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Energy Loss Reduction in Oil Refineries through Flare Gas Recovery Approaches

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***Abstract*—**For the last few years, release of burned undesirable by-products has become a challenging issue in oil industries. Flaring, as one of the main sources of air contamination, involves detrimental and long-lasting effects on human health and is considered a substantial reason for energy losses worldwide. This research involves studying the implications of two main flare gas recovery methods at three oil refineries, all in Iran as the case I, case II, and case III in which the production capacities are increasing respectively. In the proposed methods, flare gases are converted into more valuable products, before combustion by the flare networks. The first approach involves collecting, compressing and converting the flare gas to smokeless fuel which can be used in the fuel gas system of the refineries. The other scenario includes utilizing the flare gas as a feed into liquefied petroleum gas (LPG) production unit already established in the refineries. The processes of these scenarios are simulated, and the capital investment is calculated for each procedure. The cumulative profits of the scenarios are evaluated using Net Present Value method. Furthermore, the sensitivity analysis based on total propane and butane mole fraction is carried out to make a rational comparison for LPG production approach, and the results are illustrated for different mole fractions of propane and butane. As the mole fraction of propane and butane contained in LPG differs in summer and winter seasons, the results corresponding to LPG scenario are demonstrated for each season. The results of the simulations show that cumulative profit in fuel gas production scenario and LPG production rate increase with the capacity of the refineries. Moreover, the investment return time in LPG production method experiences a decline, followed by a rising trend with an increase in C_3 and C_4 content. The minimum value of time return occurs at propane and butane sum concentration values of 0.7, 0.6, and 0.7 in case I, II, and III, respectively. Based on comparison of the time of investment return and cumulative profit, fuel gas production is the superior scenario for three case studies.

***Keywords*—**Flare gas reduction, liquefied petroleum gas, fuel gas, net present value method, sensitivity analysis

I. Introduction

SINCE the birth of petroleum industry, flaring has been widely used for a method for disposal of flammable gases in downstream and upstream activities in oil industries, petrochemical and natural gas treatment plants. Associated gas co-produced during oil refining processes is often flared due to safety concerns, financial barriers to implementing flare reduction projects, low domestic gas prices, and lack of incentives and efficient regulations on flaring activities [1]. Although it is a safe method to discharge associated gas at oil and gas production units by mitigating the pressure in facilities, it causes extensive damage to the environment. According to the World Bank, the annual volume of natural gas flared or vented in the world for the year 2003 amounted to more than 100 billion cubic meters which represents the annual gas consumption for France and Germany combined [2].

Flaring as an urgent priority for private and public authorities has noticeable detrimental impacts on the environment and human health. The common emitted gases from flaring are Hydrogen sulphide (H_2S), Nitrous oxides (NO_X), Carbon dioxide and Methane. Hydrogen sulphide is a toxic and corrosive gas, which is a main source of acid rain and causes many health problems, e.g. skin disorders and respiratory diseases. Moreover, in the presence of volatile organic components (VOC), the nitrous oxides can lead to the formation of ozone [3]. The emitted methane and resulting carbon dioxide contribute to global warming. According to the global warming potential index (GWP) of carbon dioxide and methane, for a 100-year time horizon, methane gas possesses 25 times more global warming potential than carbon dioxide [4].

There are alternative solutions for gas flaring that waste less energy. Among the numerous solutions, the appropriate approaches are as follows:

- Use of associated gases as fuel gas
- LPG production from oil refineries' flare gas
- Developing a transport system for collecting gases to be shipped to a treatment plant
- Implementing technology to generate gas to liquid (GTL)
- Re-injection purge gases into the oil fields to enhance crude oil recovery if the characteristics of the reservoirs permit

The first serious flaring gas reduction plan was accomplished in 1999 in Norway. Despite the increasing levels of oil production, Norway reduced gas flaring and venting considerably through successful implementation of regulations and close cooperation between the authorities and the industry. The oil producers operating in Norway's oil fields are required to prepare an installation and operation plan, and must also obtain a permit that specifies the type and level of air emissions, technology to circumvent and mitigate emissions [5]. In recent years, Shell Oil Company has achieved a noticeable reduction of gas flaring through installation and operation of flare gas recovery (FGR) units [6]. Iran's AMAK project claimed to be the most extensive

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environmental project implemented by the National Iranian South Oil Company (NIOC), started in February 2005 to collect associated gas from one of the carbonate reservoirs in Ahwaz oil field in southern Iran. The project aims to prevent flaring of 7 million cubic meters per day of sour gas and has achieved the collection of 2.1 billion cubic meters of gas in two years since it started operations in 2005 [7].

In this regard, [8] showed that the dispersion pattern of pollutants from gas flaring is affected by the changes in the volume of gas flared, stack efficiency, and wind speed. The concentration of pollutants from gas flaring was predicted as a function of aforementioned factors which is not equal at various directions. It was observed that the simulated results are in good agreement with dispersion pattern with a correlation coefficient of 0.96.

Xu et al. studied an investigation of a general methodology on flare minimization for an ethylene plant start-up operation as the case study via plant wide dynamic simulation [9]. The research decreased flaring by almost 60 percent during start-up operation. The plant wide dynamic simulation provides an insight into process dynamic behaviours, which is crucial for the plant to minimize the flaring while maintaining operational feasibility and safety.

Johnson and Coderre utilized detailed monthly production data spanning the years 2002-2008 for the province of Alberta [10]. They investigated a comprehensive analysis of greenhouse gas (GHG) mitigation potential in a mature oil and gas producing region. This analysis was based on evaluation of the feasibility of mitigation via collection and compression of gas into pipeline to connect to existing pipeline network.

Rahimpour et al. proposed three methods: electricity generation, GTL production and using fuel gas (from flare gas), to recover flare gas instead of conventional flaring and selected the most suitable method based on the most economical evaluation [11]. Davoudi et al. studied the critical situation and the sources of flaring to reduce the wastes from a gas processing plant [12]. Zadakbar showed that, depending on vent gas composition, the recovered gas may be recycled back into the process or used as fuel gas for electricity generation [13]. In all aforementioned studies, there is a lack of specific approach to reduce, recover, and reuse flare gases in oil processing plant.

Therefore, in this study, two practical approaches are conceived for the purpose of flaring mitigation for three different oil refineries using plant simulation and economic evaluation. The methodology could be developed extended to any oil refineries in industrial scales. Tabriz, Tehran and Bandar-Abbas oil refineries are considered as the case studies in order to prevent conventional flaring. In the proposed methods, flare gases are converted to the more valuable products. The first option includes gathering, compressing and transmission of flare gas to the refineries fuel gas pipelines. Whereas the sum of propane and butane mole fraction contained in flare gas of three case studies is noticeable, LPG production from flare gas is chosen as the other scenario for flaring reduction. In the present research, the pre-installed LPG plants in the oil refineries are used to produce LPG from waste gases. Eventually, based on comparison of capital investment and payback period, the superior scenario is selected for each refinery.

II. Process Description

In this investigation, two scenarios are evaluated to reduce flare gas in three different oil refineries, i.e. producing LPG and using as fuel gas.

The first step in a flaring reduction scheme is to figure out whether the amount and quality of flare gas is enough and suitable to recover or reuse. For this purpose, calculated flow rates and compositions in three case studies are utilized. The gathered data in the refineries were randomly measured by time using gas chromatography device, and the average values of mole fraction of each component are calculated. Flare gas flow rates and compositions are measured by admitting a fairly large quantity of pure hydrogen into the flare line and performing the molecular composition and analysis of the flare gas at inlet and outlet [14]. Thus, the flare line is sampled 32 times over a 12-month period. Table II represents average values of mole fractions and physical properties of flare gas in the aforementioned refineries.

According to Table II, flare gas in three oil refineries contains noticeable amounts of propane and butane. Therefore, LPG production is a potential benefit and an acceptable option to mitigate emissions of hazardous pollutants. In addition, compression flare gas and injection into refinery fuel gas system before combustion could be considered as two alternatives instead of conventional flaring. It is worth mentioning that the most superior method to control flaring in each refinery is directly affected by composition of flare gas.

TABLE I
Flare Gas Composition (Mole Percent) in Three Oil Refineries [13]-[15]

Components	Tabriz	Tehran	Bandar Abbas
Methane	10	19.16	17.0
Ethane	30	9.24	3.3
Propane	2	12.56	4.5
i-Butane	5	3.74	1.5
n-Butane	5	5.86	1.5
i-Pentane	-	1.86	0.0
n-Pentane	-	1.1	0.4
n-Hexane	-	0.54	-
Oxygen	-	1.32	-
H_2S	5	2.82	0.7
CO_2	-	-	0.4
H_2O	-	0.04	-
Hydrogen	43	36.72	70
Nitrogen	-	5.04	0.7

TABLE II
Physical Properties of Flare Gas [14], [15]

Physical property	Tabriz	Tehran	Bandar Abbas
Vapour/phase fraction	1.0	1.0	1.00.0
Total Mass Flow (kg/hr)	630.0	1370.0	4391.0
Molar Flow (kgmole/hr)	31.7	59.4	450.0
Temperature (°C)	80.0	46.0	35.0
Pressure (kPa)	100.0	96.0	99.0

Pollutants from oil process plants discharged into the atmosphere include noticeable amounts of sulfur oxides which cause corrosion and turbulence in internal surfaces of the instruments. Therefore, in the present study, flare gas recovery units collect gas from the flare headers before reaching the stacks and send them to the individual gas sweetening plants to remove sulphur compounds and utilize them as feed stocks for both scenarios. According to the existing facilities in oil refineries of Iran, di ethanol amine (DEA) is used as an absorbent for sweetening the flare gas. The scope of this article does not involve determining a specific type of sweetening method, since it depends on available facilities in each oil production plant.

A. Liquefied Petroleum Gas (LPG)

In most oil refineries' flare gas, propane and butane constitute the notable percentage. On the other hand, LPG consists of two main commercial products, propane and butane, which are gaseous at ambient temperature and pressure and are determining components of LPG in summer and winter. Therefore, LPG production is an attractive way of utilizing oil refinery purge gas. The production and optimization of LPG are mainly discussed in chemical engineering and process control contexts [16].

Generally, it is important to note that, due to the high costs of columns and distillation towers, compared to annual income from LPG generation, designing an individual LPG unit does not have any economic justification in this scenario. Therefore, in this study, LPG production is simulated by utilizing LPG production plants already installed in the refineries. In this way, the total capital investment decreased considerably and the method of flaring management became more economical. Since the LPG plants in most oil refineries have an almost similar structure, Tehran refinery's LPG production unit is selected and simulated as a framework for simulation of LPG production scenario in two other case studies.

Three main sections of LPG generation scenario are illustrated in Fig. 1. The division involves compression of feed stock, condensation of heavy carbon fraction and separation of heavy fraction to produce LPG. In this investigation, before the flare gas is conducted to de-ethanizer column, the pressure and temperature are increased to 25 bar and 45 ℃ then the gas passes through a three-phase separator. Gas phase and liquid phase from three-phase separators enters into the de-ethanaizer and the de-boutanaizer respectively, for further processing of the light and heavy components. De-butanaizer's gaseous product enters to the de-propanizer where propane and butane are separated as the main products of LPG unit. Based on available results, 90 percent of propane and butane contained flare gas will be recovered in specific propane and butane mole fractions.

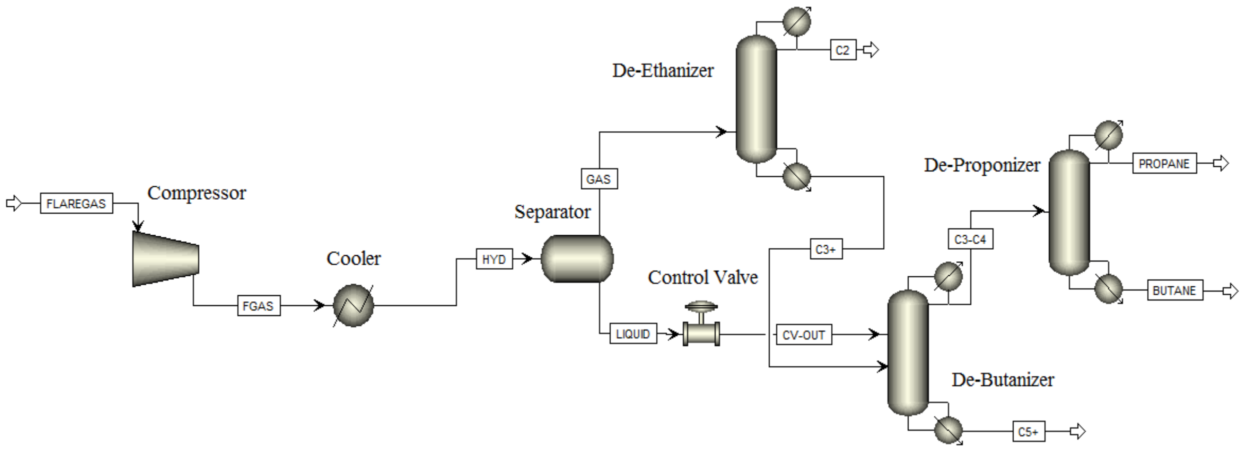

Fig. 1 The process flow diagram of LPG generation scenario

TABLE III
FLOW RATE OF C_3 AND C_4 IN THREE OIL REFINERIES [14], [15]

Refinery	Flare Gas Rate (kg/hr)	Mole Fraction	
		C_3 (%)	C_4 (%)
Tabriz	630	2.00	10.00
Tehran	1370	12.56	9.60
Bandar Abbas	4300	4.50	3.00

For LPG generation scenario, there are three crucial points that should be considered:

1. A common mistake involved in the simulation is injection of flare gas into the adsorption column. This results in flare gas being vented from column without any reaction. This occurs due to limited capacity of petroleum absorbent which is specified for a fixed volume of LPG unit feedstock.
2. A general concept that needs to be considered during modelling and simulation is assuming variable flow rate for composition of flare gas. This context is developed as sensitivity analysis.
3. As LPG plant in almost all oil refineries has an identical process, Tehran oil refinery’s LPG plant was set up as a framework to model LPG production for other flare gas streams in the other refineries.

B. *Fuel Gas*

Compression flare gas and injection into refineries fuel networks, is a conventional alternative to reduce flaring emissions. In this study, flare gas is utilized as an assistant fuel in furnaces, heaters or low pressure burners. Flare gas stream is separated through a branch between knock out drum and liquid seal and enters the flare gas recovery units. Flare gas enters the separator and compressor to increase the pressure and temperature of the gas stream to 3.8 bar and 37 °C (this condition is almost the minimum system requirement). Eventually, the sweet gaseous phase of recovered flare gas can be injected to fuel gas systems in the refineries. It is important to note that after cooling stage, the mole fraction of hydrogen sulphide declined dramatically to 0.01. Whereas the cost of an extra sweetening plant (reaching the mole fraction of hydrogen sulphide to zero) is not significant in contrast to compression and cooling steps, identifying the specific type of sweetening unit was not considered in this article.

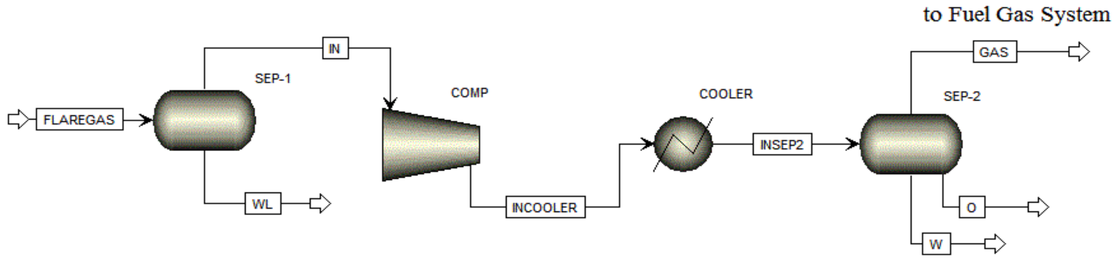

Fig. 2 The process flow diagram of fuel gas production from flare gas

III. Economic Assessment

Economic assessment in this study is based on Net Present Value (NPV) method. More details on this method are provided in [17]. For this purpose, calculated profit in each year is influenced by the interest rate and has been updated to the present value. Also, the market discount rate and the inflation rate are assumed to be 14% and 20%, respectively. Some important prices utilized in economic assessment are as follows

Electricity consumption cost: 0.12 $ $/Kwh$

LPG exportation cost: 828 $ / $tone$

The cost of fuel gas consumption in the refineries: 0.22 $/ Nm^3.

The cost of separation towers is calculated through the following formula [18]:

$$C = F_M C_b + C_a \quad (1)$$

$$C_b = 1.218 \exp[9.1 - 0.2889(\ln W) + 0.04576(\ln W)^2] \quad (2)$$

$$C_a = 300\, D^{0.7396} L^{0.7066} \quad (3)$$

The cost of other equipment, for instance compressors, pumps, etc. applied in this study was calculated according to the 17th reference which is a well-known reference for designing a new chemical plant.

The current expenditure for equipment is calculated from the cost baseline in varied references in year 2002 and 2003 [17].

$$current\ equipment\ expenditure = cost\ from\ baseline \times \left(\frac{present\ cost\ index}{cost\ index\ at\ baseline}\right) \quad (4)$$

The final cost of the products includes direct, fixed, overhead and general costs. Another parameter which needs to be considered in cost estimation is number of engineering and labouring resources that in this research is estimated by the following equation [19]:

$$N = \sqrt{6.29 + 0.23U} \quad (5)$$

where U is the number of pieces of equipment mounted in plant.

IV. Results and Discussion

In this study, the investment decision was made based on a comparison between two alternatives such as LPG production and fuel gas generation from flare gas. After simulating two aforementioned processes via the steady state process simulation software, an economic evaluation of each process is evaluated. The profitability of each process is analysed based on rate of return and total capital investment comparison.

Obviously, investigation into flaring involves some special complications because there are vast varieties in flare gas compositions during the life cycle of a factory. Therefore, it is necessary to consider sensitivity analysis in the studies related to flaring recovery and reduction methods. Hence, through sensitivity analysis, systems' behaviors would be predictable. Considering chemical composition in LPG production is influenced by concentration of propane and butane in feed stream. Furthermore, sensitivity analysis is based on total propane and butane mole fraction in flare gas.

The simulation results of LPG production rate based on the flare gas flow in case I, case II, and case III oil refineries are shown in Fig. 3. The results illustrate that increasing of propane and butane mole fraction in inlet flare gas stream raises LPG production flow rate, but there are some critical concentrations of total C_3 and C_4 within flare gas where LPG production rate has decreased for greater amounts of $C_3 + C_4$.

As earlier discussed, due to limited flow rate of flare gas in each refinery, designing and developing a separate and independent LPG unit is not applicable either economically or technically. In this study, flare gas is fed into the LPG unit as an extra feed without any modification on the LPG plant. Due to limited capacity of the LPG production unit in each refinery, LPG product rate has decreased beyond a specific concentration of $C_3 + C_4$. The critical points (total concentration of C_3 and C_4) for case I, case II, and case III refineries are 0.7, 0.6 and 0.7, respectively. Furthermore, cumulative profit in LPG production rate is increased with the capacity of the refineries.

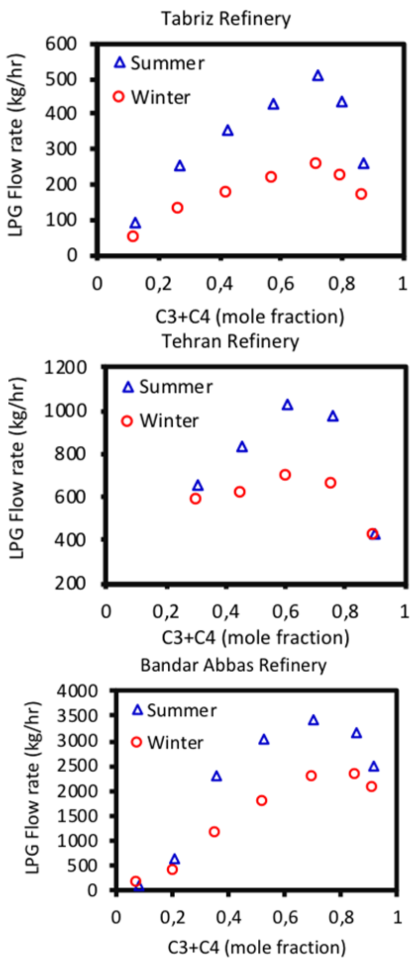

Fig. 3 LPG production rate from flare gas of Tabriz, Tehran and Bandar Abbas oil refineries

Time of investment return for LPG production scenario is shown in Fig. 4. As it is illustrated, there is a decreasing trend of return time by increasing production of LPG with a minimum time corresponding to the maximum amount of LPG flow rate. To better understand the LPG production rate, because of boiling point difference of C_3 and C_4 in summer and winter, a classification of product based on percentages of composition of C_3 and C_4 was done in each season. The LPG flow rate showed that production rate in winter is not as high as flow rate in summer. In winter, due to boiling point difference, a more significant amount of propane should be mixed with butane. The fractions of propane to butane are 60 to 40 and 20 to 70 percent in winter and summer, respectively. Contrary to the LPG flow rate in winter and summer, time of investment return varies in each season. This disparity comes from the propane and butane content of flare gas where each component could bring the limitations for LPG production rate in summer and winter.

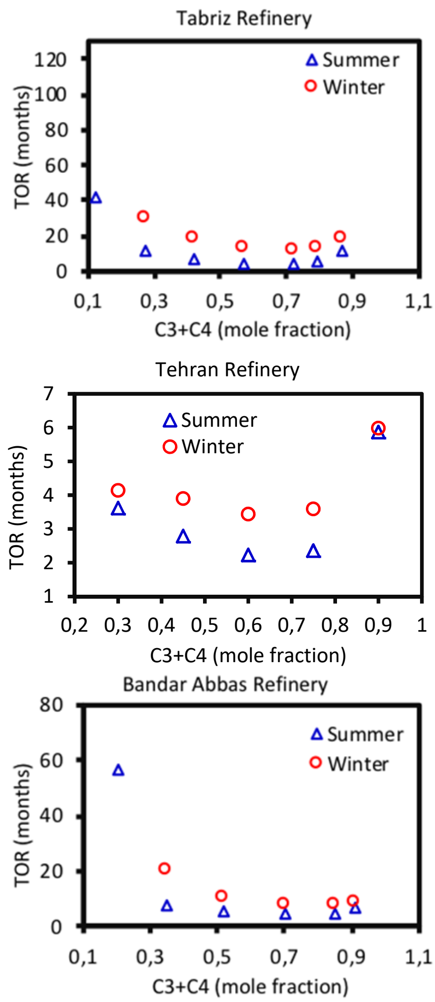

Fig. 4 Capital investment return time for LPG production scenario

Cumulative net profits for LPG production scenario in Tabriz, Tehran and Bandar Abbas oil refineries are presented in Fig. 5. The cumulative net profit is modelled during a 30-month period. Solid lines represent results in winter and the markers indicate cumulative profit in summer. Also, the numerical values in legends indicate total $C_3 + C_4$ content of inlet stream. Comparison of the results and outcomes from Fig. 3 and 4 shows that the cumulative profit during the summer period is higher than winter. At Tabriz and Bandar Abbas refineries, corresponding to some values of $C_3 + C_4$ concentration, the net profit is zero or even negative. Similar to the results in Fig. 3 and 4, cumulative profits are also maximum equivalent to the $C_3 + C_4$ content and has decreased for higher percentages of these components.

It is important to note that due to low flow rate of flare gas, designing an individual LPG unit is not an economical method to produce LPG. Because the costs of the columns are too high compared to the annual income from LPG production. Therefore, the rate of return on capital investment would have been too low. In this study, we considered LPG generation using a standardized LPG production plant located in Tehran refinery. This method results in decreasing the time of total capital investment noticeably and the method of flaring management will be more economic.

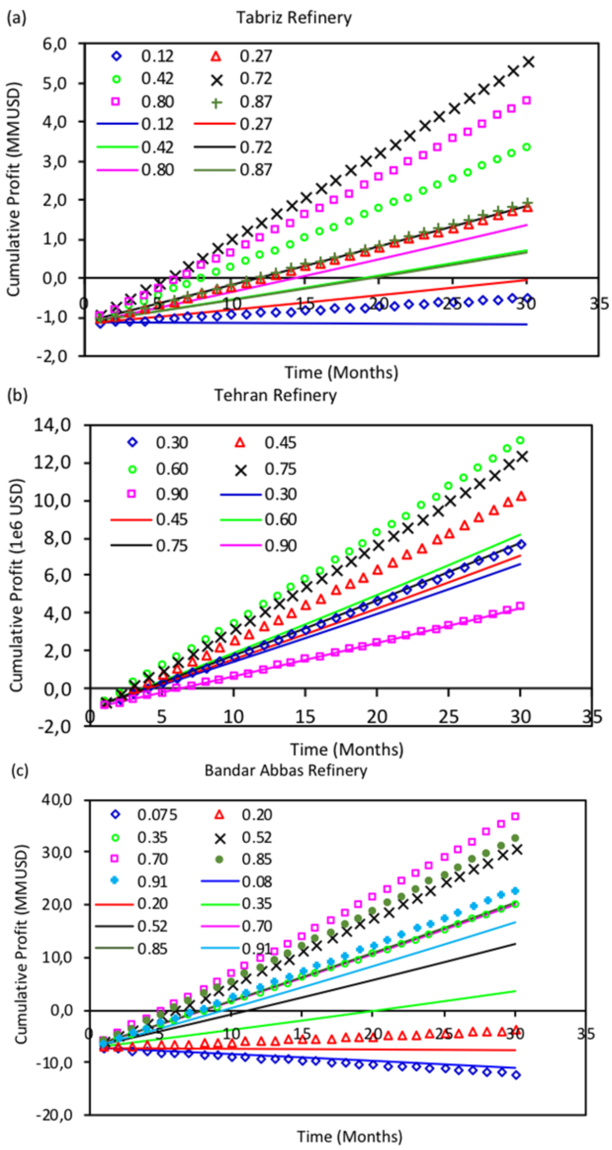

Fig. 5 Comparison of cumulative profit of LPG production in different seasons in each refinery; Solid lines represent results in winter and markers indicate cumulative profit in summer

The same analogy of cost estimation in LPG production scenario was applied to fuel gas generation from flare gas. Total cumulative profit in fuel gas option is shown in Fig. 6. A semi log plot is chosen to magnify differences in final cumulative profit comparison. As data illustrate, Tabriz refinery has the lowest cumulative profit due to small flare gas flow rate compared to the other refineries. Therefore, cumulative profit in fuel gas production scenario increases with the capacity of the refineries. In order to have a better comparison for different scenarios a unique period time is used in total cumulative cost calculations. The results of comparison for different options based on the (time of return) TOR and cumulative profit within 30-month system operation are shown in Table 4. These values are calculated based on the average composition of the flare gas components reported in Table II. The result indicates that fuel gas generation is the best scenario compared to LPG production for this composition of flare gas; however, other compositions with different C_3+C_4 contents require special consideration based on the available technology and equipment in each refinery.

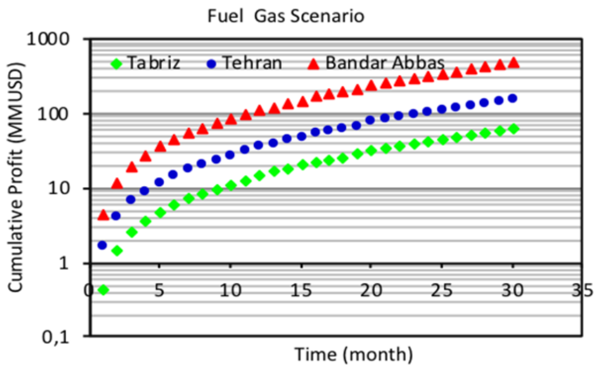

Fig. 6 Cumulative cost graphs in fuel gas scenario for a time period of 30 months

V. Conclusion

Flaring and venting of natural gas as one of the main sources of air contamination has hazardous effects on human health. It is generally recognized as a cause of energy loss worldwide. Although, there are many methods to control gas flaring in oil refineries, the main focus of this study was on recovering flare gas through the concept of two practical and economic methods at three oil refineries as the case studies.

In the proposed methods, flare gases are converted to the valuable products. The first option involves flare gas gathering, processing and converting it to a smokeless fuel which can be used in the fuel gas system of the refineries. The other scenario includes using the flare gas as a feed to the LPG production units set up in the refineries. The results show that the amount of LPG product will be increased and 90 percent of propane and butane in the flare gas will be recovered. It was found that there are the critical concentrations of total propane and butane percentage where maximum amount of LPG has been produced. These concentrations are 0.7, 0.6, and 0.7 for Tabriz, Tehran and Bandar Abbas oil refineries, respectively.

This scenario experienced the maximum cumulative profit in summer for three refineries. The comparisons of TOR and cumulative profit for the aforementioned scenarios demonstrated that fuel gas generation is the superior scenario for three case studies. However, selection and implementation between those options requires particular consideration on flare gas condition and available equipment. In case I and case II refineries, LPG production is more beneficial in summer than winter, while in case III, LPG production does not involve any economic justification.

TABLE IV
COMPARISON OF DIFFERENT SCENARIOS BASED ON THE TOR AND CUMULATIVE PROFIT

Product \ Refinery	Time of Return (Month)			Cumulative Profit (MMUSD)		
	Tabriz	Tehran	Bandar Abbas	Tabriz	Tehran	Bandar Abbas
LPG Summer	43.3	3.62	No Return	-0.47	7.71	-11.93
LPG Winter	No return	4.14	No Return	-1.18	6.59	-10.93
Fuel gas	6.51	3.13	5.08	66.3	160.7	496.6

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