Study on Application of Vacuum Degasifier for Degasification of the Reactor Coolant

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1. Introduction

Hydrogen and fission gases dissolved in the reactor coolant shall be removed for preventing hydrogen explosion and radiation exposure during reactor shutdown. Also, oxygen in the reactor coolant shall be removed for preventing general corrosion of materials during reactor heatup and power operation. Typically, dissolved gases in the reactor coolant of the Korean Standard Nuclear Power Plant (KSNP) are removed by using the gas stripper which consists of a stripping column, valves, heaters, pumps, instrumentation and so on.

Framatome-ANP (FANP) supplied the vacuum strippers for several plants in Europe while Westinghouse company plans to supply a vacuum degasifier for AP600 and AP1000. Since the Korean Utility Requirement Document requires a vacuum stripper for gas stripping of the reactor coolant, it is necessary to study its applicability to the KSNP or future plants.

2. Gas Stripper

In this section, design of various gas strippers is reviewed.

2.1 KSNP Gas Stripper

Gas stripping is achieved by heating the process fluid and passing it down through a packed column in which the stripping steam as a stripping medium is passing upward. The stripping steam is generated by heating the degassed process fluid with steam. The gas stripper includes pumps which transfer the degassed process fluid to the holdup tank or the volume control tank. Noncondensable gases along with trace quantities of fission gases and water vapor flow to the gaseous waste management system.

Control valves and pumps are operated automatically for a balance of each process flow. The performance of the gas stripper depends on the steam quality. During reactor shutdown or heatup, the steam quality is not sufficient to ensure the inherent performance of the gas stripper. Therefore, venting operation of the volume control tank is performed for gas stripping because the gas stripper is not available during reactor shutdown or heatup. However, longer period is required for venting operation since venting is less efficient for gas stripping.

2.2 Framatome-ANP Vacuum Degasifier

The vacuum degasifier designed by Framatome-ANP (FANP) consists of a degasifier part and an evacuation part. The major components of the gasifier part are packed column, preheater, pump and heat exchanger. The major components of the evacuation part are vacuum pump and refrigerator.

The operation of this degasifier is similar to that of the KSNP gas stripper. The vacuum pump of the evacuation part keeps the degasifier part under vacuum condition to achieve a higher stripping efficiency. [1]

2.3 AP600/AP1000 Model

Westinghouse plans to supply a vacuum degasifier for AP600 and AP1000. Basic components and operation are similar to the vacuum degasifier of FANP. [2][3]

2.4 Industrial Degasifier

The degasifiers in general industries are used to remove dissolved oxygen in the boiler feedwater. The degasifier consists of deaerating heater and storage tank. Feedwater is injected into upper section of heater via spray valve and heated by steam. The most dissolved oxygen is removed at this area. Then, feedwater passes through tray assembly or scrubber to strip the residual oxygen.

3. Mechanism of Vacuum Degasifier

The mechanism of the vacuum degasification is based on the Henry's law and the Le Chatelier's principle. Gases are dissolved in solutions. Since the dissolution is an equilibrium process, the equilibrium constant for this equilibrium is introduced. The equilibrium constant shows that the concentration of a solute gas in a solution is directly proportional to the partial pressure of gas above the solution. This is known as the Henry's law as follows.

$$y^* = \frac{p^*}{p_T} = mx$$

where,

y^* = gas molar fraction in gas phase

p^* = gas partial pressure in gas phase

p_T = total pressure of gas phase

m = Henry's constant

x = gas molar fraction in solution

The Le Chatelier's Principle explains the state of dynamic equilibrium. It covers changes to the position of equilibrium if concentration or pressure or temperature is changed. If a dynamic equilibrium is disturbed by changing the conditions, the position of equilibrium moves to counteract the change.

In general, process flow of gas stripper and vacuum stripper is heated by heating medium to enhance stripping efficiency based on Le Chatelier's Principle.

4. Requirement of Vacuum Degasifier

4.1 Steam Requirement

The steam quality is not sufficient during reactor shutdown or heatup as specified in section 2.1. It is recommended that the vacuum stripper should not use steam for operation in order to use it during plant heatup and cooldown.

4.2 Vacuum Pressure

The vacuum pressure is determined based on the dissolve oxygen concentration during power operation. Required vacuum pressure is estimated based on the process flow condition and determined to be less than 200 Torr.

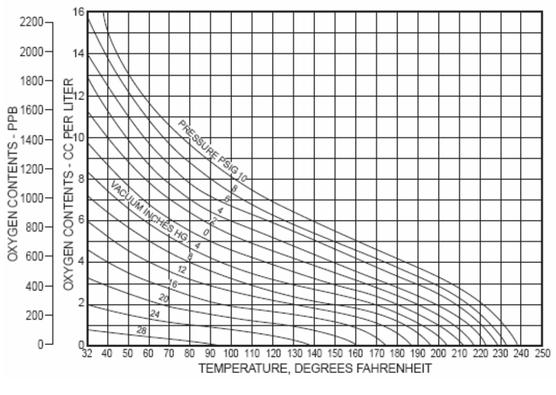

Figure 1. Oxygen Content in Water [4]

4.3 Vacuum Pump Capacity

The vacuum pump capacity shall be sufficient to maintain the required vacuum pressure of 200 Torr and to ensure continuous stripping for process flow. For this purpose, the required pump capacity is 200 gpm.

4.4 Radiation Shielding

The radioactive dissolved gases shall be removed from the reactor coolant to prevent radiation exposure. The shielding depends on the coolant inventories which are affected by the decontamination factor (meaning of stripping efficiency) of the gas Stripper. The decontamination factor of KSNP is 1000. The decontamination factor of the vacuum stripper is assumed to be 50, 300, 700 to review its effect on the shielding. The evaluation results show that if the decontamination factor of the vacuum stripper is lower than 1000, the shielding thickness of some portion of component should be increased while the shielding thickness of other portions could be retained.

4.5 Refueling Outage

The overhaul period can be reduced due to the short heatup and cooldown period by using the vacuum stripper for the primary system,. Also, the vacuum stripper is simple in design and, hence, is easy to construct and maintain with a lower maintenance frequency as compared to the gas stripper.

5. Conclusion

An evaluation for the applicability of the vacuum degasifier shows that the vacuum stripper is more flexible than the gas stripper in steam usage and maintenance. Although the efficiency of the vacuum stripper is low than that of the KSNP gas stripper, it has the advantage of reducing overhaul outage period. However, adopting vacuum stripper may require further study on the shielding requirements.

REFERENCES

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[4] Brochure, Shippensburg Pump Co., Inc