White paper

Industrial filtration

Using cold boiler feedwater for energy recovery

Feeding membrane-deaerated cold boiler feedwater to appropriate units will enable waste heat to replace substantial steam duty in a refinery

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Using cold boiler feed water for energy recovery

Feeding membrane deaerated cold boiler feed water to appropriate units will enable waste heat to replace substantial steam duty in a refinery

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Steam at different pressure levels is used for many purposes in refineries, including power production (steam turbines), heating, steam tracing, stripping, atomising and deaeration. Steam is produced from fired utility boilers, cogeneration units (gas turbine HRSGs), furnace waste heat boilers, product rundowns, column refluxes and so on by adding heat to supplied boiler feed water. Boiler feed water is conventionally supplied by deaerators, where steam is used to heat water to saturation conditions at a certain pressure to strip dissolved oxygen, with the aim of preventing corrosion in steam production units. In this article, the benefits of providing cold boiler feed water from membrane deaerators to steam-producing or water-heating waste heat streams will be explained, with some typical examples for an oil refinery.

Membrane deaerators

Membrane deaerator technology is used for degassing liquids around the world. They are widely used for removing oxygen from water, as well as for carbon dioxide removal. They have displaced the vacuum tower, forced draft deaerator and oxygen scavengers for over 20 years. Membrane contactors are used extensively for the deaeration of liquids in the microelectronics, pharmaceutical, power (boiler feed water), food and beverage, industrial, photographic, ink and analytical markets. A trial study of the scope of a heat recovery project has been carried out within a refinery, where the aim of the project was to decide whether this technology should be used extensively for the deaeration of boiler feed water, together with existing conventional steam deaerators.

Membrane deaerator systems consist of membrane contactors combined in series, parallel or both, designed according to the water flow, pressure drop limitations and oxygen concentration needed at the outlet of the system. The contactors work on the basic principle of letting only gas (oxygen) molecules pass to the other side of membranes, where a vacuum is applied via a vacuum pump and sweep gas (high-purity nitrogen) is supplied. Oxygen molecules in the water side have a high partial pressure compared to the vacuum side, so they tend to pass through the hydrophobic membranes. Here, high-purity sweep gas is introduced to the vacuum side to prevent oxygen from concentrating in the vacuum side, which sustains the mass transfer efficiency (partial pressure difference).

The maximum oxygen concentration requirement for boiler feed water in this scenario is 7 ppb. However, 1 ppb was targeted when selecting the configuration for this project (to be on the safe side). The purity of the sweep gas nitrogen has critical importance when selecting the best configuration because it obviously has to contain a minimum amount of oxygen. In this case, the refinery has a high-purity nitrogen ring (99.99 vol%) which is mainly consumed by reformers and other processes that need high-purity nitrogen. Nitrogen consumption by the membranes is very low (~10 Nm^3/h, of course depending on water flow and oxygen concentration targeted) when compared to

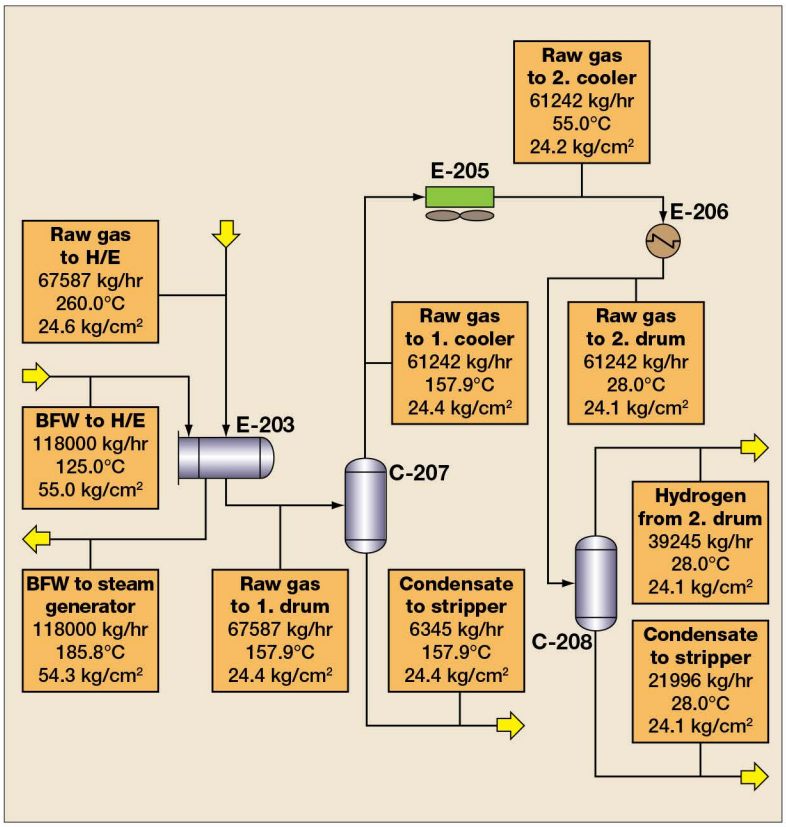


Figure 1 Hydrogen unit boiler feed water heating (before cold BFW)

process needs (in the range of several thousand Nm^3/h) and therefore does not have a negative effect on the refinery nitrogen balance.

Nitrogen is purchased by the refinery and delivered by trucks, which periodically supply high-purity nitrogen to the main tanks in the refinery nitrogen system (ring). In a refinery without an available nitrogen ring, a nitrogen tank, sized according to the capacity of the system, will be needed. This can be periodically filled with the nitrogen provided by trucks. The other needs for the system are a small amount of electricity and cooling water for the vacuum pump system, which are easily accessible in the refinery configuration.

Water temperature at the membranes is another point of importance in the system's configuration. The level of oxygen dissolved in water depends on the temperature of the water. The solubility of gases decreases with increasing temperature. Usually, at atmospheric temperatures, ~6 ppm (6000 ppb) of oxygen is dissolved in water. Depending on the water temperature, solubility can be between 5 and 8 ppm. Therefore, depending on the water temperature, the membrane system load changes. In this project's scenario, demineralised water is heated by condensate drum flash vapour and the temperature to the membrane deaerator system will change between 30 and 50°C, depending on the ambient temperature. A high temperature is good for efficient oxygen removal; however, another important point is that temperatures above 60°C are not desirable for the membranes, as they may be damaged at such temperatures, depending on the operating pressure. The demineralised water system pressure in this case is 6–8 kg/cm^2g, which can easily be decreased to 5 kg/cm^2g or less with the appropriate valves.

The advantages of the membrane deaerator system, including low investment and operating costs and relatively small size, make it an appropriate selection for the cold boiler feed water heat recovery project. Membrane deaerator systems can be purchased from various OEM firms.

Case 1

Energy recovery from a hydrocracker hydrogen production unit

Waste heat from the hydrocracker hydrogen steam reformer furnace is one of the main steam producers from a furnace waste heat boiler. Approximately 90–120 t/h of 38 kg/cm^2g steam is produced from furnace waste heat, depending on the unit's working capacity. Boiler feed water is supplied at 55 kg/cm^2g and 125°C, and this is pumped from the deaerator at the utility production unit. Boiler feed water is first heated by the shift converter outlet raw hydrogen stream, which has impurities such as water vapour (over 40 wt%), CO, CO_2, CH_4 and N_2. After heating boiler feed water, this hydrogen stream is than cooled down further by air and cooling water to get rid of water and dissolved gases. Condensate is taken from hot and cold condensate drums, then the

steam is stripped of its dissolved gases and sent back to the utility production unit. The boiler feed water heating scheme prior to the hydrogen reformer furnace steam generator inlet is shown in Figure 1.

For the most part, the latent heat of condensation of water vapour in the raw hydrogen stream is given to the boiler feed water to boost steam production. A portion of condensate recovered from this used heat is taken from the hot condensate drum, while the rest of the heat is wasted to air and cooling water. In this layout, 7.4 Gcal/h is recovered by heating boiler feed water, while 17.4 Gcal/h is wasted.

In the current project, cold boiler feed water (30–50°C) will be supplied from the membrane deaerators to this unit through existing feed water pumps. The driving force for heat transfer will be increased in exchanger E-203 (see Figure 1) and more latent heat of condensation will be recovered. In this way, steam used in the deaerators is saved and water is heated by waste heat.

The initial projected layout for 50°C feed water temperature is shown in Figure 2. The energy recovered in E203 increases to 14.6 Gcal/h. Some 7.2 Gcal/h of net energy is saved by providing cold feed water to this exchanger and recovering more heat of condensation in the raw gas stream. In other words, 118 t/h of boiler feed water at 50°C does not need to be heated to 125°C with steam in the deaerator. This is equal to ~8.8 Gcal/h steam duty saving in the deaerator according to the simple formula:

Q=m*cp*dt.

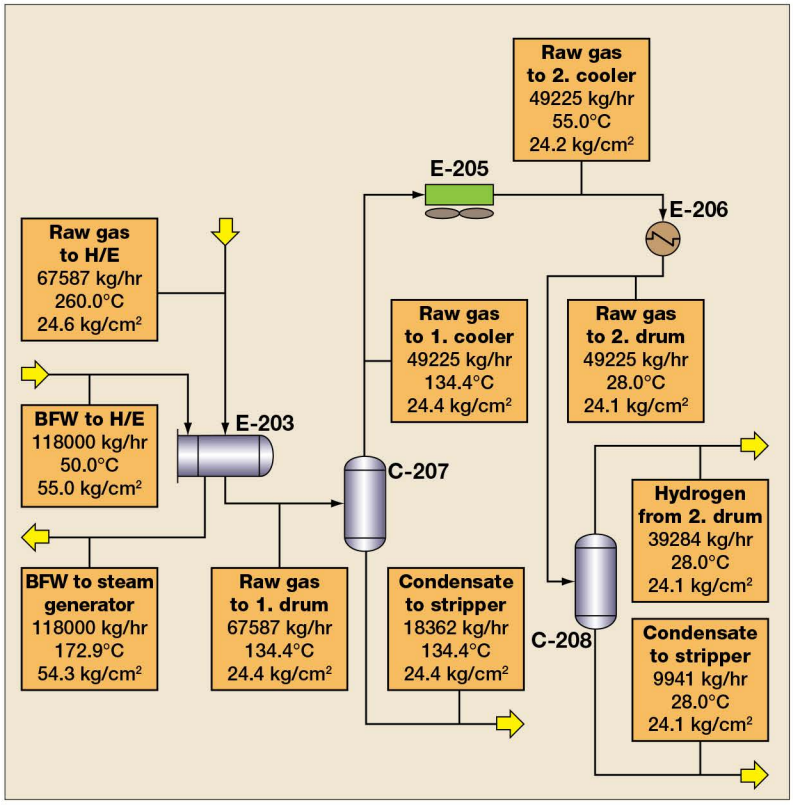


Figure 2 Hydrogen unit cold boiler feed water heating

However, because the heat exchanger exit temperature (waste heat steam generator economiser inlet) is a little lower, a portion of this saving is lost and a net 7.2 Gcal/h is saved.

This heat recovery may be increased further by adding some area to the heat exchanger, making up for the lost portion of heat recovery. For example, 33% additional surface area in E-203 increases the recovered energy by 1.1 Gcal/h.

Other side benefits of this project are electricity savings from air cooler fans and cooling water savings, as with any other process heat recovery project. The other important saving is the stripping steam from the condensate CO_2 stripper. The overall temperature of the total condensate from two drums increases, thus decreasing the CO_2 solubility, which reduces the need for stripping steam.

Case 2

Energy recovery from a gas turbine heat recovery steam generator

Boiler feed water to a gas turbine HRSG is provided from the same header to the oil-fired utility boilers. The water temperature is kept above 140°C to prevent sulphuric acid corrosion in the boiler economisers. However, only natural gas is fired in the gas turbine and there is no risk of sulphuric acid corrosion in the HRSG, so cold water can be fed to the economiser. The only concern is to keep the temperature above water dew point. In this way, the driving force for heat transfer will be increased in the economiser and more heat will be recovered

during feed water preheating. Steam used in the deaerator to heat the water will be replaced by waste heat.

Initial conditions are 69.8 t/h of 68 kg/cm^{2}g steam production and the stack temperature is 233°C. According to trial and error calculations, if water is supplied at 50°C, net heat recovered from the exhaust gas increases by 6 Gcal/h. In fact, the steam saving for boiler feed water heating is approximately 7.5 Gcal/h. However, since the economiser outlet temperature to the steam drum is lower (the approach temperature is higher), there is a steam production loss of ~1.5 Gcal/h from the HRSG, which decreases the net saving to 6 Gcal/h, as stated. By adding some additional economiser area, this loss can be compensated and more heat will be recovered from the exhaust gas, increasing it to 7.5 Gcal/h and more.

It is important that the water temperature entering the economiser should be kept above the water dew point of the exhaust gas. This is done by taking some water from the existing hot boiler feed water line and setting the temperature to the HRSG above 50°C.

Other cases

Other potential users of cold boiler feed water are product rundown or column reflux steam producers (or boiler feed water heaters), which are placed before air coolers, reactor effluent streams before air coolers, and so on. For example, steam production from vacuum residue or other product rundowns, and steam production/boiler feed water heating in column reflux streams are common in refineries. One other potential area of application is fuel gas (or natural gas) burning furnaces fitted with waste heat boilers. As in the cogeneration examples, water can be fed cold to these units provided its temperature is above the water dew point of the flue gas. Low-temperature waste heat streams can also be used for boiler feed water heating purposes, to boost steam production in process plants.

The configuration of refinery steam and electricity production is important when calculating the corresponding cash benefits of this project. After calculating the duty and amount of steam savings from the waste heat sources, we shall look at the overall steam and electricity balance to calculate the real cash income of the project. It is obvious that large amounts of low-pressure deaerator steam will be saved. In the refinery where the project is being applied, low-pressure steam is extracted from electricity-generating turbo alternators and process rotary equipment turbines. Higher-pressure turbine steam is produced via fuel-burning boilers. In addition, there are the gas turbine cogeneration unit and condensing turbines already mentioned.

In this scenario, low-pressure steam produced for the deaerators is reduced; the net reduction is approximately 15–25% (depending on the season) of the total low-pressure steam extraction from the turbo alternators. The project decreases the turbo alternator loads, together with the fuelled boiler steam loads. The electricity lost from the turbo alternators is compensated by the gas turbine cogeneration unit, which is much more efficient. Therefore, the overall efficiency of the electricity generation system is also increased, accounting for some additional fuel savings. For the sake of simplicity, this additional duty saving is not taken into account in this article. An alternative scenario would be the replacement of lost electricity by condensing turbines, which would decrease the net energy saving delivered by the project.

Conclusion

Within the ongoing project, by feeding membrane deaerated cold boiler feed water to appropriate units, it is expected that a net saving of 16 Gcal/h of steam duty will be made. This duty will be replaced directly by waste heat. The payback period for the investment is less than five months. By adding additional area to the related exchangers, savings can be increased to over 22 GCal/h. Considering the benefits, the short payback time, the possibility of implementing the project without process unit shutdowns and the use of newer technology, the project is a very important contribution to the refinery's energy roadmap studies.

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