Using the Rosemount Analytical Oxygen Analyzer to Measure Oxygen on Oil Field Steam Flood Steam Generators

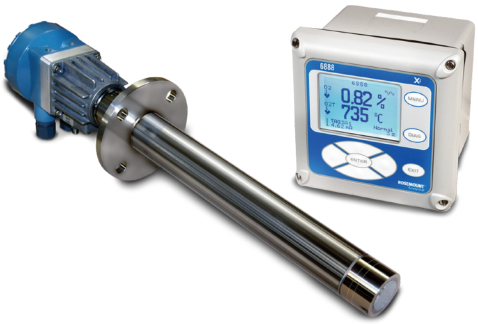
Background

Oil field steam flood steam generators have been in use to aid in the recovery of heavy oil (ex. 13 API gravity) for more than thirty years. These steam generators burn fossil fuels such as natural gas and in some cases some of the oil being produced to turn water into steam. The steam, which is injected into oil formations at very high pressures (up to 2,600 PSI), is allowed to mix with the oil in the rock formations and thus reduce the viscosity of the oil. As a result the oil may be pumped to the surface more quickly and efficiently. Without steam injection oil fields in California, Indonesia, China, Russia, and Canada could not have economically produce the large quantities of oil they did over the past several decades. This method of oil production continues today and is now being employed in several parts of the world, which until now have not relied on steam injection to enhance oil production. These areas include fields in Oman and Kuwait.

History of Oxygen Measurements in Steam Generation

The use of modern steam generators for oil production enhancement was pioneered in the oil fields of California following the 1970s oil embargo. The increasing oil prices justified the additional costs of steam generation to revive oil fields, which had previously been depleted of the easily produced light oil. While this technology dramatically increased oil production in California, it did so with a high environmental price. The use of crude oil to fuel the steam generators produced large quantities of Oxides of Nitrogen (NOx) and Carbon Monoxide (CO). These emissions had a severe negative impact on the already poor air quality in California. At the time oil fired steam generators produced as much as 175 PPM NOx and 2000 PPM CO.

Government regulations were enacted in 1980, which required oil producers to reduce emissions of NOx and CO. The new regulations set maximum NOx emission levels at 75 PPM and maximum CO emission levels at 400 PPM. In response to these new laws several methods of emission reduction were tried including the use of



In Situ Oxygen Transmitter, 6888, with Xi Enhanced Interface improves accuracy and reduces calibration maintenance costs

low NOx burners, staged combustion and improved combustion control. The improvements in combustion control evolved into better air fuel ratio control through the Application Data use of an oxygen measurement. Steam generator burners were operating at differing air fuel ratios and it was discovered that by measuring oxygen a relationship between excess stack oxygen and NOx existed. The higher the excess burner oxygen levels produced higher NOx levels as well. Conversely, the lower excess oxygen levels produced lower NOx levels. NOx formation is reduced when the availability of free oxygen is reduced in the flame since the more reactive hydrocarbon fuels tend to react with the combustion air oxygen first allowing the less reactive Nitrogen to from oxides only when the oxygen remaining after the combustion of the fuel is complete. Oil field operators did not fully appreciate but soon became aware that lower excess oxygen levels also resulted in higher combustion efficiency. This of course resulted in lower operating costs. Oxygen measurement and control was a lower capital cost solution than low NOx burners and staged combustion and since it also provided reduced operational cost benefits it became the preferred method of emission reduction.

ROSEMOUNT® Analytical

EMERSON™ Process Management

Emerson's Rosemount Analytical Oxygen Analyzers

In 1980 The Westinghouse Combustion Control Division (now Emerson Process Management) introduced the in situ low-cost Zirconium Oxide-based instrument to address the increasing demand for Oxygen analysis instrumentation capable of aiding in combustion control. As a result, Emerson's Rosemount Analytical instrumentation was soon installed on 30 % of the steam generators in use in California. The popularity of the instrument grew into the late 1980s despite the fact that it had two major shortcomings: the instrument was very difficult to repair and required clean instrument air in order to operate. Most oil field instrument air contained significant amount of oil and water, which caused the Oxygen probe to fail prematurely. Since the probe was not easily repaired a probe failure became a difficult service issue to resolve. In the late 1980s Emerson modified the instrument and solved both these problems. The new, refined analyzer was capable of operating with out the need for instrument air when used out doors. All steam generators did operate out doors and therefore the Rosemount Analytical instrument could be used without the need for instrument air. In addition to the instrument air modification, the analyzer was designed to be easily field-repaired which made the instrument very popular with oil field steam generator operators. The number of steam generators using the Rosemount Analytical analyzer in California soon rose to more than 50 %.

Despite the improvement made combustion control during the 1980s as a result of the contribution made by improved Oxygen measurement, the sheer numbers of steam generators, which burned oil, made the air quality in the vicinity of the plant unacceptable. In addition the rising cost of using crude oil as a fuel made it's continued use untenable. By the late 1980s cleaner burning natural gas had become the fuel of choice for steam generator operators. Regulators, however, pushed for still lower NOx emission limits of 30 PPM which the burners in use at the time could not meet even with the most precise Oxygen measurement and control. Oxygen measurement of another kind would soon provide a solution.

Exhaust Gas Recirculation (EGR) and Flue Gas Recirculation (FGR) Methods

During the late 1980s, a method of further reducing NOx using technology pioneered by the automotive industry in internal combustion engines known a Exhaust Gas Recirculation or EGR was applied to the external combustion process. Developments made as a result of additional research and testing by Esys The Energy Control Company and the Mobil Oil Corporation on steam generators resulted in a NOx reduction strategy, which became known a Flue Gas Recirculation or FGR. This method mixed flue gas with the ambient air to provide combustion air for the burner, which had a lower Oxygen concentration than ambient air. As a result, the volume of combustion air required to deliver the proper mass of Oxygen to the burner to achieve the proper air fuel ratio becomes greater. The larger combustion air volume produces a larger flame volume, which causes the flame temperature to be lower for the same amount of heat release. Since the oxidation of nitrogen is an endothermic reaction more NOx is produced at higher flame temperatures than at lower flame temperatures. In order to oxidize Nitrogen, Oxygen is also required. To the extent that Oxygen is reduced, as was demonstrated previously, NOx formation is reduced. The reduction of combustion air Oxygen by the introduction of flue gas therefore further contributes to NOx reduction.

Accurate Flue Gas and Oxygen Measurement with Rosemount Analytical Oxygen Analyzers

Introducing the correct amount of flue gas proved to be effective in lowering NOx levels below 30 PPM while maintaining CO levels below 400 PPM. Proper control of the air to flue gas ratio is critical. Too little flue gas for a given amount of air would result in insufficient NOx emissions reduction. Too much flue gas would result in flame instability owing to the combustion air velocity becoming too high causing flame "blow off" from the burner as the mass flow of Oxygen depleted combustion air increases due to the additional volume resulting from the addition of flue gas. Excessive flue gas also results in excessive flame volumes which allow the flame envelope to impinge on the steam generator tubes. This causes a cessation of the combustion process. Carbon, which would normally, completely combust to carbon dioxide instead forms high levels of CO. In order for the FGR strategy to work, precise control of the mixture of flue gas and air is must be maintained by continuous measurement and control. This can be achieved by measuring the mass flow of the air and the mass flow of the flue gas. Such a method would require six measurements. The flow of the air and flue gas would need to be measured using a low-pressure drop producing volumetric flow measurement device such as a petot tube. The volumetric flow readings would have to be corrected by measuring the air and flue gas temperature and the air and flue gas pressure. Another simpler method and the method which proved to be the most successful was to measure resulting mixture of flu gas and air for the proper Oxygen concentration directly using an in situ Oxygen analyzer. This eliminated the need to measure six variables in favor of one and provided a means of directly measuring the results of the air and flue gas recipe. This technique had been tested years earlier by the Southern California Edison Company on large utility boilers but was never permanently implemented. When adapted to steam generators, the measurement of Oxygen to control the flue gas to air ratio ultimately proved to be very reliable and accurate.

The Oxygen analyzer of choice for FGR control again became the Rosemount Analytical oxygen analyzer. This was due in large part to the fact that the analyzer, in order to measure the air-flue gas mixture, had to be installed at the blower discharge where the mixture become homogeneous and could be measured accurately. This area is usually operating at high pressure. The measurement required for determining proper air-flue gas ratio is the partial pressure of Oxygen the burner is presented because the partial pressure value of Oxygen is what is meaningful in order to predict flame behavior. The Rosemount Analytical oxygen analyzer can measure the partial pressure in the duct and can be calibrated taking into account the effects of the high static pressure in the duct providing the necessary data for the control system to correctly ratio the air and flue gas. Given that the flue gas contains products of combustion such as water vapor, which condenses when mixed with the cooler air, liquid water can form in the combustion air stream. This makes the use of extractive analyzers, which were typically still in use at the time for measuring stack gas Oxygen concentrations, impractical. The combustion air stream unlike the exhaust gases from the combustion process is cool. The analyzer used to measure Oxygen concentrations in the combustion air stream must therefore include a robust cell heater some competitive analyzers still in use either had no cell heater at all or were equipped with cell heaters which were inadequate when faced with high mass flows of air below 140 degrees Fahrenheit which is the typical combustion air temperature resulting from the mixture of flue gas and ambient air.

In the early 1990s use of the Rosemount Analytical in situ oxygen analyzer exceeded 75 % of all steam generation plants. The use of FGR to reduce NOx increased drastically in popularity. These steam generation plants employed Oxygen measurements and control for managing the introduction of flue gas into combustion air and most selected the Rosemount Analytical oxygen analyzer. In order to standardize, new users also selected Emerson's Rosemount Analytical oxygen analyzer for flue gas measurement as well.

Recent Regulations for Steam Generation and the Continued Use of Rosemount Analytical in SITU Oxygen Analyzers

In 2005 the regulations in California governing emissions of steam generators were tightened further. The evolving burner technology allowed the industry to comply with these regulations by offering revolutionary burner technology, including Lean Premix. This technology blends air and fuel in a very lean mixture prior to ignition. This results in a flame with Oxygen levels of eight to nine percent within the burner combustion chamber. This produces a flame, which is very cool (below 2,500 degrees Fahrenheit). This cool flame, while on the verge of instability, produces low NOx levels since temperatures in excess of 2,500 degrees are required to produce high levels of NOx. Additional amounts of fuel are added by the burner into the high excess Oxygen flame envelope as it exits the burner combustion chamber to reduce the total excess Oxygen levels to efficient levels of 2.5 % to 3.0 %. The net result of this method is to produce very low NOx emission levels of less than 6 PPM with CO levels less than 5 PPM.

These low NOx burners demand very strict air fuel ratio control in order to maintain stable operation and low emissions. A rise in total excess Oxygen above 4 % can result in violent flameouts caused by a drop in flame temperature below the level required to maintain combustion within the combustion chamber. Excess Oxygen levels below 2 % causes a rise in flame temperature and a sharp rise in NOx. Accurate control of air fuel ratio is therefore critical.

For the safe and efficient operation of this new style of low NOx burners, the use of Emerson's Rosemount Analytical oxygen analyzer continues to be the analyzer of choice.

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