Degasification of Boiler Feed Water with Liqui-Cel® Membrane Contactors

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Background

Proper treatment of boiler feed water is an important part of operating and maintaining a boiler system. As steam is produced, dissolved solids become concentrated and form deposits inside the boiler. This leads to poor heat transfer and reduces the efficiency of the boiler. Dissolved gasses such as oxygen and carbon dioxide will react with the metals in the boiler system and lead to boiler corrosion. In order to protect the boiler from these contaminates, they should be controlled or removed.

There are several different technologies that are widely used in the industry for removing these contaminants. Dissolved solids can be removed with reverse osmosis membrane and ion exchange systems. Dissolved gasses have historically been removed using forced draft degasifiers, chemical agents and steam deareators

Recently Membrane Contactors have been utilized to remove the dissolved gasses in boiler feed water. Membrane Contactors are widely used in the semiconductor, power, pharmaceutical and other industries to control dissolved gasses in water systems. Their use in boiler feed water degasification systems has grown steadily since the development of new industrial grade devices.

Membrane Contactors are constructed using microporous hydrophobic membranes. The membrane is used to bring a gas and liquid in direct contact without mixing. Contactors operate by lowering the pressure of gas in contact with the liquid to create a driving force to remove the dissolved gasses from the water. They are highly efficient, compact and can be used inline under pressure.

Chemical Treatment

Chemical treatment is widely used to control dissolved oxygen in a boiler. The cost of operating a chemical treatment program consists of chemical costs and blow down costs. As the water is converted to steam, non-volatile compounds in the boiler feed water are concentrated inside the boiler. Periodically the water in the boiler must be flushed out to remove these compounds. They are flushed out of the boiler in a process called blow down. Any chemical that is added to the water can increase the frequency of blow down. If the blow down frequency is increased or decreased this will impact the operating cost of the boiler.

The cost of blow down can be broken down into two costs. Water and steam that is purged from the boiler during blow down is sent to drain. This water must be replenished by fresh makeup water and there is a cost associated with it. The second cost is a heat or energy cost. The water blow down from the boiler is hot. It is replaced with cold water that must be reheated in order to produce steam. The energy cost can be calculated by looking at the energy needed to heat the water back to the temperature of the steam produced by the boiler.

Chemical Costs

In smaller low-pressure boilers (<10000 lbs/hr and < 50 psig), chemical treatment alone may be utilized; for larger high-pressure boilers a combination of steam deareation and chemicals is most often used.

For ease of calculation, a small low-pressure boiler using a chemical program only is evaluated. These same calculations can be used to evaluate boilers that use steam deareation. When evaluating a deareator, the cost of operation should also be included. Details of the steam deareator operations can be obtained from the supplier. The operating cost of the steam deareator can be estimated by calculating the extra feed water required to operate the deareator and the energy loss associated with venting the steam deareator.

<u>Chemical Dosage</u>

In practice, 10 ppm of pure sodium sulfite is needed to remove 1 ppm of oxygen from water. One ppm of sodium sulfite equates to 8.3 lbs per million gallons of water. The amount of dissolved oxygen in the water varies with the water temperature. If we assume that if 10 ppm of dissolved oxygen is dissolved in the water, 83.0 lbs of sodium sulfite will be required per million gallons of water.

In order to calculate the chemical costs the price of sodium sulfite per pound can be multiplied by the above relationship.

*Chemical cost (dollars/gallon*ppm O2) =*

$$\frac{83.0 \ \text{lbs of sodium sulphite}}{1{,}000{,}000 \ \text{gallon ppm O2}} \times \frac{0.5 \ \text{dollars}}{\text{lbs sodium sulfite}}$$

The feed water flow rate is the amount of water that is added to the boiler. The feed water rate is equal to the boiler capacity + water loss in blow down – condensate return.

Feed water flow rate (lb/hr)=

$$\text{boiler capacity}\left[\frac{lbs}{hr}\right] \div \left\{\frac{[100 - \text{Blowdown rate}]}{100}\right\} \times \frac{(100\text{-condensate return})}{100}$$

The chemical cost is directly associated to the gallons of water treated and the inlet dissolved oxygen level in the feed water.

Chemical cost (dollars/year)=

$$\begin{matrix}\text{Feed water}\\ \text{Flow rate}\end{matrix}\left[\frac{lbs}{hr}\right]\times\left[\frac{0.11993\,gal}{lb}\right]\times\ \begin{matrix}\text{Hours of}\\ \text{operation}\end{matrix}\left[\frac{hr}{year}\right]\times\ \begin{matrix}\text{Chemical}\\ \text{cost}\end{matrix}\left[\frac{dollars}{gal\,ppm\,O2}\right]\times ppm\,O2$$

Blow Down Costs

The blow down cost has two components. The costs associated with water loss and the energy costs associated with heating fresh feed water.

Water Costs

The water cost can be calculated by multiplying the amount of water lost during blow down by the water costs.

Blow down flow rate (lbs/hr)=

$$\text{Boiler Capacity}\left[\frac{lbs}{hr}\right]\div\left\{\frac{[100\text{- blowdown rate}]}{100}\right\}\text{- Boiler Capacity}\left[\frac{lbs}{hr}\right]$$

Blow down Water costs (dollars/yr)=

$$\text{Blow Down flow rate}\left[\frac{lb}{hour}\right]\times\left[\frac{0.1193\,gal}{lb}\right]\times \text{water costs}\left[\frac{dollars}{gal}\right]\times\ \begin{matrix}\text{Operating}\\ \text{time}\end{matrix}\left[\frac{hr}{yr}\right]$$

Energy Costs

Since the feed water is at 60F and must be heated in the boiler, heat must be added to the water. The energy costs associated with heating the water can be estimated by calculating the extra energy needed to heat the feed water. The difference in enthalpy of the steam and the feed water is essentially the difference in the heat content of the feed water and steam in the boiler.

The energy costs can be calculated by dividing the fuel cost by the energy content of the fuel.

The enthalpy of the water can be found in steam tables. The enthalpy of water at 60F is 28 BTU/lb. The enthalpy of steam at 50 psig is 297 BTU/lb.

Fuel costs (dollars/year)=

$$\text{Blow down flow rate}\left[\frac{lb}{hr}\right]\times\text{Operating time}\left[\frac{hr}{yr}\right]\times\Delta\,\text{Enthalpy}\left[\frac{BTU}{lb}\right]\times\text{Energy Cost}\left[\frac{dollars}{BTU}\right]\times\text{Boiler Efficiency}$$

Example Calculation Using Membrane Contactors

Membrane Contactors can be used to remove the dissolved oxygen from water. By removing the dissolved oxygen the volume of chemicals added to the boiler will be reduced. By reducing the chemicals added to the boiler the frequency of blow down can be potentially reduced. The example below compares operating costs of two systems. One system is a chemical only treatment system with a blow down rate of 10%. The other system assumes that the oxygen content of the feed water is reduced to 0.5 ppm and that the blow down rate can be reduced to 5% due to the reduction of chemicals in the boiler.

The boiler specifications used in this example are for reference only and used so actual calculations can be shown. These calculations can be modified in order to apply them to boilers with different operating conditions.

Boiler Operating Details		
	Chemically Treated Feed Water	**Degassed Feed Water**
Boiler capacity	10,000 lb/hr	10,000 lb/hr
Pressure	50 psig	50 psig
Efficiency	80%	80%
Fuel	Natural Gas	Natural Gas
Fuel cost	4.5 USD/ 1000 ft3	4.5 USD/ 1000 ft3
Fuel efficiency	1000 BTU/ft3	1000 BTU/ft3
Condensate return	30%	30%
Boiler blow down rate	*10%*	*5%*
Hours of operation	6600 hrs/yr (275 days/yr)	6600 hrs/yr (275 days/yr)
Feed water costs	1.2 USD/1000 gallons	1.2 USD/1000 gallons
Sodium Sulfite cost	0.5 USD/lb	0.5 USD/lb
Feed water temperature	60 F	60 F
Inlet Dissolved	*9.0 ppm*	*0.5 ppm*

Comparison of Chemical Treatment System to Degassing System			
	Chemically Treated Feed Water	**Degassed Feed Water**	**Savings**
Chemical cost	$2,299.00	$128.00	$2,171.00
Blow down water costs	$1055.00	$500.00	$555.00
Energy cost due to heat loss in blow down	$11,095.00	$5256.00	$5,839.00
Total yearly costs/savings	$13,997.00	$5,669.00	$8,565.00

<u>Membrane System Operating Cost</u>
In order to produce feed water with low levels of dissolved oxygen, a membrane system can be used. The running cost of a membrane system is made up of electricity and seal water for the vacuum pump. The costs for a system designed to operate at the conditions above is outlined below.

Operating Cost of a Membrane System	
Utility	**Yearly Operating Cost**
VP operating cost 1.5 kW	$346.50 (Based on 0.035 USD/kW)
Seal water 0.4 gal/min	$190.00
Total	$536.50

The operating cost of the membrane system is less than 550.00 dollars per year. When comparing this to the chemical treatment system only, a 1,600.00 dollar per year savings can be realized. When the savings associated with blow down is included, the operating costs savings can be more than 8,000.00 dollars per year. A typical membrane system designed to degas the water outlined in this example can have a payback in less than two years.

In addition to the operating cost savings, a membrane-based system has other advantages as well. It is an ecologically friendly system that reduces the dissolved oxygen in the water without the addition of chemicals.

ShenLan Environment Inc located in Shanghai China uses Liqui-Cel® Membrane Contactors in their boiler feed water treatment systems. These systems realize lower operating costs with the added benefit of reducing the chemicals added to the boiler feed water. Two photographs of systems built by Shen Lan are shown below.

A Liqui-Cel® Contactor System built for Boiler Degassing by Shen Lan

Steam Deaeration

Many boilers use a steam deareator to degasify the boiler feed water. These devices use steam that is produced by the boiler to remove dissolved oxygen. Steam is brought into contact with the feed water. The steam preheats the feed water and strips out the dissolved gas. Some portion of this steam must be vented off to remove the gasses from the system.

This venting is essentially a loss of energy and can be calculated in the same manner that the energy loss associated with blow down was calculated. Steam deareators typically need to vent approximately 10% of the feed to the deareator to purge the dissolved gasses from the water. They also need to operate at 2-4 psig. During peak operating times the pressure may be difficult to maintain so additional boiler capacity may be required. These added boiler loads should be included in an operating cost analysis.

Summary

Dissolved oxygen control in boiler feed water is an important process that protects the boiler from corrosion. Chemical treatment is often used to control the dissolved oxygen. Liqui-Cel® Membrane Contactors can be used to replace or supplement the chemical treatment program. The Contactors can minimize the volume of chemicals added to the feed water and offer savings to the end user by reducing chemical as well as energy costs.

References

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About the Author

Fred Wiesler is a Technical Sales Manager in the Industrial Separations Group of Membrana. He has over ten years experience in the field of membrane separations. He has authored several papers on membrane-based applications and holds patents on the design of membrane contactors. He is currently responsible for sales and service of Membrana's Membrane Contactor product line for Asia.