Gas-Liquid Separator design of SWRPRS in PGSFR

Jung Yoon [a*], Tae-ho Lee [a]
[a] *Korea Atomic Energy Research Institute, SFR System Design Div., 1045 Daedeok-daero, Daejeon*
[*] *Corresponding author: jyoon@kaeri.re.kr*

1. Introduction

There is the Sodium-Water Reaction Pressure Relief System (SWRPRS) in PGSFR to prevent the Sodium-Water Reaction (SWR) due to the break of the steam generator tube. When the SWR is occurred in the steam generator, the hydrogen is generated. And this hydrogen brings about the overpressure in the Intermediate Heat Transport System (IHTS). When the pressure in IHTS reaches the rupture pressure, the rupture disk, which is connected in the IHTS piping, is opened, and the sodium, hydrogen, and SWR products are dumped to the sodium dump tank (SDT). The solid and liquid SWR products are stored in the SDT, and the gas SWR products are exhausted to the piping to atmosphere. The piping to atmosphere includes several components such as gas-liquid separator, backpressure rupture disk, and hydrogen igniter. Among these components, gas-liquid separator separates the liquid sodium which is included in gas SWR products not to react sodium and air.

In this study, the size of gas-liquid separator, which is based on the hydrogen volume which is exhausted in the sodium dump tank, is determined.

2. Gas-Liquid Separator Selection, Sizing, and Performance

2.1 Gas-Liquid Separator Selection and Sizing

The normally used gas-liquid separator is almost the cyclone type which separates the particle in gas using the centrifugal force due to the swirl. Since the cyclone separator is very simple structure, easy to manufacture, and less maintenance costs, this type is used to wide industrial fields. But, this type has the greater pressure drop than other types.

Over the past decades, various studies on a cyclone separator has been conducted by Barth [1], Leith-Licht [2], Dies [3], and Lapple [4]. Also, the optimized standard size cyclone separator is being used as Table 1 by Stairmand, Swift, Lapple, Peterson, and Whitby [5]. The schematics of the standard cyclone separator is shown in Fig. 1.

Since the efficiency is a top priority goal in the gas-liquid separator installed in the SWRPRS according to reference [6], Stairmand's model is selected. If the cross-sectional area of the piping is same as that of the backpressure rupture disk, the body diameter (D) can be calculated below equation due to the reference [5].

$$\mathrm{D} = 0.964 \times \sqrt{A_{inlet}} = 0.193\ m \quad (1)$$

Where, A_{inlet} : the cross-sectional area of the piping

Using Table I, final dimensions about the body diameter can be calculated. Dimensions according to the cross-sectional area change of the piping are shown in Table II.

The pressure drop of cyclone separator is presented by Shepherd & Lapple [8], Casal & Martinez [9], Dirgo [10], and Coker [11]. In general, the pressure drop of cyclone separator is proportional to the velocity head.

$$\Delta\mathrm{P} = \alpha \frac{\rho_g v_i^2}{2} \quad (2)$$

Where, ρ_g : Density of gas
v_i : Inlet velocity

Also, α values in each model are as follows.

$$\alpha = 16 \frac{HW}{D_e^2} \text{ (Shepherd \& Lapple)} \quad (3)$$

$$\alpha = 11.3 \left(\frac{HW}{D_e^2}\right)^2 + 3.33 \text{ (Casal \& Martinez)} \quad (4)$$

$$\alpha = 20 \left(\frac{HW}{D_e^2}\right) \left[\frac{S/D}{((L_b+L_c)/D)(L_b/D)(D_d/D)}\right]^{1/3} \text{ (Dirgo)} \quad (5)$$

$$\alpha = 9.47 \frac{HW}{D_e^2} \text{ (Coker)} \quad (6)$$

Each calculated pressure drop of the cyclone separator using these models is 139.54 kPa, 112.02 kPa, 105.65 kPa, and 82.59 kPa, respectively. Therefore, final pressure drop of the cyclone separator is conservatively determined to 139.54 kPa.

Table I: Dimensions of Standard Cyclone Separators

	High Performance		Normal	High Capacity	
	Stairmand	Swift	Lapple	Swift	Peterson /Whitby
D/D	1.0	1.0	1.0	1.0	1.0
H/D	0.5	0.44	0.5	0.5	0.583
W/D	0.2	0.21	0.25	0.25	0.208
S/D	0.5	0.5	0.625	0.6	0.583
D_e/D	0.5	0.4	0.5	0.5	0.5
L_b/D	1.5	1.4	2.0	1.75	1.333
L_c/D	2.5	2.5	2.0	2.0	3.17
D_d/D	0.375	0.4	0.25	0.4	0.5

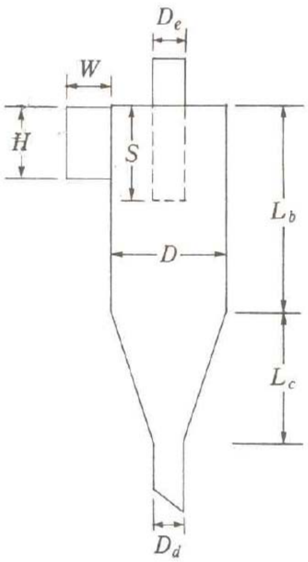

Fig. 1. Standard Cyclone Separator

Table II: Dimensions of Standard Cyclone Separators

	A*	1.5A	2A	2.5A	3A	3.5A
D	0.193	0.236	0.273	0.305	0.334	0.361
H	0.096	0.118	0.136	0.152	0.167	0.180
W	0.039	0.047	0.055	0.061	0.067	0.072
S	0.096	0.118	0.136	0.152	0.167	0.180
D_e	0.096	0.118	0.136	0.152	0.167	0.180
L_b	0.289	0.354	0.409	0.457	0.501	0.541
L_c	0.482	0.590	0.682	0.762	0.835	0.902
D_d	0.072	0.089	0.102	0.114	0.125	0.135
V**	0.028	0.051	0.079	0.110	0.145	0.182

* $A=A_{inlet}$
** Volume of separator (m^2)

2.2 Gas-Liquid Separator Performance

The model to calculate the efficiency of cyclone separator is presented by Lapple [12]. In this model, the gas flows into the cyclone separator is rotated along the inside wall, wherein the rotational speed of the gas is expressed by following equation.

$$N = \frac{1}{H}\left(L_b + \frac{L_c}{2}\right) \quad (7)$$

Also, the cut particle diameter collected with 50% efficiency (d_{pc}) is expressed by following equation.

$$d_{pc} = \sqrt{\frac{9\mu W}{2\pi N v_i(\rho_p - \rho_a)}} \quad (8)$$

Where, μ : Dynamic viscosity of gas
ρ_p : Density of particle
ρ_a : Density of gas

Using the cut particle diameter, the collection efficiency (η_j) according to the particle size is expressed by following equation.

$$\eta_j = \frac{1}{1+(d_{pc}/d_{pj})^2} \quad (9)$$

Where, d_{pj} : j th characteristic diameter

Finally, the overall collection efficiency (η) of the cyclone separator is expressed by following equation.

$$\eta = \frac{\Sigma \eta_j m_j}{M} \quad (10)$$

Where, m_j : j th average particle mass
M : total particle mass

To calculate the overall collection efficiency of the cyclone separator, it should know the mass fraction according to each particle size range which is acquired by experiment. Since this experiment is not performed yet, the assumed mass fractions as shown in Table III are used for efficiency calculation.

Table III: Assumed Mass Fraction according to Each Particle Size Range

Particle diameter (μm)	Characteristic diameter (μm)	Mass fraction (%)
0.0 ~ 0.2	0.1	2
0.2 ~ 0.4	0.3	5
0.4 ~ 0.6	0.5	8
0.6 ~ 0.8	0.7	15
0.8 ~ 1.0	0.9	20
1.0 ~ 2.0	1.5	20
2.0 ~ 5.0	3.5	15
5.0 ~ 10.0	7.5	8
10.0 ~ 20.0	15.0	5
20.0 ~ 50.0	35.0	2

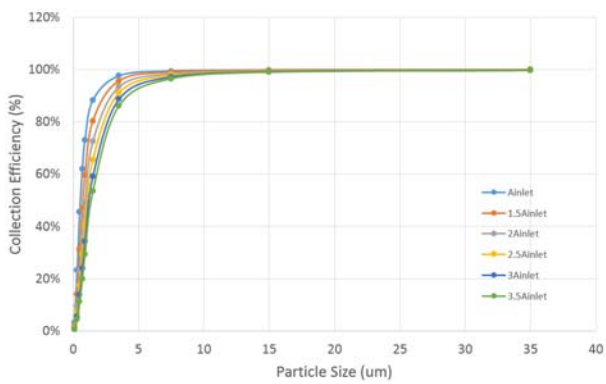

Fig. 2. Collection Efficiency of Cyclone Separator

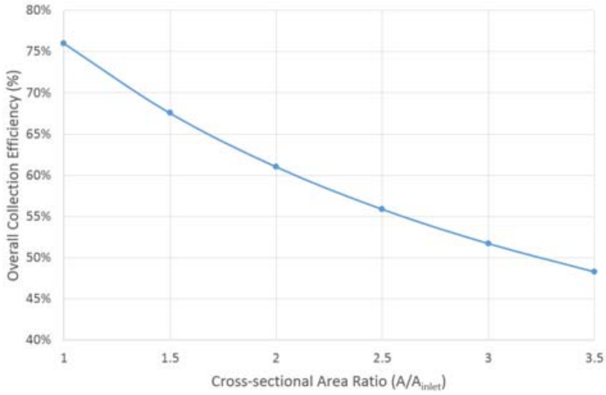

Fig. 3. Overall Collection Efficiency of Cyclone Separator

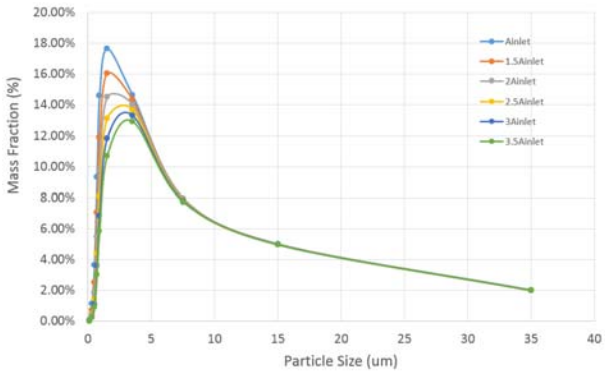

Fig. 4. Mass Fraction according to Collection Particle

The calculated rotational speed of gas, cut particle diameter, and overall collection efficiency of the cyclone separator using Eq. (7) ~ (10) and Table III are 7, 0.5474 μm, and 76.01 %, respectively. The collection efficiency according to the particle size and the cross-section area of the piping is shown in Fig. 2. The overall collection efficiency according to the cross-section area of the piping shown in Fig. 3. Also the mass fraction according to the collection particle is shown in Fig. 4.

3. Conclusions

To determine the gas-liquid separator for the separation of gas and sodium particle dumped the SDT, Stairmand's model which has high performance among standard cyclone separator models is selected. The body diameter is determined, and other dimensions are determined due to the ratio about the body diameter. Shepherd & Lapple's model is selected as the pressure drop calculation model considering the conservation. Also, the overall collection efficiency considering the assumed mass fraction of sodium particle according to the particle size range is determined to 76 %. However, the mass fraction of sodium particle according to the particle size range should be acquired by experiment to acquire the exact overall collection efficiency of gas-liquid separator.

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