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Review about Emission Reduction in Oil Extraction Using Low Methane Fuels in Natural Gas Combustion Engines

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Abstract

Gas flaring is the burning process of the unwanted raw natural gas that cannot be processed or sold during the oil and gas extraction and process operations. Some decades ago, gas flaring was considered to be environmentally acceptable. Nevertheless, the growth of the oil and gas industry has resulted in an increase of gas flaring; alerting the public its dangerous impact on the environment. After this increasing consciousness, scientists have started working to tackle it. From this review, an alternative to generate electricity and heat with associated petroleum gas (APG) is proposed in accordance with fabricants. The proposed method is to burn the APG, which is a low methane number fuel, with a new branded Siemens SGE-86EM 2MW natural gas internal combustion engine. Finally, the main conclusion obtained is a need to investigate the technical feasibility and understand the combustion phenomenon in natural gas engines operating low methane number fuels as well as proposing a technology as an alternative to the present gas flaring; which is facing severe challenges due to the stringent emissions norms.

Keywords: Associated petroleum gas; internal combustion engine; low methane number.

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1. Introduction

Gas flaring is the burning process of the unwanted raw natural gas. During the extraction process, a fluctuating amount of associated petroleum gas (APG), which is found in the reservoir together with oil, is burnt or released into the atmosphere. Companies usually consider this gas a by-product of oil, and it is disposed of by a loco flare combustion process [1].

However, it is common to use a part of the treated natural gas as fuel for covering the needs of the plant, while the remaining natural gas is processed, reinjected or sold. Only when it is not possible to sell or process it, due to reasons such as lack of infrastructure, inexistence of a close gas market or even economic causes; the natural gas in excess is flared [2].

Until the past few decades, flaring was believed to be environmentally tolerable. However, the growth of the oil and gas industry during the last decades has resulted in an increase of gas flaring; alerting the public its dangerous impact on the environment. It is noteworthy that during the combustion process several pollutants, such as nitrogen oxides (NOx), hydrogen sulphide (H2S), sulphur oxides (SOx), and volatile organic compounds (VOCs) are produced [3].

According to the Global Gas Flaring Reduction (GGFR) initiative, conducted by the World Bank [4], the annual volume of natural gas flared in the world amounts to about 150 billion cubic meters (about 30% of the European Union’s annual gas consumption) with a consequent emission of about 400 million tons of CO_2. That is why the Zero Routine Flaring by 2030 initiative has been launched and already signed by more than 55 governments, oil companies, and development institutions with the aim of reducing the flare.

As a consequence of the increasing awareness of the environmental concern, and the ratification of the Kyoto protocol by most of the member countries, gas flaring was expected to be reduced significantly [6].

Nevertheless, in spite of all the efforts, the annual flaring numbers have remained practically stable for the last years. This is justified by the growth of global oil production and thus, the increase of APG extracted which is usually found together with oil as stated before.

In the same way, the lack of regulations and the current constraints in gas utilization, infrastructure and market development are the main factors that contribute to continue flaring [5].

In a nutshell, it is evident that from a social perspective, gas flaring is a danger to human health and environment, specially, close to the areas where the flare is located. In contrast, from an economic point of view, gas flaring is a loss of natural resources since the flared gas has an energy content that is being wasted.

Currently, many approaches are being proposed by different researchers in order to take benefit of the flared gas. Nonetheless, many of them still lack of economic feasibility and efficiency.

During the past years, oil companies, motivated by environmental policies and economic reasons, have considered various alternatives to reduce the amount of flared gas Mourad and his colleagues [7] and De Gouvello [8] presented some alternatives to flaring:

1. Flare gas reinjection into fields for enhanced oil and gas recovery;
2. Construction of a transport infrastructure for collecting and shipping flared gas to treatment plants;
3. Converting flared gas to liquid: Gas-To-Liquid (GTL) or Liquefied Petroleum Gas (LPG);
4. Converting flared gas to Liquefied Natural Gas (LNG);
5. Onsite electricity generation and recovering exhaust heat for further use (CHP-Combined Heat and Power);
6. Onsite fuel source;
7. Using flared gas as a feedstock for petrochemicals production.

According to Romano [9] reinjection and sending the natural gas distribution network, at the moment only finds an economic justification for quantities of gas above tens of thousands Nm^3/h. Whereas the on-site electricity generation seems to be suitable for associated gas flows in the order of a few thousands of Nm^3/h.

It is important to remark that the work proposed herein would underline the generation of electricity and heat using wellhead gas as a fuel in internal combustion engines (ICEs). This could potentially assist companies in obtaining an economic and environmental revalorization of their oil and gas extraction and processing plants.

The decision of investigating this particular method is supported by the study conducted by Bakhteeyar and his colleagues [10]. The results showed that priority is obtained for CHP usage where availability indicator is highly weighted, while the pipeline usage is the best option where environmental indicator is the most important. Reinjection obtains the highest mark where the economic indicator is the priority. Finally, when the weighing factor of all the criteria are equal CHP is considered to be almost as good as the pipeline usage and the reinjection.

In spite of the fact that this study shows that pipe usage or injection are the best options, it is important to reiterate that these methods cannot always be applied since high flows of gas are needed as well as infrastructure and market possibilities. That is why there is a big market niche for CHP wherever there is a small quantity of APG available or just when there are no options to sell the natural gas.

Additionally, it must be noted that the main characteristic of this type of gas is its low methane number (MN) caused by the high amounts of heavy hydrocarbons. Unfortunately, this fact dramatically limits the operation of the engines, reducing the knocking limit and thus its thermal efficiency and power output [1]. Current standard gas ICEs available on the market are designed to operate with fuels with a similar composition to natural gas (MN > 65). Therefore, APG is not usually compatible with this sort of ICEs. So, in order to avoid detonation problems, some technical changes are mandatory to allow the engine run with low MN fuels close to 45.

The problem outlined in the previous paragraph can be solved in two different ways. The first method is the usage of a cleaning system, which increases the methane number of the gas permitting a standard gas ICE to run without knocking problems. The adoption of this method is known as Non-Derated ICEs (ND-ICEs)

Nowadays, several gas treatment technologies that upgrade the methane number removing a large part of heavy hydrocarbons are available on the market and the most important ones can be listed as follows [11].

1. Separation of gas fractioning;
2. Low-temperature separation;
3. Membrane technology;
4. Adsorption technology.

Using these techniques, the MN could be increased between 10 and 20 points [12]. However, each kind of technology present benefits and drawbacks.

According to Zyryanova and his colleagues [13] and his economic analysis comparing different types of engines with electric power of 1000 kW (Waukesha and Perkins) she discovered that: The plants furnished with a catalytic reformer of APG into methane–hydrogen mixture appear to provide a faster payback of capital investments, compared to the plants fed by APG directly. Advanced economic characteristics are achieved thanks to longer service life of the units, longer over-haul intervals and accomplishment of the rated power. Therefore, the technology that provides a rise of the methane number for APG looks promising for power generation applications.

On the other hand, the second method implies a reduction in the output power and thermal efficiency as well as some technical changes since the APG is directly fed to the engine without the reduction of heavy hydrocarbons. The adoption of this method is known as Derated ICEs (D-ICEs).

Direct APG fuelling adversely influences operation of the gas engine and decreases its life (most often more than twice) due to different reasons such as; fuel equipment clogging, oily and waxy deposits, knocking and overheating risks with subsequent damages and earlier failure of engine components.

Methane number determines the knocking resistance of a gas. For flare gas in particular, MN widely varies between 30 and 90 depending upon its composition [14]. In fact, that is the reason why we say that APG is a low methane number fuel, whereas natural gas MN is around 75. The higher the lower prone to knocking the gas would be.

This characteristic causes knocking to occur, which is a phenomenon that appears when the flame front propagates at a speed greater than that of sound. Being the pressure wave the one that increases the energy of the unburned gases through compression. This knocking causes an abnormal combustion that due to its violence, can cause serious mechanical damage to the pistons or other parts of the chamber.

Further to this, the intrinsic characteristics of the well gas favour auto-ignition. If a certain temperature is exceeded during the compression process, a series of free radicals are generated that trigger the auto-ignition of the unburned mixture, releasing its energy earlier than expected. In practice, it is usually really complex to differentiate between knocking and auto-ignition. This is because they produce very similar effects and the chamber pressure graphs show very similar shapes.

To overcome these two phenomenon is one the biggest challenges for the internal combustion engine technology.

The analysis carried out by Iora and his colleagues [1] who compares N-DICEs and D-ICEs from economic and environmental points of view concludes that D-ICEs have significant environmental benefits comparing to the ND-ICEs, having both a similar payback for the investment required. It has been proved that D-ICE for gas flaring reduction is a feasible and one of the most interesting ways to tackle the flaring problems analysed.

Last but not least, among all the advantages of ICEs, one of the main characteristic relies on the wide range of power outputs available (from few kW to 15 MW).

Furthermore, they are usually sold in a modular construction installing units of reduced power. This fact permits high thermal efficiency together with a high flexibility, as partial loads caused by the flow changes could be eliminated. Moreover, this configuration allows the reutilization of the engines in different plants which is especially interesting since the amount of APG reduces as the time goes by in the oilfields.

After the recent launch of SGE-86EM specifically designed for natural gas 2MWe engine, Siemens decided to design its counterpart for the oil and gas business unit. That is the main reason why a new engine that could be directly fed with low methane number fuel needs to be developed and tested.

However, this will not be an easy task due to two main constraints. The first one resides in that The utilisation of associated petroleum gas in lean burn gas internal combustion engines involves some difficulties due to a significant content of heavy C5+ hydrocarbons which are prone to knocking and soot and tar formation.

Indeed, According Arutyunov [15] gas fired engines using fuels with methane content under 70% necessitate reduction in the capacity to ≤50% of the nominal level to avoid detonation and overheat of engine, associated with a high calorific value of fuel. But some manufacturers, in the strive to be able to declare the operability with associated gas, use gas-piston engine modifications with decreased compression ratios by 25–30% and above. For example, in the case of a VHP9500GSI Waukesha engine with the nominal capacity of 1250 kW a decrease in the compression degree from 10.5 to 8.0 for reference fuel enables decreasing the methane index requirements to 36, but this is paralleled by a decrease in the engine capacity to 1050 kW.

Further to this, the SGE-86EM works with a fuel injected pre-chamber which makes the efficiency of the engine that high. But this application prioritises robustness and this technology will definitely be a working limitation. Thus, through different tests a decision will need to be taken in regards to the ignition system.

At the moment the engine is burning APG, a fuel with heavy hydrocarbons and impurities, there is a high probability of obstructing the check valve inside the pre-chamber unit. The obstruction of the valve could turn into an ignition failure finally stopping the engines. Contaminants are a serious concern with flare gas and if they are not properly removed, they can seriously damage the engine.

In case the injected pre-chamber is decided to be installed an exhaustive maintenance/cleaning procedure must be implemented. It is considered that every 500h a maintenance should be scheduled for the correct operation of the pre-chamber gas supply system. This cleaning procedure takes long and it is done through ultrasound machines, lowering the reliability and increasing the OPEX cost.

Moreover, if this combustion technology is maintained a gas cleaning process where the methane number is not increased must be included in the installation. In addition, this system requires a high pressure line and an adjacent gas train. This high pressure might be available, if not, a gas compressor would need to be fitted making the system more sophisticated and costly.

Unfortunately, the choice of not introducing an injected pre-chamber reduces the fuel efficiency for the same knocking margin. Nonetheless, as it has been reiterated robustness will prevail over efficiency.

As expressed in the previous paragraph this first challenge could be solved by introducing a new combustion technology such as using an unscavenged pre-chamber or an open chamber. This decision is vital since this fact will determine part of the rest of the elements of the combustion chamber.

It must be taken into consideration that the installation of an unfueled pre-chamber entails a challenge in charge renovation of the pre-chamber volume itself. In the previous system, a very small portion of the combustion gases inside the pre-chamber was evacuated during the exhaust stroke but most of them were evacuated after the fuel injection in the pre-chamber during the intake stroke. It is known that this last stage does not exist anymore with the unfuelled pre-chamber system and therefore makes the charge renovation more difficult. This trouble is intended to be tackled by an optimization of the pre-chamber volume, pre-chamber nozzles and spark plug position.

In this sense, from this literature revision, it is concluded a future pending task to investigate the technical feasibility of adapting a SGE-86EM engine for power generation operating with Associated Petroleum Gas (APG). In particular, it will be evaluated how much the current engine employed for this purpose has to be derated in order to safely burn a low methane number fuel. Further to this, according to experimental data a decision will need to be taken in terms of ignition technology.

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