TECHNOLOGY SELECTION FOR IRAN'S GAS FLARE RECOVERY SYSTEM

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About 70% of gas flaring in the whole world produces in less than 20 countries whereas more than 70 bcm of it is generated in just four of the mentioned countries. Iran flared 400 bcf of gas in 2011. In this paper, five options of Iran's gas flare recovery have been compared via MCDM method. For developing the model, the weighing factor of each indicator an AHP method is used via the Expert-choice software. Two groups of cases were considered in this analysis. One group was designed with priority given to individual indicators, while the other indicators had the same value, and the second group consisted of cases where the priorities were defined always keeping one criterion in first position, while the priorities of the other criteria were defined by ordinal information defining the mutual relations of the criteria and the respective indicators.

Keywords— Flare, Gas, Iran

INTRODUCTION

It is obviously cleare that by rising the living standards in Iran and also the global population growth, the greenhouse gas emissions will definitely increase during the future years.

Enormous consumption of fossil fuels to supply the demanded energy in the recent decade, causes a huge amount production of greenhouse gases which leads to global warming disaster.

Annually, over 140 billion cubic meters of natural gas are being flared and vented which is equivalent to 25% of the United States' gas demand, 30% of the European Union's gas demand, or 75% of Russia's gas exports [1].

Gas flaring in Africa is equivalent to half of that continent's power consumption. Flaring gas has a global effect on climate change by adding annually about 360 million tons of CO_2.

About 70% of gas flaring in the whole world produces in less than 20 countries whereas more than 70 bcm of it is generated in just four of the mentioned countries. Iran flared 400 bcf of gas in 2011. That would meet about a quarter of demand in South Korea. The gas is worth about $7.3 billion on Southeast Asian spot LNG markets [2]. The associated gas in Iran is usually flared for the lack of infrastructure to be processed and transported to demand markets.

The flared natural gas was about 5% of the world's natural gas production by the end of 2012 [3]. As explained, the top 20 countries accounted for the flaring of 127 billion cubic meters, which is over 86% of the total flaring in the world by the end of 2011. The ratio of CO_2 emissions to natural gas flaring have also been described. Russia stands on the first place of gas flaring in the world. The flaring of Nigeria alone amounts 12% of the total flaring and Iran holds the third place of gas flaring.

ENVIRONMENTAL EFFECTS OF CO_2

Iran has shown remarkable growth in total fossil-fuel CO_2 emissions since 1954, averaging 6.3% per year. In 2008 total emissions reached an all-time high of 147 million metric tons of carbon. With Iran being the world's fourth largest oil-producing country it is not surprising crude oil and petroleum products account for the largest fraction of the Iranian emissions, 46.4% in 2008. The CO_2 emissions time series for Iran, like other countries in the Middle East, shows sizeable emissions from gas flaring in the late 1960s and 1970s and a decline in these emissions during the 1980s and 1990s. This downturn reflects changes in oil field practices, improvements in oil field facilities, and increasing use of gas fuels. Emissions from gas fuels have grown 390-fold since the first reported natural gas use in 1955 and now account for 42.3% of Iran's total fossil-fuel CO_2 emissions. From a per capita standpoint, Islamic Republic of Iran is above the global average at 2.00 metric tons of carbon.

It is generally accepted that carbon dioxide is a greenhouse gas and contributes to global warming. About 75% of the anthropogenic emissions of carbon dioxide come from the combustion of fossil fuels. Flaring produces a great amount of carbon dioxide. Carbon dioxide emissions from flaring have high global warming potential and contribute to climate change. The mounting environmental pressure on the oil and gas production areas to cut

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CO_2 emissions is directly affecting the practice of flaring [5].

CO_2 emissions from flaring have high global warming potential and contribute to climate change. Flaring also has harmful effects on human health and the ecosystems near flaring sites. The low quality gas that is flared releases many impurities and toxic particles into the atmosphere during the flaring process. Acidic rain, caused by sulfur oxides in the atmosphere, is one of the main environmental hazards which results from this process [6].

According to research performed by the World Bank's Global Gas Flaring Reduction Partnership (GGFR), the equivalent of almost one third of Europe's natural gas consumption is burned in flares each year which is about 400 million tons of carbon dioxide emission to the atmosphere (roughly 1.5% of the global CO2 emission) [7].

Environmental and economic considerations have increased the use of flare gas recovery systems. Flare gas recovery reduces noise and thermal radiation, operating and maintenance costs, air pollution and gas emission and reduces fuel gas and steam consumption.

IRAN'S GAS STATUS

The proved natural gas reserves of Iran are about 29.6 Ttcm or about 15.8% of world's total reserves. Iran has the world's first largest reserves which is estimated up to 18% of the world's share. Iran's gas production by the end of 2012 has been about 160.5 billion cubic meters, which is 4.8 percent of the world's share. Natural gas consumption in Iran by the end of 2012, was about 156.1 Gcm.

Iran's gas production

Iran is the largest gas producer in the Middle – East and holds the 3rd place in the world following U.S. and Russia respectively. Global conventional natural gas resources are concentrated geographically, with 70% in three countries: Qatar, Iran and Russia [9]. Iran's gas production by the end of 2012 has been about 160.5 billion cubic meters, which is 4.8 percent of the world's share and shows 5.4% changes over 2011.

Iran's natural gas production has increased by over 550 percent over the past two decades, and the consumption has kept pace. As demand growth rates persist, the potential for shortfalls in natural gas supply grows.

1) South Pars field

The most significant energy development project in Iran is the offshore South Pars field, which produces about 35 percent of total gas produced in Iran. Discovered in 1990, and located about 100 km offshore in the Persian Gulf, South Pars has a 24-phase development scheme spanning 20 years. Participating foreign companies in these phases are, among others, Petronas, Total, Gazprom, ENI, Statoil and PdVSA.

The entire project is managed by Pars Oil & Gas Company (POGC), a subsidiary of the National Iranian Oil Company. Each phase has a combination of natural gas with condensate and/or natural gas liquids production. Phases 1-10 are online. The majority of South Pars natural gas development will be allocated to the domestic market for consumption and gas re-injection. The remainder will either be exported as liquefied natural gas (LNG) and/or used for gas to liquids (GTL) projects.

2) Kish field

Kish, with estimated reserves of 1,416 bcm, is expected to produce about 85 mcm per day (mcm/d) of natural gas. Phase I of the project, which experienced repeated delays is expected to come online in 2016. Phase I is expected to produce approximately 28 mcm/d and Phase II of the project will produce an additional 57 mcm/d.

In addition to Kish, there are other promising gas fields that could further boost Iran's production. However, these projects also are characterized by delays and other difficulties. These additional fields include the Golshan, Ferdowsi, and North Pars gas fields although their start-ups are unlikely to occur until the next decade.

Iran's gas production share of the Middle East by the end of 2011 is about 30% [10].

Iran's gas consumption

Iran holds the world's 3rd - largest consumer of natural gas after U.S. and Russia respectively. Natural gas consumption in Iran by the end of 2012, was about 156.1 bcm which is 4.7% of the world's share.

IRAN'S GAS IMPORT / EXPORT

Iran imports natural gas from its northern neighbor Turkmenistan. The import of natural gas from Azerbaijan and Turkmenistan was respectively equal to 0.4 and 9 billion cubic meters in 2012.

Iran exports only a small part of its total natural gas production. Natural gas exports go to Turkey and Armenia via pipeline. Turkey, an importer since 2001, received 8,190 mcm in 2011, while exports to Armenia totaled 250 mcm in 2011. Iran's natural gas exports likely will be limited due to rising domestic demand, even with future expansion and production from the massive South Pars project, and other development projects.

The Strait of Hormuz, on the southeastern coast of Iran, is an important route for oil and gas exports from Iran and other Persian Gulf countries. At its narrowest point the Strait of Hormuz is about 34 km wide, yet an estimated 70 million ton of LNG flowed through the Strait between January and October 2011.

FLARING GAS STATISTICS IN IRAN

In this section, Iran's statistics of gas flaring are presented. Iran's flaring gas amount is about 50 million cubic meter natural gas which is equivalent to the 126 million barrel oil equivalent every year. It can be indicated that flared gas from oil and gas production field is about 37 and 13 million cubic meters, respectively in Iran.

Furthermore, statistics indicate that flared gas values about eighteen million dollars a day [11] which is comparable to capital cost of 5MW photovoltaic panels.

Error! Reference source not found. study represents the historical amount of flared gas in oil fields in Iran. Despite, there are many plans for reducing the flare gas; it is increasing in recent years [11]. The study also presents the ratio of flare gas to produced oil in Iran. It can be seen that not only crude oil production decreased, but also the amount of flared gas is increased, in the recent years. The statistics shows that around 10 cubic meters of natural gas has been flared for every barrel oil production.

The average growth of which during these years is estimated about 17.97%. The Study also shows the ratio of flare gas to gas production in Iran [11]. Unfortunately, It can be indicated that the ratio of flaring gas to gas production in Iran enjoys a positive growth and more than 2.5% of Natural gas production in Iran has been flared in 2011.

This chart indicated that flaring gas from Gas production field is about 37 million cubic meters which is 40% of import natural gas. It can be concluded that by reducing flare gas, Iran can be independent of gas import. On the other hand, the Iran's gas export may be increased which leads to economic growth.

Reducing flare gas from Oil production fields causes an increase in chemical refinery production. This matter may also to higher economic growth.

The value of daily flaring gas in Iran is equal to 500 GWh per day which is equal to the 27% of annual electrical energy supply in 2012. Assuming the average efficacy of power plant in Iran around 36%, this amount of gas flaring contains a potential of Electricity production for 7.5 GW power plant rating. This is equal to the 11% of total capacity of power plant in Iran in 2012. Every year, Iran import electricity from neighboring countries. In 2011, Iran's electricity import was about 3650 GWh/yr which was equal to 6% of electricity production from flare gas. Therefore, by converting flare gas to Electricity, not only Iran can be independent of electricity import, but also exporter of it to neighborhood countries.

The daily gas flaring in Iran is equal to the 60% of daily gas injection to the oil fields in 2011. By reducing gas flaring, the gas injection to oil fields can be increased which lead to more oil production and longer life of oil fields.

Because of social consequences, the first priority of allocation of natural gas is for residential/commercial sector in Iran. As it is clear the consumption of residential sector during the cold months especially in winter extremely increases. The Residential sector carries a high share of Natural gas consumption which is equal to 10% of light gas flaring in Iran. Indeed, reducing the residential consumption share needs medium and long term programs, while reducing the light flare gas and injecting it to Gas pipeline may be so easier at this time.

It is noticeable that gas flaring ratio to oil and gas production is increasing in recent years in Iran. Therefore, it seems the recovery of flare gas is logical in this country [3].

FLARE GAS RECOVERY METHODS

The recovery of flare gas is of importance for many advanced countries around the world due to the saving resources and reducing air pollution. There are various ways to recover flare gas. The study represents some possible strategies to recover flare gas in Iran. Statistics shows that the ratio of flare gas to oil and gas production is highly increasing in this country [11].

Moreover, it can be seen that Iran stands in the third place of top flaring countries. Consequently, providing the performance of Kyoto Protocol in Iran, the recovery of flare gas becomes very significant. As a result, in this paper, the feasibility study of the methanol production in small scales from the flare gas is studied. In the first section, for observing the significance of flare gas recovery, the detailed Iran's gas flaring data are presented. Then the simulation of mini methanol plant is described in the second part. In order to present the economic results for the simulated plant, we generate two scenarios, one scenario is with consideration of the environmental taxes of gas flaring and the second one is without considering them. Afterwards, to recognize the feasibility of the simulated plant in Iran, the sensitivity analysis is done on the technical data such as the flow rate of input gas and economical data like flare gas cost and methanol price.

GTL technology

Gas-to-liquid (GTL) technology is a good alternative for reducing gas flaring. Recently, the high oil price has created considerable interest in the development of GTL technology for the manufacture of transportation fuels. The GTL process can be a good candidate for alleviating the current oil crisis, in which synthetic liquid fuels (e.g., gasoline, diesel, and wax) are produced from stranded natural gas. This means that “stranded natural gas” in remote areas can be converted to shippable liquid fuels through the GTL process [12]. Among the various alternatives for combustion of flare gas, there has been an increased interest in GTL technology.

Such technologies play an important role in bringing gas to markets as both fuel and/or petrochemicals [13]. The GTL products have important environmental advantages compared to traditional products, giving GTL a significant edge as governments pass new and more stringent environmental legislation. In addition, refineries are faced with the challenge that crude oil is generally getting heavier, making it harder and more expensive to meet the new stringent standards. It is highly unlikely that these improvements in fuel quality can be achieved without using a technique such as blending zero sulfur GTL diesels into the current crude based product mixture. Another environmental issue is the regulatory pressure to reduce the volume of flare gas, which has serious environmental consequences. 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 liquid for transportation.

Electricity generation

Electricity generation from flared natural gases via gas turbines Flare gas conversion into electricity is another way for reducing flare gas. Although natural gas has become a key primary source of energy for electricity generation, higher fuel costs of natural gas quickly outweigh the advantages in most applications.

Compressed method

Compression and transmission of gas to practical point of view is another alternative to reduce and reuse flare gas. Initially natural gas was used only in the areas in which it was produced, with excess production being vented to the air or flared. But the large demands for natural gas has developed fairly recently. The increased demand has also greatly increased the price obtained for the gas [14]. This made refineries to use flare gas recovery systems for lowering emissions by recovering flare gases before they are combusted by the flare.

A flare gas recovery system compresses the flare gas for reuse in the refinery gas system. A compressor is used to increase the pressure of a compressible fluid. The inlet pressure can be any value from a deep vacuum to a high positive pressure. The discharge pressure can range from sub atmospheric to high value in the tens of thousands of pounds per square inch. Compressors have numerous forms, their exact configurations being based on the application [15].

Piston compressors operate based on the displacement principle. Piston compressors are available both with one and several cylinders and also one and multiple-stage versions.

Multi-cylinder compressors are used for higher outputs while multistage compressors are used for higher pressures. The gas compressed in the cylinder in the first stage (low pressure stage) is cooled in the intermediate cooler and then compressed to the final pressure in the second stage (high pressure cylinder). In single action compressors, one compression action with one rotation of the crankshaft take place while in double action compressors there are two compression actions with one rotation of the crankshaft.

*CH**P***

Natural gas is the most common fuel for CHP plants and this is a reflection of its price, availability, wide range of applications and the lower environmental impact of its exhaust gases.

The supply of natural gas to a user is by pipeline from the national distribution network, much of which is owned and operated by National Grid Gas.

The installation of a gas-fired CHP plant almost always increases the site’s consumption of gas, as the new plant generates both heat and power and usually operates for a large proportion of the year. As well as the increase in total annual gas consumption, the maximum rate of consumption usually increases, and this often requires the uprating of an existing site gas connection. In addition, the gas supply pressure required for operating a gas turbine or a gas engine is often higher than the existing site supply pressure, necessitating the use of pressure-boosting equipment.

Petrochemical products

Low natural gas prices are a magnet for petrochemical producers, who are planning big investments in the province and helping it realize its long-standing priority of adding value to its oil and gas resources.

The large majority of chemical products are produced from petroleum (oil) or natural gas. Several of these base chemicals may be made more readily from natural gas rather than petroleum. Synthesis gas is an obvious candidate, due to the high hydrogen content of natural gas. Moreover, the light alkenes may be made from wet natural gas (NGL) in a process known as steam cracking.

Injection

Iran is one of the largest gas rich countries in the world that production capacity exceeds domestic consumption and gas injection requirements. Gas can be utilized as feed stock in petrochemical plants and refineries or exported through pipeline or LNG. Through re-injection of gas to oil reservoirs, while increasing the oil recovery ratios, the produced gases from fields shared with other countries could be stored into domestic gas fields.

Gas consumption in domestic markets and its substitution with oil products, in addition to providing environmental benefits, will also result in optimum consumption of these products and relieving the government from the heavy burden of existing subsidies and heavy expenditures of importing these products into country.

METHODOLOGY

Multiple criteria decision making (MCDM) refers to making decisions in the presence of multiple, usually conflicting, criteria. MCDM problems are common in everyday life. In personal context, a house or a car one buys may be characterized in terms of price, size, style, safety, comfort, etc. In business context, MCDM problems are more complicated and usually of large scale. For example, many companies in Europe are conducting organizational self-assessment using hundreds of criteria and sub-criteria set in the EFQM (European Foundation for Quality Management) business excellence model. Purchasing departments of large companies often need to evaluate their suppliers using a range of criteria in different area, such as after sale service, quality management, financial stability, etc... Although MCDM problems are widespread all the time, MCDM as a discipline only has a relatively short history of about 30 years.

The development of the MCDM discipline is closely related to the advancement of computer technology. In one hand, the rapid development of computer technology in recent years has made it possible to conduct systematic analysis of complex MCDM problems. On the other hand, the widespread use of computers and information technology has generated a huge amount of information, which makes MCDM increasingly important and useful in supporting business decision making. There are many methods available for solving MCDM problems as reviewed by [8], though some of the methods were criticized as ad hoc and to certain degree unjustified on theoretical and/or empirical grounds. There were calls in early 1990s to develop new methods that could produce consistent and rational results, capable of dealing with uncertainties and providing transparency to the analysis processes.

The ER approach and the software are now widely used in many areas. In the following section, the main characteristics of MCDM problems are summarized first, followed by a list of typical techniques used in MCDM analysis.

For multi-criteria analysis, there are a large number of combinations describing potential situations of weighting factors. In order to overcome this arbitrariness in the evaluation of these options, the multi-criteria evaluation method is introduced. This method is based on the numerical values of the indicators used in the multi-criteria analysis. The multi-criteria assessment method is based on the decision making procedure reflecting the combined effect of all criteria under consideration and is expressed in the form of a General Index of Sustainability. A selected number of indicators is taken as the measure of the criteria comprising specific information of the options under consideration. The procedure aims to express the property of the options by a respective set of indicators.

In this paper, an AHP method is used to identify the priorities of flared gas recovery in different options which are explained as follows. In order to find the priorities, Expert Choice is used as the appropriate software and the result are shown as follows.

Options

An individual criterion for evaluation of the potential flare gas recovery options is leading to a limited guidance for the respective decision making process.

In this respect, individual indicators are leading to the priorities of specific options, which will strongly depend on the selected indicator.

The different options of flare gas recovery usage are as follows:

- Liquid Fuels Production
- Electricity Production
- CHP

• Petrochemical Products
• Injection
• Pipeline Usage

Indicators

For assessing the priorities of each option different criteria are used. The criteria are as follows:

• Environment
• Economics
• Availability

The assumptions of Iran's future gas availability depend on different factors. In order to obtain the most probable ones, the three-round Delphi panel method is used in this paper.

In the first round, the Delphi process begins with an open-ended questionnaire for a 100 experts' society. This questionnaire contained a list of assumptions which have been created by the authors and is used as the survey instrument for the second round of data collection. In the second round, 50 Delphi participants received a second questionnaire and were asked to review the most probable assumptions summarized by the investigators based on the information provided in the first round. In the third and final round, the lists of all probable results are distributed to the top ten expert panelists. This round provides a final opportunity for participants to revise their answers in a meeting and discuss about their opinions.

RESULTS

For developing the model, the weighing factor of each indicator is required. In order to define the weight coefficient of each indicator an AHP method is used via the Expert-choice software. Expert Choice is decision-making software that is based on multi-criteria decision making.

Expert Choice implements the Analytic Hierarchy Process (AHP) and has been used in different fields.

SELECTION OF CASES

For evaluation of any complex system by the MCDM method, appropriate parameters, needed for its application have to be selected. In this paper, two groups of possible cases are defined, namely: a group with priority given to the single indicator, while the other indicators have equal values; and a second group with all indicators defined by the internal preference amongst the criteria.

Group 1

In evaluation of the priority list amongst the alternative options, some cases have to be selected to represent potential constraints between the indicators. This means that the cases that are to be representative for the decision making procedure have to be defined. The evaluation procedure implies that constraints have to be defined among the options in order to obtain the respective values of their weighting coefficients. In this evaluation, attention will be focused on a number of cases to be analyzed that correspond to the individual priority of every indicator with the other indicators having the same value. In this analysis, the following cases are taken.

Case 1: Env. > Eco. = Av. Case 1 is designed with priority given to the Environmental Indicator while the other indicators have the same value of weighting coefficient.

For this case, it is noticed that priority is obtained for the Pipeline usage and the injection followed by the liquid fuel and then the petrochemical and CHP and Electricity production options respectively.

Case 2: Av. > Eco. = Env. Case 2 is designed with priority given to the Availability Indicator while the other indicators have the same value of weighting coefficient. For this case, it is noticed that priority is obtained for the CHP usage and the liquid fuel followed by the Electricity production and then the injection and Pipeline usage and Petrochemical products options as the last one.

Case 3: Eco. > Av. = Env. Case 3 is designed with priority given to the economic indicator while the other indicators have the same value of weighting coefficient. For this case, it is noticed that priority is *obtained for the Injection and the Pipeline usage* followed by the liquid fuel and then CHP and the petrochemical and Electricity production options respectively.

Group 2

Group 2 cases are aimed to emphasize the role of the cases when internal priorities amongst them are defined by ordinal information that defines the mutual relations of the criteria and the respective indicators. It is obvious that the number of such cases can be very much larger than that of Group 1. The cases are formed by ordering the criteria, always keeping another criterion at the first position. In this group, the results are presented as follows.

Case 4: Env. > Eco. > Av. Case 4 is designed with the aim to give the first priority to the environmental indicator and the second priority to economic indicator. The result of running the program shows that the most probable option in this case is the pipeline usage and injection, liquid fuel production, CHP, Petrochemical products and electricity production stand at the next priorities respectively.

Case 5: Eco. > Av. > Env. Case 5 is designed with the aim to give the first priority to the economic indicator and the second priority to the availability indicator. The result of running the program shows that the most probable option in this case is the injection and pipeline usage, liquid fuel production, CHP, Petrochemical products and electricity production stand at the next priorities respectively.

Case 6: Av. > Env. > Eco. Case 6 is designed with the aim to give the first priority to the availability indicator and the second priority to environmental indicator. The result of running the program shows that the most probable option in this case is CHP and the liquid fuel production, pipeline usage, injection, electricity production and petrochemical products stand at the next priorities respectively.

Case 7: Av. = Env. = Eco. Case 7 is designed with the same priority to all the indicators. The result of running the program shows that the most probable option in this case is Injection and the pipeline usage, CHP, liquid fuel production, electricity production and petrochemical products stand at the next priorities respectively.

DISCUSSION OF THE RESULTS

Two groups of cases were considered in this analysis. One group (Cases 1–3) was designed with priority given to individual indicators, while the other indicators had the same value, and the second group (Cases 4–6) consisted of cases where the priorities were defined always keeping one criterion in first position, while the priorities of the other criteria were defined by ordinal information defining the mutual relations of the criteria and the respective indicators.

When the priorities are the same the results are presented as shown in case 7. The second group comprises cases with hierarchical constraints, with changing priority in constraints in each case. Amongst these cases, priority is obtained for CHP usage in Case 6 and Case 2 where Availability indicator is highly weighted while the pipeline usage is obtained in Case 1 and Case 4 (Environmental indicator highly weighted).

The Injection priority is obtained in Case 3 and Case 5 where economical indicator is highly weighted and also when the weighing factor of all the criteria are the same the Injection priority is obtained.

CONCLUSION

As a result, where availability is the most important criterion, the CHP usage is chosen by the model while the priority goes to injection if the economical criterion has the highest importance.

Even if this type of analysis contains arbitrariness in the evaluation of the priorities among the alternative options, it is noticed that the Injection option and the pipeline usage and CHP option are the best choices under the constraints used. By increasing the number of cases to be analyzed, a better result for decision making should be obtained.

It should also be noticed that, in this type of evaluation, further improvement of the data might lead to higher quality results.

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