

Optimization Design of Coal Dryer Using Genetic Algorithm in Power Plant

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ABSTRACT

Coal with a moisture content that reaches 40% can cause the efficiency of the plant to be not optimal. Low-efficiency values will generate electricity to increase, and the combustion process to be incomplete to cause many losses to the Steam Power Plant. From this problem, it is necessary to have a coal drying process to reduce moisture content. The technology used in the coal drying process is a coal dryer. The design of a coal dryer requires a source of steam or heat for the drying process. There is waste steam extracted from the turbine at the Steam Power Plant, which a coal dryer can use as a heat source to heat the coal. The amount of turbine extraction steam that a coal dryer can receive depends on the coal dryer design because the design process of the coal dryer will affect the availability of energy in the coal dryer. This paper will discuss the optimization calculations with the genetic algorithm method to obtain the best design of a coal dryer. The heat received can be maximized so that the drying process becomes faster. The purpose of designing this Genetic Algorithm is to obtain the maximum calorific value that the Dryer can accept by considering the geometric boundary function of the Dryer itself. In the Genetic Algorithm, there is an objective function or fitness function. It needs accuracy in this determination because the results of the Genetic Algorithm depend on this value. If there is an error in this value, it will result in a wrong value in the optimization process. The rotary dryer design optimization result using a Genetic Algorithm is 2.98 meters in diameter, 29.8 meters in length, with the resulting heat of 4,937 kJ/s. Meanwhile, the fluidized bed dryer results from the design optimization obtained a cross-sectional area of 9 square meters, a base area of 9.8 square meters, a height of 5.1 meters with an optimal heat of 5.001 kJ/s. By using the genetic algorithm method, the optimal value is obtained in the drying process.

Keywords: Genetic Algorithm; Low-Rank Coal; Coal Dryer; Steam Extraction Turbine

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I. INTRODUCTION

Coal is one of the natural resources in Indonesia. Coal production in Indonesia for 13 years increased production by 15.68% per year. In 2006 Indonesia produced 162 million tons of coal and 120 million tons of which were exported in various countries, one of which was Japan. In addition, Indonesia has coal reserves spread across Kalimantan Island, Sumatra Island, and Sulawesi Island. Among the three islands, the largest coal reserves are located on the island of Kalimantan, which supplies 75% of coal production in Indonesia [1].

Coal is generally used as a fuel in the process in the Industry. One of the companies that use coal as fuel is Paiton Steam Power Plant. Currently, coal used in Paiton Steam Power Plant is a type of low-rank coal with a caloric value of 4200 kcal/kg with a moisture content of 40%. Coal with a water content that reaches 40% can cause the efficiency process of the plant to be not optimal. Currently, the efficiency produced at Paiton Steam Power Plant reaches 83.280%, and heat loss occurs by 16.72% [2]. The low-efficiency value will cause electricity to rise and the combustion process to become imperfect, so that it can cause a lot of losses at the Paiton steam power plant.

Based on the above phenomenon, it can be concluded that there needs to be a process of drying coal to reduce the moisture content of coal. The technology used to dry coal is a coal dryer. Previously, research related to the utilization of coal dryers used for the drying process of inner coal. The study concluded that the use of coal dryers can increase the value of efficiency by as much as 1.55% and also explained the type of coal dryer. Types of coal dryers that are often used to dry coal include Rotary Dryer and Fluidized Bed Dryer [3]. In building a coal dryer, there needs to be a source of steam or heat used for the drying process. At Paiton Steam Power Plant, steam extraction from turbines (Waste Heat Recovery) can be used as a heat source to heat coal. If this steam extraction is utilized, it can lower the load of the condenser.

The amount of turbine extraction steam that the coal dryer can receive depends on the design of the coal dryer because the design process of the coal dryer will affect the availability of energy in the coal dryer. So there needs to be a study on calculating

the best design optimization of the coal dryer so that the heat received can be maximized so that the drying process becomes faster.

In 2015, research was carried out on coal dryers using the Linear Programming method [4]. The results obtained from the study are a fairly optimal design. However, previous studies still have a drawback; namely, the diameter and length design results obtained from rotary dryers still show large values. So it is necessary to do further research using different methods. Based on previous research that has been previously described, this study is proposed. This study aims to perform an optimization design on a coal dryer by utilizing steam from the turbine output at a Steam Power Plant with a genetic algorithm method.

The genetic algorithms method is done by encoding genes from a chromosome, where genes are part of a chromosome. A gene will usually represent a variable, and genes can be represented in the form of bits, real numbers, a list of rules, permutation elements, program elements, and other representations that can be implemented for genetic algorithms. Genetic algorithms are widely used in solving optimization problems because genetic algorithms can provide the best solution by basing on the evolutionary process to effectively solve problems related to optimizing [5].

II. METHOD

This section contains the stages of research. The research procedure consists of several steps to be able to achieve the objectives of the research. In general, the research procedure is illustrated using the flowchart in Fig. 1.

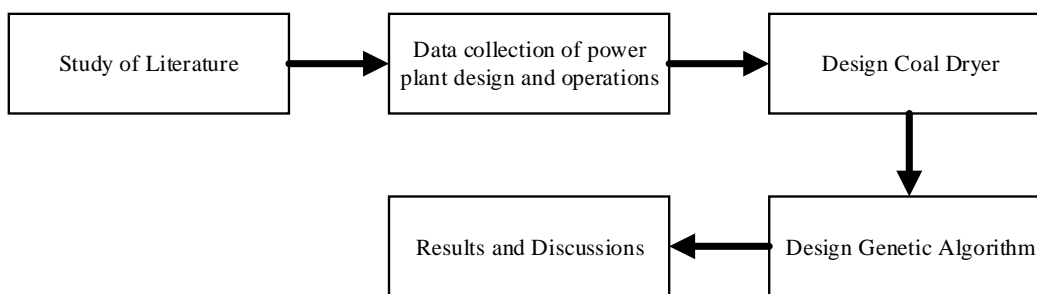


Fig. 1. Research Flowchart

A. Study of Literature

In the study stage of literature, researchers studied matters related to Coal Dryer, including the work process, heat transfer process, and design model of Coal Dryer, besides that also learn about genetic Algorithm.

1. Coal Dryer

Coal dryer is a technology that can be used to dry coal, the process of drying coal aims to increase the caloric value of coal. Coal dryers generally require a heat source used for the drying process. Heat sources used to dry coal can be taken directly or indirectly. Directly means heat taken without intermediaries (Direct Dryer) and indirectly means there is a barrier to drain hot steam (Indirect Dryer) [3]. The heat source used can be obtained from exhaust gas (Waste Heat) and Steam Extraction Turbine (Waste Heat Recovery). Inside the Paiton steam power plant, there is still residual heat from Steam Extraction Turbine (Waste Heat Recovery) [6]. If this hot steam is utilized, it can increase the heating value of coal and reduce the condenser load. The process can be seen in Fig. 2.

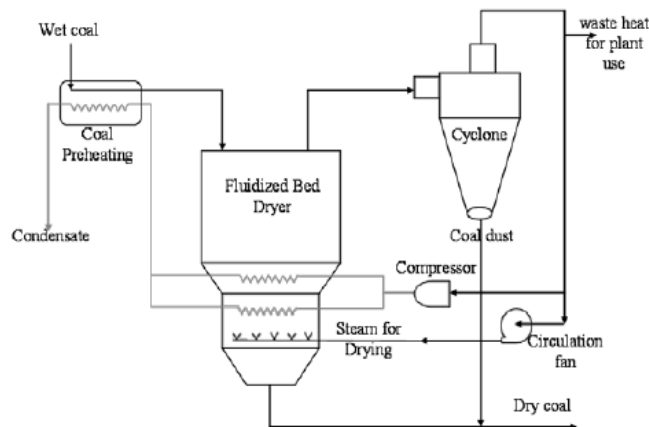


Fig. 2. Coal Dryer

Currently, coal dryer technology began to be developed in Indonesia. Especially in Steam Power Plant because this coal dryer can increase many advantages in the plant because of the efficiency of the plant increases. In general, pre-drying itself is very important because coal has a high water content to increase operational costs and maintenance costs [6]. In addition, it can also cause the consumption of coal use to increase and will certainly require a larger boiler.

The inclusion of coal with a high humidity level can result in an imperfect combustion process (due to the high oxygen content). Therefore, it is necessary to do the drying process of coal in advance so that the process in the steam power plant becomes more maximal and generates a large profit.

2. Genetic Algorithm

Genetic Algorithm is one of the search techniques based on the natural selection process. The calculations in this Algorithm are based on the selection process of living things, and the role in the process of genetic algorithms is called population; in the population, there are various individuals, each containing various types of chromosomes [7]. In these chromosomes, there are various possibilities for solving a problem. Each generation formed on each chromosome will undergo evaluation based on a fitness function.

The value of fitness indicates the quality of the chromosomes present in the population. The greater the fitness value of the chromosome, the higher the chances of survival, and if the fitness value obtained is small, he will die at the next population formation. At first, the population is formed randomly, and hereafter the new population is formed based on the parameters in the genetic Algorithm that has been determined. So the new chromosome is a parent while the old chromosome is a child. Crossing techniques carry out the marriage process. After producing a new offspring, changes in the genes' shape on the chromosome are called mutations [8].

In Genetic Algorithms, there are various parameters to solve a problem. These parameters include population number, number of generations, number of chromosomes, interbreeding ratio, and mutation ratio. The number of generations is a representation of the number of iterations to be achieved. The more iterations performed, the better the value of fitness. Then there is the crossover rate; the higher the value of a crossover, the more varied the resulting solution will be to reduce the probability of the desired optimum value.

B. Data Collection of Power Plant Design and Operations

Data collection in Table I was conducted at Paiton Steam Power Plant Unit 7. The data taken are as follows:

- a. Mass flowrate output steam.
- b. Temperature input turbine.
- c. Temperature output turbine.
- d. Mass flowrate coal.

TABLE I
 DATA OPERATIONAL PROCESS SPECIFICATION

| Parameter | Unit | Value |
|-----------------------------|-----------|--------------|
| Mass flow rate output stean | m_a | 350.935 kg/s |
| Temperature input turbine | T_{in} | 122 °C |
| Temperature output turbine | T_{out} | 95 °C |
| Mass flow rate coal | M_s | 71.18 kg/s |

C. Design Coal Dryer

Types of coal dryers that will be designed are rotary dryers and fluidized bed dryers.

1. Design Rotary Dryer

On rotary Dryer has a cylindrical shape where the input side is a circle with a specific diameter. Therefore, the steam mass flow rate that is inversely proportional to the area is called mass velocity (G). Can be seen in equation (1)

$$G \times A = m_a \tag{1}$$

where:

G = mass velocity (kg/m².s)

A = cross sectional area rotary dryer (m²)

m_a = mass flow rate low pressure turbine (kg/s)

To get the diameter value of the dryer side there is described from the equation (1) and (2) so that the diameter equation rotary dryer into:

$$D = \sqrt{\frac{4m_a}{\pi \times G}} \quad (2)$$

where:

D = diameter rotary dryer (m)
 m_a = mass flow rate low pressure turbine (kg/s)
 G = mass velocity (kg/m².s)

Because it is cylindrical, therefore rotary Dryer has a certain diameter and length. Therefore, to find the length of the rotary Dryer can be described as equation (3)

$$L = \frac{Q}{U_a \times \frac{1}{4} \pi \times D^2 \times (T_{out} - T_m)} \quad (3)$$

where:

L = Length rotary dryer (m)
 Q = Heat receive coal dryer (kJ/s)
 U_a = Volumetric heat transfer coefficient (kJ/m³.s.K)
 D = Diameter rotary dryer (m)
 T = Temperature (°C)

2. Design Fluidized Bed Dryer

Calculate the height of the fluidized bed dryer can be described in equation (4).

$$H = \frac{m_s \times (1 + X_{so}) \times t_R}{\rho_s \times A \times (1 - \varepsilon)} \quad (4)$$

where:

H = Height fluidized bed dryer (m)
 X_{so} = Water content in coal (S)
 m_s = Wet coal mass flow rate (kg/s)
 t_R = Residence Time (S)
 ρ_s = Density Coal (kg/m³)
 A = Cross sectional area fluidized bed dryer (m²)
 ε = Porosity

The cross-sectional area of the fluidized bed dryer can be searched using equations (5) :

$$A = \frac{\rho_g \times u_{mf} \times \varepsilon}{m_a} \quad (5)$$

where:

m_a = Mass flow rate low pressure turbine (kg/s)
 u_{mf} = Velocity minimum fluida (m/s)
 ρ_g = Density Steam (kg/m³)
 A = Cross-sectional area fluidized bed dryer (m²)
 ε = Porosity

D. Design Genetic Algorithm

The purpose of designing this Genetic Algorithm is to produce optimal value. In the Genetic Algorithm itself, there is an objective function or fitness function, and it is necessary to be careful in this determination because the result of the Genetic Algorithm depends on that value, if there is an error in the value, it will result in a poor value in the optimization process. The objective function used in the final task this time is the amount of heat received by the Dryer to the maximum as possible, as in equation (6).

$$f(x)_{\max} = Q \quad (6)$$

where:

$f(x)$ = Objective function
 Q = Heat receive coal dryer (kJ/s)

The parameters of the Genetic Algorithm used refers to Table II.

TABLE II
 DESIGN GENETIC ALGORITHM

| Parameter Genetic Algorithm | Notation | Value |
|-----------------------------|----------|--------|
| Generation | Maxit | 20-100 |
| Population | Npop | 50-500 |
| Chromosome | Nbit | 18 |
| Mutation Ratio | Pm | 0.002 |
| Interbreeding Ratio | Pc | 0.8 |
| Ethylism Ratio | EI | 0.95 |

Objective function or $f(x)_{max}$ according to the intended limit value. The constraint value of each coal dryer is:

- Rotary Dryer with the value obtained [9].
- Length limit rotary dryer (meter)
 $15 \leq L \leq 30$
- Diameter limit rotary dryer (meter)
 $0.3 \leq D \leq 3$
- Fluidized Bed Dryer with the value obtained according to the reference on [4]:
- Surface area limit fluidized bed dryer (square meter)
 $0.9 \leq A \leq 9$
- High limit fluidized bed dryer (meter)
 $1.88 \leq H \leq 5.1$

III. RESULT AND DISCUSSION

A. Heat Potential Calculation Result

Utilization of heat potential in Power Plant Paiton steam comes from Turbine Steam (Waste Heat Recovery). The results of the calculation of heat energy potential can be seen in Table III.

TABLE III
 HEAT POTENTIAL OUTPUT CALCULATION RESULT

| Variable Process | | |
|----------------------|---------------|--------------|
| Parameter | Notation | Value |
| Mass flow rate steam | m_a | 350.935 Kg/s |
| Specific heat input | $C_{p_{in}}$ | 2.18 Kj/kg.C |
| Specific heat output | $C_{p_{out}}$ | 2.06 Kj/kg.C |
| Temperature input | T_n | 122°C |
| Temperature Output | T_{out} | 95°C |
| The Result | | |
| Heat Potential | Q | 24.656 kj/s |

With a coal time rate of 71 kg/s and moisture of 40%, the availability of residual heat that can be used in the Paiton power plant can reduce coal-water content by 9.65 kg/s. So that with the availability of heat by 24,656 kJ /s, it can reduce the water content of coal to 30% or increase the value of the heating value of coal to 4,800 kcal/kg.

B. Rotary Dryer Design Optimization Result

After the design stage of the Rotary Dryer, the next step is to optimize the design results of the rotary Dryer to obtain the results of rotary dryer design by the Industry. Optimizations are performed using a Genetic Algorithm. After optimizing the design, the result of the rotary dryer design becomes by the limitations / constrain determined. In addition, the optimization result of the rotary Dryer will improve the performance of the Rotary Dryer. The smaller the rotary dryer dimensions, it will make it easier for vendors to make rotary dryers according to their wishes. It will speed up shipping rotary dryers, and the results of the optimization of rotary dryer design can be seen in Table IV and Table V.

TABLE IV
 RESULT OPTIMIZATION ROTARY DRYER DESIGN BY CHANGING POPULATION PARAMETER

| Population | Generation | Diameter (m) | Length (m) | Heat Potential Q (kj/s) |
|------------|------------|--------------|------------|-------------------------|
| 60 | 20 | 2.943 | 29.96 | 4838.166 |
| 100 | 20 | 2.983 | 29.98 | 4870.421 |
| 160 | 20 | 2.986 | 29.992 | 4930.531 |
| 200 | 20 | 2.987 | 29.992 | 4956.071 |
| 260 | 20 | 2.984 | 29.992 | 4956.335 |
| 300 | 20 | 2.986 | 29.922 | 4956.628 |
| 360 | 20 | 2.986 | 29.922 | 4956.892 |
| 400 | 20 | 2.985 | 29.922 | 4956.921 |
| 460 | 20 | 2.984 | 29.922 | 4957.068 |
| 500 | 20 | 2.987 | 29.922 | 4957.508 |

The results in table IV, the population of 500 is the best result because in that population, the heat value obtained is more optimal compared to other populations. This is because the more the population, the more likely it is to interbreed so that the possibility of heat values obtained is more varied and higher.

TABLE V
 RESULT OPTIMIZATION ROTARY DRYER DESIGN BY CHANGING GENERATION PARAMETER

| Population | Generation | Diameter (m) | Length (m) | Heat Potential Q (kj/s) |
|------------|------------|--------------|------------|-------------------------|
| 160 | 20 | 2.986 | 29.99 | 4930.531 |
| 160 | 30 | 2.987 | 29.99 | 4955.748 |
| 160 | 40 | 2.987 | 29.99 | 4956.921 |
| 160 | 50 | 2.987 | 29.99 | 4957.508 |
| 160 | 60 | 2.987 | 29.99 | 4957.537 |
| 160 | 70 | 2.987 | 29.99 | 4957.772 |
| 160 | 80 | 2.987 | 29.99 | 4957.801 |
| 160 | 90 | 2.987 | 29.99 | 4957.947 |
| 160 | 100 | 2.987 | 29.99 | 4958.094 |

From the results in Table V, the number of generations of 100 is the best result because, in the 100 generations, the value of heat received from the coal dryer is more optimal. This is because the more generations raised, the more likely it is to produce the best individuals.

Before optimization using genetic algorithms, the results were obtained for a rotary dryer length of 82.68 meters and a diameter of 11 meters. After optimization, the results obtained for the rotary Dryer are 29.9 meters long and 2.98 meters in diameter. This proves that the optimization using the genetic algorithm method produces very optimal values in rotary dryer designs.

C. Fluidized Bed Dryer Design Optimization Results

After the design stage of the fluidized bed dryer, the next step is to optimize the design results of the fluidized bed dryer to obtain the results of the rotary fluidized bed dryer by the Industry. Optimizations are performed using a Genetic Algorithm. After the design optimization is carried out, the fluidized bed dryer design results are by the specified constraints. In addition, the optimization results of the fluidized bed dryer design will improve the performance of the fluidized bed dryer. The results of the fluidized bed dryer design optimization can be seen in Table VI and Table VII.

TABLE VI
 RESULT IN OPTIMIZATION FLUIDIZED BED DRYER DESIGN BY CHANGING POPULATION PARAMETER

| Population | Generation | Surface area (m ²) | High (m) | Heat Potential Q (kj/s) |
|------------|------------|--------------------------------|----------|-------------------------|
| 60 | 20 | 8.9995 | 5.0743 | 4984.7 |
| 100 | 20 | 8.9916 | 5.0689 | 4995.0 |
| 160 | 20 | 8.9969 | 5.1 | 5000.0 |
| 200 | 20 | 8.9929 | 5.0994 | 5000.4 |
| 260 | 20 | 8.9969 | 5.0823 | 5001.1 |
| 300 | 20 | 8.9339 | 5.0828 | 5001.2 |
| 360 | 20 | 8.8989 | 5.0922 | 5001.3 |
| 400 | 20 | 8.9291 | 5.0623 | 5001.4 |
| 460 | 20 | 8.8929 | 5.0822 | 5001.7 |
| 500 | 20 | 8.8899 | 5.1 | 5001.9 |

The results in Table VI, the population of 500 is the best result because, in that population, the heat value obtained is more optimal compared to other populations. This is because the more the population, the more likely it is to interbreed so that the possibility of heat values obtained is more varied and higher

TABLE VII
 RESULT IN OPTIMIZATION FLUIDIZED BED DRYER DESIGN BY CHANGING GENERATION PARAMETER

| Population | Generation | Surface area (m ²) | High (m) | Heat Potential Q (kj/s) |
|------------|------------|--------------------------------|----------|-------------------------|
| 160 | 20 | 8.9969 | 5.07 | 4996.00 |
| 160 | 30 | 8 | 5.1 | 4997.20 |
| 160 | 40 | 8.9962 | 5.0993 | 4997.60 |
| 160 | 50 | 8.9964 | 5.0994 | 5000.20 |
| 160 | 60 | 8.9963 | 5.0995 | 5001.10 |
| 160 | 70 | 8.9962 | 5.0996 | 5001.20 |
| 160 | 80 | 8.9963 | 5.0994 | 5001.29 |
| 160 | 90 | 8.9961 | 5.0992 | 5001.36 |
| 160 | 100 | 8.9962 | 5.0992 | 5001.39 |

The results in Table VII the number of generations of 100 is the best result because, in the 100 generations, the value of heat received from the fluidized bed dryer is more optimal. This is because the more generations raised, the more likely it is to produce the best individuals.

Before optimization using genetic algorithms, the results were obtained for the fluidized bed dryer cross-sectional area of 73.4 meters and a height of 0.18 meters. After optimization, the results obtained for the rotary Dryer are 9 meters long and 5.1 meters in diameter. This proves that the optimization using the genetic algorithm method produces a very optimal value in the fluidized bed dryer cross-sectional area design. However, for the height, the value is less than optimal.

IV. CONCLUSION

Based on the data analysis results that have been done, conclusions from research on the design of a Coal Dryer using genetic Algorithm in power plants is rotary Dryer has a diameter of 2.98 meters, length 29.9 meters. Maximum acceptable heat rotary dryer 4957kJ/s with the most optimum genetic algorithm parameters at the population of 500 and the number of generations 100. For the Fluidized bed, the Dryer has a cross-sectional area of 9 square meters and a height of 5.1 meters. Maximum acceptable heat fluidized bed dryer 5001.9kJ/s with the most optimum genetic algorithm parameters on the population of 500 and the number of generations 100. Using a Fluidized Bed Dryer obtained a greater heat compared to Rotary Dryer.

For further research, it is necessary to research with a source of heat energy in the form of a heater. Using a heater, researchers can design a coal dryer more quickly because the mass rate of hot air and temperature changes can be manipulated. So that it can compare the optimal condition of the Dryer and how many benefits are obtained.

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