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A Feasibility Study on Improvement of Boron Recovery System using Vacuum Equipment

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1. Introduction

A function of the APR1400 Boron Recovery System (BRS) is to receive recoverable reactor coolant quality water and to recycle it for reusing by purification, degasification in the Gas Stripper (GS) and processing in the Boric Acid Concentrator (BAC).

The GS removes dissolved hydrogen and fission gases from influent stream to preclude buildup of explosive mixture of hydrogen and oxygen and to minimize release of radioactive noble gases to the environment. The GS is designed to reduce the concentration of hydrogen, Krypton-85 and Xenon-133, each by a minimum factor of 1000

A feasibility study for improving the APR1400 design of GS and BAC has been conducted.

The purposes of this paper are to develop the system design of GS and BAC using vacuum and to evaluate its impact on performance and equipment size.

The BAC concentrates boric acid solution in process fluids by means of evaporation. Process fluids enter the concentrator and are heated via recirculation through a steam heater. The vapor leaving the recirculation flow is stripped of entrained liquid by demisters and condensed.

2. System of Package Unit

2.1 Description of the Current System

2.1.1 Gas Stripper (GS)

As shown in Fig. 1, the GS performs gas stripping of reactor coolant by heating process fluids and passing it through a packed stripper column which employs steam as a stripping medium. The gas stripper package includes pumps to transfer the degassed process fluid to the holdup tank or to the volume control tank. Noncondensible gases, along with trace quantities of fission gases and water vapor, flow to the waste gas system.

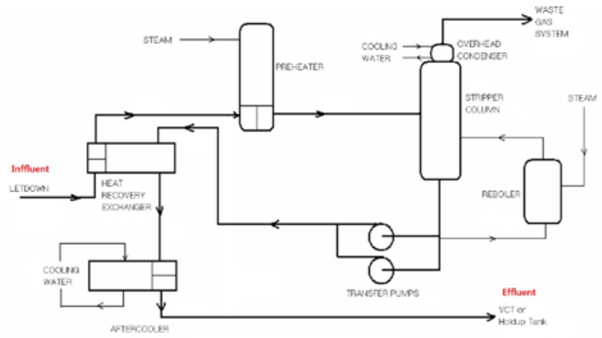

Fig. 1. Schematic diagram of GS (APR1400)[4]

2.1.2 Boric Acid Concentrator (BAC)

The distilled water having less than 10 ppm boron is pumped to the reactor makeup water tank. The concentrated fluids (bottoms), which have the maximum concentration of 4,400 ppm boron, are cooled and pumped to either the boric acid storage tank (BAST) or the liquid waste management system (LWMS). The schematic flow diagram of the BAC is shown in Fig. 2.

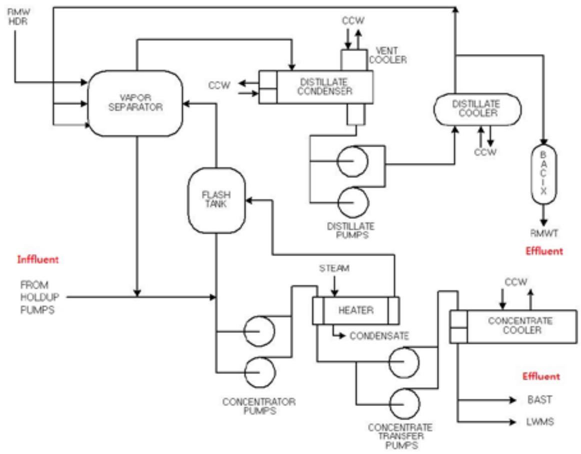

Fig. 2. Schematic flow diagram of BAC (APR1400)[4]

3. Design Evaluation and Results

3.1 Design Evaluation of Vacuum Gas Stripper (GS)

3.1.1 *Modified Design of Gas Stripper (GS)*

The schematic flow diagram of the vacuum GS is shown in Fig. 3. The design of the modified GS is optimized to simplify its system and reduce the amount of heat load required. The operating conditions are determined to meet all performance requirements of the APR1400 GS except its design flowrate.

The design flowrate of 150 gpm, which is greater than the design flowrate (140 gpm) of the APR1400, is applied for conservatism.

The modified GS has a heat recovery exchanger only without preheater and cooler. An Electric immersion heater is used for heating the fluid in a stripper column because of reduction of heat load.

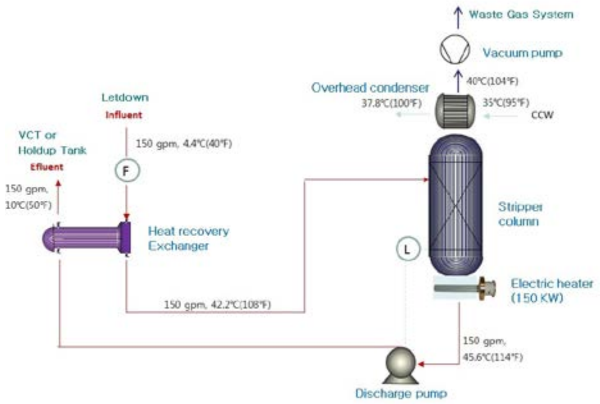

Fig. 3. Schematic flow diagram of Vacuum GS[3]

3.1.2 Evaluation Results

The design of the Vacuum Stripper Column (VSC) is compared with the steam heating type in Table 1. The diameter of the stripper column increases, but its height decreases.

Heat duty of the modified heat recovery exchanger decreases due to low temperature difference between influent and effluent flow, but its size is bigger than the steam heating type.

The vacuum GS does not require as high temperature condition as the APR1400 design, because saturation condition can be reached at lower pressure and temperature under vacuum conditions.

It is evaluated whether the modified stripper column and heat exchanger can be installed in the limited space. The overall size of the optimized vacuum GS is reduced to about 60% compared with the steam heating type as listed in Table 4.

Table 1. Comparison of stripper column design

Comparison factor	Steam Heating Type	Vacuum Type
Size	O.D 0.76 m Height 6.33 m	O.D 0.8 m Height 5.5 m
Operation pressure	1~ 3 bar (absolute)	0.1 bar (absolute)
Operation Temperature	115℃	50℃(Max.)
Number of Plate	3	2
Column Internal Type	1"PALL RING	2"Flexiring Tray+Packing

Table 2. Comparison of heat recovery exchanger design

Comparison Factor	Steam Heating Type	Vacuum Type
Tubeside Temp. (Inlet/Outlet), ℃	4.4 / 66	4.4 / 42
Shellside Temp. (Inlet/Outlet), ℃	116 / 54	46 / 10
Size	O.D 0.3 m Length 4.9 m	O.D 0.95 m Length 5.2 m
Type[1]	BFU	BEM
Heat Duty, kW	2,275	1,522

Table 3. Comparison of heater

Comparison Factor	Steam Heating Type	Vacuum Type
Size	O.D 0.2 m Length 2.4 m	O.D 0.25 m Length 0.9 m
Type	Shell and Tube (BEM)[1]	Immersion Electric Heater
Heat Duty	360 kW	150 kW

Table 4. Comparison of GS Size

Comparison Factor	Steam Heating Type	Vacuum Type
Space	69.30 m^3	23.12 m^3
Flow	140 gpm	150 gpm
Ratio (Flow/ Volume)	2.02	6.49

3.2 Design Evaluation of Vacuum Boric Acid Concentrator (BAC)

3.2.1 Modified Design of Boric Acid Concentrator (BAC)

The schematic flow diagram of the vacuum BAC is shown in Fig. 4. The design of the vacuum BAC is performed using an iterative method to meet less than 10 ppm boric acid concentration of flash tank effluent and maximum 4,400 ppm boric acid concentration of concentrated water.

Influent temperature and pressure of the BAC are same as the APR1400.

The design flowrate of 24.8 gpm, which is greater than the design flowrate (20 gpm) of the APR1400, is applied to enhance capacity and operation margin.

Size of the flash tank is dependent on liquid level and application of a vapor separator. In the vacuum BAC, the vapor separator can be easily unified into vacuum type flash tank due to low steam velocity.

The sizes of concentrated water heater and distillate condenser are smaller than the steam heating type owing to lower operating temperature. The distillate cooler and the concentrate cooler can be removed because of low effluent temperature as shown in Fig 4.

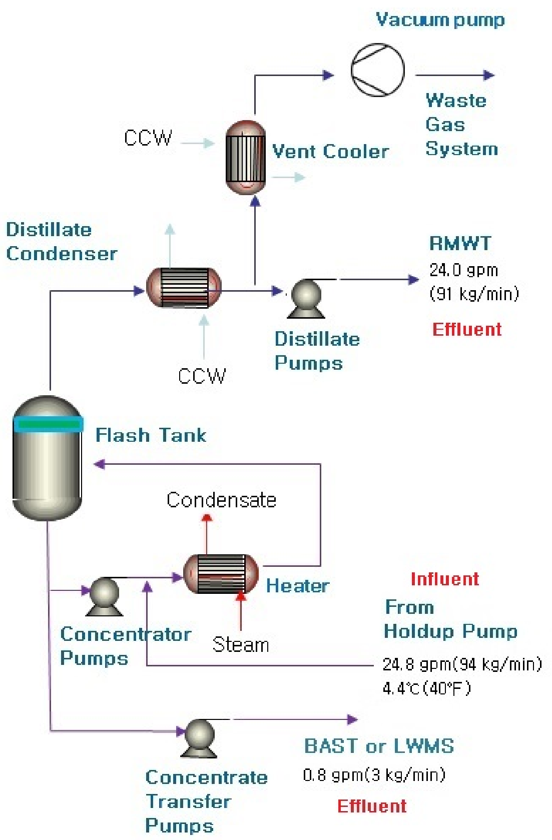

Fig. 4. Schematic flow diagram of Vacuum BAC[3]

3.2.2 Evaluation Results

Table 5. Comparison of flash tank

Comparison Factor	Steam Heating Type	Vacuum Type
Size	O.D 1.8 m Height 4.6 m	O.D 1.7 m Height 4.7 m
Operation Temperature	110℃	50℃(Max.)

Table 6. Comparison of concentrated water heater

Comparison Factor	Steam Heating Type	Vacuum Type
Size	O.D 0.5 m Height 5.5 m	O.D 0.4 m Height 3.4 m
Heat Duty, kW	3,733	2,882

Table 7. Comparison of distillate condenser

Comparison Factor	Steam Heating Type	Vacuum Type
Size	O.D 0.3 m Height 3.0 m	O.D 0.9 m Height 3.3 m
Heat Duty, kW	11,134	8,598

Table 8. Comparison of BAC Size

Comparison Factor	Steam Heating Type	Vacuum Type
Space	109.82 m^3	27.26 m^3
Flow	20 gpm	24.8 gpm
Ratio (Flow/ Volume)	0.182	0.908

Comparison of the flash tank between the steam heating type and the vacuum type are listed in Table 5. The size of the vacuum flash tank is similar to the steam heating type, but the BAC design is simplified by removing the vapor separator.

The concentrated water heater and the distillate condenser between the steam heating type and the vacuum type are compared in Tables 6 and 7.

It is evaluated whether the modified flash tank, heater and condenser can be installed in the limited space. The overall size of the optimized vacuum BAC is reduced to about 70% compared with steam heating type as listed in Table 8.

4. Conclusions

This paper carried out a feasibility study on application of the package units using vacuum and evaluated its impacts on heat load and equipment arrangement. The modified designs are expected to provide the following benefits:

1. The increased processing capacity reduces plant's outage durations.
2. The simplified design improves operability and maintainability.
3. Less components, smaller package size and less heat load reduce costs.

REFERENCES

[1] " Standards of the Tubular Exchanger Manufacturers Association", TEMA, Oct., 1999, 8th Edition.
[2] Kuppan Thulukkanam, "Heat Exchanger Design Handbook", 2th Edition, 2013.
[3] Yuseok Jeong and etc., "Design & Development of Package Unit (Gas Stripper, Boric Acid Concentrator) using Vacuum", KEPCO E&C journal, Vol. 27, No.1, 2016
[4] Yuseok Jeong and etc., "System Impact Assessment for the Increase in the Gas Stripping Capacity", KEPCO E&C journal, Vol. 28, No.1, 2014
[5] Robert H. Perry, "Perry's Chemical Engineers' Handbook", 2007.