

De-entrainment of Boron by Evaporation.

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(Received August 18, 1986)

증발에 따른 붕소의 탈비말 동반

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(1986. 8. 18 접수)

Abstract

The purpose of this research was to investigate the de-entrainment of boron for evaporators used in nuclear power plants. The forced circulation and semi-continuous type evaporator was used in the experiment. Cyclone and glass-wool packed column which is supposed to provide good decontamination factor as well as easy maintenance, were selected as de-entrainment devices to be used in the evaporation of radioactive liquid wastes. The de-entrainment device combined with cyclone and glass-wool column has shown overall DF more than 1,000 for boron.

요 약

원자력발전소에서 사용되고 있는 증발기에 대해 boron의 탈비말 동반을 분석하기 위하여 강제순환식 및 반연속식 증발기가 실험에 사용되었다. 보수가 용이하고 제염효율이 높은 Cyclone과 glass-wool 충전탑을 액체방사성폐기물을 처리하는 데 탈비말동반장치로 사용되었다. Cyclone과 glass-wool 충전탑을 연결하여 사용하였을 때 붕소에 대한 제염효율은 1,000 이상을 나타내었다.

1. Introduction

Evaporation, the process by which a solution or slurry is concentrated by boiling away the solvent, is a unit operation that is widely used in the nuclear industry for reducing waste volume and for concentrating radioactive nuclides in liquid effluent. Evaporation is usually used for radioactive wastes that require a high degree separation between volatile and nonvolatile components and can not be easily treated by other treatment methods.

In the design of evaporator to concentrate

radioactive liquids, vaporliquid separation is more important object than heating costs and volume reduction. Even a small amount of entrainment is likely to contaminate the condensed vapor and thus reduce the decontamination to unsatisfactorily low level. Evaporators can separate water from solids very effectively, and a system decontamination factor (DF) of 10^3 to 10^4 is generally expected for a single evaporator to separate the water from a nonvolatile solute.¹⁾ DF is decreased by entrainment, splash-over, foam and volatilization of solutes, but is almost a function of entrainment, which are fine droplets that are carried along the rising vapor

stream. Entrainment increases at high evaporation rates, thus the DE generally decreases with the increasing evaporation rate. These tendency also was known from an empirical correlation of DF with entrainment and imply that the lower evaporation rates the DF would be higher; however, at very low evaporation rates, the DF decreases with decreasing evaporation rate.^{2,3,4)}

Entrainment can be controlled by adjusting the vapor velocities. However, the trapping of entrainment from the entrainment separators such as glass wool cyclones and tray mainly depends on the vapor velocities. None of entrainment separator can be a panacea for all liquid carry-over problems. It is important to select an entrainment separator with good efficiency, economy and benefit for process operations.⁵⁾ The optimum DF is the point at which the product of the system DF for the evaporator and entrainment separators is a maximum.

In order to analyze the entrainment separator, we conducted quantitative measurement of decontamination factors for a forced circulation evaporator body, a cyclone and a glass-wool packed column, which have an easy maintenance as entrainment separators. This study evaluates DF of boron with a glass wool packed column and a cyclone.

II. Experimental device and method

Fig. 1 shows a evaporator body, a heat exchanger and a condenser of the forced circulation type evaporation unit used in this experiment. The feed enters into the evaporator body through the heat exchanger by a pump. The operation mode is semi-continuous. The vapor, passing through the cyclone and glass-wool packed column, reaches to the condenser and is condensed into liquid. Table 1 gives the dimensions of the major parts of the evaporation

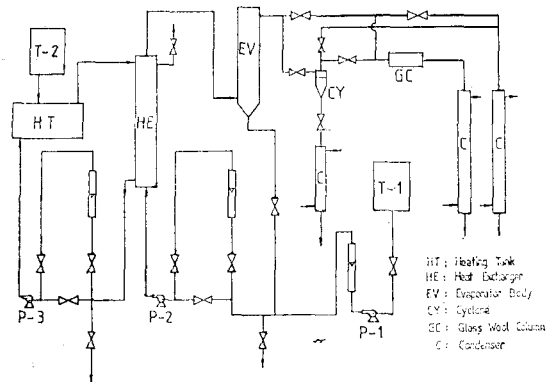


Fig. 1. Flow Sheet of Evaporation System

Table 1. Dimensions of Major Parts of Evaporation Unit (mm)

Evaporator body	
Inner diameter	130
Height	735
Vapor conduct	
Inner diameter	21
Cyclone (spiral type)	
Inlet	6×13
Diameter of out cylinder	30
Diameter of inner cylinder	20
Height of cylindrical part	30
Height of circular cone part	60
Glass wool packed column	
Inner diameter	114
Glass wool packed layer	110

unit. Because boron is one of the major components in radioactive liquid waste from nuclear power plant, the distilled water including 1~2 wt % boric acid (1700~3500 ppm boron) was used as the simulated liquid waste in the evaporation boiler for this experiment and DF was determined by comparing the concentration of boron in the condensate from the evaporator with that of the feed. Sampling lines between separators are installed to measure DF of each separator. The devices and lines are insulated to prevent heat loss and to maintain the constant heat in the evaporator body. In order to maintain an approximated level in the evaporator body,

level controller is installed. A feed was continuously evaporated until a certain degree of concentration in the evaporator body was reached. Then the feed supply was terminated and the concentrated liquid in the evaporator body was taken into the concentrated liquid tank. This evaporation unit reached the stationary state in about 2 hours, although such length of time depends upon the rate of evaporation. Therefore, measurement was made after a lapse of 3 hours in all cases. The total heat transfer area in the heat exchanger was 0.3m^2 . The concentration of boron was measured by carmine method at low concentration and by titration at high values.⁶⁾

III. Results and discussion

Measurement was carried out on the concentration of the condensates from the separation systems; 1) evaporator body, 2) evaporator body and cyclone, 3) evaporator body, cyclone and glass-wool packed column, and 4) evaporator body and glass-wool packed column. For each of

the experimental runs, the entrainment entered the condenser was measured from the color metric analyses of the condensate samples and expressed as parts of feed per million parts of condensate (DF). DF are affected by entrainment, splash-over, foam and volatilization of solute. However, splash-over losses are usually insignificant if sufficient distance between the surface of the boiling liquid and the outlet of the splash chamber is provided and evaporation rates is low. Also, foaming and the volatilization phenomena are negligible when the distilled water is used with 1-2 wt% boric acid. Assuming that the condensate is only contaminated by the entrainment, DFs are measured and analysed.

Fig. 2 shows the DF values for each case. In this figure, the DF is on the ordinate and the mass velocity of the vapor in the evaporator chamber is on the abscissa. From the experimental results as shown in the figure, it is noticed that DFs for entrainment separators are affected by the evaporation rates. DFs for the evaporator body decrease with an increase of the evaporation rate. From this Figure, we notice that the low

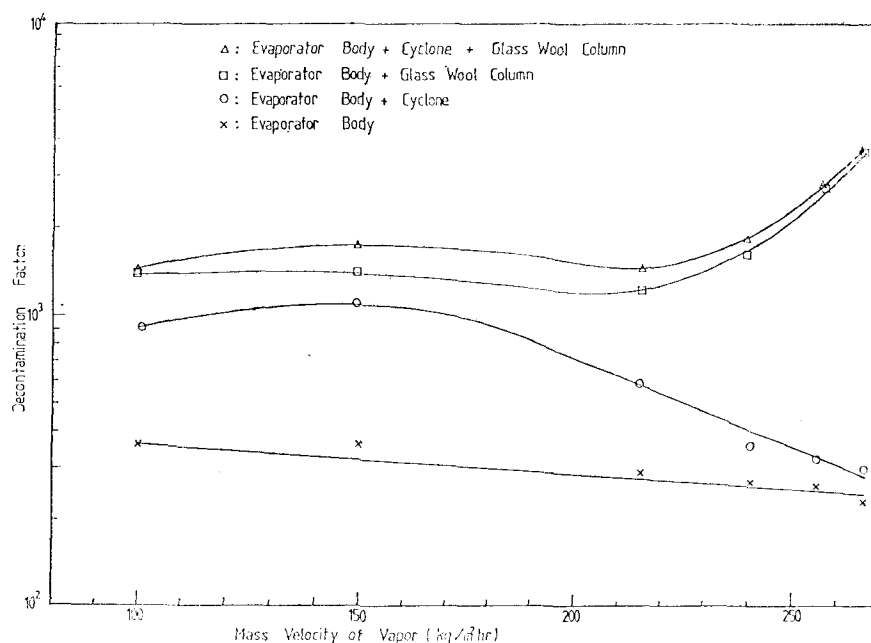


Fig. 2. Decontamination Factor of Boron for Forced Circulation Type

value of DF for evaporator body is due to the fact that evaporation does not take place smoothly as the evaporation rates increases.⁷⁾ In the evaporator body, droplets of large diameter originating from the breaking up of rising jets of liquid have larger terminal velocities and reach some definite height depending on the initial jet and ascending vapor velocities. Then falling terminal velocities are usually larger than the velocities of rising vapor. Small droplets are carried out of the evaporator body with the vapor stream and then contaminate the condensate. It is obvious that entrainment separators must be installed to obtain higher DF. When a cyclone is used as the entrainment separator, DFs for the cyclone and evaporator body increase with the increase of evaporation rate and reach the maximum value of about 1,000 at the vapor velocity of 150 kg/m hr. After that, the DF tends to fall steadily with the further increase of the evaporation rate. It is shown that the excellent performance for cyclone depends upon the condition of operation.⁸⁾ When a glass wool packed column is installed behind the cyclone in order to improve decontamination factor, the overall DF for a system including the evaporator body-cyclone-glass wool packed column reached about 1500 to 4000. This shows that the DF is increased with the use of the glass-wool packed column. Since the DF increases with higher evaporation rate, DF increase is due to the high entrainment efficiency of the glass wool with the effects of the inertial forces of entrainment.⁹⁾ The more evaporation rate is, the more inertial force of entrainment is. In PWR and BWR plants the boron recycle evaporator can only give DFs of 10 to 100. However, this experiment shows that DFs are higher than those of the boron evaporators. Also, de-entrainment system including a glass wool packed column and cyclone has easy maintenance. Therefore it is considered the de-entrainment devices used in

this experiment could be useful to radwaste evaporator in nuclear power plants. In case a glass wool packed column is only used as an entrainment separator, DF for this system is not so much high as the system involving the cyclone-glass wool packed column.

Fig. 3 shows that DF for the glass wool packed column was compared with DF for the evaporator body-glass wool packed column. DF for glass wool packed column increases with an increase in the rate of evaporation. However, the life time for a glass wool packed column only can be shorter than that of a glass wool packed column and a cyclone. If a cyclone and a glass wool packed column are used as the entrainment separator, life time for glass wool packed column is prolonged because a cyclone remove droplets up to 10 μm diameter in the vapor. Therefore, it is seen that the installation of a cyclone prior to a glass wool packed column

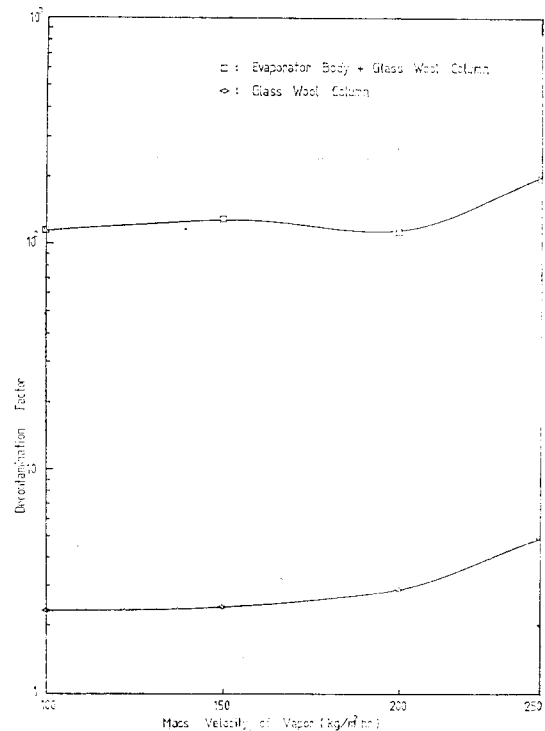


Fig. 3. Decontamination Factor of Boron for Forced Circulation Type

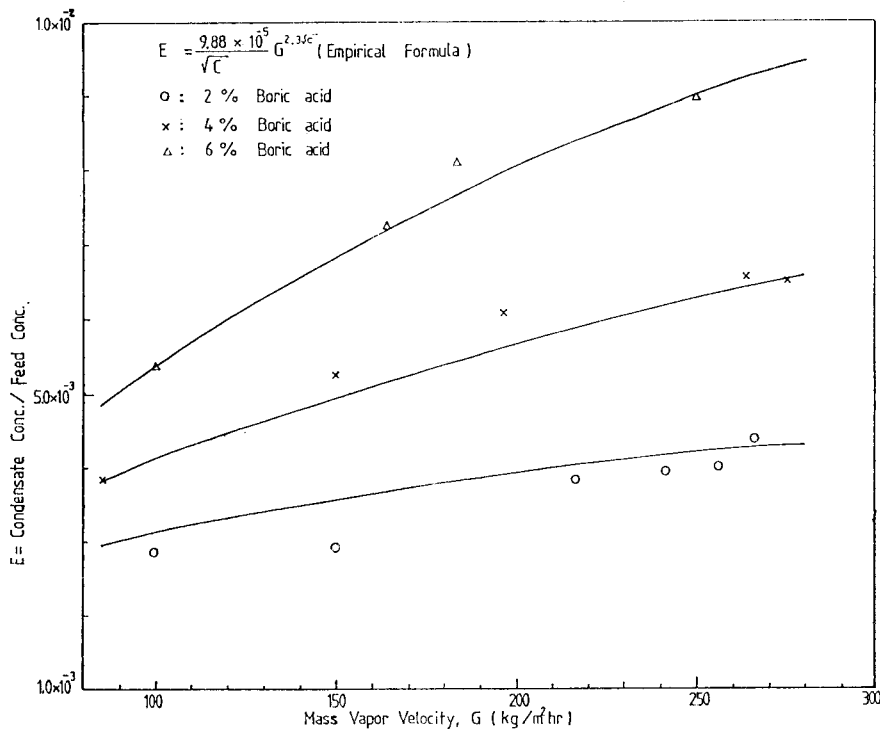


Fig. 4. Entrainment Factor of Boron as a Function of Mass Vapor Velocity

is the more effective.

In Fig.4, entrainment factor, E, is represented as the inverse of DF. Entrainment increases with an increase of boron concentration in the evaporator body and of evaporation rates. The empirical entrainment factor derived by the results of this experiment is shown as follows:

$$E = \frac{9.88 \times 10^{-5} G^{2.34} C}{\sqrt{C}}$$

Where G: mass velocity of vapor [kg/m. hr]

C: fraction of boric acid concentration [-]

E: entrainment factor = $\frac{1}{DF}$ [-]

IV. Conclusion

This paper describes that the combined cyclone and galss-wool packed column could become a good de-entrainment device to improve the DF of waste evaporator in nuclear power plant.

A summary of the results is shown below.

1) The empirical equation of the entrainment factor for boron evaporation is calculated as follows.

$$E = \frac{9.88 \times 10^{-5} G^{2.34} C}{\sqrt{C}}$$

2) The combination of cyclone and glass-wool packed column as deentrainment equipment prove an overall DF more than 1,000 at 150-230 kg/m²·hr vapor mass velocity for boron experiment.

3) Cyclone and glass-wool packed column are supposed to have good decontamination factor.

V. References

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