Influence of drain hole inclination on drainage effectiveness of coal open pit mine slope

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Abstract. Drain hole has an important role to reduce groundwater table on a slope of coalopen pit mine. Groundwater condition on acoal open pit mine slope with a homogeneous groundwater flow media is highly dependent on the type of lithology and the groundwater bearing-rocks. The drain hole on acoal open pit mine slope is very influential on the water discharge and the length of the drain hole. This paper presents a discussion on the effect of drain holeinstallation with an inclination angle of 65º and 90º on the discharge and drain hole length. The results show that the drain hole with an angle of 65ºresults in greater groundwater discharge than the 90º angle. In addition, the drain hole with inclination angle of 65º is shorter than that of the drain holeinstalled with an inclination angle of 90º, thus reducing the operating costs of the open pit mine slope drainages.

Keywords: discharge, drain hole, drain hole inclination, homogeneous media, mine drainage

1. Introduction

The presence of groundwater in an open pit coal mine needs to be considered because it can cause potential landslides hazard on the open pit mine slopes. The high groundwater level can increase the pore pressure that affects the amount of load on the open pit mine slope. To lower the groundwater table needs drain hole that functions to drain water naturally. Research using drain holes has been done by several researchers, such as Leech and McGann [1]; Rahardjo et al. [2]; Cook et al. [3]; Cahyadi et al. [4]; Cahyadi [5].

Drain holes are horizontal drainage mounted on slopes with a certain slope above the horizontal plane by utilizing the force of gravity [6]. Generally drain hole is installed to lower the phreatic surface [7]. Research on the drain hole of fractured media media in the Batu Hijau mine, Newmont Nusa Tenggara Barat was conducted by Leech and McGann [1] who argue that the decrease of groundwater level in piezometer is closely related to the accuracy of the location of the drain hole installation. In addition, Rahardjo et al. [2] also suggests a slightly better drain hole in accordance with the conceptual model but is well targeted in the installation. Cook et al. [3] conducted a study on the effect of drain hole spacing on the effectiveness of groundwater degradation on homogeneous media. Drain holes are

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fitted with the following divisions: 1) Drain holes with spaces between 8 - 15 m mounted uniformly and parallel to soil medium with large permeability; 2) Drain holes with spaces between 1 - 8 m are mounted uniformly and parallel to the soil medium with a small permeability; 3) Additional drain holes adjust the field conditions.

Groundwater lowering is highly dependent on the distribution of hydraulic conductivity distribution. Placement of drain holes at the right location can decrease the number of drain holes in the fractured media [4]. The optimization of drain hole location determination on the fractured media is influenced by several factors such as groundwater level, drain hole discharge, number and length of drain hole, inclination angle, spacing [5].

This paper aim to describe the role of drain holes mounted on a homogeneous medium to see the effect of the 65^{o} and 90^{o} inclination angles to the effectiveness of groundwater lowering that impacts on the minimum operational cost of dewatering. This case study study was conducted at Pit E site BMO PT. Berau Coal. Problem solving is approximated by using a finite difference.

2. Hydrogeological Setting

PT Berau Coal is one of the coal mining companies located in Berau, North Kalimantan. The mine has been operating long enough to produce some Pits. The research that has been done is at Pit E site BMO. Based on the information of drill data, the rock lithology consists of clay, mudstone, coal and sandstone. The presence of groundwater in the study site is influenced by the presence of sand layer. The conceptual model of bedding layers at the study site can be seen in Figure 1.

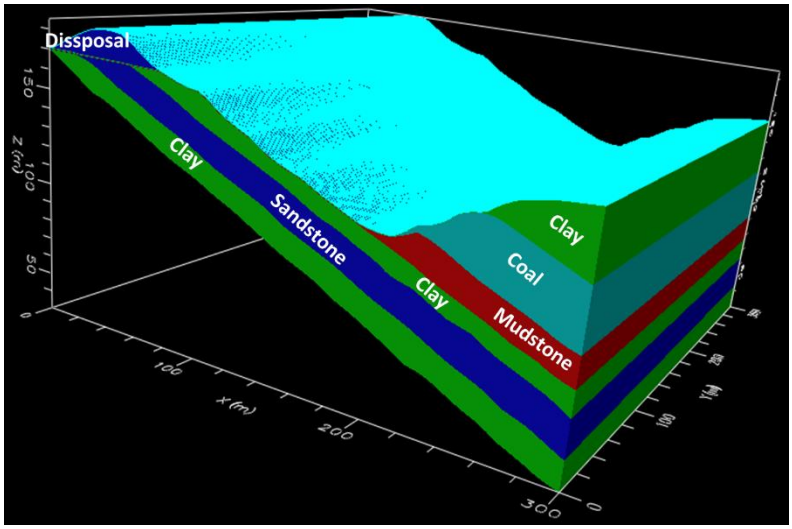

Figure 1. Conceptual Model of Bedding Layers

Pit E at BMO site is one of the active mine openings located at PTBC. The elevation of the pit bottom which reaches -150 masl leads to groundwater seepage, as well as run-off water on one side of the eastern part of the pit bottom. The site is currently used as a temporary water reservoir for later pumping to move to another location so as not to inundate the mine floor (Figure 2). Based on observations of topography and drill log data, bedding layers have the main direction of the East to the West with a slope towards the North. This observational data is very important to predict the direction of groundwater flow in general. The rainfall condition at the pit location of E BMO reaches 3035 mm/year, with the number of rainy days 221 days (data of 2016). The average climatological data from 1997 - 2009, among others are as follows: air humidity 86.3%, irradiation 45.2%, temperature

26.2%, wind speed 2.3 m/sec. The data was obtained from the Meteorology and Geophysics Agency of Kalimaru [8].

Figure 2. Pit E site BMO, PT. Berau Coal

3. Methods

The study is based on groundwater flow modeling using numerical simulations based on different methods using Visual Modflow software, developed by Schlumberger Water Service [9]. In this study, calibration and validation is conducted by comparing the model that has been designed with actual conditions. In general, this study is divided into three main stages, namely literature study, data collection, and processing and data analysis.

This series of study begin with a literature study aimed at obtaining a preliminary overview of the study area. The preliminary description was obtained during the field observation of BMO site. The results of these activities serve as a guide for the next research phase. Furthermore, the study entered into the primary and secondary data collection stage. Primary data obtained from observation in the field, one of them is morphological observation activities. Secondary data used include groundwater measurements, topographic maps, geological maps, rainfall data, and mine planning data.

The next stage is the processing and analysis of data that has been collected from previous activities. Primary and secondary data are processed using Modflow software to obtain the parameters used to design the model. The designed model can be used to analyze the effect of the drain hole installation with inclination of 90^{o} and 65^{o} on the open pit mine drainage system. Flow diagram of groundwater modeling can be seen in Figure 3.

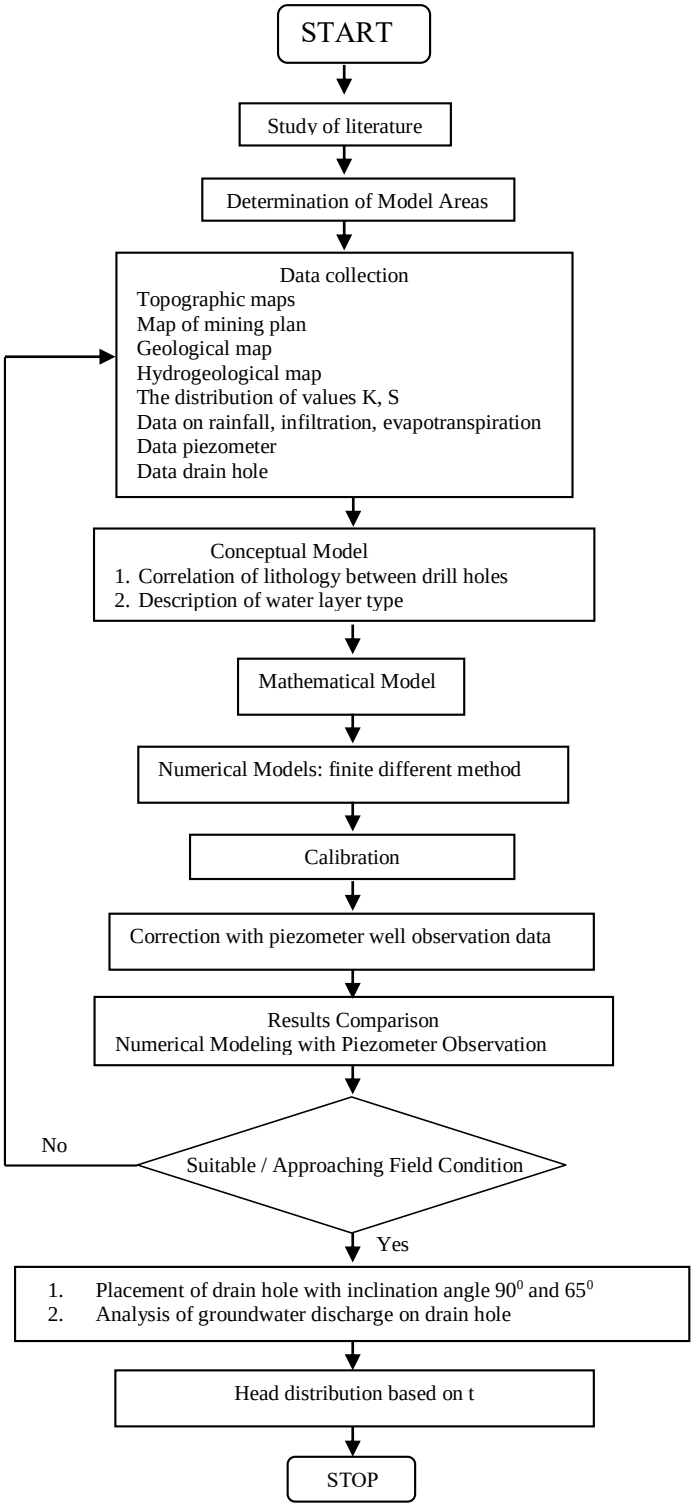

Figure 3. Flow Diagram of Groudwater Flow Modeling

4. Result

4.1. Steady State Calibration Model

Groundwater flow modeling for Pit E BMO under steady state conditions is based on measurement data from September - October 2016 from nine piezometer points previously installed. These nine points have not covered the entire research area. Therefore, it is assumed that groundwater in the study area is at the same elevation as shown in piezometers, that is at a depth of approximately 25 m above the topography surface.

Calibration is conducted to bring the value of modeled head with the observed piezometer head. The hydraulic conductivity is the main element causing uncertainty, so sensitivity analysis is required by varying the value of hydraulic conductivity around the most conductive value of the conductivity, until the optimum value is obtained, in this case measured from the correlation coefficient (R = 0.96) with a standard deviation of 4.3 m. The calibration results can be seen in Figure 4.

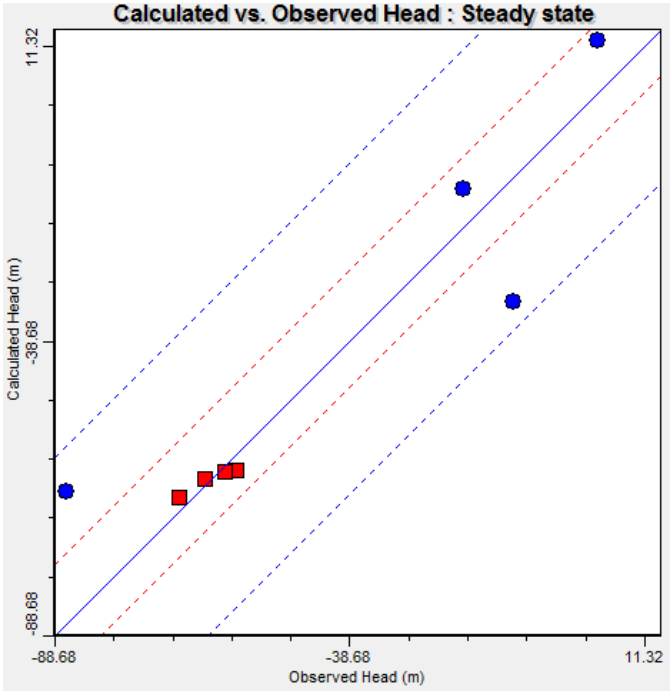

Figure 4. Calibration Result between Model and Observed Value

4.2. Transient Model

The transient model is the state of the model with head fluctuations over time. The model simulation is run over a period of time, in this case within 360 days with 10 time step. The boundary conditions applied in the form of drain representing inclined drain holes (IDHs) and vertical drain holes (VDHs), with a conductivity of 0.8 m/day according to Cahyadi et al. [4]. Installation of the 65^{o} IDHs and 90^{o} VDHs in the model is carried out according to location, drill length and direction of the drilling activity. To improve accuracy in model simulations, the grid size reduction process is performed in both horizontal and vertical fields.

4.3. Vertical Drain Hole with inclination 90^{0}

Simulation of transient synthetic model was conducted for 360 days. The installed VDH is one piece, the other existing VDH drain holesare three with 100 m spacing and also five other holes spaced 50 m with drilling holes each reaching 27 m with an inclination angle of 90^{o}, whereas the reality in the field

is about 50 m. Based on the current placement, the VDH distribution can be said to be ineffective. The resulting discharge is 1 L/s from one VDH; 2.5 L/s from three VDHs with 100 m spacing and 3.8 L/s from five VDHs with 50 m spacing. The use of angle variation turns causing changes in head losses and pressure drop. The larger the turn angle, the greater the value of head losses and pressure drop [10]. The results of VDH installation simulation can be seen in Figure 5.

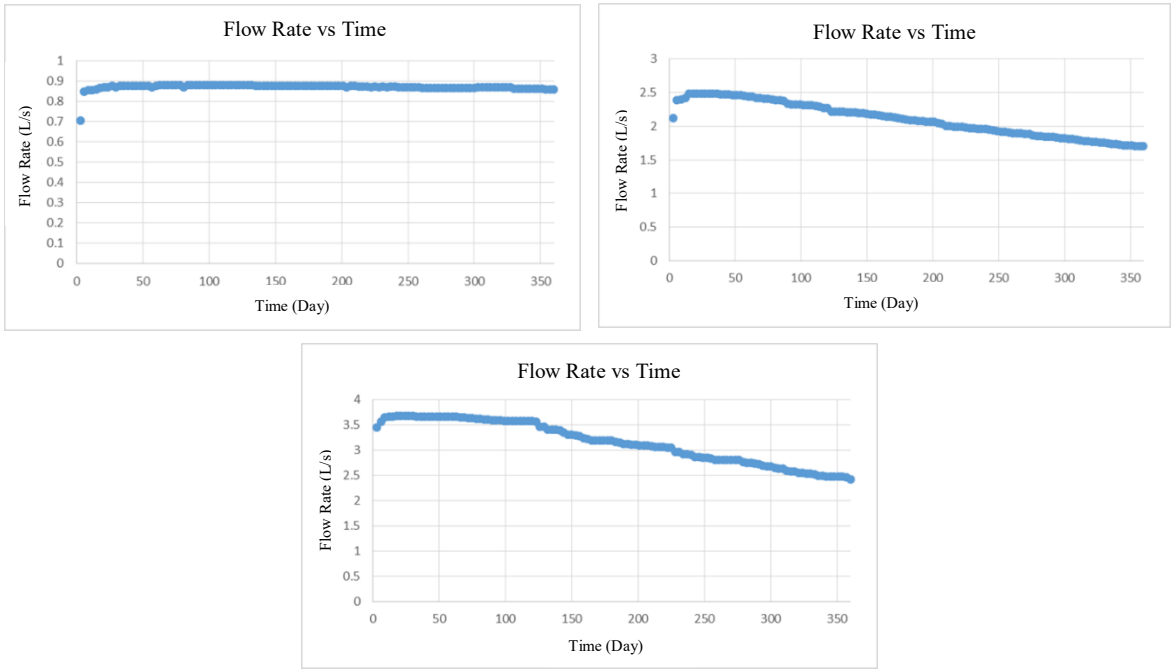

Figure 5. Temporal Flow Rate for a) 1 Hole VDH; b) 100 m-Spaced 3 VDH Holes; c) 50 m-Spaced 5 VDHHoles

4.4. Incline Drain Hole (IDH) with inclination 65⁰

The simulation of the IDH synthetic model is conducted by mounting the drain hole on a single drill point with a slope of 65° through the aquifer layer with a drilling length of 20 m, a fact that is in the field along 50 m and 80 m. Installation of IDH in the field is now in the right location, in at the lowest pit base elevation point. Installation at the lowest point provides an advantage, as it can lower groundwater pressure around the slopes much larger than installed at higher elevation levels, as does the current VDH. Based on the model simulation, the IDH flow rate currently value is 5.5 L/s. The simulation result of IDH can be seen in Figure 6 and Figure 7.

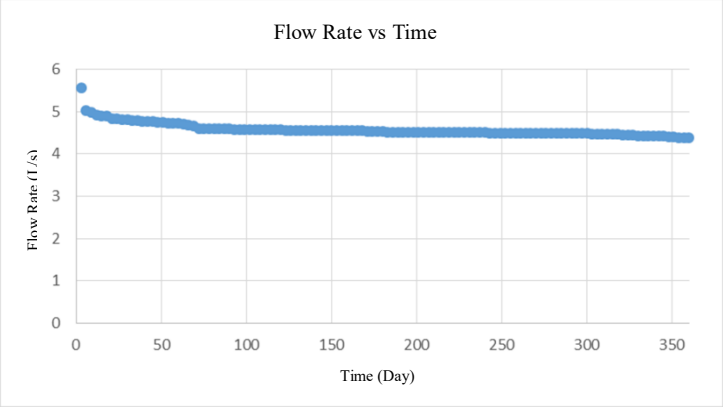

Figure 6. Temporal Flow Rate from 1 IDH Hole

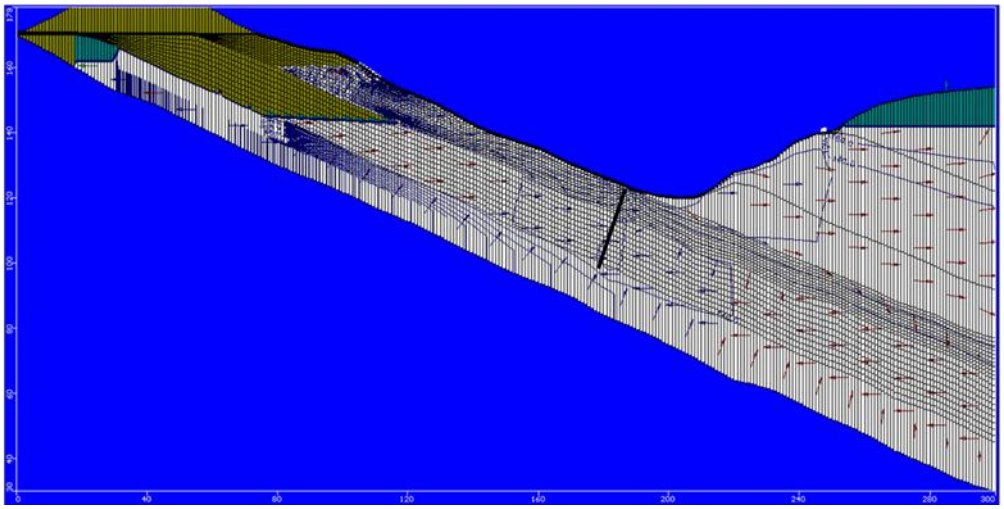

Figure 7. Simulated Flow Distribution due to IDH Hole in a *Open Pit Mine Slope Cross Section*

5. Discussion

5.1. Simulation of porous media groundwater flow models

Determination of drain holes in porous media is easier than in fractured media. Drain holes that are installed at the base of the porous media can generally remove groundwater in surrounding of bench. This happens if the presence of the groundwater level is higher than the position of the elevation of the drain hole. Determination of the drain hole with a certain inclination before being installed in the field is more easily approached by using a simulation of groundwater flow. The porous media flow model in this case is approached using the assumption of one lithological layer using the same aquifer parameter values. Calibration results obtained in this study use steady state conditions. In the calibration process, the head model value is expected to be appropriate or close to the situation in the field. Calibration in a transient state cannot be done because data is not available. Calibration with steady state conditions is considered to meet the requirements to describe the effect of installing drain holes with inclination variations of 65^0 and 90^0.

Calibration value with R of 0.96 gives results that the head model in the field is considered to be similar to the modeled. The method used to obtain calibration parameters is to change the value of hydraulic conductivity on each layer based on a certain percentage. For example, by increasing the

value of the hydraulic conductivity by 10% from the initial value, the comparison of the head model and the field with the indicator R and the standard deviation are obtained. This is done continuously until the optimum R value is obtained. Failure in simulation can be caused by incorrect usage of parameters in the Visual ModFlow engine. The default WHS Solver parameter from Visual Modflow is as follows: max. outer iteration 50; max. inner iteration 25; head change criterion 0.01 m; residual criterion 0.01 m; damping factor 1; relative residual criterion 0 [9]. While the parameters used to reach a convergent state in this paper are: max. outer iteration 10,000; max. inner iterations 5,000; head change criterion 0.5 m; residual criterion 0.5 m; damping factor 1 and relative residual criterion 0.

5.2. Selection of drain hole model based on inclination

Making the IDH and VDH simulation models in the BMO pit E site aims to get the most optimal drain hole design. Drain hole length affects the dewatering operational costs. This condition is the basis for optimizing, by comparing the effectiveness of VDH and IDH. Drain hole simulations at the same point with different inclination have been carried out through simulation 1 through simulation 4. To penetrate the same aquifer, the VDH drill hole is longer than the IDH hole, because VDH penetrates the apperent thickness, while IDH penetrates the true thickness. To drain groundwater at the same target, VDH with a slope of 90^0 requires a drain hole length of 27 m, while IDH with a slope of 65^0 only requires a drain hole length of 20 m.

The synthetic model has given the hypothesis that IDH is more productive than VDH. This condition is supported by research by Zainudin et al. [10] who have conducted research with the title "analysis of the effect of variations in the angle of the bend connection to the pipe losses head losses" with the results of using turn angle variations causing changes in head losses and pressure drop. The greater the turning angle, the head loss value and the resulting pressure drop will be greater.

6. Conclusion

Synthetic model simulation results for Pit E BMO can be summarized as follows:

1. Installation of inclined drain holes with an angle of 65^o gives a great effect on the discharge and decrease of groundwater level compared to those of vertical drainholes.
2. The length of inclined drain holes is generally shorter than those of vertical drainhole, so it saves the operational cost.

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