HydroFlame – A Low Carbon Intensity Process for Low-Mobility Oil Recovery

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ABSTRACT

HydroFlame is a new concept of burning a fuel directly inside a rotating stream of water. Because of the direct contact between the flame and water, very high heat transfer coefficients are achieved which render the HydroFlame devices as quite compact and highly efficient heat transfer systems. This process has several engineering applications, including hot water heaters, and compact Surface/Downhole steam generators for thermal heavy oil recovery. Steam generators developed using this unique "flame-in-water" concept can be applied either on surface or downhole at any depth, enabling the delivery of high quality steam along with exhaust gases, containing CO_2 and N_2, into the reservoir reducing greenhouse gas emissions. The injected gases rise to the top of the reservoir, forming a gas blanket that prevents heat loss to the overburden, thus improving the economics of thermal enhanced oil recovery (EOR).

Keywords: hydroflame, downhole steam generator, heavy oil, greenhouse gas, enhanced oil recovery

1 INTRODUCTION

With declining light oil discoveries (light oils are those with API gravity greater than 25°API), the vast reserves of heavy oil (oils with API gravity between 10°API and 20°API inclusive and viscosity greater than 100 cP) and bitumen (oils with API gravity less than 10°API and viscosity greater than 10,000 cP) are becoming increasingly important as a future energy source. According to the United States Geological Survey, approximately 2 trillion barrels of heavy oil and bitumen are located in reservoirs deeper than 2500 feet [1]. Both heavy oil and bitumen are too viscous to flow in their naturally occurring state. Steam injection into these unconventional reservoirs is widely applied to reduce oil viscosity in order for it to flow to a producing well.

Once-through surface steam generators (OTSGs) are currently the state-of-the art for steam generation. In OTSGs, steam is generated on the surface and injected downhole into the formation through thermal tubing/casing. Some of the limitations of OTSGs include:

1. Heat losses through transmission pipelines, long wellbores and vent flue gases can add up to 50% of total heat generated.

2. Surface generators cannot be applied economically to reservoirs deeper than 2500 ft due to heat losses during delivery and the loss of steam quality at the sandface (physical interface between the oil formation and the wellbore) [2]. Use of vacuum insulated tubing (VIT) is not a viable option to many producers due to the high costs (15times that of conventional tubing) and reliability issues [3]. Furthermore, heat losses from the couplings that connect the individual VIT joints results in disappointing performance [3].

3. At oil/steam ratios ranging from 0.3 to 0.5, surface steam generators produce 80 to 140 lbm of carbon dioxide for every barrel of heavy oil produced [4].Cosequently, the heavy oil producers are faced with difficulties in obtaining government permits to produce these heavy oil reserves.

In order to overcome these limitations, it is necessary to develop reliable, long-lasting steam generators that can operate on surface (for depths < 2500ft) as well as in downhole (for depths >2500ft). As opposed to surface-operated OTSGs, HydroFlame Surface/Downhole Steam generators can be lowered into the oil well close to sandface (the oil bearing zone) eliminating heat losses through pipelines, wellbores and vent flue gases. The flue gases, comprising mainly of carbon dioxide and nitrogen, are injected along with steam into the oil formation thereby not only reducing greenhouse gas emissions but also repressurizing the reservoir to enable longer production life.

2 HYDROFLAME PROCESS

Although the concept of Downhole Steam Generator (DHSG) has been and is still being explored by many, the real issue at the center, namely effective heat management to control the combustor wall temperature, remains to be addressed.

The past as well as present designs address the cooling of burner walls by running feed water in a sleeve or liner placed around the combustion chamber. Examples of some DHSGs that apply this principle include Sandia National Laboratory's DHSG designed and field tested for project

Deep Steam in the 1980s [5], Precision Combustion's downhole catalytic combustor steam generator [6], as well as other patented designs [7][8][9][10].

This method of external cooling results in extreme thermal stresses due to high temperature differences across the combustor walls that eventually lead to thermal degradation. One consequence of this is blocking of water passage by deformed wall preventing cooling to some areas of the combustor, and even melting of the walls. Another could be cracks in the combustor walls that results in water leaking into the combustion chamber [5]. These issues were observed during the Deep Steam project. Thus, a DHSG based on this pattern of outside cooling does not perform reliably over extended periods of operation.

The novel HydroFlame process in which flame is in direct contact with the feed water provides an innovative solution to this major problem. This is achieved by creating rotating films of the feed water so as to cover the combustor inner walls and igniting flame within the air core of the rotating body of water. This concept is illustrated in Figure 1 below. The combustor walls are exposed to only the water temperature, thus, eliminating thermal stresses that result in combustor failure.

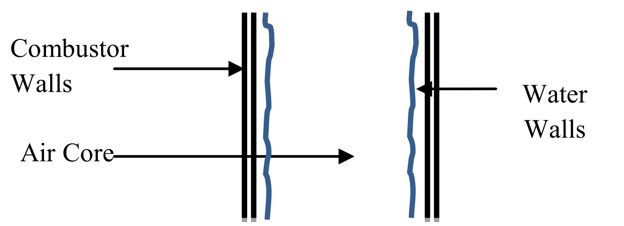

Figure 1: Illustration of air core surrounded by water walls inside combustor

The air core is formed by injecting water tangentially into the lower interior of the combustion chamber. A high intensity flame is generated in the air core by injecting air and fuel at the top of the combustor and igniting them by means of glow plugs positioned at the top of the combustor. The fuel and air mix within the combustor giving rise to a diffusion flame that is safe to operate and also is self-sustaining. The films of rotating water protect the combustor walls from the flame in the middle of the combustion chamber.

This "flame-in-water" concept of HydroFlame is the fundamental change in the way combustion has been traditionally carried out in various devices designed for generating heat energy. This innovative concept provides opportunities to develop compact DHSGs required in heavy oil and bitumen recovery operations.

3 TECHNICAL PROGRESS

As part of research &development, a 1-MMBtu/h 100 psi working prototype of the steam generator has been built and successfully tested at HydroFlame facility in Baton Rouge, Louisiana. Figure 2 shows a natural gas flame surrounded by water films in a 1-MMBtu/h steam generator. A polycarbonate tube forms the walls of the combustion chamber and is unharmed by the high intensity flame due to protection by water walls thus depicting the significance of HydroFlame process.

Figure 2: 1-MMBtu/h -100 psi steam generator in operation at HydroFlame facility in Baton Rouge

This was followed immediately with the design, development and successful testing of two 5-MMBtu/h - 500 psi steam generators. These are fully automated, skid mounted trailer units that are applicable for the surface or downhole operations. A trailer-mounted compact HydroFlame steam generator is shown in Figure 3 below. Although designed for 750 psi with 500 psi operational pressure, it was successfully operated at 600 psi in the field and has turndown ratios of 2-6 MMBtu/h depending on pressure.

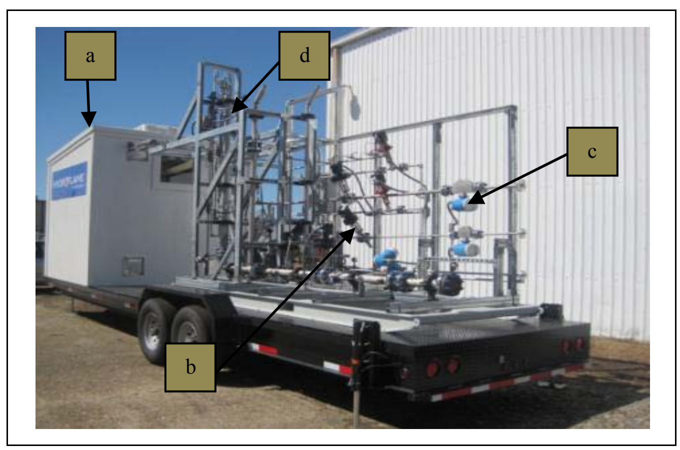

Figure 3: 5-MMBtu/h – 500 psi HydroFlame steam generator on a skid-mounted trailer – (a) Control room (b) Control valves (c) Flow meters (d) 5-MMBtu/h -500psi HydroFlame Tool

4 FIELD OPERATIONS & RESULTS

The first surface field test of 5-MMBtu/h steam generator was conducted in a heavy oil field in Louisiana during February – April, 2012. Reservoir depth and oil gravity were 1100 feet, and 16.8º API, respectively. The Test well last produced in 1985 at 5 BOPD that declined to 2 BOPD and it was shut-in since then. Production attempts were made in 2006 which failed to produce any oil. When steam and flue gas were injected from the surface using the 5-MMBtu/h HydroFlame steam generator in a Cyclic Steam Simulation (CSS) process, a total of 1153 bbls of oil were produced over a few months when the well was put on production after a week of steam injection/soaking. In April – May, 2014, a second cycle of steam injection was started on the same well for one week. The well tested at 14 BOPD when placed on production on second week of May, 2014. It accumulated 1698 bbls of oil as of October, 2014 and, as per the last report from the Producing Company, it was still continuing to produce at 9 BOPD.

Figure 4: 5-MMBtu/h – 500 psi HydroFlame steam generator in operation at an oil field in Louisiana

With success of these two surface field tests, preparation for a downhole test, and research and development of higher capacity units have begun.

5 ADVANTAGES OF HYDROFLAME

The impacts and benefits of HydroFlame process steam generators compared to other conventional steam generators are:

- *Reduction in greenhouse gas emissions* - All exhaust gases from the combustion reaction are injected into the reservoir along with the steam, resulting in natural sequestration of CO_2.
- *Pressure maintenance* - Reservoir pressure declines as fluids are produced from the reservoir. As a result, the production rate declines and eventually stops when the reservoir pressure is depleted. At this point, mechanisms to improve production such as artificial lift (pumps), water injection, or gas injection are implemented. In the application of the HydroFlame DHSG, flue gases (carbon dioxide and nitrogen) are injected into the reservoir along with the steam. These flue gases rise to the top of the reservoir and form a blanket. The reduction in reservoir pressure when fluids are withdrawn is offset by the increase in pressure when these gases are injected thereby maintaining the reservoir pressure or significantly lowering the pressure decline rate. This enables higher production rates, longer production times, and improved recoveries – without the need for additional pumping equipment.
- *Smaller footprint* – Since flame is in direct contact with water, very high heat transfer coefficients are achieved which render the HydroFlame devices as quite compact and highly efficient heat transfer systems. The compact HydroFlame DHSG has a significantly smaller footprint than the presently used oil-field steam generators.
- *Reduction in heat losses and increased thermal efficiency* **-** Heat losses of up to 50% that occur in conventional surface steam generators in deep heavy oil applications are eliminated by the use of HydroFlame DHSG. These heat losses arise from stack gases, pipelines and wellbore losses. With surface steam generators, large insulated pipelines from the location of the steam generator to the well head are required to reduce pipeline heat losses. Building insulated pipelines adds to the capital cost of an already expensive steamproject, in addition to leaving a large footprint. Even if the HydroFlame DHSG were operated on the surface, it could be operated in close proximity to the well head, eliminating both pipeline losses and stack gas losses.

- *Production of heavy oil reserves from deep reservoirs and offshore* - The HydroFlame DHSG appears to have no depth limitation. Hence, it can be applied to reservoirs that are too deep for surface steam injection (typically, reservoirs located at depths greater than 2500ft). In addition, conventional steam generators cannot be applied offshore due to lack of space for equipment. However, this limitation would not be an issue for the HydroFlame DHSG, due to its compact design and high efficiency and low space requirement for compression equipment.
- *Reduced water treatment* **-** Because the transfer of heat between the hot combustion gases and the water is direct in the HydroFlame DHSG, and because no heat conduction materials are required, water of lower quality can be used, compared to that used in surface steam generators. In situations where scaling ions (carbonates and sulfates) are present in the produced water in high concentrations, scale inhibitors can be injected with the water to prevent scaling. Less stringent water quality requirements mitigate the need for expensive water treatment.

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