

- The conditions of gas flaring in a real gas refinery plant were measured.
- We developed two feasible scenarios to reuse the flare gases.
- Engineering Equation Solver tool is used to investigate the two studied scenarios.
- Burning flare in gas turbine as a mixture with natural gas showed better performance.
- Sending flare to middle stages of Gas Turbine was preferable for lower than 0.8 kg/s.

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ABSTRACT

This study is aimed to develop two feasible scenarios to reuse the flare gases. The conditions of gas flaring in a real gas refinery plant are measured and two feasible structures for electrical power generation from the flare gas are investigated as two scenarios. The first scenario is burning the mixture of the flare gas and a conventional fuel, while the second one is sending the flare gas to an intermediate stage of a gas turbine after burning it in a combustor. In order to improve the power generation and mitigate the environmental issues, a steam power cycle is coupled as a bottoming cycle in both scenarios. By considering the power generation status and parametric study through an EES coding, the scenarios are studied and compared. Considering the flow rate of the flare gas which is variable with respect to time, the results show that the first scenario is preferable from technical and economic aspects for all of the flare and natural gas flow rates except when the amount of flare flow rate in the plant is lower than 0.8 kg/s.

1. Introduction

Flaring or venting directly to atmosphere of gas is one of the basic sources 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 to air each year [2]. Global Gas Flaring Reduction (GGFR) introduced Russia, Nigeria, USA and Iran as the major flare gas producers of the world in 2013 [3]. One of the reasons for flaring gas in industries and preferring it to ventilating is its lower greenhouse gas effect. Although flare systems are considered as a tool for controlling air pollution, it should be considered that flaring has natural and economic capital wastes as well [4]. Hence, firstly it is needed to reduce the volume of flaring by improving process conditions and then looking for recovery methods and generating electrical power or using it in other applications is necessary [5]. The gas can be utilized in a number of ways, i.e. it can be included in the natural gas distribution networks, used for on-site electricity generation, injected for enhanced oil recovery, or used as feedstock for the petrochemical industry [6], however, in some countries like Iran, power generation seems to be more attractive noticing that Iranian government has opened up competition in the generation by considering facilities and removing some constraints on ownership of electric generation facilities and encouraging competition in the wholesale electric power business [7]. Using flare gas as a fuel for electricity generation is investigated by few studies, however, many have discussed about the political, economic and environmental impacts of flare gas and the necessity to decrease the amount of gas flaring. Regarding the electricity generation, Rahimpour and Jokar [8], investigated on entering an amount of Farshabad gas refinery flaring purge gas to produce about 25 MW electricity and by comparing electricity generation with some

* Corresponding author.
E-mail address: mohammadheydari86@yahoo.com (M. Heidari).

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Nomenclature

c_p	specific heat at constant pressure (kJ/kg K)
Ex	exergy (kJ)
$\dot{E}x$	exergy flow rate (kW)
h	specific enthalpy (kJ/kg)
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
Q	heat transfer (kJ)
$\dot{Q}$	heat transfer rate (kW)
S	specific entropy (kJ/kg)
T	temperature (K)
$\dot{W}$	work rate (kW)
Z	investment cost ($)
LHV	lower heating value (kJ/kg)
R	gas constant (kJ/kg K)

Greek symbols

η	efficiency

Subscripts

AC	air compressor
b	Bryton cycle
cc	combustion chamber
D	destruction
eva	evaporator
eco	economizer
in	inlet
i	initial
in	inlet
L	loss
NG	natural gas
out	outlet
ph	physical
st	steam cycle
r	Rankin cycle
w	work
0	dead state

other methods, they found it as the superior method economically. Rahimpour et al. [7] made a comparative study between flare gas electricity production potential with gas turbine and two other methods in Assalouye. Finko et al. [9] also introduced an electricity generation facility of a refinery in Russia which could produce 49 MW electricity including 16 MW for own use. Anosike [10] showed that utilization of associated gas for onsite power generation is a promising technology for converting waste to energy in Nigeria. He simulated and compared several gas turbines (including 30 MW) with some having advanced and regenerative cycles with pure natural gas and flare gas of a region in Nigeria and concluded that both fuels have a similar performance. Although, in these works the potential and feasibility of electricity generation by flare gas for conventional gas turbines are well introduced, but no paper in literature has discussed about the operational details of the gas turbines considering variable flow rate and low LHV of flare gas which are its inherent characteristics. Flare system is a network in which extra gases from different units of the refinery or gases produced in emergency shutdown of the units are gathered to be burned. As the result, flare flow rate and composition will be variable based on the conditions of different units. During normal operation, the amount of gas flowing is low, in the event of an upset or other non-normal operation of each unit of the refinery, the flow rate may increase. There are many books about gas turbine theory, performance and gas turbine cycles notably by Walsh and Fletcher [11] and Horlock [12] which can be used to design appropriate novel systems to notice these characteristics of flare gas. Furthermore, several parametric studies in power generation cycles are available which can be useful. Most of these papers are about evaluating the impact of changing important parameters of the gas turbine (like high temperature or pressure) on its efficiency or achievable power. For instance, Nayak and Mahto [13] conducted a parametric analysis for a combined cycle power plant with an inlet vapor compression cycle. They simulated power output and cycle efficiency with respect to the cycle temperature and pressure ratio for a typical set of operating conditions. Poullikkas [14] performed parametric study and also cost-benefit analysis concerning the use of various combined cycle technologies for power generation, by independent power producers in Cyprus. In another work, Rahim [15] investigated the effects of site conditions (ambient temperature, altitude) on a combined cycle plant located Ankara. None of the papers in the literature have considered a similar parametric study for using flare gas for power generation purpose. Hence, there remains many works to do in order to operate the exact and appropriate turbines for generating power from flare gases. This survey tries to introduce new methods of entering the flare gas as a fuel to gas turbines. This subject is more attractive knowing that some companies are willing to pay for power generation by flare gas as much as $60.22 per MW h [16]. This interesting proposal was presented according to "Flare Gas Power Generation Program" from SaskPower which is the principal electric utility in Saskatchewan, Canada in 2014. Their principal aim was reducing greenhouse gas emissions with cooperation of small to medium sized power producers. $60.22/MW h was the initial contract base rate, assuming the project starts generating power in 2015 [16].

In the first part of this study, flare gas stream of a sample plant will be introduced. Then for generating electrical power, two methods of using the flare gas will be presented and compared. The specific objectives of this work which make it different from the literature works related to flare gas recovery are: introducing two novel methods for power generation considering inherent characteristics of flare gas, considering natural gas as a complementary fuel for flare gas, parametric study and exergy analysis of the proposed methods, economic analysis of the systems and techno-economic comparison of the two methods.

2. Material and methods

The composition of the studied flare gas is reported in Table 1. It is worthy to note that characteristics of the gas (flow rate and composition) to be flared vary due to different operating conditions of the plant. For instance, during continuous load of different units, the compositions are very similar to the ones mentioned in Table 1, however in case of depressurization of some units named Fire Zone, the percentage of Propane may increase harshly to around 34% or in case of a special compressor (export gas compressor) failure, water content of the gas decreases to zero and nitrogen and methane proportions increase to around 4% and 49% respectively and in case of acid gas removal from some units of the plant, the percentage of Ethane and Methane decrease and Propane percentage increases. Hence, the data provided in Table 1, represents the average composition. The flow rate of this gas varies from 0 to 2.24 kg/s.