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Gas Flaring Reduction: Perspective Environmental and Economical

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ABSTRACT

Flaring expresses the process of safe disposal of associated or waste gas by burning in many processes. The World Bank estimates that the amount of flared gas annually equivalent to the annual gas consumption of Germany and France, twice the gas consumption of Africa annually, 75 % of the Russian gas export, or sufficient to provide the entire world with gas for 20 days. Other pollutants during gas flaring are emitted to the atmosphere such as CO_2, CO and NO_x. Also, flaring generates noise, heat and provided large areas uninhabitable. According to environmental and economic considerations flaring reduction becomes a crucial issue. The reduction can be occur by minimize or recover the wasted energy and reduce the greenhouse gases emissions. This paper is a review of the flaring reduction by reporting the different methods of flare gas recovery systems used in the industry to improve environmental performance by reducing emissions and save the energy.

Keywords: Greenhouse Gas Emissions, Flare Gas Recovery Systems, Electricity Generation, Gas to Liquid Conversion, Gas Collection and Compression

I. INTRODUCTION

Gas flaring is now recognized as a major environmental problem. The World Bank estimates that between 150 to 170 billion m^3 of gas is flared or vented annually [1-3]. This amount is equivalent to the annual gas consumption of Germany and France, or twice the gas consumption of Africa annually [4]. It is also equivalent to 75 % of the Russian gas export, or sufficient to supply the entire world with gas for 20 days [4]. This flaring is geographically concentrated in a small number of countries contribute the most to global flaring emissions. At the end of 2011, 10 countries accounted for 72 % of emissions, and twenty for 86 % [5]. The largest flaring operations occur in the Niger Delta region of Nigeria [4]. In 2012 Russia and Nigeria accounted for about 40 % of global flaring [6]. Gas flaring contaminating the environment with about 400 Mt-CO_2 annually [1,2]. The EPA estimates that the cost of compliance will rise to \$ 754 million/year by 2015 for gas wells alone [7].

Definition of gas flaring according to Canadian Association of Petroleum Producers is the controlled burning of natural gas that cannot be processed for sale or use because of technical or economic considerations [8]. Flaring are considered the single largest loss in many industrial operations, such as oil-gas production, refinery, chemical plants, natural gas processing plants, coal industry and landfills. Wastes or losses to the flare include process gases, fuel gas, steam, nitrogen and natural gas. A flare is normally visible and generates noise and heat. The low quality gas composition that is flared releases many impurities and toxic particles into the atmosphere during the flaring process. Burning of gas flaring produces combustion by-products such as CO_2, CO and NO_x that are emitted to the atmosphere. Acidic rain, caused by sulfur oxides in the atmosphere, is one of the main environmental hazards which also results from this process [9].

Greenhouse gases (GHG) such as CO_2 and CH_4, when emitted directly into the air, traps heat in the atmosphere, resulting in raised temperatures and rendered large areas uninhabitable. For example, about 45.8 billion kW of heat into atmosphere of Niger Delta from flared gas daily released [10]. CO_2 emissions from flaring have high global warming potential and contribute to climate change. About 75 % of the CO_2 emissions come from the combustion of fossil fuels [11]. CH_4 is actually more harmful and has about 25 times greater global warming potential than CO_2 on a mass basis [12,13]. It is also more prevalent in flares that burn at lower efficiency [10]. Therefore, there are concerns about CH_4 and other volatile organic compounds from oil and gas operations.

Other emissions also discharged from flaring such as sulfur oxides (SO_x), nitrogen oxides (NO_x) and volatile organic components (VOC) [11,14-16]. It was concluded that the emissions between 2.5 to 55 tons/day of total organic compounds, and 6 to 55 tons/day SO_x from a number of oil refinery flare processes in the Bay Area Management District (California-US) [16]. Therefore, flare emissions may be a significant percentage of overall VOC and sulfur dioxide emissions.

A smoking flare may be a significant contributor to overall particulate emissions [17]. Because the most flare gas normally has not been treated or cleaned, pose demanding service applications where there is a potential for condensation, fouling (e.g., due to the build-up of paraffin wax and asphaltine deposits), corrosion (e.g., due to the presence of H_2S, moisture, or some air) and possibly abrasion (e.g., due to the presence of debris, dust and corrosion products in the piping and high flow velocities) [18].

Gas flaring is one of the most challenging energy and environmental problems facing the world today. Environmental consequences associated with gas flaring have a considerable impact on local populations, often resulting in severe health issues. From an economic perspective, gas flaring is a dissipation of non-renewable natural resources since the flared gas has energy content (calorific value) that is wasted without use as soon as the gases are combusted at the flare [19]. The technology to address the problem of gas flaring exists today and the policy regulations required are largely understood. Reducing flaring and increasing the utilization of fuel gas is a concrete contribution to energy efficiency and climate change mitigation [20]. Additionally, flare gas recovery systems (FGRS) reduce noise and thermal radiation, operating and maintenance costs, air pollution and gas emission and reduces fuel gas and steam consumption. Thus, a reduction or minimize the amount of gas flaring is a crucial issue according to environmental and economic considerations [14, 21]. The purpose of this paper is to create an overview on the different methods of flare gas recovery systems according to the environmental and economic considerations.

II. METHODS AND MATERIAL

A. Flaring Reducing and Recovery

Nowadays world is facing global warming as one of its main issues. This problem can be caused by a rise in CO_2, CH_4 and other GHG emissions in the atmosphere. On the other hand, the flared gas is very similar in composition to natural gas and is a cleaner source of energy than other commercial fossil fuels [1]. Because of the increasing gas prices since 2005 and growing concerns about the scarcity of oil and gas resources the interest in flare gas has increased and the amounts of wasted gas have been considered. For example, the amounts of flared gas could potentially supply 50 % of Africa`s electricity needs [1]. Thus saving energy and reducing emissions are become the worldwide requirement for every country.

In recent years, there has been an international direction to reduce gas flaring and venting through the World Bank global gas flaring reduction (GGFR) partnership and the global methane initiative [12]. Several countries are now signatories on the GGFR partnership's voluntary standard for flare and vent reduction [22], and both the GGFR partnership and GMI actively promote demonstration projects to reduce flaring and venting [12]. Other regulations can be used to reduce flaring such as direct regulation include Norway, where there is an enforced policy of zero flaring [23] and North Dakota in the U.S., where oil producers will be required to meet gas capture targets or face having their oil production rates capped [24]. Additionally, the United Nations' Clean Development Mechanism by offering 'Certified Emissions reductions' provides flaring and venting reduction projects [25].

Several steps may be help to reduce the flared gas losses such as: proper operation and maintenance of flares systems, modifying start-up and shut-down procedures. Also, eliminating leaking valves, efficient use of fuel gases required for proper operation of the flare and better control of steam to achieve smokeless burning all contribute to reducing flare losses. Recovery methods may also use to minimize environmental and economic disadvantages of burning flare gas. In recent years, several technologies in flare tip design offers the greatest reduction in flare loss [21]. Even in most advanced countries only a decade has passed from FGRS, thus FGRS is a new methods for application in processes wastes. USA, Italy, the Netherlands and Switzerland are the active countries in flare gas recovery. Most FGRS has been installed based primarily on economics, where the payback on the equipment was short enough to justify the capital cost. Such systems were sized to collect most, but not all, of the waste gases. The transient spikes of high gas flows are typically very infrequent, meaning normally it is not economically justified to collect the highest flows of waste gas because they are so sporadic. However, there is increasing interest in reducing flaring not based on only economics, but also on environmental stewardship [19]. There is a range of alternatives methods of FGRS, it is summarized as the followings [9,11,15,18,26]:

1. Collection, compression and injection/reinjection
   - into oil fields for enhanced oil recovery;
   - into wet gas fields for maximal recovery of liquids;
   - into of gas through an aquifer;
   - into the refinery pipelines;
   - collection and delivery to a nearby gas-gathering system;
   - shipping the collected gas to treatment plants before subsequent use;
   - using as an onsite fuel source;
   - using as a feedstock for petrochemicals production;
2. Gas-to-liquid
   - converting to liquefied petroleum gas (LPG);
   - converting to liquefied natural gas (LNG);
   - converting to chemicals and fuels;
3. Generating electricity
   - Burning flared gas in incinerators and recovering exhaust heat for further use (generation and co-generation of steam and electricity).
   - The methods for FGRS can be also classified as the following general categories [14]:
   - Physical: The gases are recovered and purified by special equipment and pressurized (if required) for process units to be used as fuel or feedstock;
   - Chemical: The flare gases are reacted over a catalyst and converted into industrial materials that can be recovered;
   - Biochemical: This newest method of recovery is performed using bacteria that carry out degradation reactions in the towers, thereby converting the flare gases into simpler components.

In order to select the best method for FGRS, operators must have a good understanding of how the flare gases are produced, distributed and best consumed at the production facility. FGRS have been also impeded by a number of technical challenges [19], such as a combination of highly variable flow rates and composition, low heating value and low pressure of the waste gases [2,14]. In the case of very large volumes of associated flared gas, gas-to-liquid (GTL) conversion this gas into more valuable and more easily transported liquid fuels, or production of liquefied natural gas (LNG) to facilitate transport to distant markets, are potential options [27]. Both GTL and LNG options require enormous capital investments of infrastructure and must process very large volumes of gas to be economic [12]. However, reinjection has been successfully used at several sites to dispose of residual “acid-gas” (primarily H_2S and CO_2 with traces of hydrocarbons) from gas sweetening plants where the costs of reinjection are less than the costs of sulphur removal [28]. The use of associated gas to generate electricity for on-site use is a demonstrated option, but this approach is not always economic and can be limited by the on-site demand for electricity [29]. By contrast, the collection and compression of gas into pipelines for processing and sale is a well-established and proven approach to mitigating flaring and venting [12]. Generally, decision of flaring or processing of gas depends on gas prices. Flare gas would be processed and sold if prices would remain high enough for a long period, and all required infrastructure could be built for gas processing and transportation [1]. Rahimpour and Jokar [15] compared three methods for FGRS of Farashband gas processing plant in Iran. These methods are GTL production, electricity generation with a gas turbine and compression and injection of flared gas into the refinery pipelines. The results show that the electricity production gives the highest rate of return, the lowest payback period, the highest annual profit and mild capital investment. Hence, the electricity production is the superior method economically [15].

With increasing awareness of the environmental impact and the ratification of the Kyoto protocol by most of the member countries, it is expected that gas flaring will not be allowed in the near future [30]. This will require significant changes in the current practices of oil-gas production and processing [31]. As reported by the World Bank (2005), economic viability of FGRS projects are constrained in many countries mainly due to high project development costs, lack of funding and lack of distribution infrastructure [32]. In Norway, several concepts and technologies of FGRS have been proven and extensively applied in offshore oil-gas production fields [33]. For example, flare gas is pumped back down into the reservoir, to maintain the pressure and flow rate of the oil being produced in the Oseberg field in Norway [1]. By using the associated gas in the production, they are able to recover much higher percentage of oil than if they were to simply inject water for example [34]. Qatargas company has made significant progress flaring from its LNG trains in line with the increased national focus on flare minimization and the company`s desire to reduce its emissions and carbon footprint [35]. Enhanced acid gas recovery and operational excellence initiatives on source reduction and plant reliability at Qatargas` older, conventional LNG trains have successfully reduced flaring by more than 70 % between 2004 and 2011 [35].

In Nigeria several efforts have been made to reduce gas flaring, including the establishment of a LNG plant, a pipeline to transport gas to some neighboring countries, and legislative measures to regulate the oil and gas industry [36]. According to Al-Blaies, Nigeria flared a total of 15.2 billion m^3 of gas in 2010, the second largest in the world [37]. When compared with the quantity of flared gas in 2005 there is about 29 % decrease in gas flaring in Nigeria, mainly due to the implementation of some FGRS [36,37]. Even then, the quantity of flared gas in Nigeria is still substantive and as at 2010, the country remains one of the worst offenders when it comes to natural gas flaring, after to Russia [36]. Since 2000**,** *Shell Petroleum Development Company* (SPDC) of Nigeria began an ongoing multiyear program to install equipment to capture gas from its facilities. In total SPDC flaring dropped by more than 60 % between 2002 and 2011 from over 0.6 BCF/d to about 0.2 BCF/d, and flaring intensity reduced in the same period from about 0.8 MSCFD/bbl to 0.45 MSCFD/bbl [38].

Tengizchevroil (TCO) executed with excellence multiple capital projects to reduce flaring [39]. TCO has invested $ 2.8 billion on environmental programs over the last 14 years. Since 2000, TCO has reduced flaring volume by more than 93 %. At the same time, TCO has achieved a 99 % gas utilization rate and increased its oil production volumes by 158 % [40].

B. FGRS by Collection and Compression

Gas flaring collection and compression for transport in pipelines or other ways for processing and sale is a well-established and proven approach to mitigating flaring and venting. Several projects have included the collection of associated gases during recent years in Iran [41]. In 2008 in Alberta [42], about 72 % from 9.72 billion m^3 of associated gas produced during oil and heavy oil production was captured and sold into pipelines. An additional 21 % was used as onsite fuel (e.g. for process heaters or to drive natural gas fired compressors). The remaining percentage of gas at upstream oil and heavy oil sites (0.69 billion m^3) was flared or vented [42].

Tahouni et. al., [43] integrated flared gas stream to the fuel gas network with waste and fuel gas streams in the refinery case study. A fuel gas network collects fuel gases from various source streams and mixes them in an optimal manner, and supplies them to different fuel sinks such as furnaces, boilers, turbines, etc. They concluded that by utilizing flared gas stream to the network, the optimal fuel gas network can reduce energy costs and flaring emissions.

Environmental and economic considerations have increased the use of FGRS to recover or reduce flared gases for other uses. By using recent technology in this field, a gas compression and recovery system (FGRS) can be used to reduce the volume of flared gases. Figure 1 shows a general view of a FGRS [44]. To recover flare gas using FGRS, after collecting from flare header, it is diverted to the FGRS downstream of the knockout drum by a liquid seal vessel and passes through a compressor. The compressed gas is then discharged into a mixed phase separator. The liquid-phase is pumped through a heat exchanger and back to the service liquid inlet on the compressor. The compressed gas is separated from the liquid and is piped to the plant fuel gas header, or other appropriate location. The compressor recycle valve is regulated with control signals based on the inlet flare gas pressure. This ensures that the flare header is under positive pressure at all times. In the event that the flow capacity of the FGRS is exceeded, the liquid seal vessel will allow the excess waste gas to go to the flare where it is safely burned [21]. Based on refinery structure or related unit, the compressed gases used as a feed or fuel. If required, to reach entrance gas temperature to FGRS and external gas temperature from this unit to an optional temperature, heat exchangers are used.

The compressor design is the main part of the FGRS. Proper selection of the type of compressor for each application is very important. Several compression technologies are available for FGRS. The most proper compressor for FGRS depends on many factors such as initial cost, process requirements, physical size, efficiency, operating and maintenance requirements [9,45]. Over the last 35 years various companies have used several compressor types including dry screw compressors (DSC), sliding vane compressors (SVC), reciprocating compressors (RC), liquid ring compressors (LRC) and oil injected (or oil flooded) screw compressors (FSC) both single and dual screw designs [30]. In general, LRC or RC are used to compress gases and to design FGRS. Advantage of LRC is that gas is cooled during compression by heat transfer of gas through water inside compressor (usually water). It is possible to use amine instead of water in such compressor to separate H_2S from flare gases [19]. Additionally, LRC are used because the design of the compressor can process two-phase flow that commonly exists in flare headers [21,45]. RC are purchased easily than LRC, also spare parts provision, repair and maintenance is much easier. If using RC, but it will explode if temperature exceeds over allowable limit [30,45].

FGRS are seldom sized for emergency flare loads. FGRS often are installed to comply with local regulatory limits on flare operation and, therefore, must be sized to conform to any such limits. The normal flare loads vary widely depending on refinery throughput and operating mode. To enable recovery of over 90 % of the total annual flare load and keep flaring to a practical minimum, the compression facilities should be designed to handle about 2 to 3 times the average normal flare load. Other plants, such as chemical plants, may have lower normal variation in flare rates [30]. For this reason, the installations may be sized for a lower flow range.

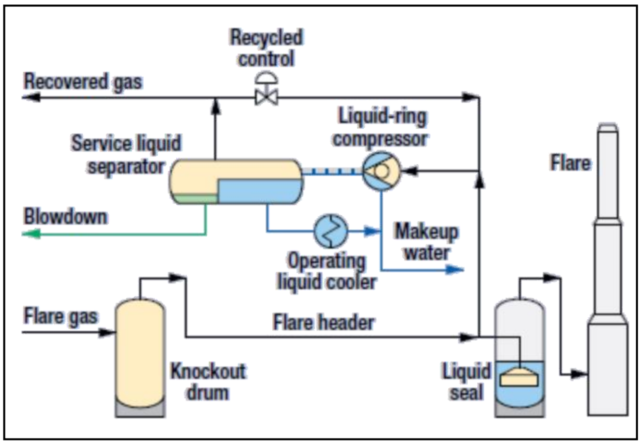

Figure 1 : A view of a flare gas recovery system [44].

The composition of the flare gas is the strongest influence parameters on the FGRS. In general, changes in molecular weight in the stream going to the FGRS can generate the potential for overloading the compressor, leading to possible damage and a large increase in the specific heat ratio. Molecular weight changes can also increase the discharge temperature of the gas after compression [14]. Generally, the compressor performance can be achieved if the variation in the gas composition remains within the ranges specified in the data-sheet [46]. The following three compositions have the most notable influence [14]:

1. The effect of gases such as N_2, H_2 and light gas on heat exchangers and compressor performance.
2. The effect of steam on the separation drum, compressor and membranes.
3. The effect of inlet gas temperature to the compressor must also be controlled. If the compressor inlet temperature is higher than the design temperature, the gas must be discharged to the flare. It should be pointed out that the capacity of the FGRS is a function of the capacity of the compressor system that is used.

The FGRS significantly reduced the GHG emissions from the different industries and the harmful impacts normally associated with flaring. Duck [21] reported that about 60 MMBTU/hr of flare gas was recovered by using FGRS in oil refining plant in Dushanzi-China. The FGRS contain the LRC is a skid-mounted packaged system located downstream of the knockout drum since all the flare gases are available at this single point**.** The results of using FGRS showed that, the plant prevented 32.5, 176.8 and 67,000 metric tons per year of NO_x, CO and CO_2 from being emitted to the atmosphere, respectively. Additionally, thermal radiation from the flames was significantly reduced which resulted in an increase in overall safety of the plant. Light and noise were also significantly reduced. Furthermore, installation of the FGRS allows substantial cost savings because the recovered gases can be used as fuel or process feedstock. Assuming a fuel gas cost of $ 5.00 per MMBTU the plant will save more than $ 5,000,000 per year on fuel gas costs if the FGRS operate at full capacity. With an expected operating cost of $ 300,000 per year, the cost of the FGRS could be recouped in less than 9 months.

FGRS includes LRC for reducing about 163,000 tCO_2e/year of baseline emissions from Suez oil refinery company in Egypt was presented [2,47]. For about 94 % of gas emissions will be decreased [2] and a payback period of about 2 years [47]. Another FGRS in Farashband gas refinery in Iran, piston compressors operate to recover about 4.176 MMSCFD of flared gas, provides a compressed natural gas with 129 bar pressure for injection to the refinery pipelines [15].

In Uran plant [20] (205 Km from the Mumbai High offshore field), the FGRS was used to recovery all of the flare gases and process them to utilize valuable hydrocarbon of about 30,000 - 150,000 SCMD from gas processing in order to achieve technical zero flaring. Screw compressor (oil flooded) was used in this FGRS and designed to capable of handling gases of molecular weight between 19.5 - 36.2. FGRS has significantly reduced the CO_2 emissions released into the environments. The total estimated reduction of CO_2 977,405 tCO_2e from 2007 - 2008 to 2016 - 2017 considering the avoidance of 44 MMSCM of gas per year. Another FGRS at Hazira plant (232 Kms from the Mumbai offshore oil field) was designed to recover and utilize the tail gas of about 14,000 - 73,000 SCMD from gas processing plant in order to achieve technical zero flaring [20].

Zadakbar et. al., [41] offered the results of two case studies of reducing, recovering and reusing flare gases from the Tabriz Petroleum Refinery and Shahid Hashemi-Nejad (Khangiran) Natural Gas Refinery in Iran, including eleven plants of petroleum refineries, natural gas refineries and petrochemical plants. In the Tabriz petroleum refinery, the recommended FGRS includes two LRC, two horizontal 3-phase separators, two water coolers, piping and instruments. For about 630 kg/hr flared gas will be used as fuel gas by $ 0.7 million capital investment corresponds to a payback period of about 20 months, and also 85 % of gas emissions will be decreased. In the Shahid Hashemi-Nejad (Khangiran) gas recovery, three LRC, three horizontal 3-phase separators, three water coolers, piping and instruments, proposed FGRS. For about 25000 m^3/hr flared gas will be used as fuel gas by $ 1.4 million capital investment corresponds to a payback period of about 4 months, and 70 % of gas emissions will be decreased.

Sangsaraki and Anajafi [30] investigated the design criteria of FGRS and steady sate and dynamic simulation of the FGRS. The recovery of 5916 normal m^3/hr of sweet natural gas, 24 ton/hr of gas condensates and production of 297 m^3/hr of acid gas would be possible, according to steady state simulation results. Also, the changes in the temperature of the gases sent to the flare during total shutdown of the refinery as well as the impact it had on FGRS behavior was studied. It is obvious that the efficiency of the compressor is reduced due to the increase in the temperature of the gas sent to the flare network; therefore, the value of separation in two and three-phase separator shows a drastic change.

C. FGRS by Gas-To-Liquid Conversion

One of the best methods for reducing gas flaring is the application of environmentally friendly technologies such as gas-to-liquid (GTL) conversion. It is one of the most promising topics in the energy industry by the conversion of flare gas to hydrocarbons due to economic utilization of control waste gas to environmentally clean fuels. Another environmental issue is the regulatory pressure to reduce the volume of flared gas, which has serious environmental consequences. Recently the development of GTL technology has been an increased interest. GTL technology plays an interest role in delivering gas to markets as both fuel and/or chemicals [48]. The products from GTL have interest environmental advantages compared to traditional products, giving GTL a significant edge as governments pass new and more stringent environmental legislation. So, conversion of flared gas to synthetic fuel has attracted more attention in some countries because of the economic and environmental benefits derive from it [49].

Flare gas to liquids conversions can be achieved via several chemical reaction processes resulting in a range of end products. The Fischer-Tropsch (F-T) technologies are currently the most widely deployed [50]. In F-T technology, associated gas firstly pass through a steam methane reformer to produce syngas (a mixture of CO and H_2,). After that, syngas feeds into a F-T reactor that coverts to longer chain hydrocarbons (synthetic crude oil), water, and a "tail gas" comprising H_2, CO and light hydrocarbon gases at an elevated pressure and temperature. The synthetic crude oil is then delivered to a conventional refinery for onward processing. The excess heat generated from the reaction has typically been removed by inserting boiler tubes that carry water. F-T products are of high quality, being free of sulfur, nitrogen, aromatics, and other contaminants typically found in petroleum products, which is especially true for F-T-gasoline with a very high octane number. However, drawbacks also exist for the F-T process: the capital costs of F-T conversion plants are relatively higher and the energy efficiency of producing F-T liquids is relatively lower than the one for other alternative fuels such as hydrogen, methanol, dimethyl ether and conventional biofuels [51].

In the history of F-T technology process development, the various types of reactors, including multi-tubular fixed bed reactor; bubble column slurry reactor; bubbling fluidized bed reactor; three-phase fluidized bed reactor; and circulating fluidized-bed reactor, have been considered [52]. The F-T process was first developed by Franz Fischer and Hans Tropsch used iron-based catalyst followed by using both iron and cobalt-based catalysts in Germany between 1920s and 1930s [53]. From 1950s to 1990s, South Africa SASOL developed F-T commercially (in conjunction with coal gasification) to convert coal to hydrocarbons with total capacity 4,000,000 Mt/year in three plants; two still in operation [54]. From 1980s to present, Shell using F-T to convert natural gas to fuels and waxes in Bintulu, Malaysia [55]. From 1980s to present, a number of entrants into the fields, a number of projects announced and planned (including demonstration projects), Qatar and Nigeria have started design and construction on world scale GTL facilities [56]. Oguejiofor discussed some aspects of using GTL technology for reducing flare gas in Nigeria [57]. The main issue in Nigeria is to gather gas from more than 1000 wells by building gas collection facilities at the oilfields and constructing an extensive pipeline network to carry gas to an industrial facility where it turns into liquids for transportation [58]. Gas flaring in Nigeria was reduced from roughly 49.8 % in 2000 to fewer than 26 % in 2006 [59].

A small scale simpler F-T processes can be deployed in small modular units to process associated gas [50]. The smallest potential plant evaluated by studying the conversion of 2000 - 10000 MCF per day of gas into 200 - 1000 bbls per day of liquid products [60]. A novel catalyst using atomic layer deposition in small-scale mobile systems was investigated for convert low-value natural gas to high value synthetic crude oil (GTL) [61]. A novel catalyst yields 2.5 times more synthetic crude with high conversion about 90 % and low methane selectivity for about 6 wt% than state-of-the-art catalysts for GTL. Additionally, it is robust and has a low deactivation. Preliminary economic assessments predict that the scaled-up 100 barrel per day process using 1 MMSCFD natural gas, having a $ 5 MM - $ 7.5 MM total investment, would achieve a 15 - 30 % internal rate of return at a breakeven price of $ 20 - 75 per bbl depending on natural gas cost [61]. However, by using GTL in the Farashband gas refinery in Iran is produced 563 bbl/day of valuable products from the 4.176 MMSCFD of flared gas [15].

The application of microchannel technology to F-T enables cost effective production at the smaller-scales appropriate for both onshore and offshore GTL facilities for stranded and associated gas reserves [55]. The microchannel technology to steam reforming of methane and F-T synthesis using cobalt as catalyst was studied [55,62]. The steady state CO conversion was over 70 % and selectivity to methane was under 10 % [55]. The reactor operated steadily and had minimal change in conversion level even after 1,100 hr of operation [55]. Branco et. al., [49] estimated the total emissions from an offshore microchannel GTL plant in Brazil. The results show that GTL plant allows the production of low-sulfur diesel, reducing gas flaring and co-producing high-quality naphtha, additionally, an average of $ 37.00 per tCO_2e reduced.

Knutsen [63] investigated the simulation of operational performance and optimization of a GTL plant based on autothermal reforming and a multi tubular fixed bed reactor containing a cobalt catalyst. The economics optimized process was found to produce of syncrude with a carbon efficiency of about 77 % and thermal efficiency of about 62 %. Ultimately a production cost of $ 16.10 per bbl and revenue of $ 59.89 per bbl was obtained. With current crude oil price at $ 98.90 per bbl, it indicates a good economical environment for the GTL process.

Rahimpour et. al., [64] compared the performance of the two cascading membrane dual-type reactors in the form of fluidized-bed and fixed-bed for F-T synthesis. According to the results, fluidized-bed reactor is superior to fixed-bed reactor for FTS in GTL technology owing to achieving 5.3 % increase in the gasoline yield and 12 % decrease in CO_2 yield, in addition, excellent temperature control and a small pressure drop and consequently higher gasoline yield and lower CO_2 yield.

D. FGRS by Electricity Production

A basic part of nature is power and it is as a secondary energy source, from the conversion of many sources of energy such as coal, natural gas, oil, nuclear power and other natural sources. About 16 % of the power was produced from natural gas [65]. To be reduce the thermal emissions from several processes, such as petrochemicals, industrial gases and agricultural chemicals, in which high-temperature exhaust is released that could be recovered for power generation [66]. The conversion into electricity by using flared gas as a primary source is the other method for FGRS. Power station can be produced an electric by using a turbine, engine, water wheel or other similar machines to drive an electric generator. 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 [65]. Gas turbines can be burned flared gas to produce hot combustion gases that pass directly through a turbine, spinning the blades of the turbine to generate power. Electricity generation with a gas turbine provides 25 MW electricity from the 4.176 MMSCFD of flared gas from the Farashband gas refinery in Iran [15]. The flared gas can also be used to produce electricity in gas-fired turbines called “microturbines”, to be an energy source to provide power for industry operations, like pumping, compression machines and gas processing [67].

In other words, the electrical power generation using of flared gas is described in two scenarios [68]. A simulation of power generation by gas turbine working in a simple Brayton cycle is the first scenario. Fog method is added to improve the efficiency by cooling inlet air of a simple cycle of gas turbine, in the second scenario. The two scenarios were compared from both technical and economical point of view [68]. The results indicate that, the first scenario is more economically but the power generation has a better situation in the second scenario. From the first and second scenarios, the power generation are 38.5 and 40.25 MW, and the payback periods about 3.32 and 3.48 years, respectively. Additionally, a compressor with an efficiency of 90 % is used to increase the fuel pressure from 6 bar to 23.7 bar [68].

There are other cycles to generate power. Steam Rankine Cycles (SRC), the most commonly used system for power generation from waste heat involves using the heat to generate steam in a waste heat boiler, which then drives a steam turbine [66]. Organic Rankine Cycles (ORC), other working fluids, with better efficiencies at lower heat source temperatures, are used in ORC heat engines. ORC use an organic working fluid that has a lower boiling point, higher vapor pressure, higher molecular mass, and higher mass flow compared to water. So, the turbine efficiencies of ORC are higher than in SRC. Additionally, ORC systems can be utilized for waste heat sources as low as 148 ºC, whereas SRC are limited to heat sources greater than 260 ºC. ORC have commonly been used to generate power in geothermal power plants, and more recently, in pipeline compressor heat recovery applications [66].

Russia in 2007, to check economic options for associated gas monetization, the World Bank commissioned a large study by PFC Consulting. Electric power generation and development of gas processing plants were found to be the most efficient ways to use flared gas. In addition, a netback price of around $ 50 per MCM close to 80 % of Russia’s associated gas could be economically recovered [69].

A fuel cell can be considered as a new approach to recovery of flared gas. It is a power-generation systems that convert directly the chemical energy of fuel to electricity [70]. Solid oxide fuel cell (SOFC) is more efficient from the various types of fuel cells [71]. SOFC is known as an environmental friendly power generation technology. SOFC contains two porous electrodes, which are separated by a nonporous oxide ion-conducting ceramic electrolyte. It uses hydrogen containing gas mixture as a feed and the oxygen of air as an oxidant at temperatures between 600 - 1000 ºC [70]. The high operation temperature leads flexibility of using various fuel types such as methane, methanol, ethanol, biogas and etc. [72]. Saidi et. al., [13] developed an electrochemical model for a steady-state, planar SOFC by considering the direct internal methane steam reforming for FGRS of Asalouyeh gas processing plant in Iran. There is no pre-reforming and the sweetened flare gas is fed to SOFC directly. SOFC generates about 1200 MW electrical energy, and decreases the equivalent mass of GHG emission from 1700 kg/s to 68 kg/s, especially, reduces CO_2 emission by about 55 %. Additionally, there are approximately zero emissions of other pollutants (NO_x, SO_x, CO, particles and organic compounds) and very low noise emission. Furthermore, the total capital investment of this method is significantly lower than other no gas flaring approaches.

A project to recover landfill gas was initiated in Tianjin Municipal Government - China, which was otherwise being released into the atmosphere, and burn pretreated landfill gas for electricity generation or discharged to flaring. The produced landfill gas consists of 50 % CH_4 and 50 % other gases, such as CO_2 and additional gases including non-methane organic compounds. The project will obtain revenues from the sale of electricity, which over the project's life, will amount to $ 36.2 million. The project has been registered as a CDM project under the Kyoto protocol and reached an agreement with the World Bank to purchase the certified emission credits (CERs) from the project [73].

E. FGRS - Other Methods

Several methods are used for FGRS such as collection and compression, conversion gas to liquid and electricity production. Other methods investigated of FGRS to reduce the emissions from different industries and reduce fuel costs, visible flame, odors and the auxiliary flare utilities such as steam. Mourad et. al., [26] investigated the recovery of flared gas through crude oil stabilization by a multistage separation with intermediate feeds. Xu et. al., [74] studied a general methodology on flare minimization for chemical plant start-up operations via plant wide dynamic simulation. Ghadyanlou and Vatani [14] investigated methods to recover flare gases by using it in olefin plants. They reported that significant amounts of ethylene about 43.3 Mt/hr and fuel gas about 10.8 Mt/hr can be recovered. Additionally, about $ 9 million/year of valuable gases are returned to the plant and the investment costs are recovered after about 3 years of operation of the FGRS. The economic potential of using flared natural gas as a feedstock to produce a low-cost, reliable, and sustainable supply of nitrogen fertilizer for North Dakota farmers in the US was examined [75].

For most processing plants the biggest problem has been removing the H_2S in the natural gas. In the case where they couldn't remove it, the gas would be flared. If the gas contains too much sulfur it cannot be sold and flared. In the case it satisfies the sulfur contents, but still contains some sulfur, it is sold and burned by the consumers. Either way, the sulfur will contaminate and pollute the environment, creating acid rain and other problems, like supporting reactions that deplete the ozone in the stratosphere [76]. Reducing acid gas flaring was a high priority. Tengizchevroil (TCO) [77] company implemented and automated procedure to address this problem. The gas treatment process is a selective chemical absorption of hydrogen sulfide, carbonyl sulfide and carbon dioxide from the sour gas streams by diethanolamine. On the other hand, one of the newest technologies being used is bacteria that remove the sulfur from low volumes of sour gas [67]. The sulfur bacteria create a sustainable process that remove the sulfur compounds under highly alkaline and oxygen-limited conditions. Byproducts from the sulfate and thiosulfate will then be removed from the stream before being disposed of. This is also done by bacteria, but different ones, that remove sulfate and thiosulfate [76].

Companies would perform repairs and maintenance of the pipelines, where venting was a problem, but through new methods the flaring and venting have been cut down to nearly zero. An example of one of these methods is "hot tapping", which is a method used to prevent venting of natural gas when connecting pipelines [1]. Hot tapping makes it possible to work on a live system, like pipes and pressure vessels without having to vent or shut down operations. Example of "hot tapping" vessel is shown on Figure 2.

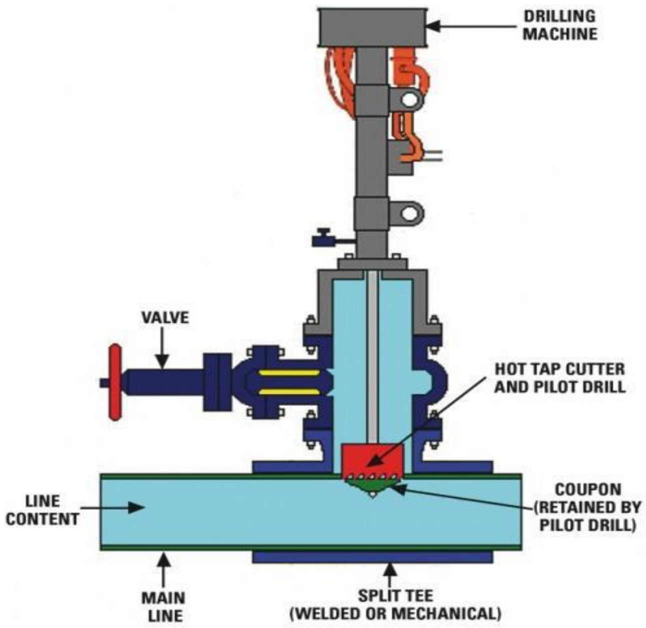

Figure 2 : Hot tapping [16].

Rao et. al., [3] reported that by adopting new technologies of advanced process control with automation of steam control system, black carbon or soot from flare stacks can be minimized and save human being health from dangerous particulate matter emission from sooty flares. This automatic control system keeps always zero soot formation from the flare stack in any emergency situation.

New waste heat refrigeration units are useful for using low temperature waste heat to achieve sub-zero refrigeration temperatures with the capability of dual temperature loads in a refinery setting. These systems are applied to the refinery's fuel gas makeup streams to condense salable liquid hydrocarbon products and considered as a new environmentally friendly technologies reduces flare emissions [78].

III. CONCLUSION

Gas flaring reduction and recovery has high priority as it meets both environmental and economic efficiency objectives. This paper is an overview of reduction and recovery flared gas by using FGRS according to environmental and economic considerations. There are many methods for FGRS in industry such as collection and compression, gas-to-liquid, and generating electricity. FGRS have been impeded by a number of technical challenges, such as a combination of highly variable flow rates and composition, low heating value and low pressure of the waste gases. GTL plants are perfectly suited for natural gas rich countries, especially where the reserves are underutilized or where large amounts of associated gas are flared during conventional oil production. However, the collection and compression of gas into pipelines for processing and sale is a well-established and proven approach to mitigating flaring and venting. In addition, the gas can also be used to produce electricity in gas-fired turbines, to be an energy source to provide power for industry operations, like pumping, compression machines and gas processing.

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