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SIMULATION AND EVALUATION OF A FLARE GAS RECOVERY UNIT FOR REFINERIES

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ABSTRACT

Flare gas recovery systems are essential process units necessary for all oil and gas processing facilities, refineries inclusive, to put into good use the gas being wasted at the stacks by combustion causing environmental challenges. This paper focused on the design and simulation of a flare gas recovery unit for a typical conversion refinery, using ASPEN HYSYS process simulator version 8.6 for the process condition of a typical refinery in Nigeria. The design gave a throughput efficiency of 97.95% using a single liquid-ring-compressor to handle any flow upsurge up to 40% of the usual gas rate and saving $35,924.00 on equipment cost over the use of conventional reciprocating compressors. The product gas after amine treatment met the pipeline quality gas specification of 4ppm of H_2S*, 3mol% of* CO_2 *and was found suitable and capable of generating 8MW of electricity using a gas turbine. With a total capital cost of $26,767,050.89, and an operating cost of $2,139,483.54, the project yielded revenue of $9,419,920.00 from electricity sales at the industrial tariff class rate of ₦48.39 per kWh. The research proved viable with a payout or breakeven period of 4 years and 4 months, a net-present-value (NPV) of $ 35,555,817.46 after a project life of 20 years, and an internal rate of return of 17.10%. However, investment decisions are advised only when interest rates are below 34.6% and inflation rates higher than -6%.*

Key words: Flare gas, Refinery, Simulation, Analysis, Efficiency

INTRODUCTION

Gas flaring is a combustion process of burning-off associated gas from wells, refineries, hydrocarbon processing plants, chemical plants or coal industries, either as a safety measure to relieve pressure or as a means of gas disposal [1]. This practice contributes to the contamination of the environment with about 400 metric tons of CO_2per year all around the world [2].

The impact of gas flaring is of global and local concern. It earns the reputation of being the most challenging energy and environmental issue facing the world today, being an environmental catastrophe, a multi-billion dollar waste and a global energy problem which has persisted for decades, has earned the reputation of being the largest single loss in many industrial operations [3].

In petroleum-producing areas where insufficient investment is made in infrastructure to utilize natural gas, flaring is employed to dispose the associated gas. Reasons why the gases are subjected to such a process are either because they are waste or it is difficult to store and transport them. Non-waste gases are burnt off to protect the processing equipment when unexpected high pressure develops within them [4].

Off spec gases and flare gases are usually released during routine operation, depressurizing of unit for maintaining, malfunction of pressure safety valves (PSVs), valves and drains or controlling crisis. Therefore flare system is one of the most essential units at any refinery. Although flare system object is safety and security for personnel and equipment but it produces large amount of toxic gas like NOx and SOx, greenhouse gas like CO_2 and CO. Further large amount of energy wastes by burning gas at flare. Recently, in order to prevent energy loss at flare systems zero flaring projects have been developed to minimize flare gas flow rate. The first step of any flare gas recovery project is determination of flow rate, compositions and their sources [5].

The flare gas recovery system (FGRS) is designed to capture waste gases that would normally go to the flare system. This flare gas recovery system is located upstream of the flare to capture some or all of the waste gases before they are flared. There are many potential benefits of a flare gas recovery system. The flare gas may have a substantial heating value and could be used as a fuel within the plant to reduce the amount of purchased fuel. In certain applications, it may be possible to use the recovered flare gas as feedstock or product instead of purchased fuel. The flare gas recovery system reduces the continuous flare operation, which subsequently reduces the associated smoke, thermal radiation, noise and pollutant emissions associated with flaring [6].

The devastating effect of gas flaring which negatively affects the environment, human health and the economy is of a growing global concern and a lot of regulations are being placed upon this practice as a measure to reduce the menace of which one of it is the regulation by the Nigerian government to all operating companies in the country to cut down their gas flaring to zero by the year 2020. However, most of the attention is only channeled to reducing the flaring of gases at the production well heads while the flaring of gases at the refineries which contributes a good fraction to the total bulk flaring, is being overlooked. This project work seeks to develop the best way to curb the flaring of gases at the refineries by way of recovering the gases for utility purposes.

Also, with the current efforts by the Nigerian government to deregulate the downstream sector of the oil and gas activities, newer refineries have been encouraged to come on stream to support the supply of petroleum products in the country. However, the high concerns raised from the environmental impact of gas flaring activities during the course of these refineries' operations especially from the modular refineries which at the moment, have their acceptance being threatened if their flaring activities persists and are not being reduced.

The aim of this paper is to develop an efficient and a realistic template for the optimal recovery of flare gases and it's usage in a typical Nigerian refinery.

METHODOLOGY

Design Basis/Simulation Tool

The method of recovering flare gases adopted was using a liquid ring compressor for a large capacity or a refinery of higher complexity.

Both design models of the flare gas recovery system were modeled and simulated using the ASPEN HYSYS V8.6 software using Peng-Robinson property fluid package for the compression, storage and utility part of the simulation while the Acid-Gas property fluid package was used for the amine treatment simulation.

The Feed Stream Parameters

The feed stream for this study work is the gas expelled from the involving process units such as the crude distillation unit (CDU), vacuum distillation unit (VDU) and the fluid catalytic cracking unit (FCCU) of the refinery to the flare stack for combustion.

From the data obtained from a typical conversion refinery in Nigeria, which was designed to 150,000bpd capacity but operates an average of 90,000bpd throughput, the feed condition which is the steady condition to which the flare gas from the refinery is sent to the flare stack are stated in Table 1.

Table -1 Feed stream condition

Property	Value
Temperature	40^{o}C
Pressure	1.1 atm
Gas flow rate	5.7 m^3/h
Composition (mole fraction)	
Methane	0.8726
Ethane	0.0416
Propane	0.0190
n-Butane	0.0042
i-Butane	0.0025
n-Pentane	0.0012
i-Pentane	0.0016
n-Hexane	0.0008
Carbon dioxide (CO_2)	0.0202
Hydrogen Sulphide (H_2S)	0.0010
Nitrogen	0.0336
Water (H_2O)	0.0017

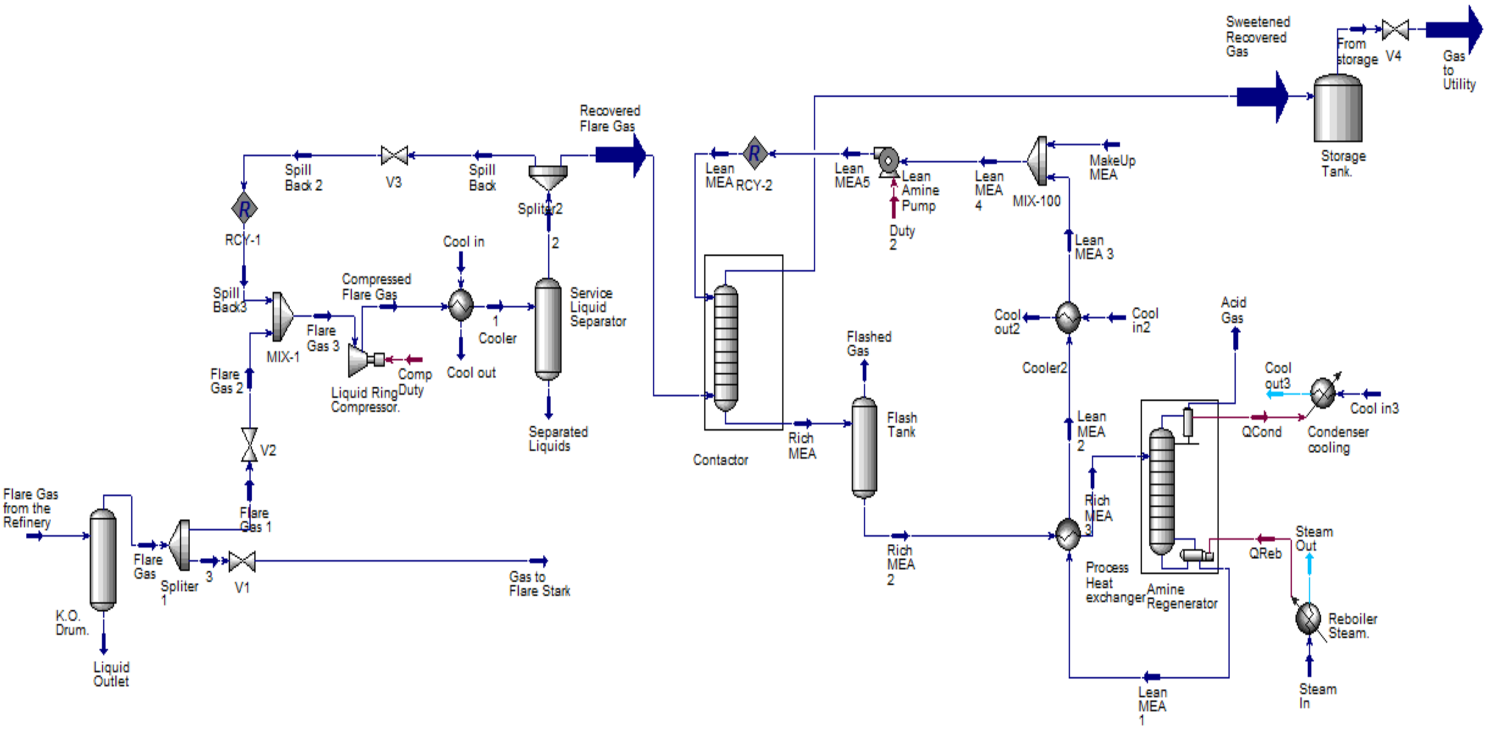

Fig. 1 The process flow diagram of the flare recovery by compression

Product Specification

The product which was the treated recovered flare gas from the compression method of recovery was simulated to meet the specification for pipeline quality gas as specified by Arthur and William [7] in Table 2.

Table -2 Specification for pipeline quality gas [7]

Component	**Minimum**	**Maximum**
Methane	75 mol %	None
Ethane	None	10 mol %
Propane	None	5 mol %
Butane	None	2 mol %
Pentane and heavier	None	0.5 mol %
Nitrogen and other inerts	None	3 mol %
Carbon dioxide	None	2-3 mol %
Hydrogen sulfide	None	0.3g/100scf
Water vapor	None	7 lb/MM scf
Oxygen	None	1.0 %

Economic Evaluation

The capital cost of the flare gas recovery system was calculated based on the bare module costing approach which is the commonest technique in estimating the cost of a new plant. The bare module cost C_{BM} for each equipment in the process was calculated using Equation 1 and added together to obtain the total estimate for the fixed capital cost.

$$C_{BM} = C_p^o \times F_{BM} = C_p^o(B_1 + B_2 F_M F_p) \tag{1}$$

Where F_{BM} is the bare module factor which accounts for direct and indirect costs, material of construction, and operating pressure associated with the equipment.

B_1 and B_2 are constants for the bare module cost taken from Turton *et al*., 2012 [8].

F_M is the material factor for each equipment

F_P is the pressure factor for each equipment

C_p^o is the purchased equipment cost calculated as:

$$\log_{10} C_p^o = K_1 + K_2 \log_{10}(A) + K_3[\log_{10}(A)]^2 \tag{2}$$

With A being the capacity measure for the given process equipment e.g. Volume in m^3, surface area in m^2 or duty in kW depending on the equipment.

While K_1, K_2, and K_3 are item specific constants for parameter fitting of the equation taken from [8].

Pressure factors F_p for process vessels are calculated using the equation

$$F_p = \frac{\frac{(P+1)D}{2(850-0.6(P+1))}+0.00315}{0.0063} \quad (3)$$

Where, P is the operating pressure and D is the vessel diameter

The costs of all equipment are updated from a historical data of each equipment cost using the equation.

$$C_{BM,2017} = C_{BM,2001}\left(\frac{I_{2017}}{I_{2001}}\right) \quad (4)$$

I_{2001} is the cost index when it is known as at the year 2001which is 397 according to Turton *et al.*, [8].

I_{2017} is the cost index as at the desired year 2017 according to the Chemical Engineering Plant Cost Index [9] and its 562.1.

Evaluation

This paper was evaluated using the key economic indicators which included the payback period, Net Present Value (NPV), the Internal Rate of Return (IRR), a Discounted Cash Flow Analysis (DCFA), the break even analysis, straight line depreciation model and sensitivity analysis of varying the interest rates and also varying the inflation factor upon profitability of the project.

RESULTS AND DISCUSIONS

Mass and Energy Balances

Material and energy accounting for the processes were conducted to check that conservation is maintained in the simulation undertaken.

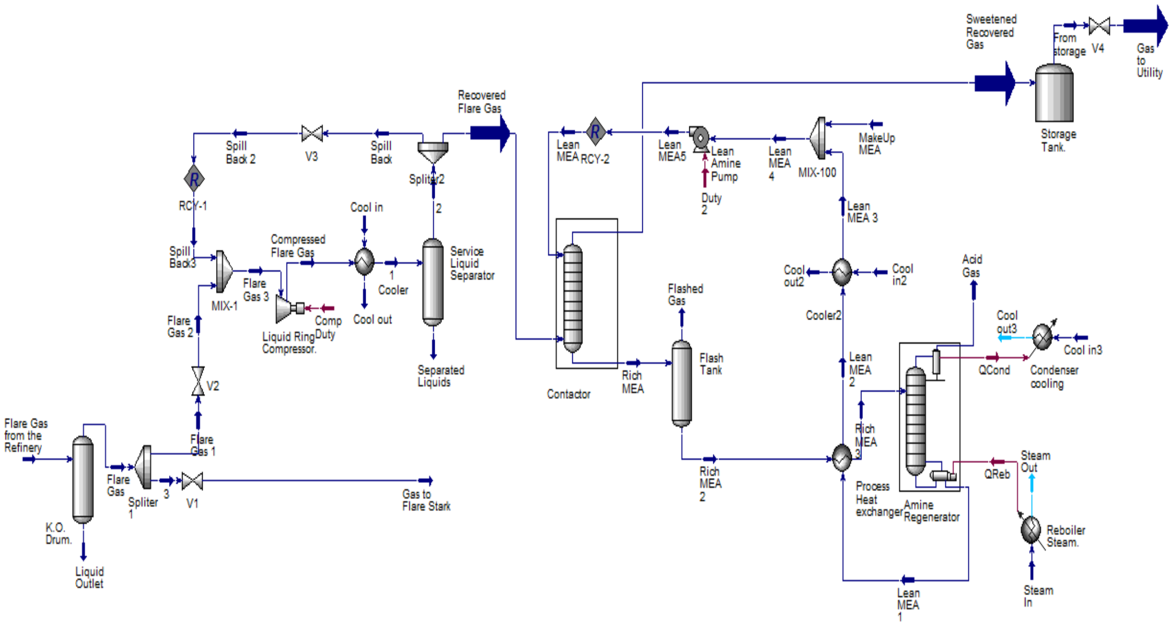

Fig. 3 Process flow diagram of the simulated flare gas recovery unit

Mass balance of the process

Table -3 Overall mass balance of the process

Mass inflow		Mass outflow	
Stream	**Mass flow** (kg/hr)	**Stream**	**Mass flow** (kg/hr)
Flare gas from the refinery	1920.00	Liquid outlet	0
Makeup MEA	21.0873	Gas to flare stack	0
		Separated liquids	0
		Flashed Gas	0.6173
		Acid Gas	98.47
		Gas to Utility	1842.00
Total	**1941.0873**	**Total**	**1941.0873**

$$Imbalance = Total\ mass\ in - Total\ mass\ out \quad (5)$$

$$Imbalance = 1941.0873 - 1941.0873 = 0$$

$$\% \, Error = \left(\frac{Imbalance}{total \;\; mass \;\; in}\right) \times 100\% = 0\% \tag{6}$$

With the mass inflow being equal to the mass outlet giving a difference of zero and also a percentage error of zero, confirms that material is excellently conserved in the system from the results of the simulation, thus revealing a coherent plant design with materials well accounted for.

Energy Balance

Table -4 Overall energy balance of the process

Heat inflow		**Heat outflow**	
Stream	**Heat flow (kJ/h)**	**Stream**	**Heat flow (kJ/h)**
Flare Gas from the Refinery	-8250060.54	Liquid Outlet	0.00
Comp Duty	770559.40	Separated Liquids	-0.00
Duty 2	13502.04	Gas to Flare Stark	0.00
MakeUp MEA	-769313.46	Flashed Gas	-3058.33
Steam In	-393270368.85	Gas to Utility	-7853587.42
Cool in	-474396583.13	Acid Gas	-862489.76
Cool in2	-332079497.37	Steam Out	-20393270368.85
Cool in3	-474399281.96	Cool out	-473595885.56
		Cool out2	-329238734.82
		Cool out3	19516295635.68
Total energy inflow	**-1682381043.88**	**Total energy outflow**	**-1688528489.06**

$$Imbalance = Total \; energy \; inflow - Total \; energy \; outflow$$

$$Imbalance = (-1682381043.88) - (-1688528489.06) = -6147445.18$$

$$\% \, Error = \left(\frac{Imbalance}{total \; energy \; inflow}\right) \times 100\% = 0.37\%$$

From the result of the energy balance, the plant design was further confirmed of its coherency with the very low percentage error in the energy accounting.

Product Specification

Table -5 The product stream properties

Property	**Value**	
Temperature	60^{o}C	
Pressure	5.2 atm	
Gas flow rate	5.585 m^3/h	
Component composition of the product stream		
Component	**Mass composition**	**Mole composition**
Methane	0.782349	0.873524
Ethane	0.069909	0.041645
Propane	0.046828	0.019022
n-Butane	0.013646	0.004205
i-Butane	0.008123	0.002503
n-Pentane	0.000000	0.000000
i-Pentane	0.000000	0.000000
n-Hexane	0.000000	0.000000
CO	0.000000	0.000000
CO_2	0.000437	0.000178
H_2S	0.000002	0.000001
Oxygen	0.000000	0.000000
Nitrogen	0.052613	0.033643
H_2O	0.025144	0.025001
MEAmine	0.000947	0.000278
Total	**1.000000**	**1.000000**

From the results of the product stream specification, the output temperature of 60^{o}C comes within the storage temperature of the gas.

The pressure of 5.2atm is a good compression pressure for the natural gas storage which allows for a compression of up to 3.155 times the volume of the uncompressed gas thereby saving a storage volume space of68.31%.

The throughput efficiency of the plant calculated from the gas flow rate is:

$$Throughput\ Efficiency = \frac{Discharge\ \ gas\ flowrate}{Feed\ \ gas\ flowrate} \times 100\% \quad (7)$$

$$= \frac{5.583m^3/h}{5.700m^3/h} \times 100\%$$

=97.95%

This is a very high and excellent plant efficiency which reveals effectiveness of the process indicating that the small percentage (2.05%) unaccounted for at the discharge line, mostly constituted of the unwanted gases (H_2S and CO_2) removed from the natural gas at the absorption column using amine solution. However, a 0.0947masspercentage carry-over of amine follows the discharge gas which is a very negligible percentage.

The composition of this product reveals that the appropriate specification of a pipeline quality gas was met as required by Arthur and William [7] shown in Table 2. The hydrogen sulfite composition of the discharge gas was 2ppm which is lower than the maximum acceptable limit of 4ppm. Carbon dioxide is 0.02 mol% which is also lower than the 3mol% limit. This confirms a high quality of the discharge gas as regards environmental and equipment safety regulations.

Revenue Estimation

For the proposed project the revenue comes from the utilization or the sale of the product which is the discharge gas.

Several literatures [10-12] have performed various studies on the most economically effective way to utilize recovered flared gas from various refineries and have recommended that electricity generation is the best among the options. In the light of this, the recommendation of utilizing the recovered flare gas for electricity generation is taken into consideration for this very project and evaluated accordingly.

With a charge rate of 0.5117 kg/s, this FGRS best fits to serve a gas turbine capable of generating 8MW of electricity and the recommended is a Siemens® Gas Turbine model version SGT-300. The correlation of the selection of this gas turbine model was derived from (www.siemens.com/gasturbines, [13]).

With the electricity charge rate of ₦48.39 per kWh for industrial tariff class [14], the project yields ₦387,120 each hour or₦9,290,880.00each day or₦3,391,171,200.00 each year converted to $9,419,920.00 yearly at the conversion rate of ₦360/$ (www.abokifx.com, [15]).

Project Evaluation

Table -6 Simple payback estimation

Capital cost investment	$ 26,767,050.89
Revenue/ year	$9,419,920.00
Operating cost	$ 2,139,483.54
Annual savings	$7,280,436.46
Payback period	3.68 years

From the result of the simple pay-back period, it can be deduced that the project is capable of paying back the invested capital after 3 years and 8months of the production commencement. This proves the viability of the project as it comes within the interval of 2-5 years suggested by Towler & Sinnott [16] for most typical viable process plants.

The Project Cash Flow Projection

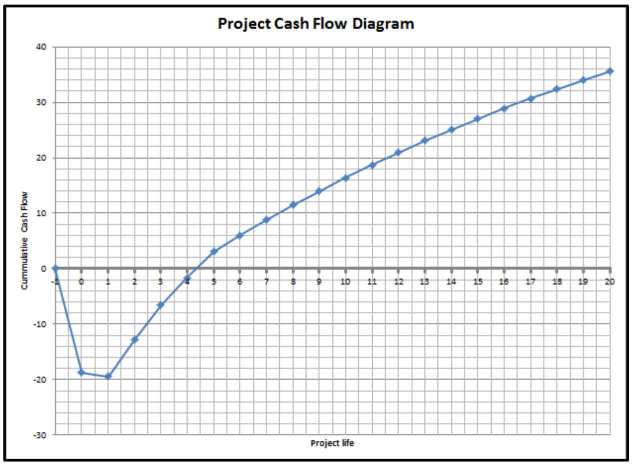

Fig. 4 The cash flow projection

From the discounted cash flow projection of the project produced on excel, the cumulative net present value (NPV) after 20 years project life was calculated as $ 35,555,817.46

This as an economic indicator proves that this project is viable as positive values of NPV reveal profitability and the farther the value is from zero, the more the profitability of the project during the project period. The Internal Rate of Return (IRR) was calculated and found to be 17.10% from the prepared spreadsheet. This is an acceptable value as an economic indicator because it is found to be greater than the 15% adopted as the interest rate for the project.

Sensitivity Analysis

From the sensitivity analysis result of varying interest rates on a constant inflation rate of 10%, the project reveals a high profitability at the lower interest rate of 1% but progressively decreases in profitability with increasing interest rates. From the interest rates of 34.6% and above, the venture proves to be non-profitable in the long run. Therefore, it is advised to only invest into the project from the interest rates of lower than 34.6%.

The result of varying inflation rate on a constant interest rate of 15%, the project reveals profitability at all the positive inflation rates with higher profitability at the higher inflation rates. However, it is not advisable to invest on the project from inflation rates of lower than -6%.

CONCLUSION

The flare gas recovery unit design minimum gas flow rate of about 5.7m^3/h of flare gas from the CDU, VDU and FCCU to the flare stack for combustion. From a typical refinery in Nigeria was simulated using ASPEN HYSYS process simulator version 8.6 .following the stated methodology and using the equipment specifications to best match the available process condition and feed rate, The design gave a throughput efficiency of 97.95% as only a minimal amount of material was lost during the process.

The proposed flare gas recovery system proved to be an economically viable venture from the positive results of the economic indicators considered to rate this project. A payout or breakeven period of 4 years 4 months, a net-present-value (NPV) of $ 35,555,817.46 after a project life of 20 years, and an internal rate of return of 17.10%. However, investment decisions are advised only when interest rates are below 34.6% and inflation rates higher than -6%.

REFERENCES

[1]. Ghadyanlou, F. and Vatani, A., (2015). Chemical Engineering, Essentials for the CPI Professional.

[2]. Abdulrahman, A.O.; Huisingh, D.; Hafkamp, W. (2015). *Journal of Cleaner Production*, 98, 116-122.

[3]. Ismail, O. S., & Umukoro, G. E. (2012). Global Impact of Gas Flaring. Energy and Power Engineering, 4, 290-302.

[4]. Ayoola, T. J. (2011). Gas flaring and its Implication for Environmental Accounting in Nigeria. *Journal of Sustainable Development*, 244-250.

[5]. Feizi, Y (2012). Considerations for Flare Gas Recovery Design in Khangiran Gas Treating Plant.

[6]. Sangsaraki, E.M and Anajafi E (2015):’’ Design Criteria and Simulation of flare gas recovery system’’. International Conference on Chemical Food and Environmental Engineering (ICCFEE15) Dubai (UAE).

[7]. Arthur, J. K., William, R. P. (2006). Fundamentals of Natural Gas Processing. CRC Press.

[8]. Turton R., Bailie R., Whiting W., Shaeiwitz J., Bhattacharyya D., (2012). Analysis, Synthesis and Design of Chemical Processes. 4th edition Prentice Hall.

[9]. Chemical Engineering Plant Cost Index (CEPCI, 2017).

[10]. Mohabbat Z., Vahid P., Hossein S. (2017). Technical characterization and economic evaluation of recovery of flare gas in various gas-processing plants. *Energy.* Iran.

[11]. Eman, A. (2016). Gas Flaring Reduction: Perspective Environmental and Economical. *IJSRSET* | Volume 2.

[12]. Rahimpour M. R. and Jokar S.M. (2016). Feasibility of flare gas reformation to practical energy in Farashband gas refinery: No gas flaring. *Journal of Hazardous Materials.* 209–210

[13]. www.siemens.com/gasturbines, 2017, assessed 05-10-2017.

[14]. www.nercng.org assessed 05-10-2017.

[15]. www.abokifx.com assessed 05-10-2017

[16]. Towler G, and Sinnott R (2008): ‘’ Chemical Engineering Design’’, Butterworth-Heinemann, London.