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A dynamic model of coal products discharge in a jig

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ABSTRACT

The paper presents a simple dynamic model of coal product discharge in a jig. The model is based on the principle of mass conservation of coal density layers transported in the jig's bed. It can be used to investigate dynamic properties of a discharge zone in a jig and to design control systems of products discharge in a jig. The model has been developed with the use of Matlab/Simulink software. The transfer function of the discharge system in a jig can be approximated by a nonlinear integrating element with saturation determined by the height of the coal layer placed above the upper product overflow gate. Dynamic parameters of the system depend on the dimensions of the jig compartment, parameters of the bottom product discharge gate and tonnage of the yield of density fractions in the feed. The model can be used to design and optimise control systems of refuse discharge in jigs. The simulation model generates the separation density signal similar to the signal produced in the jig and measured by the density meter. The root mean squared error between the measured and simulated changes is ca. s = 0.027 g/cm^3.

1. Introduction

Most models of the coal washing process in jigs have been developed to simulate how coal particles travelling along the coal bed stratify due to the particles density and shape in a pulsating coal/water media. The coal particles should separate according to increasing density up from the surface of the bed down to the screen deck. Separation is not ideal as the settling and rising velocity of particles also depends on their shape and size. First models simulating the partition curve of a gravitational process (also in jigs) applied a normal or logarithmic distribution or a table of discrete values of partition coefficients. These models were developed by Tromp (1937), Terra (1955) and later by Gottfried and Jacobsen (1977) and King (2001). The more recent models developed by Srinivasan et al. (1999), Xia et al. (2007) and others have been based on the discrete elements method (DEM). The models include forces directly affecting each particle and forces interacting among coal particles. They can be used to determine the position of each particle based on the parameters of a pulsation cycle such as air pressure, periods of valve opening and closing. These models can reliably predict results of a coal washing process mainly in steady conditions. However, much less research has been done on models simulating the dynamic process of products discharge from a jig in the end zone of the compartment where the horizontal flow of the material is affected by the vertical flow of the stratification process. Such models are used to design a proper control algorithm for operation and to reduce unwelcome reactions of a technological system to disturbances in the feed. This paper presents a simple dynamic model of products discharge, which is essential to design and optimise a control system with a float as a measuring device or a radiometric density meter (providing an on-line measurement of the separation density). The model simulates dynamic characteristics of a discharge zone in a jig compartment (transfer function) with tonnage of the discharged bottom product as an input signal and the separation density as an output signal. The disturbances in the model are associated with the tonnage of the feed, its density composition and measurement errors of the float (or a radiometric density meter).

2. Jig as a control object

The beneficiation process of fine coal in jigs consists of two phases: stratification of coal particles in the bed according to the particles density and then splitting the stratified material into the product and the discharged refuse. At first, during subsequent water pulsations induced by opening and closing of air valves, coal particles stratify according to various velocities of upward and downward movement. Particles of low density migrate to upper material layers while particles of high density migrate to lower layers. The material is transported on the screen along the jig compartment with the additional horizontal flow of water. The stratification of particles due to density is not perfect because the particles velocity depends in part on their diameter and shape, and variations in the degree of material loosening during a

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pulsation cycle. The distribution of coal density fractions in the bed, characterized by the imperfection factor *I*, has been investigated by many researchers, e.g. King (2001) and Cierpisz (2012). Stratified material is separated according to a chosen separation density, which is the density of a layer reporting in half to the upper product (concentrate) and in half to the discharged lower product (refuse). Refuse is removed through the discharge gate and concentrate overflows the splitting gate. The separation layer is usually monitored with the use of a metal float of the relevant shape and density (Fig. 1).

To stabilize the desired position of the float, the system should control the amount of the lower product discharged through the bottom gate. Floats are not accurate in indicating the position of the selected layer, especially when the amount of the feed and its density composition changes. In new experimental systems, floats are being replaced with more accurate radiometric density meters which can monitor the process of material loosening/compressing during each coal/water pulsation cycle (Lyman, 1992; Cierpisz, 2012). The output signal from a radiometric meter can be used for two purposes: (a) to stabilize the shape of dynamic changes in density, (b) to stabilize the separation density measured during the compressed state of the material at the end of a cycle.

3. Dynamic model

During subsequent media pulsations particles stratify into distinct layers of material. They travel horizontally with velocities v_i and volumetric flow rates q_i. The model of a refuse discharge zone is presented in Fig. 2.

It is assumed that the layers do not mix and there is no interaction between the stratification zone and the product discharge zone. At this stage of considerations, we shall also disregard the stratification of layers below the first layer entering the discharge gate at the cross section A–A. The dynamic simulation model is based on the principle of the conservation of volumetric flows through the discharge zone in time *dt*. For the *i*-th material layer its volumetric flow rate q_i can be calculated from Eq. (1):

$$q_i(t) = m(t) \cdot \frac{w_i}{100 \cdot \rho_i} \tag{1}$$

where

$m(t)$ – mass flow rate of the feed, Mg/h,
$q_n(t)$ – volumetric flow rate of the feed, m^3/h,
$w_i(t)$ – yield of the "*i*-th" fraction in the feed, %,
ρ_i – density of the "*i*-th" fraction, g/cm^3.

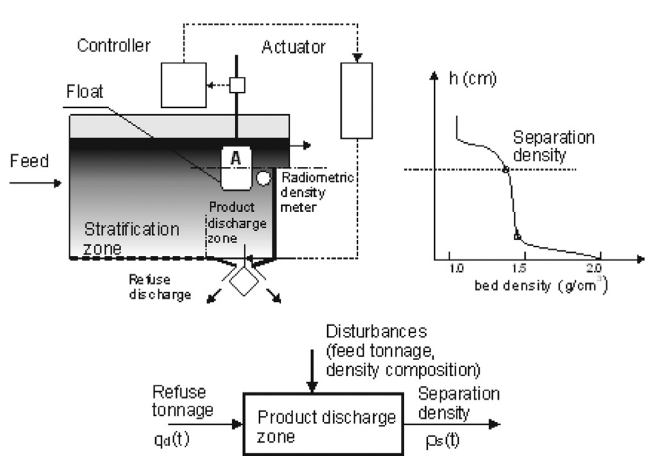

Fig. 1. Product discharge zone in a jig.

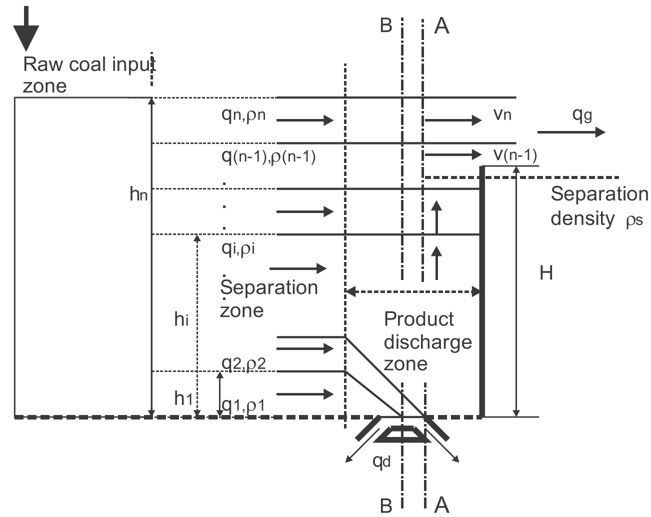

Fig. 2. Model of a product discharge zone in a jig.

The balance of volumes for the first layer in time *dt* is given by Eq. (2):

$$q_1 dt - q_d dt - q_g dt = S \cdot dt \tag{2}$$

where

q_1 – flow rate of the first material layer, m^3/h,
q_d – refuse discharge flow rate, m^3/h,
q_g – product flow rate, m^3/h,
S – cross section area of the product discharge zone, cm^2,
h_1 – position of the first layer in the product discharge zone, cm.

Eq. (2) finds its solution in Eq. (3):

$$h_1(t) = \frac{1}{S} \cdot \int_0^t [q_1 - (q_d + q_g)dt + h_{10}] \tag{3}$$

where $S = b \cdot l$ and $h_{10} = \frac{q_1}{b \cdot v_s}$ for the A–A cross section (Fig. 1).

Eq. (3) is valid for equal velocities of density fractions $v_i = v_s$ with the following conditions:

$q_1 = 0$ for $h_1 < 0$; $q_g = 0$ for $h_1 < H$; $q_g = b \cdot v_1 (h_1 - H)$ for $h_1 > H$; $(q_1 - (q_d + q_g) > 0)$.

where

H-height of the upper product discharge gate, cm,
b-width of the jig compartment, cm.
l-length of the discharge zone, cm,
v_1-velocity of the first fraction, cm/s.

For the second material layer we have:

$$h_2(t) = \frac{1}{bl} \int_0^t [q_1 + q_2 - (q_d + q_g)]dt + h_{20} \tag{4}$$

where $h_{20} \frac{q_1 + q_2}{b \cdot v_s}$.

with the following conditions:
$q_1 = 0$ for $h_1 < 0$; $q_2 = 0$ for $h_2 < 0$; $q_g = 0$ for $h_1 <$ H; $q_g = 0$ for $h_2 < H$; $q_g = b \cdot v_s\,(h_2 - H)$ for $h_2 > H$; $(q_1 + q_2) - (q_d + q_g) > 0$.

An example of positions of interfaces h_1 and h_2 between layers for three moments of time is shown in Fig. 3.

For the *i*-th material layer with flow rate q_i, density ρ_i and horizontal velocity v_i, the mass balance is given by Eq. (5):