

The Peluit Heat Utilization for Low-Rank Coal Upgrading

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Abstract— BATAN is developing a power reactor called the Peluit. In addition to electrical generation, the reactor's heat is used for cogeneration. A possible cogeneration process is coal upgrading. Indonesia holds 161,0 billion tons of coal reserves, 60% of which is low-rank coal with a moisture content of over 25%. During combustion, the low-rank coal produces extremely low heat and high CO₂ emissions. To increase the coal quality, a drying process is needed. Peluit is designed to generate superheated steam on the secondary side with temperatures above 500°C. It can be used for coal upgrading. Peluit can be built side by side with a coal-fired plant and provide it with good quality coal. Various studies on coal drying using conventional heat have been done and found it ineffective and inefficient. This research aims to determine the total amount of dried coal producible by utilizing Peluit superheated steam. The ChemCAD software package is used for modeling and simulation. Superheated steam is assumed at 500°C, 15 kg/s, and 5 bars. The dry coal combustion heat value is assumed to increase from 4840 kcal/kg to around 6170 kcal/kg. The temperature of the rotary drum is maintained at 150°C to prevent spontaneous dried coal combustion, and the moisture content is set at 10%. Approximately 600 tons/day of low-rank coal can be dried with this method, and its moisture content is reduced from 40% to 10%.

Keywords— Low-rank coal; moisture; upgrading; heat; cogeneration; Peluit.

Manuscript received 24 Mar. 2021; revised 30 May 2021; accepted 27 Aug. 2021. Date of publication 31 Dec. 2021.
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I. INTRODUCTION

National Nuclear Energy Agency/Badan Tenaga Nuklir Nasional (BATAN) is currently developing two conceptual designs of power reactors called *Pembangkit Listrik dan Uap Untuk Industri* (Peluit) and Reaktor Daya Eksperimental (RDE). Both of these reactors were pebble bed gas-cooled reactors (HTGR) [1]. RDE is 10 MW_{th} and Peluit is 150 MW_{th} of thermal power. Peluit is designed by joint-lab cooperation between BATAN and Tsinghua University of Beijing, China. It is a pebble-bed type reactor with indirect cycle power conversion [2]. Pebble bed type reactor was chosen due to its strong passive safety features [3]. Peluit is expected to be a prototype for the future Indonesian commercial nuclear reactor to fulfill the large electricity demand [4]. The pebble-bed type is also flexible in terms of different fuel cycles, including the standard U, Th, or Pu cycle [5]. The reactor core inlet and outlet temperatures are ~250°C and ~750°C, respectively [6]. The thermal heat generated in the core is circulated by a helium gas blower to the steam generator for electricity generation and a heat utilization plant via an intermediate heat exchanger (IHX) [7]. The use of a steam generator or IHX ensures that the safety of the installation is

maintained due to the possible of water ingress into the primary coolant [8]. The Peluit secondary coolant is water after it flows into steam generator/IHX, dry steam is produced, and at turbine and generator, this dry steam generates electricity. The steam discharged from the steam turbine could be condensed and recycled into the steam generation system [9]

HTGR including Peluit offers many advantages for industrial applications [10]. Peluit can implement cogeneration processes, including several industrial process applications i.e. desalination, enhance oil recovery, coal upgrading, coal gasification/ liquefaction, hydrogen production, etc. [11], [12].

Indonesia holds 161,0 billion tons of coal reserves, 2-3 percent of the world's reserves, but 60% of them are medium and low-rank coal (lignite) with more than 25% of high moisture content [13]. The high water content in low-quality coal could affect its utilization [14], including resulting in high CO₂ emissions during firing [15], low combustion efficiency, probable spontaneous combustion in storage facility [16] and increased shipping costs [17]. Due to their characteristics, low-rank coals also have low calorific values that make it difficult for Indonesian fired-coal stations to

utilize [17]. During coal burned in a power station, it produces very low heat and high CO₂ emissions [13]. Therefore, to increase the coal quality, the drying process is needed [17]. Peluit is designed to produce dry steam on the secondary side with temperatures above 500°C. This temperature can be used for coal upgrading with a large capacity. To support a coal-fired power plant that requires a continuous supply of coal, small nuclear power reactors such as Peluit can be built side by side at the same location so the coal-fired power plant gets a good quality of coal [14].

This research aims to prescribe the amount of dry coal that can be generated by using the secondary dry steam of Peluit. ChemCAD software is used to simulate it to achieve this objective, and the calculation results were compared to other literature study results. The simulation output is 7-10% of coal moisture content within the temperature inside of the rotary drum below 150°C. Various literature sources of scientific

publications are used to compare data and information on coal drying philosophies.

II. MATERIALS AND METHOD

A. The Conceptual Design of Peluit Cogeneration

HTGR is one of the nuclear power reactors that is justified to be the most promising choice to meet future energy needs. It has higher thermal efficiency than a light water reactor (LWR). HTGR can be used for heat generation for supporting the cogeneration process and industrial electricity supply [2]. The cogeneration process includes heat supply for the chemical industry, steel [12], coal gasification/liquefaction [11], oil mine [18], coal drying, hydrogen production, and desalination. Based on this fact, Peluit can be used as a supporting power in industrial areas in Indonesia through cogeneration conceptual design for coal drying of Peluit (See Figure 1).

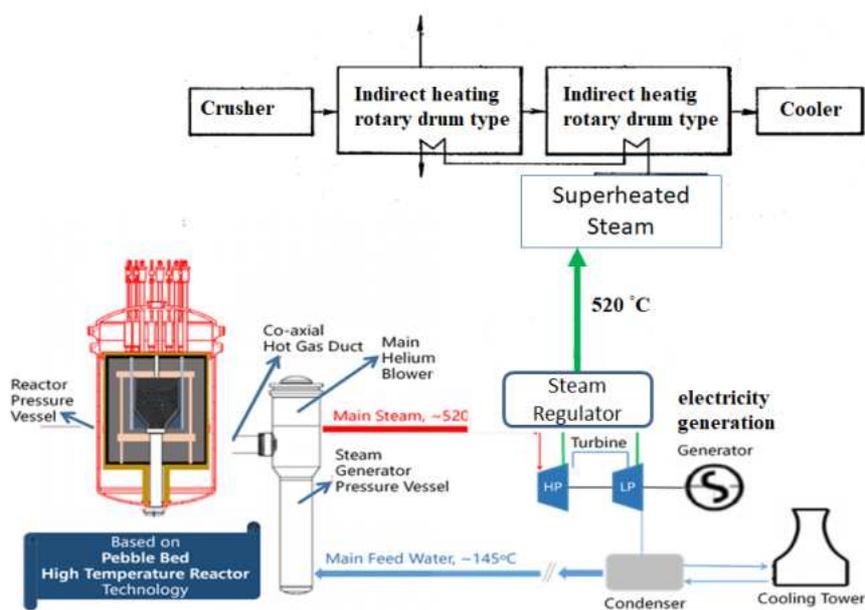


Fig. 1 The cogeneration conceptual design for coal drying of Peluit .[1]

The Peluit uses pebble fuel, it has an indirect cycle energy conversion, and the thermal power is 150 MW, equal to 60 MW electrical power. Peluit is designed and could be used for mainly electricity generation, and the other function is to supply the heat for cogeneration processes i.e., hydrogen generation, coal drying, coal gasification/liquefaction, enhanced oil recovery, waste treatment, desalination, and other industrial processes [19]. The cogeneration conceptual design for the coal drying of Peluit is shown in Figure 1.

In Peluit, the heat is transferred from primary to secondary coolant through a steam generator (SG) [4]. The secondary coolant is good quality water with a certain specification. The dry steam in the secondary coolant moves towards a single shaft turbine with an electric generator to generate electricity. The kinetic energy of dry steam is converted into electrical energy by an electric generator. The condenser condenses the turbine steam outlet, and the water formed is returned to the secondary coolant for recirculation [20]. The technical specification of Peluit is shown in Table 1.

TABLE I
THE PELUIT TECHNICAL SPECIFICATION

Reactor Core	Nominal	Units
Height	650	cm
Diameter	300	cm
The void above the core	30	cm
The thickness of the top reflector	150	cm
The thickness of the side reflector	115	cm
The thickness of the bottom reflector	150	cm
Fuel loading scheme	Multipass	
Inactive core fuel element	247.813	FE
The Core residence time	1043	EFPD
Fuel element discharged	3565	FE/day
Fresh FE per day	~238	FE/day
Graphite balls per day	---	FE/day
		MWd/Kg-
Average Discharge BU	87.69	HM
Avg. power density	3.26	W/cm ³
Max. power density	5.12	W/cm ³

Max. power per fuel ball	1.447	kW/FE
Primary Coolant		
Primary coolant mass flow rate	57	Kg/s
Reactor pressure operation	7	MPa
Inlet temperature of the core coolant	250	°C
The outlet temperature of the core coolant	750	°C
Max. Fuel Temp. under normal operation	903.7	°C
Avg. Fuel Temp under normal operation	540.8	°C
Max. Fuel temp. under DLOFC	1450	°C
Time to max. fuel temp. under DLOFC	30	Hours
Power Conversion System		
Media	Superheated steam	
Flow rate at nominal operation	59.5	Kg/s
SG outlet pressure	14	MPa
SG outlet temperature	540	°C
Feedwater Temperature (input to SG)	200	°C
Feed water Pressure (input to SG)	~14.9	MPa
Feed water mass flow rate	59.5	Kg/s

B. Low-Rank Coal Resources in Indonesia

In terms of fulfillment of energy demands, coal plays a key role in supporting global economic development. At present, 27% of the world's primary energy needs and 41% of the world's electricity comes from coal. In some countries, the percentage of coal-fired power plants is much higher, for example, in China, 79%, South Africa, 93%, Poland, 92%, and Australia, 77%. In Indonesia, coal-fired power stations

supply almost 61% of national energy demand. The use of coal to fuel power plants in Indonesia is also increasing and leads to low rank or lignite coal which has a calorific value of +4,200 kcal/kg (gross as received or GAR) [21].

The existing coal power plant in Indonesia cannot use all available lignite because some lignite has a calorific value of less than 4,200 kcal/kg. Coal drying technology has been developed in the world since the 1920s. The first project was in Austria. The Flessner process was developed to reduce the water content of low-rank coal using superheated steam. At present, many coal drying technologies have been developed and based on the water phase that comes out of coal during the process itself.

Coal has many benefits, including raw material for chemical synthesis and as a power plant fuel [22]. Coal quality is determined at its initial moisture content. Coal is dried to increase its calorific value, thereby increasing boiler combustion efficiency. Coal drying technology is categorized into evaporative and non-evaporative technologies. In evaporative technology, water is removed from coal in the gas phase, whereas in non-evaporative technology, the water is released from coal in a liquid phase due to the use of high pressure. Most of coal drying technology is evaporative technology, such as upgraded brown coal (UBC) technology [14], binderless coal briquetting (BCB), coal upgraded briquettes (CUB), and others [14]. UBC coal drying is shown in Figure 2. The non-evaporative technology such as continuous *hydrothermal* dewatering (CHTD). Tools used for coal drying also vary, such as rotary dryers, flash dryers, fluidized bed dryers, slurry evaporators, autoclaves, and hydraulic presses.

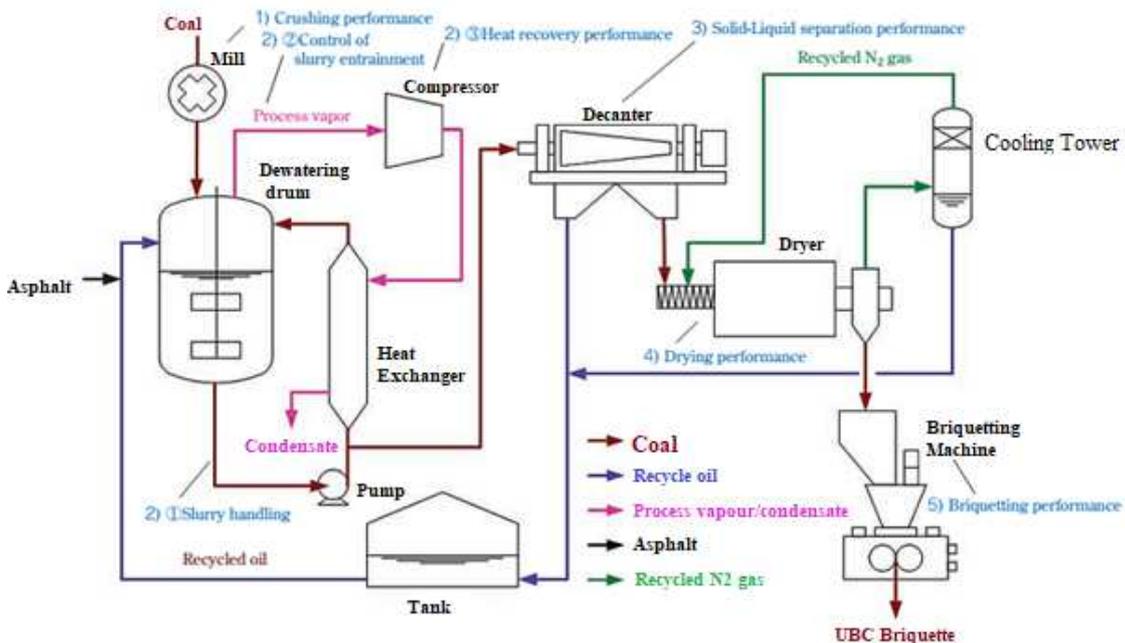


Fig. 2 The schematic diagram of UBC coal drying

In line with the issue of global warming, coal drying technology has been developed in several countries that can reduce total CO₂ emissions from power plants, such as coal drying technology using heat waste energy from a power plant and nuclear cogeneration systems. For example, the heat

waste in a power plant is heat energy in the exhaust stream or energy in hot water that could lead to the cooling process at the cooling station. Cogeneration or combined heat and power (CHP) power plants are power plants designed to produce

steam for industrial purposes in addition to steam for power generation turbines.

The utilization of waste heat for coal drying was developed in America by the Great River Energy Company, in Germany by RWE, and in Australia by Monash University. A cogeneration coal drying system was developed in Japan and has been implemented in Indonesia. The companies named Sojitz and Tsukishima Kikai have implemented coal drying with energy from low-pressure steam from the Suralaya and Labuhan power plants using a rotary dryer equipped with pipes to flow steam (steam tube rotary dryer or STD). In STD there is no direct contact between coal and steam to be recycled directly to the boiler. There was a reduction of CO₂

emissions by 250,000 tons/year after the technology was applied to the coal-fired station with a capacity of 700 MW, and coal moisture content before and after the drying process are 43.6% and 10%, respectively.

C. The ChemCAD Model and Simulation

The energy conversion system of Peluit has been modeled using ChemCAD, as seen in Figure 3. Helium as primary system and secondary is water/steam. The helium mass flow rate is 57 kg/s, and 70 bars. The core inlet temperature is 250 °C and 750°C at the outlet. The superheated steam at secondary coolant can be utilized for electricity and otherwise for cogeneration.

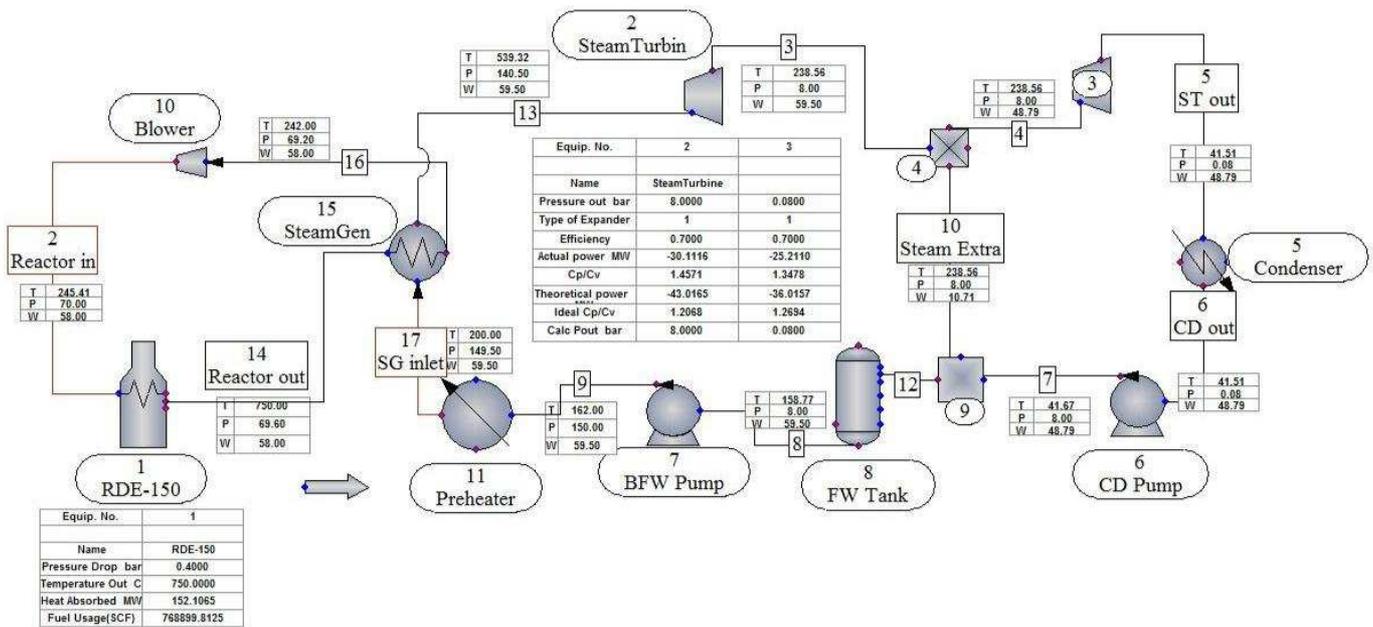


Fig. 3 The ChemCAD simulation of the power conversion system of Peluit

This research assumes that the coal upgrading process uses a direct heating rotary dryer with a co-current flow using steam output from low-pressure turbines with a temperature of 500 °C. The steam mass flow rate used is assumed 15 kg/s (about 25% of the total mass flow rate) as a drying media. There is direct contact between the dry steam and the coal to be dried in the direct heating coal drying. The direct heating method is chosen because it is the simplest and most economical unit. The simulation is targeted to produce coal with a total moisture content of 7-10% and a calorific value of 5000-6000 kcal/kg (GAR) [13]. To achieve this dry coal production, the temperature of the dried coal is maintained at less than 150°C in the solid dryer to prevent spontaneous combustion. The low-rank coal feed to the direct rotary drum varies from 100 kg/h to 600 kg/h.

The simulations performed in this study used a solid dryer unit, as seen in Figure 4, with an input of low-rank coal with moisture content ranging from 20% to 45%. The solid dryer is working as a rotary drum, direct contact heating. Direct heating is used due to its simple technology and economic aspect. Moisture content in the dried coal product is 7-10%; the maximum temperature set up in the dryer is 150 °C. The cyclone was installed before wet coal was fed into the solid

dryer. The cyclone was separated from the fine coal dust. The expander was used to reduce the superheated steam.

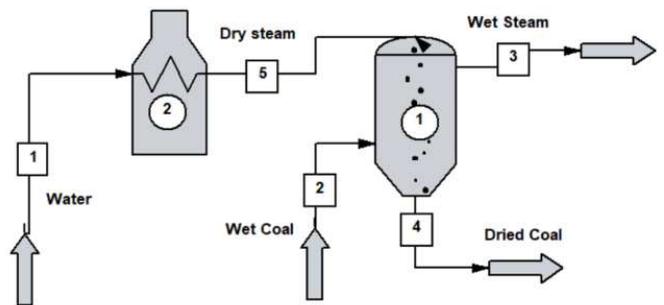


Fig. 4 Solid dryer model for coal dewatering

III. RESULTS AND DISCUSSION

A. Energy Needs for Coal Drying

The solid dryer unit operation in ChemCAD is one component can be used for coal drying simulation. Drying is the removal of water from wet coal to form dried coal by vaporization. The mechanism of coal drying is categorized into indirect contact (conduction), direct (convection),

dielectric or microwave (radio frequency), and radiant (radiation) drying. Heat and mass transfer are crucial aspects of the drying process. Heat is transferred to the coal to evaporate moisture, and mass is transferred as a vapor into the surrounding gas. The solid dryer is working as a rotary drum, direct contact heating. Direct heating is used due to its simple technology and economic aspect. Moisture content in the dried coal product is 10%, with the maximum temperature set up in the dryer being 150 °C. The temperature must be maintained at this setpoint to avoid coal combustion.

Figure 5 shows the relationship of moisture content of coal with a calorific value that the coal itself could generate. The reducing moisture content in the coal could increase the carbon ratio content in the coal and automatically increase its calorific value. In general, the moisture content of coal needs for the coal-fired station is less than 20-23%. Therefore, the assumption of 10% moisture content for coal drying is sufficient to meet these needs. For low-rank coal such as lignite, less than 8% moisture content could easily affect spontaneous combustion. Dry steam, which is fed into a solid dryer, has a mass flow rate of 15 kg/s a quarter of the total mass flow rate in the secondary coolant, a temperature of 500 °C, and the pressure after being decreased 5 bars. To mitigate the coal dust, a cyclone was installed at the input stream of a solid dryer. The cyclone is set up to separate the fine and coarse dust lower than 50 microns in diameter. The coal is set as a solid carbon material as a coarse dust particle.

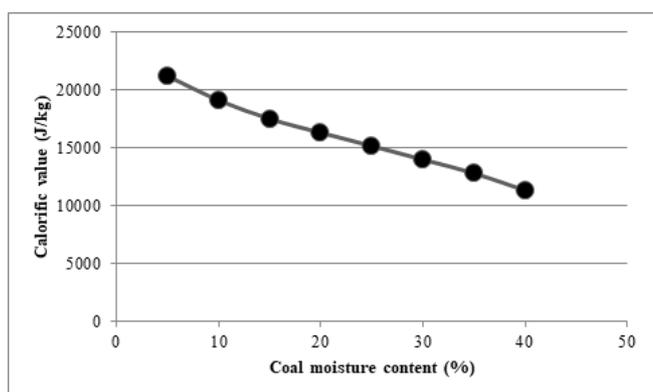


Fig. 5 The coal moisture and its calorific value changes

The energy needed for the evaporation process from lignite coal (Q_t) includes the energy needed to raise the temperature of the coal (Q_1), the energy needed to raise the temperature of the water (Q_2), and the energy needed to evaporate water at boiling point (Q_3). Thus, the total energy needed to dry coal (Q_t) is defined as follows:

$$Q_t = Q_1 + Q_2 + Q_3 \quad (1)$$

$$Q_1 = m_1 Cp_1 dT \quad (2)$$

$$Q_2 = m_2 Cp_2 dT \quad (3)$$

$$Q_3 = m_2 l \quad (4)$$

Where: m_1 is raw coal mass flow rate, Cp_1 is coal heat capacity (0.33 kcal/kg°C), m_2 is mass of water, Cp_2 is heat capacity of water (1 kcal/kg°C), and l is the latent heat of water (542.18 kcal/kg). The total energy requirement (Q_t) to evaporate water in ideal conditions at 100% of efficiency is 799 cal/g of water [13].

Figure 6 shows the relationship between superheated steam mass flow rate and energy generated for coal drying processes

from the secondary coolant of Peluit. Some assumptions are considered, i.e., the superheated steam temperature outlet of the steam generator is 500°C, the bypass flow in the secondary coolant is varied from 5 kg/s to 15 kg/s, the moisture/water evaporation temperature in the coal is 100°C, the heat latent of water is 542.18 kcal/kg.

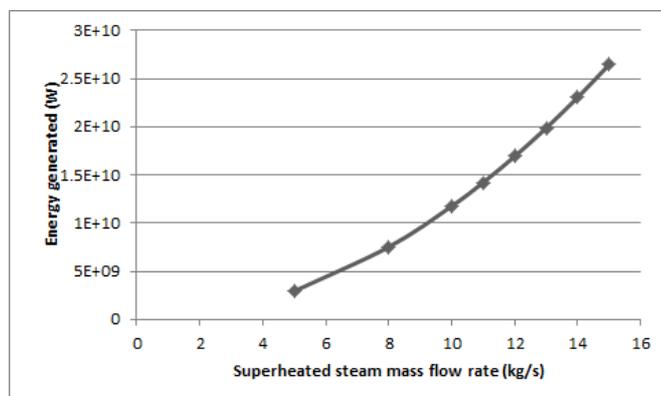


Fig. 6 The correlation between superheated steam mass flow rate and energy generated for coal drying processes.

The larger of bypass flow rate at secondary coolant results the greater heat energy that can be used for the drying process. Superheated steam bypass flow rate is a key parameter for coal upgrading, and it determines the total amount of low-rank coal that can be dried. However, there is a limit of bypass flow that does not interfere with the reactor electrical generation. It is a maximum of a quarter of the main secondary flow rate used for coal drying. Almost all heat energy is directly transferred to the coal to evaporate the moisture by direct heating.

In ChemCAD simulation, at first, it is assumed that stream no. 2 is wet (low-rank) coal, a temperature of 30 °C, moisture content of 40%, with a mass flow rate of 10 kg/s. Stream no. 5 is superheated steam flow from the reactor core at 15 kg/s, 500 °C. It is also assumed that the dry coal product still has 10% of moisture/water. Simulation results show that the amount of dry coal produced is 624428.0747 kg per day. The amount of dry coal could increase if the wet coal feed has less water content, as seen in Figure 7.

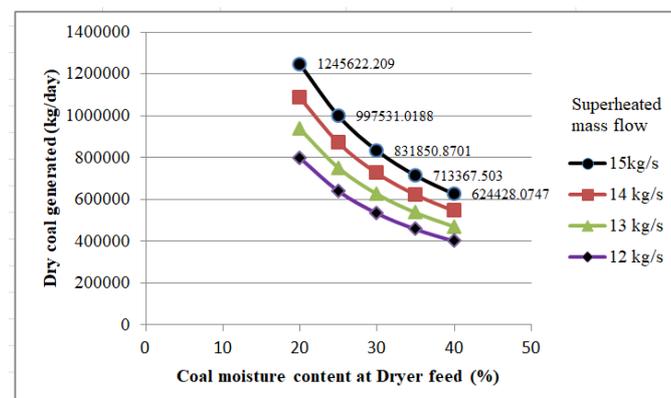


Fig. 7 The correlation between coal moisture content and dried coal generated by using a quarter superheated steam mass flow rate at secondary coolant of Peluit

The superheated steam mass flow rate changes affected to amount of dry coal production and is shown further in Table

2. By varying the superheated steam flow rate of 12 kg/s, 13 kg/s and 14 kg/s, the dry coal obtained is less than at mass flow rate of 15 kg/s.

TABLE II
DRY COAL PRODUCTION FROM SUPERHEATED STEAM OF PELUIT

Superheated steam mass flow rate/stream no.5 (kg/s)	Low-rank coal moisture content at feed/stream no. 2 (%)	Dry coal production/stream no.4 (kg/day)
12	20	399,633.9678
	25	456,555.2019
	30	532,384.5569
	35	638,419.8520
	40	797,198.214
13	20	935,600.6818
	25	749,256.6319
	30	624,812.4314
	35	535,818.2578
	40	469,014.8650
14	20	108,5075.347
	25	868,960.3541
	30	724,634.5358
	35	621,422.3582
	40	543,946.2340
15	20	124,5622.209
	25	997,531.0188
	30	831,850.8701
	35	713,367.5030
	40	624,428.0747

B. Water Re-absorption in the Dry Coal

One of the problems in drying the coal is the occurrence of water re-absorption by coal. Dried coal has a hydrophilic nature. Oxygen (O_2) in coal pores easily reacts with hydrogen (H_2) to form water (H_2O), and it is simply contained in the coal matrix. Water in coal is located in pores and easily attaches to the surface, which contains oxygen. There are three ways to prevent water from returning to the coal by closing the pores of the coal with additives, destroying the pores through grinding or heating, and drying the coal at a rather high temperature so that the oxygen function group is released from the coal. Although in the drying process to be studied (GRE technology and Sotitz & TSK technology) the temperature is low and does not use additives to close the coal pores, the absorption of moist water by dry coal is expected to be difficult because the product is directly utilized at the power plant. It takes a long time (3-7 days) for water to be reabsorbed until it reaches equilibrium moisture, and a maximum of only 30% of moist water could be reabsorbed by lignite after the drying process.

Low-quality coal has high water content. With the heating process, practically the water content in coal is drastically reduced. Thus, the quality of coal could be better if it is used as a fuel for a coal-fired power plant. The combustion process could be more efficient, clean, and environmentally friendly [23]. Even so, this technology still has a few weaknesses. The process of heating coal could leave large pore holes, so it is riskier to burn if in contact with air. Because it is highly recommended, the process of direct heating / indirect heating should be placed close to the power plant with an ideal distance of about 40 meters so that coal that has been heated can be directly used.

Blending low-calorie coal with high calories is another way to produce quality coal with a calorific value according to the design of the power plant. Blending coal can be done by mixing several types of coal in the stockpile, in the conveyor belt, in the hopper, in the crusher, in the grinding machine, and others. The choice of blending method depends on the conditions at which the blending could take place, the capacity of the blending facility, the required blending accuracy, and the type of user (end-user) of the blending product. Although the application of blending technology is estimated to have lower investment costs compared to coal drying technology, the blending process requires coal with higher calorific value or coal at a higher price.

The drying low-rank coal method with a temperature above the boiling point of water is used to dry the coal without big affected due to high temperatures. Thus, this process has the advantage of maintaining the coal matrix integrity and a small amount of thermal oxidation. Various drying technologies, such as steam tube dryers, are used for the process. The obstacle is that the large latent heat could increase energy requirements, and the bad impact is the occurrence of spontaneous combustion.

Some power plants use a rotary dryer equipped with pipes to flow steam (steam tube rotary dryer or STD) for coal drying. In STD, there is no direct contact between coal and steam so that steam can be recycled directly to the boiler. Based on the study results, there could be a reduction of CO_2 emissions by 250,000 tons/year if the technology is applied to the coal-fired station (PLTU) with a capacity of 700 MW and coal moisture content before and after the drying process is 43.6% and 10%, respectively

IV. CONCLUSION

Coal drying research has been carried out using a solid dryer model. The superheated steam of Peluit is flown to the dryer at 500 °C, 15 kg/s, and 10 bars. A 10 kg/s of low-rank coal is fed to the dryer generated 600 tons per day of dry coal with 10% of moisture content. Drying coal is hydrophilic. Oxygen in coal pores easily reacts with hydrogen to form water. Water in coal is located in pores and easily attaches to the surface, which contains oxygen. There are three ways to prevent water from returning to the coal by closing the pores of the coal with additives, destroying the pores through grinding or heating, and drying the coal at a rather high temperature so that the oxygen function group is released from the coal.

ACKNOWLEDGMENT

The authors thank the Ministry of Research and Higher Education for funding this cogeneration research through Insinas Ristek-BRIN. In addition, this research is also supported by DIPA PTKRN BATAN of the fiscal year 2021.

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