FULL STEAM AHEAD

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Around the world, plant owners are looking to improve the operation of existing facilities and expand their capacity as part of strategies for growth. In the example described in this article, one customer, as part of a plant expansion project, was seeking recommendations and practical support for the best method of treating process condensate in a hydrogen production unit.

Air Liquide Engineering & Construction was contracted to design and select a new hydrogen production unit (HPU-2) capable of treating process condensate which could not be treated in the existing plant (HPU-1) because the condensate quality deviated from expected design figures and values, rendering the process condensate flow scheme in HPU-1 (Figure 1) unsuitable.

After evaluation, a combined process was selected to treat imported (HPU-1) and own process condensate (HPU-2). The preferred solution consisted of the combination of segregated steam systems, a high pressure (HP) steam stripper and a process condensate vaporiser. The new unit was commissioned and performance tests successfully completed.

Since there was no dedicated steam drum to produce the export steam in HPU-1, poor process condensate quality had directly affected the export steam quality. The customer had to direct the process condensate to the waste water plant, which in turn increased the makeup water consumption.

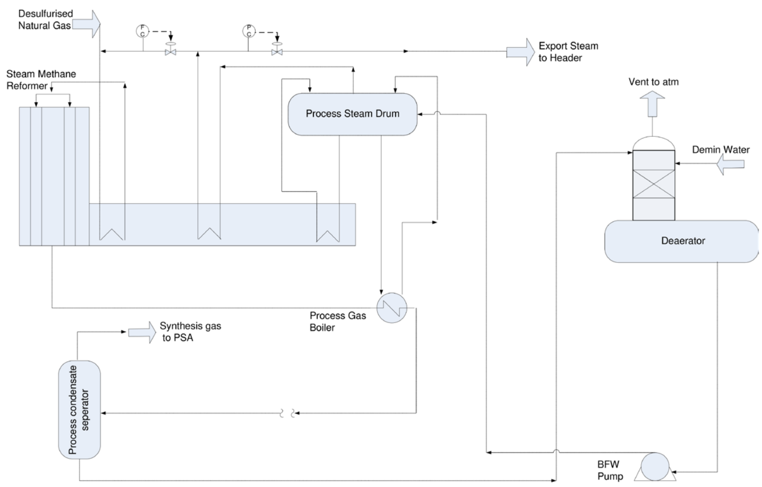

Figure 1. HPU-1 process condensate flow scheme (illustrated on a single steam drum system).

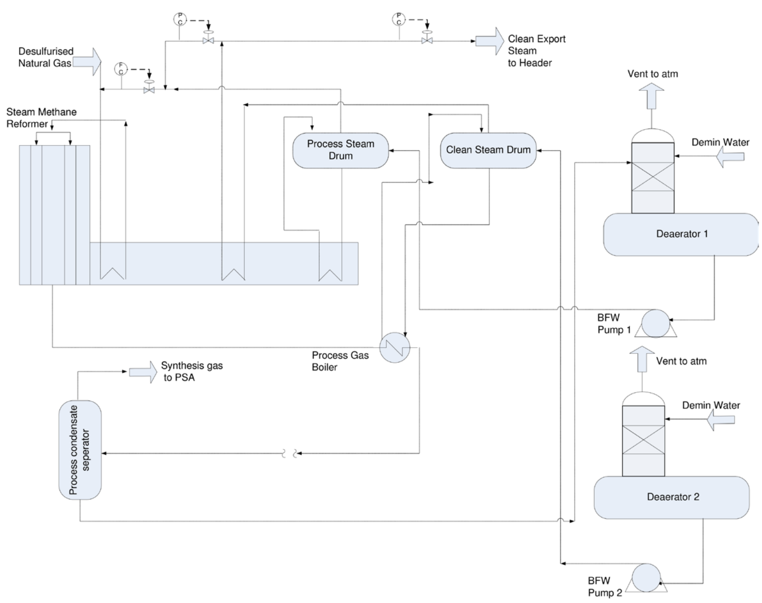

Figure 2. Scheme for segregated steam systems.

Process condensate of steam reformer

Process condensate from a steam methane reforming (SMR) plant includes various impurities such as dissolved ammonia (NH_3), methanol, dissolved gases, organic salts or acids, corrosion products, and other impurities from demineralised water.

The quality of process condensate can be determined from properties including pH, electrical conductivity and dissolved organic carbons content. Quality can vary between SMR plants and depends on plant design, especially the carbon monoxide (CO) shift technology, catalyst, feedstock, steam quality and chemical dosing scheme.

While the recycling of process condensate within an SMR plant will not be a challenge for the unit itself if chemical dosing, monitoring and action plans exist, the quality of the exported steam might not be sufficient for use in condensing steam turbines. However, the use of steam from recycled process condensate as process steam for SMR, for back-pressure

Table 1. Advantages and disadvantages of a segregated steam system vs a single steam drum system

Advantages	Disadvantages
Export steam system is completely separated from the process condensate and process steam system	CAPEX is higher due to additional equipment including second steam drum, second BFW pump and second de-aerator, plus interconnecting piping
Highest-quality steam suitable for condensing-type steam turbine, dependent only on demineralised water quality	Larger plot area required
	Depending on plant design and operating parameters, e.g. turndown, the amount of process condensate recycling may be limited
	Venting of ammonia and methanol to the atmosphere or additional combustion of de-aerator vent required

Table 2. Advantages and disadvantages of a single steam drum system with LP de-aerator

Advantages	Disadvantages
Lowest CAPEX	Venting of ammonia and methanol to the atmosphere or additional combustion of de-aerator vent required
Standardised solution for low steam-quality consumers, like back-pressure turbines, process steam or heating steam	

Table 3. Advantages and disadvantages of a process condensate vaporiser system

Advantages	Disadvantages
Export steam system is completely separated from the process condensate and process steam system	CAPEX is higher due to additional equipment requirements, including a second steam drum, second process condensate pump and process condensate vaporiser and interchanger
Highest-quality steam suitable for condensing-type steam turbine, dependent only on demineralised water quality	Additional plot area required
All impurities in process condensate are recycled to the reformer as process steam	Non-de-aerated process condensate will require stainless steel material or high volumes of chemical dosing for pH adjustment
All the process condensate can be recycled without restriction	
As much additional imported process condensate can be treated as heat is available in the clean export steam	

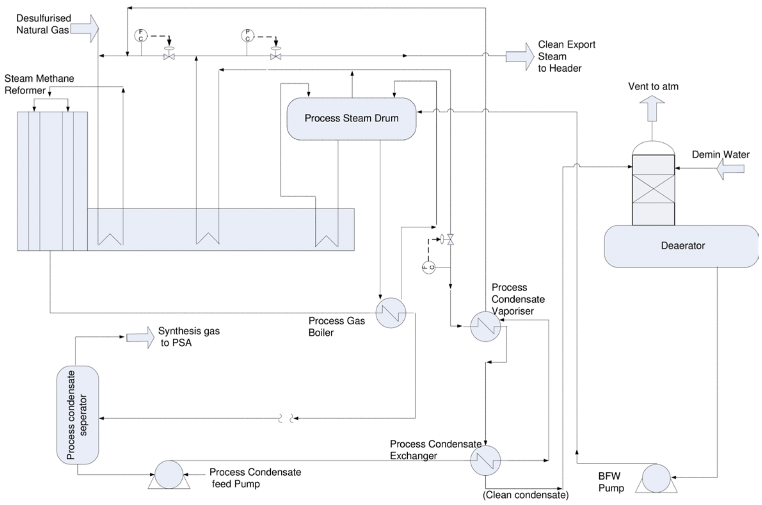

Figure 3. Scheme for process condensate vaporiser systems.

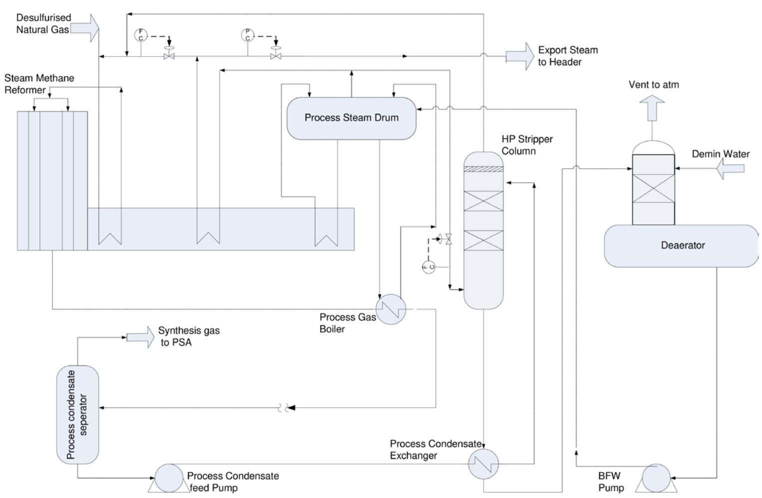

Figure 4. Scheme for HP steam stripper systems.

steam turbines or as heating steam will typically not be an issue as long as certain material requirements are implemented.

New hydrogen production unit

The solution chosen comprises a conventional hydrogen plant consisting of zinc oxide purification, a top-fired SMR, high temperature shift conversion and a pressure swing adsorption (PSA) unit.

Available technologies

Several methods are available for treating process condensate, each with advantages and limitations:

- Segregated steam systems for process condensate and steam and for high-quality export steam.
- HP steam process condensate stripper.
- Low pressure (LP) steam process condensate stripper.
- Process condensate vaporiser.
- Pressurised de-aerator.

Selection should mainly be defined by customer requirements. Efficient performance depends on the system being treated and on process requirements. The selection of suitable technology for process condensate treatment must consider criteria including operating and capital cost, plant reliability and the quality requirements of steam consumers.

Segregated steam systems

Segregated steam systems (Figure 2) are used in many hydrogen plants to produce

Table 4. Advantages and disadvantages of an HP steam stripper system

Advantages	Disadvantages
Steam quality is better than in the single steam system	Some impurities remain in the stripped process condensate and end up in export steam
Most of the impurities in process condensate are recycled to the reformer as process steam	Steam quality is insufficient for certain steam consumers
All the process condensate can be recycled without restriction	Conductivity is at least one order of magnitude higher than in solutions with complete separation of process condensate and export steam systems
	CAPEX is higher due to the additional equipment including steam drum, second process condensate pump, HP steam stripper column, stripped condensate interchanger
	Additional plot area required
	Non-de-aerated process condensate will require stainless steel material or high volumes of chemical dosing for pH adjustment
	Risk of process condensate stripper overflow and subsequent water introduction and damage of plant

Table 5. Steam mass balance and quality – HP steam stripper

	Process condensate from existing plant HPU-1	Process condensate from HPU-2	Process condensate to stripper top	Heating steam to HP stripper bottom	Process steam from stripper top	Stripped condensate from bottom	Stripped condensate after cooling
Stream no.	190	191	192	161	163	193	194
Flowrate (kg/ hr)	35 000	32 772	67 772	33 886	24 403	77 255	77 255
Operating pressure (barg)	45	32	32	33	31	32	31 .5
Operating temperature (°C)	50	81 .9	144	254	237	239	209
pH	‹7	9 – 9.5	9 – 9.5	8.5 – 9.5	8.5 – 9.5	8.5 – 9.5	8.5 – 9.5
Conductivity (uS/cm)	‹200	‹500	‹500	50 – 150	–	50 – 150	50 – 150

high-quality export steam to battery limit. To meet the export steam quality required for condensing steam turbine operation, the design includes two separate steam systems: one to generate export steam, operated exclusively with boiler feed water (BFW), and one for process steam, which operates with process condensate generated internally from the hydrogen plant and additional BFW to balance the water demand for steam production.

Table 1 explains the advantages and disadvantages of this method compared to the traditional single steam drum system with single LP de-aerator where BFW and process condensate are de-aerated.

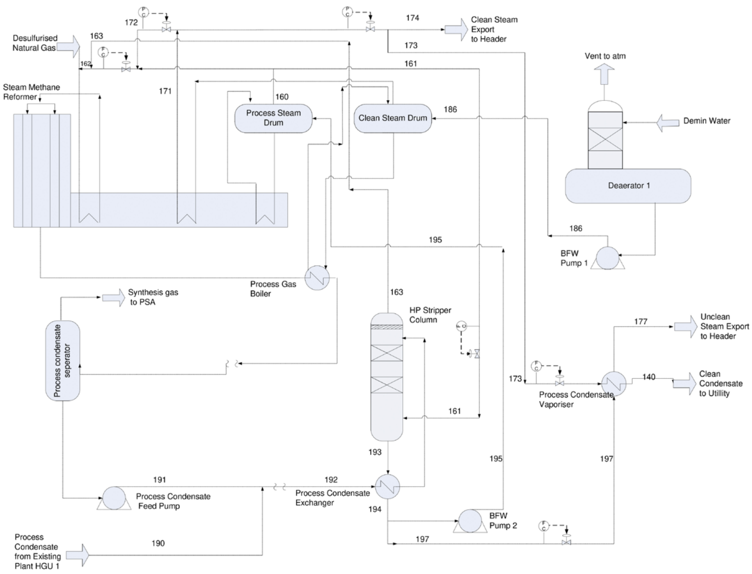

Figure 5. HPU-2 process condensate flow scheme.

Single steam drum system with LP de-aerator

In this arrangement (Figure 1), process condensate from the SMR plant is de-aerated in an LP de-aerator with process heat as the heating medium. De-aerated process condensate is pumped to the single steam drum to produce the steam. The de-aerator is operated at around 0.2 barg and part of the carbon dioxide (CO_2) and impurities like NH_3 and methanol are vented to atmosphere. Using this method, it is not possible to produce high-quality steam suitable for use in condensing turbines. See Table 2 for the advantages and disadvantages of this system.

Process condensate vaporiser

With this method (Figure 3), process condensate generated from the SMR plant is pumped to the

Table 6. Steam mass balance and quality – process condensate vaporiser

	Stripped process condensate inlet to process condensate vaporiser	Unclean steam export to battery limit	Heating steam inlet to process condensate vaporiser	Clean condensate outlet to utility
Stream no.	197	177	173	140
Flowrate (kg/hr)	11 415	11 355	10 750	10 750
Operating pressure (barg)	30	11	42	42
Operating temperature (°C)	209	194	385	385
pH	8.5 – 9.5	9 – 9.5	9 – 9.5	9 – 9.5
Conductivity (uS/cm)	50 – 150	50 – 150	<10	<10

Table 7. Steam mass balance and quality – other steam system

	Steam generated from process steam drum	Heating steam to HP stripper bottom	Steam injected to reformer	BFW to clean steam drum	Clean high pressure super-heated steam produced	Clean high pressure super-heated steam used for reformer	Stripped condensate to process steam drum	Clean high pressure steam export to battery limit
Stream no.	160	161	162	186	171	172	195	174
Flowrate (kg/hr)	64 523	33 886	63 437	68 352	67 785	8397	65 840	178 724
Operating pressure (barg)	34	33	28	50	47	42	34	42
Operating temperature (°C)	243	254	240	245	389	385	208	385
pH	8.5 – 9.5	8.5 – 9.5	–	9.2 – 9.5	9 – 9.5	9 – 9.5	8.5 – 9.5	9 – 9.5
Conductivity (uS/cm)	50 – 150	50 – 150	–	0.1	<10	<10	50 – 150	<10

process condensate vaporiser after pre-heating with the clean condensate generated from the process condensate vaporiser in an interchanger.

In the process condensate vaporiser, clean steam generated from the export steam drum is used as the heating medium. Process steam generated from the process condensate vaporiser is directly recycled to the reformer with all impurities, which are decomposed at high reforming temperature.

Typically, the process condensate vaporiser is a kettle-type or plate-and-shell-type heat exchanger.

See Table 3 for the advantages and disadvantages of this system.

HP steam process condensate stripper

This process (Figure 4) involves condensate generated from the SMR plant being pumped to the HP steam stripper column after pre-heating with the stripped condensate generated from the HP steam stripper column in an interchanger.

In the HP steam stripper column, saturated or superheated steam generated from the export steam drum is directly injected to the HP steam column as heating medium. Process steam generated from the HP steam stripper column is directly recycled to the reformer with part of the impurities like NH_3 and methanol. Other impurities, such as organic salts, remain in the stripped condensate, which is sent to the de-aerator after pre-heating the process condensate feed entering the HP stripper column. See Table 4 for the advantages and disadvantages of this system.

Technology selection

Based on the requirements of producing high-quality export steam and treating optionally imported process condensate during HPU-1 operating periods, the following concept was selected.

The HP export steam system is completely separated from the process steam system to produce the highest superheated export steam quality for condensing turbine use. This clean steam is produced in the process gas boiler and superheated in the flue gas waste heat system of the SMR.

Process condensate from HPU-2 and imported process condensate from HPU-1 is cleaned in an HP stripper by part of the steam produced in the clean steam system (Figure 5). The stripper overhead is used as process steam.

Part of the stripped process condensate is used as BFW in the process steam boiler in the flue gas waste system to provide the required process steam flowrate.

The remaining stripped process condensate is vaporised in the process condensate vaporiser by part of the steam produced in the clean steam system and exported as process steam to battery limits. The process condensate vaporiser will only be in operation in case of process condensate import from HPU-1.

This configuration ensures that the customer receives, in both cases (process condensate import/no process condensate import), the maximum amount of high-quality HP steam and high-quality process steam from stripped process condensate.

Tables 5 – 7 summarise the mass balance and quality of the stream across each equipment setup. HE