Feed Tank vs Deaerator Return on Investment:

The primary reason for using a deaerator is oxygen removal. A deaerator mechanically removes dissolved oxygen, therefore, less oxygen scavenging chemicals can be utilized which results in large chemical savings. This paper will explain the potential cost savings associated with using a deaerator.

Oxygen Scavengers

Sodium sulfite is one of the most commonly used oxygen scavengers in the boiler industry. Therefore, we will use sodium sulfite for this example. The equation below can be used to estimate sodium sulfite consumption:

$$Na_2SO_3 = O_2\ x\ 8 + \frac{SO_3}{CoC}$$

Where:
Na_2SO_3 = Sodium sulfite required in Parts Per Million (PPM)
O_2 = Dissolved oxygen content in the feed water in PPM
SO_3 = Desired residual amount of SO3 as measured in the boiler in PPM
CoC = Cycles of Concentration

For this example, we will assume we have an average steam production of 10,000 lbs/hr or roughly 300 HP. Assuming the steam plant operates 24 hours a day, 365 days per year, this equates to a steam production of 87.6 million lbs. per year. Assuming a blowdown rate of 5% (Cycles of Concentration = 20), the annual water consumption will equal 92.2 million lbs. per year. The table below shows the estimated sodium sulfite consumption under these conditions for an atmospheric feed tank operating at different feedwater temperatures.

Table 1: Annual Sodium Sulfite Costs by Feedwater Temperature (300 HP Example)

Feedwater Temperature	**160**	**170**	**180**	**190**
Feedwater Dissolved Oxygen (PPB)	3700	3300	2700	2000
Feedwater Dissolved Oxygen (PPM)	3.7	3.3	2.7	2
Residual Sulfite in Boiler (PPM)	30	30	30	30
Cycles of Concentration	20	20	20	20
Sulfite Dosing (PPM)	31.1	27.9	23.1	17.5
Chemical Concentration	30%	30%	30%	30%
Chemical Dosing (PPM)	103.7	93.0	77.0	58.3
Chemical Dosing (lbs/MM-lb)	103.7	93.0	77.0	58.3
Unit Chemical Cost ($/lb)	3.5	3.5	3.5	3.5
Cost per MM-lbs of Water ($/MM-lbs)	363	326	270	204
Annual Water Consumption (MM-lbs)	92.3	92.3	92.3	92.3
Annual Sodium Sulfite Cost ($)	**$33,490**	**$30,044**	**$24,875**	**$18,845**

As Table 1 shows, the chemical consumption drastically decreases as the feed water temperature increases. Note, except for atmospheric deaerators, you should never operate an atmospheric boiler feedwater system above at or above 200°F due to steam efficiency and pump NPSH requirements.

Next, we will analyze the sodium sulfite costs when utilizing a deaerator. Most deaerators are rated to remove the dissolved oxygen content to 7 PPB at full capacity. However, it is important to note that certain deaerator designs can become less efficient when operating at low turndown ratios.

Spray Tray: Spray tray deaerators can typically meet 7 PPB when operating anywhere between 5% to 100% of the deaerator's maximum capacity.

Spray Scrubber: Spray scrubber deaerators relay on high velocity steam in the scrubber section to remove trace amounts of dissolved oxygen. Therefore, the quantity of steam consumed has an impact on performance. The quantity of steam consumed is depended on two factors: the incoming water temperature and the quantity of incoming water. Therefore, the turndown ratio is a little more complicated for spray scrubber deaerators. For this reason, most spray scrubber deaerator manufactures don't advertise the guaranteed operating range. When operating at low loads, a spray scrubber deaerator can be expected to operate in the 20-50 PPB range.

The table below shows the estimated annual sulfite consumption assuming the deaerator is operating at three different perform levels: 7 PPB, 25 PPB, and 50 PPB. Note, at dissolved oxygen contents this now, most of the sulfite dosing is actually going toward maintaining the desired residual sulfite reading in the boiler, very little is actually needed to treat the water. Therefore, the actual consumption doesn't increase too much between 7PPB, 25 PPB, and 50 PPB. For this reason, a spray scrubber deaerator is typically recommended for most applications. A spray tray deaerator is typically reserved for very large systems and/or demanding applications that required critical water treatment such as large industrial power plants.

Table 2: Deaerator Annual Sodium Sulfite Costs (300 HP Example)

Feedwater Dissolved Oxygen (PPB)	**50**	**25**	**7**
Feedwater Dissolved Oxygen (PPM)	0.050	0.025	0.007
Residual Sulfite in Boiler (PPM)	30	30	30
Cycles of Concentration	20	20	20
Sulfite Dosing (PPM)	1.9	1.7	1.6
Chemical Concentration	30%	30%	30%
Chemical Dosing (PPM)	6.3	5.7	5.2
Chemical Dosing (lbs/MM-lb.)	6.3	5.7	5.2
Unit Chemical Cost ($/lb.)	3.5	3.5	3.5
Cost per MM-lbs of Water ($/MM-lbs.)	22	20	18
Annual Water Consumption (MM-lbs.)	92.3	92.3	92.3
Annual Sodium Sulfite Cost ($)	**$2,046**	**$1,831**	**$1,676**

Steam Consumption

A common misconception about deaerators is the belief that they consume a lot of steam, causing the overall boiler system to become less efficient. In reality, the deaerator puts a very low steam demand on the overall boiler system. First lets consider the amount of energy required to make steam. For this example we will assume we are using 100% makeup water (no condensate return) and the boiler is producing steam at 100 psi. Lets assume the boiler has a heat input value of 12,500,000 BTU/hr and an operational efficiency of 80%, therefore, the heat output will be 10,000,000 BTU/hr.

In this example, we need to take makeup water at 50°F and convert it to steam at 100 psi. At 50°F, each lb. of water contains 18 BTUs of energy. At 100 PSI, each lb. of steam contains 1190 BTUs of energy. Therefore, we need to add 1,172 BTUs to one lb. of water to make one lb. of steam. We could add all of this energy in the boiler, or we could add some energy in the feed tank and the remainder of the energy in the boiler. Neglecting radiation loss, conservation of energy states we should end up with the same result. Figure 1 below shows two examples: one, we will feed the boiler with 50°F feedwater, two, we will preheat the feedwater using a deaerator then feed 225°F feedwater to the boiler. In example two, the incoming water is hotter, therefore assuming the boiler consumes the same amount of gas, the boiler will actually produce more lbs. of steam. The excess steam is used to preheat the tank. In the end, we have the same amount of steam available to the process. Neglecting radiation losses, preheating the makeup water puts no added load on the process.

Example 1 **Example 2**

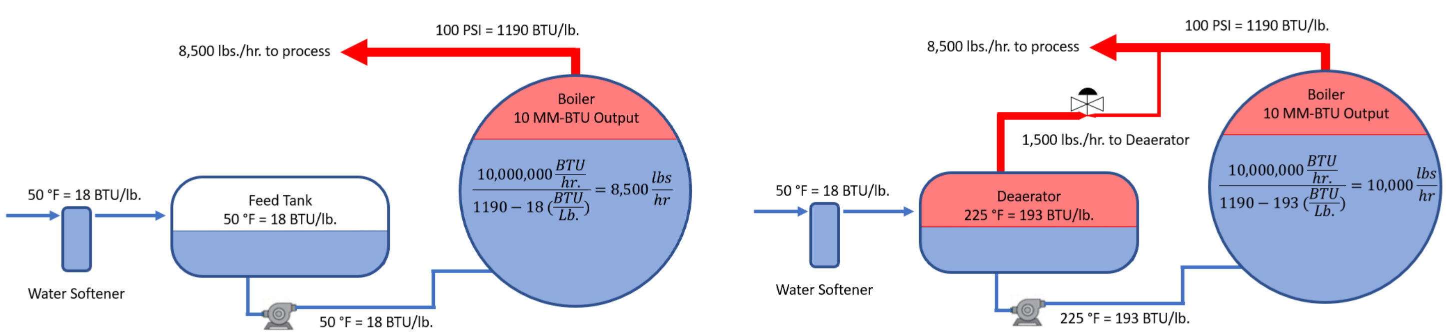

Figure 1: Conservation of Energy

A well-insulated feed water system should radiate a very small amount of energy. While it is true the radiation rate will increase as the feedwater tank increases, the radiation rate is very small compared to the chemical savings associated with utilizing hotter feed water. Considering the example from the first page, the table below shows the estimated costs associated with radiation losses for an insulated feed tank and deaerator sized for a 20,000 lb/hr system (10,000 lb/hr average load).

Table 3: Boiler Feed System Radiation Costs by Temperature

	Atmospheric Feed Tank				Deaerator
Feed Water Temperature (°F)	**160**	**170**	**180**	**190**	**225**
Outer Lagging Temperature (°F)	96	97	97	98	101
Boiler Room Temperature (°F)	90	90	90	90	90
Surface Area (ft^2)	117	117	117	117	123
Tank Heat Loss Rate (BTU/hr)	733	857	857	982	1431
Suction Piping (ft)	6	6	6	6	6
Uninsulated Heat Loss per ft (BTU/hr/ft)	92	108	125	143	209
Suction Piping Heat Loss Rate (BTU/hr)	551	649	751	856	1254
Feedwater Piping (ft)	100	100	100	100	100
Insulated Heat Loss per ft (BTU/hr/ft)	10	11	12	14	20
Feedwater Piping Heat Loss Rate (BTU/hr)	950	1094	1243	1396	1950
Total Heat Loss (BTU/hr)	2234	2600	2851	3234	4635
Heat Loss per year (MM-BTU)	19.6	22.8	25	28.3	40.6
Steam Cost ($/MMBTU)	5	5	5	5	5
Cost of Radiation ($/year)	**98**	**114**	**125**	**141.5**	**203**

A pressurized deaerator utilizes a fixed orifice vent in order to vent dissolved gases out of the system. A properly sized orifice will vent 1/10 of 1% of the deaerators maximum rating. For example, a deaerator that is rated for 20,000 lbs/hr should vent 20 lbs/hr of steam. At 5 psi, this equals roughly 23,120 BTUs/hr or $1,013. Again, the loss is minimal compared to the potential chemical savings.

Efficiency Loss when using Economizer

Another common concern is how a deaerator will affect the efficiency of a feedwater economizer. Non-condensing feedwater economizers typically add somewhere around 5% efficiency to the boiler system. The argument is that using cooler feedwater improves the heat transfer within the economizer resulting in higher system efficiencies. While this is true, again the potential chemical savings typically outweighs the fuel savings. Consider the same 10,000 lb/hr boiler operating at 100 PSI from the previous example. Let's assume the steam demand in the plant is 8,500 lbs/hr. A typical boiler will operate around 80% efficiency. Assuming a water inlet temperature of 160°F, an economizer will be able to add roughly 5% efficiency for a total efficiency near 85%. When using a deaerator, the incoming water temperature would be roughly 225°F. At this temperature, the economizer should add roughly 4% efficiency for a total efficiency near 84%. The table below shows the fuel cost comparison between these conditions. When using the deaerator, the fuel cost will increase by approximately $5,750 per year. However, as shown in Table 1 and Table 2, the chemical costs will decrease by over $31,000 per year. This is a total savings of over $25,000 per year.

Table 4: Economizer Efficiency vs Temperature

Feedwater Temperature (°F)	**160**	**190**	**225**
Load to Process (lbs/hr)	8,500	8,500	8,500
Added Energy (BTU/lb)	1,172	1,172	1,172
Heat Output (BTU/hr)	9,962,000	9,962,000	9,962,000
Economizer Efficiency Gain	5%	4.50%	4%
System Efficiency	85.0%	84.5%	84.0%
Heat Input (BTU/lb)	11,720,000	11,789,349	11,859,524
Annual Fuel Consumption (MM-BTU)	102,667	103,275	103,889
Unit Fuel Cost ($/MM-BTU)	4	4	4
Annual Fuel Cost ($)	410,669	413,099	415,558
Economizer Loss Cost ($)		**2,430**	**4,889**

Final Summary

Putting everything together from the above examples, lets run through an example return on investment calculation. The initial cost represents the typical list price for a basic system with standard tank and typical trim. Note, this price is for demonstration purposes only, actual prices will vary based on feedwater pumps and added options. We will look at three different situations, situation one will use a low feed water temperate to illustrate the "economizer effect". Situation two, will follow the industry standard for atmospheric feed tanks and operate at 190°F. Situation three, will show a spray scrubber deaerator performing at 25 PPB dissolved oxygen. As the table shows, a deaerator can typically pay for itself in one to three years! If the steam plant runs 24 hours a day, 7 days a week, it makes absolute sense to invest in a deaerator.

Table 5: Total Return on Investment

	750 Gallon Stainless Steel Feed System		**20SS Deaerator**
Feedwater Temperature (°F)	**160**	**190**	**225**
Initial Cost ($)	42,000	42,000	68,000
Dissolved Oxygen Content (PPM)	3.7	1.3	0.025
Annual Sodium Sulfite Cost ($)	33,490	18,845	1,831
Annual Insulated Tank Radiation Cost ($)	98	142	203
Annual Tank Venting Cost ($)	0	0	1013
Annual Economizer Efficiency Loss Fuel Cost ($)	0	2,430	4,889
Annual Cost Comparison ($)	**33,588**	**21,417**	**7,936**
Annual Savings by using Deaerator ($)	**25,652**	**13,481**	-
Return on Investment (Years)	**1.0**	**1.9**	-