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Internal Technical Paper

FEEDWATER FOR OILFIELD STEAM GENERATORS

Oilfield steam generators are designed to produce wet steam in the range of 80% quality and at pressures up to 2500 psia for injection into heavy oil reservoirs to enhance the recovery of viscous crude oils. Steam injection is a successful and expanding enhanced oil recovery technique which is being widely used in heavy oil reservoirs in California, Western Canada, Venezuela, Indonesia, the U.S.S.R., and the People's Republic of China. Because of the widespread and increasing usage of the steam injection process, the reliable operation of oilfield steam generators is receiving considerable attention.

Oilfield steam generators are unique in the field of steam generation in that they are generally required to operate with feedwater having a much higher total dissolved solids content than in any other steam generation application. The usual practice in the oilfields is that the oilfield steam generator feedwater is produced water which has been pumped from the producing wells with the crude oil, separated from the oil, and then treated. In its passage through the formation, the condensate from the injection steam leaches solids from the formation, with this leaching process continuing as the water is recycled through the formation. There are two basic reasons for using the produced water as feedwater for oilfield steam generators:

In many areas where steam injection is being used, fresh water supplies are limited.

Reuse of the produced water in this application minimizes the problem of disposal of the high salinity brine produced with the crude oil.

The Table I, shows typical feedwater compositions for which oilfield steam generators must be designed. It can be seen the oilfield steam generators can take feedwaters ranging in total dissolved solids content from 1000 to 12000 ppm. The oilfield steam generator design which has proven successful was based on a philosophy of converting the solids to soluble form, and then leaving sufficient water at the steam generator outlet to maintain the solids in solution. This is the basic concept of the so called "wet steam generator". The objective of the design is to generate steam from feedwater containing high total dissolved solids without allowing the solids to deposit on the tube walls which would lead to rapid tube burnout.

Oilfield steam generators with carbon steel tubes have operated at elevated temperatures and pressures for over forty years handling feedwater with high levels of complex salt mixtures, including high chlorides, without any significant tube side corrosion. The approximately forty years of experience with oilfield steam generators have proven that high pressure steam can be generated from high TDS feedwater in carbon steel tubes, provided the proper precautions are followed in pretreatment of the feedwater.

Certain factors which experience has shown to be important in preventing corrosion in the carbon steel tubes of oilfield steam generators handling produced water with high total dissolved solids include the following:

Steam/Water mixture velocity through the tubes
Oxygen content of the feedwater
Hydrogen sulfide content of feedwater
pH of feedwater
Iron content of feedwater
Silica content of feedwater

Each of the above factors will be individually discussed.

Steam/Water Mixture Velocity

Investigations have shown that an oxide film forms on the inside of the tubes after a short period of operation which serves as a protective barrier against corrosion. While it is important to design an oilfield steam generator for high tubeside velocities in order to achieve the highest possible heat transfer film coefficient and minimize the tube wall temperature, it is also critical that tube side mixture velocities are maintained below the level where erosion would be experienced. If tubeside mixture velocities in the erosive range are reached, the protective oxide film will be continuously removed and fresh metal will be exposed to the flowing stream. Excessive tube side velocities will definitely result in accelerated corrosion of the tubes.

It is recommended that the following mixture velocities based on the average mixture density not be exceeded for oilfield steam generator service:

Outlet Steam Pressure PSIA	Minimum Outlet Velocity Ft/Sec.
600	180
1000	150
1500	95
2500	60

At the above maximum recommended oilfield steam generator mixture outlet velocities, experience has indicated that the protective oxide film on the tube walls will not be eroded.

Oxygen Content of Feedwater

Oxygen is highly corrosive to the carbon steel tubes used in oilfield steam generators, and must be reduced to low levels in the steam generator feedwater. The maximum oxygen content of feedwater for oilfield generators is recommended not to exceed 0.1 ppm.

The feedwater to oilfield steam generators will typically range in temperature from 60^{o}F to 170^{o}F, depending on the source of the water and the type of pretreatment to which it is subjected.

On gas fired steam generators, it is desirable to maintain the feedwater inlet temperature as low as possible in order to achieve the maximum steam generator thermal efficiency. On oilfield steam generator fired with sulfur bearing oil, it is generally necessary to preheat the feedwater before it is introduced into the economizer section of the steam generator in order to avoid acid dewpoint corrosion on the outside of flue gas side of the tubes. These considerations may dictate the type of oxygen removal technique to be used.

The oxygen content of the feedwater may be reduced to acceptable levels either by the addition of oxygen scavenging chemicals, or by low pressure steam deaeration. Removal of oxygen by chemical additives is normally accomplished by the addition of sodium sulfite or hydrazine. Sodium

sulfite is the less expensive and may be used for steam pressures up to approximately 1000 psia.

Above this steam pressure level and corresponding temperature, sodium sulfite decomposes and it is recommended that hydrazine be used. It should be noted that the addition of hydrazine tends to slightly increase the level of total dissolved solids, but this is not considered a problem in this application.

Alternately, the oxygen content of the feedwater may be reduced to acceptable levels for use in oilfield steam generators by the use of low pressure steam deaerator using steam at 25 to 45 psig. A typical deaerator such as used by electric utilities is employed in which a fine spray of feedwater is countercurrently contacted by steam to drive off the dissolved oxygen by both agitation and the elevation of the feedwater temperature. Steam for deaeration may be extracted from the oilfield steam generator outlet stream as shown in Slide No. 2. With this arrangement, no supplementary source of steam is required for the deaerator.

Both chemical scavenging and deaeration have been used successfully to reduce the oxygen level of feedwater to an oilfield steam generator to an acceptable level. For the larger installation, steam deaeration is preferred because it eliminates the need for the continuing cost of chemical additives.

Hydrogen Sulfide Content of Feedwater

Hydrogen sulfide is occasionally present in the produced water used as oilfield steam generator feedwater, and must be reduced to low levels in order to prevent tube corrosion in the steam generator at the relatively high temperatures used on thermal enhanced oil recovery projects. It is recommended that the hydrogen sulfide level in feedwater to oilfield steam generators not exceed 0.05 ppm.

Hydrogen sulfide present in produced water may be reduced to acceptable levels either by steam deaeration of the feedwater, or by the addition of chlorine. Both methods have proven satisfactory for hydrogen sulfide removal.

pH of Feedwater

Oilfield steam generators are typically designed to operate with feedwater having a pH level ranging from 7.5 to 9.5 so that it is well on the alkaline side. This pH level has been found to be the most compatible with the carbon steel tubes used in the oilfield steam generators. The carbonates and bicarbonates present in the feedwater tend to decompose under the high oilfield steam generator operating temperatures to release carbon dioxide, which can combine with the water to form carbonic acid. By maintaining the feedwater well on the alkaline side, any carbonic acid formed as a result of the decomposition of carbonates and bicarbonates will be neutralized by the alkaline water before it can attack the carbon steel.

Iron Content of Feedwater

Iron in all of its various forms can be quite detrimental to the performance of an oilfield steam generator. While the pure iron will not cause corrosion of the water side of the tubes, it will plate out on the tube walls at the elevated temperatures at which oilfield steam generators are operated, and can significantly increase the tube wall temperature. The result can be accelerated oxidation of the outside of the tubes, and eventual tube burnout. Iron in combination with sulfur or with silica oxides can produce a corrosive environment for the carbon steel tubes. It is recommended that feedwater to oilfield steam generators contain a maximum of 0.2 ppm of iron, and preferably less. Even at this low level, approximately 0.25 pounds per day of iron may potentially be deposited in the tubes of a

50 million Btu/hr oilfield steam generator. Methods are available for removing the iron from the feedwater. Iron in the ferrous form is relatively easily removed, whereas iron in the ferric form requires a considerably more extensive removal procedure. In any event, it is important to reduce the iron content of oilfield steam generator feedwater to as low a level as possible in order to avoid overheating and resultant accelerated eternal oxidation of the tubes.

Silica Content of Feedwater

The once-through oilfield steam generator is fairly tolerant relative to the silica content of the feedwater up to a level of about 170 ppm. At much above this level, the silica solubility in residual liquid available in the latter passes of the steam generator is exceeded and silica will tend to deposit on the tube walls. This has the same effect as iron plating out on the tues, i.e., elevating the tube wall temperature and causing accelerated oxidation of the outside tube surfaces. Because silica has a lower thermal conductivity than iron, it requires less silica deposition on the tube walls to significantly elevate the tube wall temperature.

The once-through oilfield steam generator is required to generate high pressure wet steam from a feedwater quality which would be considered totally unacceptable for any other steam generating application. The fact that oilfield steam generators with carbon steel tubes have operated successfully for as long as twenty-five years with no significant tube corrosion attests to the fact that the corrosive factors have been properly identified, and that the necessary feedwater treatment procedures have been established. The oilfield steam generator operates with a difficult feedwater environment, and caution must be exercised to prevent rapid and destructive corrosion of the tubes.

TABLE I.

FEEDWATER REQUIREMENTS – OIL FIELD STEAM GENERATORS

The following is a summary of feedwater conditions recommended for oil field steam generators (see note 3).

FACTOR OR COMPONENT	LEVEL REQUIRED
Hardness ($Caco_3$)	1 ppm or less (recommends equipment Design capable of ½ ppm or less)
Total dissolved solids (TDS as CaCO) equiv.)	12,000 ppm or less (see note 1)
pH control (against carbon dioxide)	7.5 min. adequate to 8.3 max. effective
Free oxygen	Eliminate (to negligible level achievable by 0_2 scavenging
Free chlorine	Eliminate (to negligible level achievable by 0_2 scavenging or by activated carbon filters.
Iron (ferrous or ferric)	0.25 ppm or less
Sulfur (usual H_2S)	Eliminate (to negligible level achievable by chlorinating plus chlorine carbon filter)
Manganese	Eliminate (to negligible level achievable by softener)
Barium (rarely encountered)	Eliminate
Silica oxides (dissolved)	100 ppm recommended maximum (see note 2).
Oil	1 ppm or less (achievable by WEMCO type filter) plus filter
Dissolved organics	most common organics are acceptable.
Undissolved organics, Miscellaneous debris, and Undisolved sand	Remove to 40 micron size, 20 micron preferred achievable with multilayer bed, or cartridge type filters

NOTES

(1) Oil field generators can usually handle up to 12,000 TDS routinely. Experimental runs up to 24,000 ppm have been made with good success. It is believed that even higher values could be handled. Above 12,000 ppm, a detailed consideration of a detailed water analysis should be made.

(2) Re $Si0_X$, existing literature recommends values much lower than 100 ppm. However, oil field steam generators have run successfully at levels of 250 ppm. Detailed consideration is presently required at levels above 100 ppm.

(3) Details given in the above table cover the most important of the more commonly encountered factors, and will suffice for most 'inquiry' purposes, and most actual installations. It is recommended that in all actual installations, the steam generator manufacturer should review the detailed actual or typical water analysis and treatment proposed.

(4) Down-hole equipment and other considerations may require finer filtering, and/or supplementary filters behind the steam generator.