The Selection of Geometry and Flow Rate on The Fluidized Bed Reactor for Coating Particle

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ABSTRACT. The “Reaktor Daya Eksperimental” has been designated to be built in Indonesia and the selected type of this reactor is a high-temperature gas-cooled reactor. The fuel system used in this reactor is pebble bed fuel. The process of coating the sintered kernel into coated particles, is one of the processes in the manufacture of gas cooled high temperature reactor fuels. The geometry of the fluidization reactor determines the level of contact between the kernel and the filling gas. The flow rate of the fluidizing gas also affects fluidization at the rate at which stable fluidization occurs. Both of the above thing are important role in the success of the coating process. Based on data and information from previous researcher, designed a tool for coating process. The design of the sintered UO$_2$ kernel coating reactor into coated particles is carried out based on the coating process data, the purpose of the reactor making and the selection of its capacity. The reactor prototype is used to obtain useful process data for the manufacture of a production reactor. The type of fluidization reactor made by the prototype is a conical spout bed reactor or conical reactor. The fluidization reactor prototype was chosen to have a 2 cm diameter cylinder, 0.3 cm inlet diameter, and 60° conical angle. The flow rate for the reactor operation is between the maximum fluidization flow rate at the inlet and the minimum fluidization velocity on the cylinder. The gas stream according to the calculation above is 2.5279 m/sec at the inlet pipe or 1.0716 L/min. up to the flow 1.38 m/s or 26.1255 L/min. Comparison of other research results with modeling using CFD, its flow rate is about 10 m/s or 4.239 L/min.

1. Introduction

The National Nuclear Energy Agency (Batan) has planned the construction of a non-commercial nuclear reactor called Reaktor Daya Eksperimental (RDE) [1]. The proposed RDE reactor to be built in Serpong Tangerang is a nuclear reactor with a high temperature gas cooled reactor (HTGR) type. The type of reactor is chosen because of its good security system, it can be for cogeneration system, has fuel flexibility, has been tested, competitive price, multipurpose and can be developed in all area to fulfill requirement of electricity supply. The RDE reactor, has a passive safety system that ensures a very minimum radiation release to the environment under any conditions including severe accident conditions as experienced in the Fukushima reactor[2,3]

Technology of RDE is a HTGR reactor type. The preferred RDE reactor technology is the Pebble Bed Reactor (PBR) so that the manufacture of RDE fuel must also adapt to the technology. The very important activity in the route of HTGR fuel technology is coating process. The coating process is carried out in the fluidization reactor. Design of fluidization reactor should consider the variables that
affect the success of the coating process, especially reactor geometry and gas flow rate. The reactor geometry is important to maintain the contact rate between particles and gases during fluidization. Likewise, the fluidization gas flow rate determines the fluidization pattern that is formed.

The route of the RDE fuel-making technology has also been established that ADU gel making through external gelation uses gelation columns. The diagram of the RDE fuel manufacturing process can be seen in Figure 1. The steps of making RDE fuels starting from purifying uranium into pure nuclear uranium of uranyl nitrate solutions that can be directly used as sol solution. of $U_3O_8$ is used for sol solution feed. It needs to be dissolved first with nitric acid in a certain mole ratio to produce a solution of uranyl nitrate with the least acid residual content possible. The sol solution is prepared using a certain concentration of uranyl nitrate solution, is neutralized by NH$_2OH$ and added additives and heated and stirred into a sol solution. A solvent solution having a certain uranium concentration and certain physical properties, used as a gelation feed, produces ammonium diuranate gel. The gelation process chosen is an external gelation process. In an external gelation process, the gel with certain properties is dripped through a vibratory nozzle vibrated by a vibrator. The frequency of vibration set to a certain value then the flow rate of the sol gel solution and amplitudo of vibration was arranged so that the gelation process produce a uniform ammonium diuranate gel (ADU) gel.

Drops of a spherical sol solution, falling through the ammonium gas zone, there is a process of presolidification on the surface of the droplets. The droplet surface hardens so that it does not result in a change in the sol form as it falls on the surface of the gelation medium. The round granules of the sol fall through the gelation medium of the ammonium hydroxide solution and during falling motion, the gelation process continues so that the grains are getting downward harder. The changed sole grains into ADU gel are accommodated in a gel container placed on the bottom of the gelation column [4,5,6,7].

The wet gel of the gelation process is aged in an ammonium hydroxide solution for the purpose of perfecting the gelation process to the inside of the ADU gel. Gel gelation process is immersed in a solution of ammonium hydroxide while rotated on a rotary flask until the gelation process is complete. The wet gel was then performed by successive washing process using dilute ammonium hydroxide solution, water and the latter using water-absorbing solvents such as iso propyl alcohol. Furthermore, the wet sole is subjected to a vacuum drying process, calcination, reduction and sintering resulting in a sintered kernel having a diameter of 0.5 mm [8,9].

![Figure 1. Diagram of RDE Fuel Preparation](image1)

![Figure 2. Coated Particle Layer of TRISO](image2)

Coating of coated particles for HTGR fuel has been progressing. HTGR fuel used to have only 3 layers called BISO (bi structural isotropic layer), then modified to TRISO (tri structural isotropic layer). Bendels of HTGR fuel there are 2 kinds, namely the prismatic and pabble bed. The subsequent development of the HTGR fuel is the replacement of SiC in TRISO with ZrC enabling the operation of the reactor to take place at higher temperatures so that the fuel burns are higher and generate high process heat. The heat of the resulting process can be more flexible for industrial processes. Pebble bed fuel is selected to be developed in Indonesia. The pebble bed core is selected for high temperature
reactors or Reaktor Daya Eksperimental. The inner particles contain sintered UO$_2$ particles coated with 1 buffer layer and 3 isotropic layers so often referred to as the TRISO layer [5,6].

The layers in the HTR fuel have their respective functions as follows: 1. The inner layer is a buffer layer with a thickness of 100 μm is a low-density pyrolysis carbon that serves to absorb the energy radiating from the material fission results after a fission reaction and accommodates the fission gases fission uranium. This layer withstands excessive internal pressure in order not to affect the three outer layers. 2. The second layer is the inner pyrocarbon layer (IPyC) having a high density of ~ 40 μm thickness. This layer does not penetrate the gas to protect the fuel core during the deposition process on the silica carbide (SiC) layer. This layer also protects the silicon carbide layer (SiC) from chemical reaction by carbon monoxide and fission results during irradiation. The pyrocarbon layer becomes the first barrier to the diffusion of fission results having high radioactivity. 3. The third layer is a SiC silica carbide layer having a thickness of ~ 35 μm. Silica carbide serves as a structural framework and a barrier to the diffusion of fission products and confines the fission of gaseous and solid form. 4. The outer pyro carbon layer is a high density pyro carbon film with a thickness of ~ 40 μm. This layer protects the silica carbide from mechanical damage during handling and the final barrier to the diffusion of fission products [6,10].

The size of the fuel and the thickness of the TRISO layers in the HTGR fuel depends on the planning of the reactor. As a benchmark on the size and thickness of each layer can be seen in Table 1, the fuel size of the German and Chinese NUKEM reactors. As an illustration of the layers on the coated particles can be seen in Figure 2 [11].

![Diagram of TRISO Coating Process](image1)

**Figure 3.** Diagram of TRISO Coating Process [2]

![Fluidization Bed Reactor](image2)

**Figure 4.** Fluidization Bed Reactor [12]

The sintered kernel coatings in the manufacture of RST fuel, through four layers of coating are performed alternately on the same coating device. The first coating process is followed by a second coat and so on until the fourth layer by changing the coating reactor temperature and the replacement of the reactant gas entering the reactor. It should be noted during the gas shift, the flow rate of mixed gas flow into the coating reactor is maintained constantly so as not to affect the particles that are
fluctuating. The first layer is a buffer layer which is a low density pyrocarbon layer produced from decomposition of reactant gas $\text{C}_2\text{H}_2$ diluted with argon at a temperature of 1100 - 1400°C. The second layer of the inner pyrocarbon which is a high density pyrocarbon produced from a propylene gas deposition is diluted with argon carried out at a temperature of 1350 - 1450 °C. The third layer is silica carbide is a deposition of methyl trichlorosilant gas diluted with argon and H$_2$ gas. The coating of silica carbide was carried out at a temperature of 1500-1670°C. The outer pyrocarbon layer is produced from propylene gas pyrolysis deposition at a temperature coating temperature of 1350 - 1450 ° C [2]. Temperature and Gas during coating can be seen in Figure 3. Spesifikasi Bahan Bakar reaktor HTR dapat di lihat dalam Table 1

### Table 1. Spesification of UO$_2$ Kernel [11]

|                  | HTR MODUL | HTR 10 |
|------------------|-----------|--------|
| **Kernel UO$_2$** |           |        |
| Diameter (µm)    | Density g/cm$^3$ | Spericity (Dmax.Dmin) | O/U | Thermal conductivity 1000°C (W/cm/K) | Diameter (µm) | Density g/cm$^3$ | Spericity (Dmax.Dmin) | O/U | Thermal conductivity 1000°C (W/cm/K) |
| 500 ≤10.4        |           |        |
| **Coated Particles** |           |        |
| Tebal (µm)       | Density g/cm$^3$ | Anisotropy Factor |       | Tebal (µm) | Density g/cm$^3$ | Anisotropy Factor |       |
| Buffer           | 95        | ≤1.05  |       |           | 95        | ≤1.10  |       |
| Inner Pycarbon   | 40 ±0.1   | ≤1.10  (BAF) |       |           | 40 ±0.1   | ≤1.03  (OPTAF) |       |
| Si Carbida       | 35 ±3.18  | ≥3.18  |       |           | 35 ±3.18  | ≥3.18  |       |
| Outer Pycarbon   | 40 ±0.1   | ≥3.18  |       |           | 40 ±0.1   | ≥3.18  |       |
| **Matrix Graphite** |           |        |
| Density g/cm$^3$ | Anisotropy Factor | Corrosion Rate (mg/cm$^2$/j) | Erosion Rate (mg/ballon/j) | Density g/cm$^3$ | Anisotropy Factor | Corrosion Rate (mg/cm$^2$/j) | Erosion Rate (mg/ballon/j) |
| 1.75 ±0.02       | ≤1.3      | ≤1.3   | ≥0.25 |       | 1.76 ±0.02 | ≤1.3   | ≤0.25 |
| **Fuel Pebble**  |           |        |
| Diameter (µm)    | U loading (g/bola) |       |
| 60 ±0.25         |           | 59.6-60.2 | 5 ±0.25 |

The coating process is carried out on a coating device with a fluidized bed chemical vapor deposition (FB-CVD) system. The UO$_2$ kernel coating process is carried out in a fluidized bed reactor using the Chemical Vapor Deposition (CVD) method. The fluidization reactor has a portion of the gas distributor at the bottom of the reactor and coated kernel outlet at the bottom of the reactor. In the fluidization reactor the reactant gas decompose into many compound and parts of deposition compound deposite to the coated kernel surface.

The contact system between fluidizing gas and fluidized solids can vary. One device for contact of gas with the solid in the fluidization system is conical shape. If the fluidization reaction occurs only on the cone, it is called a conical spouted bed (CSB) reactors. If the solid material is high up above the cone called conventional fluidization reactor. The fluidization reactor can be seen in Figure 4 [12]
Investigation of hydrodynamic behavior against fluidization in a conical spouted bed reactor is necessary to understand what happens in the fluidization reactor. The hydrodynamic behavior of fluidization at the conical spouted bed reactor can be seen in Fig. 5. The fixed bed condition shown in (a), the gas flow has not been able to lift the kernel. If the gas flow is added slightly which means that the pressure difference is increased slightly, not to change the state of the bed, until a certain pressure difference occurs the movement of the kernel bed in the reactor cone. This is called the minimum velocity of fluidization. The slightly added gas stream produces a stable Spouting Operation (b). If the gas stream is added again it will result in fluidization of the transition regime (c) and if the gas flow is added again the state (d), the jet spotting. In this stable fluidized state there is a good contact between solids and gases. In the transition state, contact between gas and particles not very effective because it has started bubbling and bubble slugging gas. In conventional spouted reactors with large bed heights, bubbles and clumps are easy to occur so fluidization does not work well. This will be easy to do when large diameter solids and rough shapes.

The advantage of using a conical spouted bed reactor is reducing the occurrence of solids clumping [12]. The relationship between pressure drop on the fluidized bed material with the gas flow rate can be seen in Figure 6. Up to a certain pressure drop the solid material does not move and then begins a
movement on the solid material, the pressure pressure decreases. The state of the ramps at the steady operation on stable spouted and jet spouted.

Modifications to the incoming gas distribution in the fluidized reactor have been widely developed as can be seen in Fig. 7. Besides the conical gas distribution also can be made with many gas inlets. But what needs attention is the issue of coating outcomes. In the conical reactor the outlay of the coating results is sufficient by stopping the gas flow so the layered kernel will fall directly to the container under the reactor, but with the multi-inlet not necessarily able to go straight out and the tricks are needed.

Things that need to be considered in the design dimension of conical bed spouted reactor is the geometry size of reactor. Things to note include the ratio of inlet diameter and particle diameter (Di/Dp), inlet diameter/diameter ratio of cone base (Di/Do), cone angle and kernel bed height. Values of variables by Gegenheimer, J.B [12] from various sources can be seen in Table 2.

Table 2. The Bist Geometry Comparison of Conical Spouted Bed Reactor [12].

| No | Variable               | Minimum Value | Maximum Value | Explanation                          |
|----|------------------------|---------------|---------------|--------------------------------------|
| 1  | (Di/Dp)                | 30            |               | Mathur                               |
| 2  | Di/Do                  | 0.5           | 0.83          | Olazar                               |
| 3  | Cone Angle             | 28°           | 180°          | Olazar and Sharma                    |
| 4  | Height of bed          |               |               | Depend of the diameter particles, cone angle and ratio Di/Do |

It is no less important is the determination of gas flow rate for fluidization. The process flow rate is determined from the minimum fluidized flow rate and the maximum fluidization rate. The flow rate of gas entering the reactor determines the contact between the kernel and the fluidized gas. The inlet gas flow velocity makes the fluidization kernel or even carried the gas out of the reactor.

1.1. Minimum Flow rate fluidization

The occurrence of kernel fluidization in the fluidization reactor is strongly determined by the gas phase flow in the kernel. The low gas flow rate cause fluidization does not occur and even in fluidization with conical spouted bed system, the kernel can fall down into the container. In the conical spouted bed system, the flow rate must be greater than the minimum fluidization velocity in the inlet, but should be less than the maximum flow velocity in the cylinder reactor fluidization section so that the kernel is not carried by the gas stream. The minimum velocity of fluidization is derived from the Ergun equation, can be estimated using the equation:

\[ U_{mf} = \frac{(\Psi d_p)^2}{150 \mu} \left[ g(\rho_s - \rho_g) \right] \frac{\epsilon_m^3}{1-\epsilon_m} \]  \hspace{1cm} (1)

The sperity value \( \Psi \) is a measure that states the state of the grain shape seen from the roughness and is compared with perfectly rounded grains. This is calculated by visualizing the area of a spherical volume equal to the spherical particles, and dividing the surface area of this sphere as measured by the particle surface area. The volume of spherical particles is expressed by [14][15]

\[ V_p = \pi d_p^3 / 6 \]  \hspace{1cm} (2)

And its surface area is

\[ A_s = \pi d_p^2 = \pi \left[ \frac{6V_p}{\pi} \right]^{1/3} \]  \hspace{1cm} (3)
These parameter values $\Psi$ range from 1-1.2, and values of 1.1 are commonly used values for solid granular. The second parameter is the void fraction at the minimum point of fluidization, $\varepsilon_{mf}$. There is a correlation that seems to provide an accurate prediction of the $\varepsilon_{mf}$ values for the particles in the small fluidized bed:

$$\varepsilon_{mf} = 0.586 \Psi^{-0.23} \left( \frac{\mu^2}{(\rho_s - \rho) (\rho_s - \rho) d_p^3} \right)^{0.029} \left( \frac{1}{\rho_s} \right)^{0.031}$$

(5)

Another commonly used relationship is Wend an Yu

$$\varepsilon_{mf} = [0.071/\Psi]^{1/3}$$

(6)

### 1.2. Maximum Fluidization Flow Rate

If the gas velocity increases with a sufficiently high value, the resistance on the individual particles will go beyond the gravitational force on the particles, and the particles will rise in the gas and carry out of the bed. The point at which the resistance on individual particles will exceed the force of gravity is called the maximum flow rate of fluidization. When the upward velocity of the gas exceeds the particle terminal velocity, $U_t$, the particle will be carried upward by the gas stream. Reynolds number for small particles, will be small. The maximum flow rate of fluidization can be calculated using the 2 equations presented by Kunii and Levenspiel

$$U_t = \eta d_p^2/18 \mu$$

for $Re < 0.4$

$$U_t = \left( \frac{1.78 \times 10^{-2} \eta^2}{\rho g \mu} \right)^{1/3} (d_p)$$

for $0.4 < Re < 500$

(7)

(8)

With $\eta = g (\rho_s - \rho)

According to Gegenheimer, J.B [12] from various sources the minimum fluidizing flow velocity can be calculated from the equations of empirical equations as shown in Table 3.

| No | Empiric Equations | Sources |
|----|-------------------|---------|
| 1  | $(Re_o)_{ms} = 0.30 - 0.27/\left( \frac{D_o}{D_p} \right)^2 \left[ Ar \left( \frac{D_o}{D_p} \right) \left( \frac{D_o}{D_p} \right)^2 + \left( \frac{D_o}{D_p} \right) + 1 \right] /3$ | [9] Bi et al. (1997) |
| 2  | $(Uo)_{ms} = 0.147 \sqrt{2gH_o \left( \frac{\rho_p - \rho}{\rho} \right)} \left( \frac{d_p}{D_c} \right)^{0.477} \left( \frac{H_o}{D_c} \right)^{0.61} \left( \frac{D_o}{D_c} \right)^{0.243}$ | [10] Choi (1992) |
| 3  | $(Re_o)_{ms} = 0.174 Ar^{0.5} \left[ 1 + 2 tan \left( \frac{Y}{2} \right) \right] \left( \frac{H_o}{D_o} \right)^{0.25} tan \left( \frac{Y}{2} \right)^{-1.25}$ | [11] Gorshtein (1964) |
| 4  | $(Re_o)_{ms} = 0.028 Ar^{0.57} \left( \frac{H_o}{D_o} \right)^{0.48} \left( \frac{D_c}{D_o} \right)^{1.27}$ | [12] Markowski (1983) |
| 5  | $(Re_o)_{ms} = 3.32 Ar^{0.33} \left( \frac{H_o}{D_o} \right)^{1.25} tan \left( \frac{Y}{2} \right)^{0.55}$ | [13] Mukhlenov (1965) |
| 6  | $(Re_o)_{ms} = 717.26 Ar^{0.08} \left( \frac{H_o}{D_o} \right)^{0.85} \left( \frac{d_p}{D_o} \right)^{1.23}$ | [14] Sharma (2011) |
| 7  | $(Re_o)_{ms} = 0.4 Ar^{0.52} \left( \frac{H_o}{D_o} \right)^{1.24} tan \left( \frac{Y}{2} \right)^{0.42}$ | [15] Tsivik et al. (1967) |
| 8  | $(Re_o)_{ms} = 0.126 Ar^{0.5} \left( \frac{D_b}{D_o} \right)^{1.68} tan \left( \frac{Y}{2} \right)^{-0.57}$ for $D_p > 1$ mm | [16] Olazar et al. (1992) |
The fluidization reactor can be used for a variety of purposes both involving chemical reactions and without chemical reactions. The fluidization reactor which involves chemical reactions such as coating process, pyrolysis process, craking process etc. Processes that do not involve chemical reactions such as drying.

The fluid flow in the fluidization reactor can also be modeled with Computation Fluid Dynamic (CFD) software. Sukarsono et al. [14] has modeled CFD using UO₂ kernel fluidization in conical reversed reactor with 0.3 mm inlet diameter and 2 cm cylinder diameter. The contour of the kernel phase fraction with the reactor can be seen in Figure 9. The best condition of the coating process at 0.3 cm inlet diameter is at 10 m/s as shown in Figure 9R. At flow rate > 10 m/s the kernel granular movement is getting higher and at 22 m/s the flow rate allows the kernel to bounce out.

With the data and information above, it can be used to calculate the design of fluidization reactor making both for small scale (prototype) and for larger scale. The fluidization reactor prototype that will be made is a fluidization reactor which will be used for the research of TRISO coated particle coating process. The fluidization reactor is equipped with an induction heater of graphite material which also functions as a reactor whose temperature reaches the temperature of decomposition of reactant gas and solids deposition into coated particles.

\[
(Re_{o})_{ms} = 0.126Ar^{0.39} \left( \frac{D_{p}}{D_{o}} \right)^{1.68} \tan \left( \frac{Y}{2} \right)^{-0.57} \quad D_{p} \leq 1 \text{ mm} \quad [17] \quad \text{Olazar et al. (1996)}
\]

\[
(Re_{ms})_{o} = \frac{Um_{ms} d_{p} \rho}{\mu}
\]

\[
Ar = g d_{p} \frac{3}{2} \rho (\rho_{p} - \rho)
\]

2. Methodology

The design of the fluidization reactor is made by selecting the reactor geometry and calculating the fluidized gas flow rate. The geometry of the reactor is chosen which in operation is easy to do and not much variables has to be controlled. After the geometry of the reactor is selected, then calculations relating to the operation of the reactor such as minimum fluidization flow rate, maximum fluidization flow rate, etc is done. Equations and data are used in this design are equations and data from the other researches and the author’s data from the other research. The results of the design have to can be guaranteed that operator of the coating process apparatus can operate the variety variables process of coating particles so that can find the optimum condition process.

Figure 9. Kernel phase fraction contour variation inlet diameter 0.3 cm with inlet gas flow velocity: Q: 7, R: 10, S: 13, T: 16, U: 19, V: 22, W: 25, X: 28 m / s.
3. Discussion

The fluidization coating process is used in the nuclear fuel kernel coating process. As the fluidizing gas is argon gas mixed with reactant gas and the fluidized material is a sintered UO$_2$ kernel. The mixture of gas entering in the reactor at high temperatures and reactants gas decomposes into another gas in the form of free radical form. The combined free radical gas will join to produce other gas and solid that is deposited into a thin layer on the surface of the kernel. During the coating process, maintained fluidization and circulation is always good, so the contact between gas and kernel occurs evenly and the formed layer can be evenly distributed throughout the kernel surface. Solid-gas contact and residence time of the gas in the reactor determines the efficiency and quality of the coatings formed. The better the distribution and the greater the gas residence time in the bed kernel, the coating will get better. Fluidization in the transition conditions and jet spout conditions, result the contact between the gas and the kernel is poor and will lead to the low efficiency coatings because the decomposition of the gas is not deposition in the kernel. Therefore the gas flow rate is arranged in such a way, made slightly above the minimum fluidization flow rate.

The gas distribution and coating efficiency is determined by the geometry of the fluidization reactor used. In the process of coating occur in the reactor, the carrier gas (Ar gas) and reactant gas (acetylene, propylene or methyltrichlorosilane + hydrogen) fluidize the sintered kernel in the fluidization reactor. The carrier gas and reactant gas are flown from each gas cylinder and liquid methyltrichlorosilane is passed through gravity from the MTS tube through the heater/vapor and into the fluidization reactor through the gas mixer. The reactor is heated to the temperature of the decomposition reaction and solid deposition occurs on the surface of the sintered kernel. Heating the reactor using heating elements or induction heating. At certain temperatures, reagent gas will decompose into other gas and some of these gas become solids deposited to the surface of the sintered kernel. The carrier gas and the residual gas, exiting the reactor for discharge into the environment. Before being discharged into the environment the hazardous gas present in the exhaust gas is absorbed by the absorbent liquid and the flue gas is burned on the gas burner. The device diagram of the kernel coating system can be seen in Figure 10. The fluidization reactor, at the bottom of which is installed gas distributor connected from mixing system of the carrier and reactant gas. The gas distributor is made in reverse cone or other forms which optimize the occurrence of UO$_2$ kernel fluidization in the reactor. The conical reverse fluidization reactor is called a conical spouted bed (CBS) reactor) which can be seen in Fig. 8.

During the coating process, the sintered kernel diameter increases because added by 4 layer of buffer, inner pyrocarbon, silica carbida and outer pyrocarbon. So to see changes in diameter, volume and density during the coating process from the first layer to the last layer is calculated as in Table 4. Sintered kernel feed, has 0.5 mm in diameter. According to C.Tang after buffer coating, the layer of buffer is 95 µm, so diameter after buffer coating process is 0.69 mm and average diameter is 0.595 mm. The density of particles also change from 10.4 g/cm$^3$ to 4.6077 g/cm$^3$ after buffer coating. The average diameter during buffer coating is 7.5039 g/cm$^3$. Similar with buffer coating, inner pyrocarbon, silica carbida and outer pyrocarbon can be caculated average diameter and average density which can be used for fluidization gas flow rate.
Figure 10. Design of UO$_2$ Kernel Coating Devices

|                  | Buffer                | Inner PyC              |
|------------------|-----------------------|------------------------|
|                  | particle diameter, mm | density g/cm$^3$       | Particle diameter mm | Volume mm$^3$ | density g/cm$^3$ |
| beginning        | 0.5                   | 10.400                 | 0.69                | 0.17191971   | 4.607741188     |
| after            | 0.69                  | 4.6077                 | 0.77                | 0.23891894   | 3.848418515     |
| average          | 0.595                 | 7.5039                 | 0.73                | 4.228079852  |
| addition         | 0.19                  | 5.7922                 | 0.08                | 0.06699923   | 0.759322673     |

|                  | Si C                  | Outer PyC              |
|                  | particle diameter mm  | density g/cm$^3$       | Particle diameter mm | volume mm$^3$ | density g/cm$^3$ |
| beginning        | 0.77                  | 3.848418515            | 0.84                | 0.310182     | 3.694852         |
| after            | 0.84                  | 3.694852456            | 0.92                | 0.407513     | 2.821917         |
| average          | 0.805                 | 3.771635486            | 0.88                | 3.258385     |
| addition         | 0.07                  | 0.153566059            | 0.08                | 0.097332     | 0.872935         |

3.1. Geometry of Prototype Reactor
To determine the geometry and size of the reactor, it cannot be separated from the planned capacity of the reactor to be made. For small capacity or prototype, the size of the geometry is also small. Design capacity of prototype reactor is about 2-3 g kernel/batch. For reactor diameter is 2 Cm, from Fig 8,
can be calculated \( D_c = 2 \), \( H_c = 1 \times (D_c/2)^2 = 1.732 \) cm. Selecting conical spouted bed reactor, of 2 cm diameter is chosen. The conis for coating capacity of approximately 2 gram \( D_p = 0.5 \) mm, \( D_i/D_p \) taken = 6 from Table 2, then \( D_i = 6 \times 0.5 = 3 \) cm. From Table 2 \( D_i/D_o \) taken 0.83 then \( D_o = 0.3/0.83 = 0.36 \) cm. Angle \( \theta \) is taken 60° and diameter reactor silinder \( D_c \) taken = 2 cm then can be calculated \( H_c = (1 - 0.18) 3^{1/2} = 1.420 \) cm. Conical height; \( 1 \times 3^{2/3} = 1.732 \), then the volume of the cone = \( \frac{\pi}{3} \times 2^2 \times 3^{2/3} = \frac{1}{3} \pi \times 0.36 \times 3^{2/3} \times (1.732 - 1.420) cm^3 = (1.813 - 0.147) cm^3 = 1.666 cm^3 \).

Bulk density estimate 3.033g/cm³, then the weight of kernel/batch if the conical space full with sintered kernel = \( 1.666 \times 3.033 = 5.05 \) g. If coating process 50% capacity, so kernel feeding is 2.26 g/batch.

From Table 4 it was calculated that the kernel before coating has changed from 0.0654 mm³ to 0.4175 mm³ after coating, so the volume becomes 0.4075 / 0.0654 = 6.2310 times.

For larger scales, the capacity of design reactor is about 50 g/batch. Cylinder diameter is used 5 cm and \( D_i = 0.5 \) cm. Value \( D_i/D_p = 5/0.5 = 10 \). The value is still below 30 from Table 2. From the provision \( D_i/D_o \) taken maximum \( D_i/D_o = 0.83 \) then \( D_o = 0.5/0.83 = 0.60 \) cm. The angle \( \theta \) is taken 60° for example taken \( D_c = 5 \) cm then \( H_c = (2.5 - 0.3) 3^{1/2} = 3.81 \) cm Conical height; \( 2.5 \times 3^{1/2} = 4.33 \) then the conical volume = \( ((\pi/4) \times 2^2 \times 3^{1/2}) \times 4.33 \) - \( ((\pi/4) \times 0.62 \times 3^{1/2}) \times 4.33 \times 3.81 = 28.325 \times 0.1054 = 28.220 \) cm³ or 85.59 g/batch. Kernel is feeded to reactor 50% max capacity = 47,795 g/batch.

Prototype’s size geometry and fluidization reactor plan can be seen in Figure 11.

\[
\begin{align*}
D_p &= 0.5 \text{ mm} \\
D_i &= 0.3 \text{ cm} \\
D_o &= 0.36 \text{ cm} \\
\theta &= 60^\circ \\
D_c &= 2 \text{ cm} \\
H_c &= 1.42 \text{ cm} \\
\text{Vol cone} &= 1.333 \text{ cm}^3 \\
D_p &= 0.5 \text{ mm} \\
D_i &= 0.5 \text{ cm} \\
D_o &= 0.6 \text{ cm} \\
\theta &= 60^\circ \\
D_c &= 5 \text{ cm} \\
H_c &= 3.381 \text{ cm} \\
\text{Vol cone} &= 28.22 \text{ cm}^3
\end{align*}
\]

\[\text{Figure 11. Geometry of Prototype Reactor and Designed Reaktor}\]

3.2. Calculation of Minimum and Maximum Fluidization Flow rate

When the fluidization begins, the gas flows at a certain flow rate, then the kernel is inserted through the top. Using Equation No. 1 can be calculated the minimum flow velocity on the inlet and minimum fluidization on the cylinder. Using the equation 8 can be calculated the maximum fluidization flow rate on the inlet and on the cylinder. Using data: \( \Psi = 1.1; \) \( dp \) beginning, \( = 0.0005 \) m which changes after coating process; \( \mu = 2.12 \times 10^{-5} \) kg/m/dt; \( g = 9.8 \) m/s²; \( \rho_s \) initial = 7503.8 kg/m³, which also changed during coating and \( \rho_g = 1.6229 \) kg/m³, obtained \( \epsilon_{mf} = 0.4011 \) and the minimum fluidization flow rate \( (U_{ms}) \) as can be seen in Table 5. Similarly, maximum fluidization \( (U_t) \), calculated using equation 8, can be seen in Table 5.

Calculation of inner pyrocarbon coating: \( \Psi = 1.1; \) \( dp = 0.00073 \) m, \( \mu = 2.12 \times 10^{-5} \) kg/m/dt, \( g = 9.8 \) m/dt², \( \rho_s = 4228.1 \) kg/m³.

Using Eq 6 calculate \( \epsilon_{mf} \):

\[
\epsilon_{mf} = \left[ 0.071 / \Psi \right]^{1/3}
\]

Using Eq 1 calculate minimum fluidization flow rate \( U_{mf} \):

\[
U_{mf} = (0.071/1.1)^{1/3} = 0.40117
\]
The minimum and maximum fluidization for buffer, inner pyrocarbon, silicacarbida and outer pyrocarbon in inlet and reactor can be calculated similarly with calculation above. Calculation result can be seen in Table 5.

The operation of the fluidization reactor is carried out by looking at the minimum fluidization flow rate and maximum fluidization flow rate. On the inlet because the inlet pipe is hollow and connected directly to the container, the particles can fall down to the container if gas flow rate lower than maximum fluidization in the inlet. The flow rate must be above the maximum fluidization of inlet and about 1.3 x minimum fluidization in top end of particles. In the conical spouted bed reactor, reactor fluidization is inverted cone, so the minimum fluidization flow rate depend on height of particles bed (H0). The diameter of reactor contain of particles variate from diameter of inlet (Do) to diameter of reactor (Dc).

The minimum and maximum fluidization flow rates at both points have been calculated as shown in Table 5. Geometry reactor choosen, the inlet is Do = 0.3 cm and reactor diameter is 2 cm. From the Table 5 seen that the higher maximum fluidization flow rate at inlet is 2.5279 m/s or 1.0716 L/min of fluidizing gas. So, flow rate must higher than 1.0716 L/min. Because the reactor is conical, the reactor diameter is increasingly larger and the upper limit flow rate is the maximum fluidization at diameter of 2 cm: 2.1155 m/s or 39.85 L/min. The operation flow rate maximum 1.3 x minimum fluidization flow rate in reactor = 1.3 x 1.0677 m/s = 1.38 m/s or 1.3 x 20.117 L/min = 26.1255 L/min. The real condition of conical spouted bed reactor depends on the height of the moving material, variate bed between 1.0716 L/min to approximately 26.1255 L/min.

### Table 5. Flow rate of Gas on Coating Process

| No | Coat            | Minimum Fluidisation Flow Rate | Maximum Fluidisation Flow Rate |
|----|-----------------|--------------------------------|--------------------------------|
|    |                 | At reactor, diameter of 2 cm    | At inlet, diameter of 0.3 cm    |
|    |                 | m/s       | L/min     | m/s       | L/min     |
| 1  | Buffer Coating  | 1.0677    | 20.1171   | 2.5279    | 47.65     |
| 2  | Inner PyC Coating | 0.9055    | 17.0596   | 2.1155    | 39.85     |
| 3  | SiC Coating     | 0.9822    | 18.5044   | 2.1617    | 40.72     |
| 4  | Outer PyC Coating | 1.0138    | 19.1029   | 2.1435    | 40.38     |
| 1  | Buffer Coating  | 1.0677    | 0.4526    | 2.5279    | 1.0716    |
| 2  | Inner PyC Coating | 0.9055    | 0.3838    | 2.1155    | 0.8967    |
| 3  | SiC Coating     | 0.9822    | 0.4163    | 2.1617    | 0.9163    |
| 4  | Outer PyC Coating | 1.0138    | 0.4296    | 2.1435    | 0.9086    |
Sukarsono et al. [14], has modeled this fluidization reactor using Computational Fluid Dynamic (CFD). This data rate corresponds to the data obtained from the model [10]. Inlet diameter (Di) reactor 0.3 cm good flow rate according to CFD results that does not cause the kernel to fall and fluidization is stable at a flow rate of 10 m/s or or 4.239 L/min. This value of gas flow rate is in the range of 1.0716 L/min to 26.1255 L/min.

The gas medium used depends on the layer to be deposited. An argon gas carrying acetylene, propylene, or methyl tri chlorosilan and hydrogen gas, is used to coat the first, second and third layers and propylene for the fourth layer. The inner side of an inverted cone reactor or other form is where the kernel is fluidized because of the gas flow from the bottom. As the gas stream is still running above the maximum flow rate at the inlet, kernel fluidization in the reactor remains unchanged. The gas stream is stopped, the particles in the reactor stop fluidized and falling down and collected under the reactor. At the bottom of the reactor is equipped with the introduction of the gas mixture after each gas passes through the flowmeter to be controlled its flow rate. The exit gas from the reactor is the residual gas, argon carrier gas and the untreated decomposition gases of the reactants on UO₂ particles. The gas is burned first before being dumped into the air. If there is a toxic gas, the gas flows into the absorbent column to absorb the gases.

An important component used for reactor heating is a reactor heating furnace. As a heater can be used heating element or induction heater that can reach 1700°C reactor temperature. The reactor temperature, coating gas composition and coating time plays an important role in the coating process. The reactor temperature and the gas composition determine the properties of the formed layer. The duration of the coating operation determines against the thickness of the coating, the longer the thicker it becomes

4. Conclusion
The design of the coating reactor to coat the sintered UO₂ kernel into coated particles is selected based on the coating process, the intended use of the reactor and its capacity. The reactor prototype is used to obtain useful process data for the manufacture of a production reactor. The fluidization reactor chosen for its prototype is a conical spout bed reactor or conical reactor. Reactor with a diameter of 2 cm, inlet diameter 0.3 cm, angle of conis 60° was selected to be made prototype reactor. The flow rate for the reactor operation is between the maximum fluidization flow rate at the inlet and the 1.3 x minimum fluidization flow rate on the cylinder. The gas stream is in the flow above 2.5279 m/sec at the inlet or 1.0716 L/minute upto the flow 1.38 m/s or 1.3 x 20.117 L/min = 26.1255 L/min. Comparison of other research results with modeling using CFD, its flow rate is about 10 m/s or 4.239 L/min

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