Analysis of hydrocyclone as river water pre-treatment for tertiary coolant of RDE

Sriyono, Rahayu Kusmastuti, Sofia L. Butarbutar, Djati Hoesen Salimy, Febrianto, Ign. Djoko Irianto, M. Pancoko, Geni R. Sunaryo

Center for Nuclear Reactor Technology and Safety, BATAN Puspiptek Area Building 80, Serpong, South Tangerang City, 15310, INDONESIA

Email: sriyono@batan.go.id

Abstract. RDE is an experimental power reactor that planned to use Cisadane river water for its tertiary coolant. For maintaining the condenser reliability material its quality should be concerned. Therefore pre-treatment should be applied. Hydrocyclone is a separation device to remove larger solid particles from water. It can be an alternative component and installed for pre-treatment before water delivered to the water treatment system. Hydrocyclone designed to reduce solid particles concentration in water by means centrifugal forces. This paper discusses the hydrocyclone performance related to the solids particle separation efficiency of Cisadane river water. The amounts of solids that can be separated by an hydrocyclone will be explained. The ChemCAD software is used to simulate the cleaning process. The high efficiency hydrocyclone is used to simulate the separation process. The water intake is 50 m$^3$/h and the solids particles size distribution majority more than 10 µm are set and the largest one is 100 µm is assumed. The amount of solids in water intake is 10% of total mass flowrate input. The hydrocyclone is installed in the first stage of cleaning system after water pump. The solid particles distribution are set in the inflows of cleaning system and the particles in hydrocyclone outlets are analyzed. At 0.3 m of hydrocyclone diameter the separation efficiency is 38%, and at the 1.1 m of diameter the efficiency is only 2.7%. The smaller diameter resulted higher separation efficiency, also causes the higher pressure drop and vice versa. The pressure drop increased significantly when the diameter is below 0.4 m. The dust particles size has been separated (D50) value is increase linearly from 12.18 to 71.27 micron with the hydrocyclone diameter from 0.3 to 1.1 m.

Keywords: RDE, Hydrocyclone, ChemCAD, separation process, water treatment

1. Introduction

Batan is developing the experimental power reactor which called Reaktor Daya Eksperimental (RDE). It is designed based on High Temperature Gas Cooled Reactor (HTGR) technology [1]. This reactor has an indirect cycle with primary coolant is helium gas and it secondary is water. It uses graphite as moderator and structural material. The primary coolant flows in the fuel gap from the bottom to the upper of reactor core. Helium is an inert gas; it will not chemically react with any compounds [2, 3]. The RDE is designed to generate electricity; otherwise the heat will be used to support hydrogen production process, the coal gasification and liquefaction, etc [3].
RDE uses Cisadane river water as a tertiary coolant. The tertiary coolant function is transferred heat from the secondary coolant condenser and it will discharge to the environment through cooling tower. The water river need to treat before delivered as tertiary reactor coolant [4]. The water treatment system used a mechanical separation component such as hydrocyclone, mechanical water filter, etc. Hydrocyclone is a separation device also known as liquid cyclone. It is an important device for the separation of solid-liquid suspensions of river water [5]. The dirty water enters to the hydrocyclone by tangential and it is separated from the solids by centrifugal forces. As an option, hydrocyclone is installed for pre treatment before delivered to the water treatment system [6]. Hydrocyclone is designed to reduce the concentration of dispersed solid particles in water by means centrifugal forces [7]. This paper discusses the hydrocyclone modeling and simulation for the cleaning process of Cisadane river water. The purpose of water treatment unit is to clean raw water from Cisadane River to reduce the suspended solid to certain specification as tertiary water supply.

The objected of this research is to determine the hydrocyclone performance related to the solid particles separation of river water. The amounts of solids that can separated by hydrocyclone will be described. The ChemCAD sofware is used to simulate the cleaning process [8]. Many papers have discussed the ChemCAD capability for simulating the industrial processes such as water treatment [9].

2. Theory

2.1 Cooling Water Systems of RDE

Water is used for the secondary and tertiary coolant circuits of RDE. The circulating and service water system is taken from water supply balance of plant (BOP) systems outside the nuclear site. The water service is mechanically cleaned and filtered before delivered to water pond. The circulating water system is a recirculation system using a cooling tower which passes from the cooling tower basin to the circulating water pumps. The water is pumped through the condenser of the condensing turbines and back to the cooling tower. The water supply source is come from the river and other sources such as puspiptek water supply [4].

Raw water is used for process and utility consumption of RDE will be supplied from Cisadane River. This raw water will be treated as feed water, cooling water make up, service water, drinking water, hydrant supply water and others. The water quality of the Cisadane is known by its physical and chemical factors. These factors are: temperature, pH, current velocity, and brightness/TSS (total suspended solid) of water. In the rainy season, turbidity increases with increasing TSS value. The TSS value of Cisadane water during rainy season in the upstream, middle and downstream were 3-126 mg/L, 114-164 mg/L and 172-1181 mg/L, respectively. In the dry season, TSS values of upstream, middle and downstream were is 8-15 mg/L, 20-114 mg/L and 22-52 mg/L. The river water (upstream and middle) is still suitable for the designated river water Class 1 and 2. However, in the rainy season, river water is only suitable for agriculture and livestock (river water Class 3-4) [10, 11].

For RDE, submerged pipe is connected between river and water intake pond in the pump room. The submerged pipe is installed underground and inclined to deliver river water to water intake pond and to minimize the solid sedimentation inside pipe. Underground pipe is constructed submerged below expected minimum level of river water during dry season to ensure the continuity of water supply. Coarse filter installed at the inlet of the pipe to prevent large material entrained in the water flow to the water intake pond. From this submerged pipe, raw water from river will free flowing to the water intake pond. Water control box and mechanical filter build between river and water pond to
settle the solid matter in the river water and to monitor amounts of the solid matter. Pump room is a building contains a water intake pond and water intake pumps. Raw water in the pond is pumped with water intake pumps to the clarifier in the RDE area. Water intake pumps is a vertical centrifugal pump, with design configuration 2 x 100% flow rate capacity or 1 (one) pump running, 1 (one) pump stand by. The capacities of these pumps are 50 m$^3$/h of mass flow rate [4].

Pressure switch low is installed in the discharge of the pump. In case main pump is shut down, the pressure in the discharge will decrease and the low pressure setting is reached. In this condition, the logic will automatically start the stand by pump to maintain the supply water to RDE [4].

2.2. Hydrocyclone and Its Working Principle
A hydrocyclone as shown in Figure 1 is a mechanical device to separate particles in a liquid suspension based on the ratio of their centrifuge fluid resistance. This ratio is high for dense and coarse particles, and low for fine particles. Hydrocyclone is suitable for application in the separation of liquids of different densities. It has been widely used in many industries. The hydrocyclone has various advantages, including compact structure, simple design and operation, high production capacity, low operation and maintenance costs, small volume and light weight [12, 13]. A hydrocyclone is designed to reduce or increase the concentration of a dispersed phase, solid, liquid or gas of different density, by means of centripetal forces or centrifugal forces within a vortex [14]. Hydrocyclones are characterized by their high operational reliability and efficiency with increasing flow rates, their high throughput, their simple structure (no moving parts), small size, and low maintenance and support costs.

![Figure 1. The hydrocyclone specification and working principle [15]](image)

The liquid mixture is flowed into the hydrocyclone to create the vortex and, depending upon the relative densities of the two phases, the centrifugal acceleration will cause the dispersed phase to move away from or towards the central core of the vortex. A hydrocyclone will normally have a cylindrical section at the top where liquid is being fed tangentially, and a conical base. The angle, and hence length of the conical section, plays a role in determining operating characteristics. A hydrocyclone is a classifier that has two exits on the axis: one on the bottom (underflow or reject) and one at the top
The underflow is generally the denser or coarser fraction, while the overflow is the lighter or finer fraction. It has no moving parts and its operation depends on two major parameters i.e. characteristics of the feed stream and geometry of the cyclone. The characteristics of the feed stream include size distribution of solids in the feed stream, pulp density (percent solids in the slurry), pulp viscosity and the inlet pressure for solid/liquid separation [16].

The geometry of the cyclone involves inlet shape and area, cyclone dimensions (cone angle, length of cylindrical section and total length of the cyclone) and inlet, vortex and apex diameters. Internally, inertia is countered by the resistance of the liquid, with the effect that larger or denser particles are transported to the wall for eventual exit at the underflow side with a limited amount of liquid, while the finer, or less dense particles, remain in the liquid and exit at the overflow side through a tube extending slightly into the body of the cyclone at the center [16].

Forward hydrocyclones remove particles that are denser than the surrounding fluid, while reverse hydrocyclones remove particles that are less dense than the surrounding fluid. In a reverse hydrocyclone the overflow is at the apex and the underflow at the base. There are also parallel-flow hydrocyclones where both the accept and reject are removed at the apex. Parallel-flow hydrocyclones remove particles that are lighter than the surrounding fluid [17].

Hydrocyclones can be made of metal (mostly steel), ceramic or plastic (such as polyurethane, polypropylene, or other types). Metal or ceramic hydrocyclones are used for situations requiring more strength, or durability in terms of heat or pressure. When there is an occurrence of much abrasion (such as occurs with sand particles) polyurethane performs better than metals or ceramics. Metal lined with polyurethane is used in cases of combined abrasion and high pressure.

In a suspension of particles with the same density, a relatively sharp cut can be made. The size at which the particles separate is a function of cyclone diameter, exit dimensions, feed pressure and the relative characteristics of the particles and the liquid. Efficiency of separation is a function of the solids' concentration: the higher the concentration, the lower the efficiency of separation. There is also a significant difference in suspension density between the base exit (fines) and the apex exit, where there is little liquid flow.

If the size range of the particles is limited, but there are differences in density between types of particles, the denser particles will exit preferentially at the apex. The device is therefore a means of selective concentration of, for example, minerals. This device is also related to the centrifuge; both of them are intended to separate heavies and lights in liquid by application of centrifugal force [16]. Centrifuges generate the separation force by rotation of the entire equipment; hydrocyclones utilize centrifugal forces from the movement of the fluids to achieve separation.

3. Methodology

The Cisadane water inlet is pumped to the water treatment system of RDE in 50 m$^3$/h of mass flow rate. This inlet water is called as dirty water because of solid and clay suspension in it. The solid particles are assumed of SiO$_2$ to be used in this model. The hydrocyclone in the water treatment system is modelled by using ChemCAD as shown in Figure 2.
The hydrocyclone type that used is high efficiency as shown in Table 1. The river water is pumped to the system inlet in stream no.1. Water specification is assumed with 10% of solid particles and is described as SiO$_2$. It has been simulated the Cisadane river water treatment process model using hydrocyclone. The distribution of solid particles in river water impurities is assumed as shown in Table 2. The solid particles size is distributed with a majority composition between 10 µm to 100 µm, whereas a size below 10 µm is assumed to be below 30%.

Based on Cisadane River data [6], it is known that the worst water condition is during the rainy season, with total suspended solid (TSS) concentration of 1181 mg/L, equivalent to 10% of the total mass flow rate. The mass flow rate input of the RDE water treatment system is 50 m$^3$/h with total solid impurities of 5 m$^3$/h.

![Figure 2. The hydrocyclone modelled using ChemCAD](image)

### Table 1. The parameters and specification related to the hydrocyclone type [14].

| Parameters                  | Hydrocyclone type |
|-----------------------------|-------------------|
|                            | High efficiency   | Conventional | High throughput |
|                            | (1)               | (2)          | (3)            |
| Body diameter, D/D          | 1.00              | 1.00         | 1.00           |
| Heigh of inlet, H/D         | 0.50              | 0.44         | 0.50           |
| Width of inlet, W/D         | 0.20              | 0.21         | 0.25           |
| Diameter of fluid exit,     | 0.50              | 0.40         | 0.50           |
| Length of vortex finder, S/D| 0.50              | 0.50         | 0.625          |
| Length of body, Lb/D        | 1.50              | 1.40         | 2.00           |
| Length of cone, Lc/D        | 2.50              | 2.50         | 2.00           |
| Diameter of particle outlet, Dd/D | 0.375 | 0.40 | 0.25 | 0.40 | 0.375 | 0.40 |

### 4. Results and Discussion

It has been simulated the Cisadane river water treatment process model using hydrocyclone. The distribution of solid particles assumed as river water impurities as shown in Table 1. In ChemCAD, these solid particles are assumed as SiO$_2$. The solid particles size is distributed with a majority composition between 10 µm to 100 µm, whereas a size below 10 µm is assumed to be below 30%.

Based on Cisadane River data [9], it is known that the worst water condition is during the rainy season, with total suspended solid (TSS) concentration of 1181 mg/L, equivalent to 10% of the total mass flow rate. The mass flow rate input of the RDE water treatment system is 50 m$^3$/h with 5 m$^3$/h of solid impurities.
Tabel 2. Particle size distribution of suspended solid of Cisadane water river.

| Particle size (µm) | Weight fraction |
|-------------------|----------------|
| 0.1               | 0.03           |
| 1                 | 0.03           |
| 2                 | 0.03           |
| 3                 | 0.03           |
| 4                 | 0.06           |
| 5                 | 0.06           |
| 6                 | 0.06           |
| 7                 | 0.06           |
| 8                 | 0.06           |
| 9                 | 0.06           |
| 10                | 0.10           |
| 20                | 0.10           |
| 30                | 0.10           |
| 50                | 0.10           |
| 100               | 0.10           |

In ChemCAD, whether in Rating or Design mode, hydrocyclone can define cyclone performance based on either of two methods. The Dahlstrom method is empirical and the Bradley method is theoretical. Both predict $D_{50}$, the calculated size of particles with 0.5 efficiency, and pressure drop. Both methods are variants of Stokes’ law as applied to a self-induced centrifugal field. $D_{50}$ becomes a function of cyclone diameter, drag coefficient, flow, and density difference between fluid and particles. Pressure drop in both methods is a function of flow and cyclone diameter. Particle Size Distribution $D_{50}$ is also known as median diameter or medium value of particle size distribution, it is the value of the particle diameter at 50% in the cumulative distribution. Particle Size Distribution $D_{50}$ is one of an important parameter characterizing particle size. For example, if $D_{50} = 5.8$ µm, then 50% of the particles in the sample are larger than 5.8 µm, and 50% smaller than 5.8 µm. $D_{50}$ is usually used to represent the particle size of group of particles. Besides constructional factors such as height, radius, and inlet size (influence the inlet velocity) of the hydrocyclone, also the density difference between the fluid and the solids, and the viscosity of the fluid determine the separation process of the hydrocyclones. With an increasing density difference between the fluids and the particles, also the efficiency of the separation process increases. The relation between efficiency and cyclone diameter is represented in Figure 3. This model used single hydrocyclone. The hydrocyclone diameter has been varied and the separation efficiency of each is obtained. The smaller diameter resulted higher separation efficiency, but it causes the higher pressure drop and vice versa. The pressure drop increased significantly when the diameter is below 0.4 m.

![Figure 3](image_url)
The D50 value is increase linearly with the hydrocyclone diameter as shown in Figure 4. It caused by the collision probability between smaller solid particles and the cyclone wall is getting lower.

![Figure 4](image)

**Figure 4.** The correlation between cyclone diameter vs D50 number of separation

Thus, just only coarse particles can be separated. Coarse solid impurities will come out through the underflow side while the cleaner water will come out through the overflow side.

Hydrocyclone efficiency can be increased by adding the number of hydrocyclone that installed in the system. This efficiency will increase double if they installed in parallel line as shown in Figure 5. The mass flow rate input can be divided into two lines and it can reduce the hydrocyclone diameter.

![Figure 5](image)

**Figure 5.** The effect of number hydrocyclone and its efficiency

Water turbidity is the measure of relative clarity of water. Water turbidity is closely related to the level of suspended substances because turbidity in water is caused by suspended substances present in the water. Suspended substances present in water consist of various substances, such as fine sand, clay and natural mud which are inorganic materials or can also be organic materials floating in water. Organic substances that are suspended substances consist of various types of compounds such as cellulose, fats, proteins that float in water or can also be micro organisms such as bacteria, algae, and so on. These organic ingredients other than derived from natural sources also come from discharges of human activities such as industrial activities, agriculture, mining or household activities. Turbidity is caused by suspended substances in water, but because suspended substances present in water are
composed of various substances of different shapes and weights, the turbidity is not always proportional to the degree of suspended substance.

5. Conclusion
The hydrocyclone performance has been analyzed by ChemCAD model simulation. At 0.3 m of hydrocyclone diameter the separation efficiency is 38%, and at the 1.1 m of diameter the efficiency is only 2.7%. The smaller diameter resulted higher separation efficiency, also causes the higher pressure drop and vice versa. The pressure drop increased significantly when the diameter is below 0.4 m. The dust particles size separated (D50) value is increase linearly from 12.18 to 71.27 micron with the hydrocyclone diameter from 0.3 to 1.1 m. It can be concluded that for the RDE water treatment facility 0.3 m of hydrocyclone diameter is suitable to install. The hydrocyclone is good to reduce or separate coarse suspended solids in river water before deliver to the next stage treatment such as mechanical filter.

6. Acknowledgments
This research is supported by Insinas (flagship) and PTKRN budget of the year 2018. The authors appreciate thank you very much to the Ministry of Research, Technology and High Education and also Mr. Sukmanto Dibyo, thank you very much for his guidance.

References
[1] Sriyono, Rahayu K, Sofial L. Butarbutar, Geni R. Sunaryo, 2017 Analysis of helium purification system capability during water ingress accident in RDE Proceeding of ICoNETS, Makassar, Indonesia
[2] PTKRN 2014 Dokumen Justifikasi Teknis Pembangunan Reaktor Daya Eksperimental No. Dokumen : DT 001.KRN.2014, BATAN, pp 1-10 Indonesian
[3] PTKRN, 2014 Spesifikasi Teknis Reaktor Daya Eksperimental No. Dokumen : DT 002.KRN.2014, pp 14-15 Indonesian
[4] PTKRN, 2015, RDE Conceptual Design of Cooling Water Systems No. Dokumen : RDE/DS-WBS 002-209 BATAN, 2015
[5] Vieira LGM, Barbosa EA, et.al., 2015 Performance Analysis and Design of Filtering Hydrocyclones Brazilian Journal of Chemical Engineering Vol. 22 No.01, pp 143-152, ISSN 0104-6632
[6] Sriyono, Rahayu K, , Geni R. Sunaryo, 2012 Analisis dan Pemodelan Cyclone Separator sebagai Prefilter Debu Karbon pada Pendingin RGTT200K Prosiding Seminar TKPFN Universitas Pendidikan Indonesia, Bandung, pp 35-42
[7] Yumeng Zhang, Pu Cai, Feihua Jiang, Kejun Dong, Yunchao Jiang, Bo, Wang 2017 Understanding the separation of particles in a hydrocyclone by force analysis Powder Technology Vol. 322, pp 471–489
[8] PT. Ingenious 2012 CHEMCAD Process Simulation Manual Software Training BATAN, Serpong, 2012
[9] S.K. Tripathy, S.K. Bhoja, C. Raghu Kumar, N. Suresh 2015 A short review on hydraulic classification and its development in mineral industry, Powder Technology. 270 (Part A), pp 205–220.
[10] Nur Cahya Eka Damayanti, Azwar Manaf, Budi Briyatmoko 2010 Identifikasi Kandungan Senyawa Kimia Pada Pasir Mineral Prosiding Seminar Nasional Bahan Magnet I, Serpong, Indonesian
[11] Ratna Siahaan, Andry Indrawan, Dedi S, Lilik B. Prasetyo 2016 Kualitas Air Sungai Cisadane Jawa Barat Banten Prosiding Seminar Sains dan Teknologi 2016, FT-Universitas Muhammadiyah Jakarta, Indonesian
[12] Coulson, J.M., Richardson, J.F., Backhurst, J.R and Harker, J.H. 1991 Chemical Engineering: Particle Technology and Separation Processes *Journal of Separation*, Vol. 2, 4th Edition, Pergamon Press, Oxford, U.K

[13] Sriyono, dkk 2013 Pengaruh Diameter terhadap Efisiensi Pemisahan Cyclone pada Sistem Purifikasi Helium RGTT200K *Prosiding Seminar Energi Nuklir, SEN-PEN*, PPEN-Universitas Pancasila Jakarta

[14] Su En Wu, Kuo Jen Hwang, et.al., 2017 Effectiveness of a Hydrocyclone in Separating Particles Suspended in Power Law Fluids *Powder Technology* 320 pp 546-554

[15] Chih Yuan Tsu, et.al., 2015 Particles Separation and Tracks in a Hydrocyclone, *Tamkang Journal of Science and Engineering*, Vol. 14, No. 1, pp 65-70

[16] Baiyo Cui, Caie Zhang, Dezhou Wei, Shuaishuisi Lu, Yuqing Feng, 2017 Effects of feed size distribution on separation performance of hydrocyclones with different vortex finder diameters *Powder Technology* 322, pp 114-123,

[17] Gujun Wan, Guogang Sun, Xiaohu Xue, Mingxian Shi 2008 Solids concentration simulation of different size particles in a cyclone separator, *Powder Technology*, Vol 183, pp 94-104