JURNAL APTEK

Artikel Ilmiah Aplikasi Teknologi
homepage: http://journal.upp.ac.id/index.php/aptek

p-ISSN 2085-2630
e-ISSN 2655-9897

Mathematical Modeling of Linear Momentum to determine The Breaking Pattern of Coal Physical Collision

Fahrizal[a], Lukman Hakim Nasution[b,*], Yoan Purbolingga[a], Dila Marta Putri[a], Asde Rahmawati[a], Bastul Wajhi Akramunnas[a]

[a]Institut Teknologi Bisnis Riau
[b]Badan Riset dan Inovasi Nasional

INFO ARTIKEL

Histori artikel:
Tersedia Online: 24 Juni 2023

ABSTRAK

Sebuah penelitian menunjukkan bahwa 40% dari pembangkit listrik tenaga uap di Indonesia menggunakan batu bara sebagai bahan bakar dalam sistem boiler. Jumlah pembangkit listrik yang menggunakan batu bara terus meningkat; pada tahun 2030, diperkirakan akan menghasilkan 4.500 GW listrik. Untuk mencapai pembakaran yang optimal, bahan bakar batu bara harus berbentuk bubuk. Secara umum, proses ini melibatkan penggunaan penghancur untuk mengubah batu bara menjadi potongan-potongan kecil, yang kemudian dihaluskan menjadi bubuk menggunakan penggiling. Dengan menggunakan model matematika momentum linear, pola pemecahan batu bara dapat diprediksi. Studi ini mengklasifikasikan keadaan batu bara selama proses transformasi menjadi tiga tahap, yaitu keadaan awal, dampak statis, dan efek momentum. Penelitian ini akan berdampak pada pemodelan matematika pola pemecahan dan transformasi fisik batu bara saat mengalami tabrakan. Oleh karena itu, untuk menghasilkan batu bara dalam bentuk bubuk, pendekatan sistem dampak dapat digunakan, bukan hanya mengandalkan proses penggilingan seperti yang umumnya dilakukan.

Kata kunci: Pola pemecahan; Tabrakan fisik; Batu bara; Model matematika; Momentum linear

E-MAIL

Fahrizal.upp@gmail.com
lukm019@brin.go.id

ABSTRACT

A study shows that 40% of steam power plants in Indonesia use coal as a fuel in boiler systems. The number of power plants using coal is increasing; in 2030, it is estimated to produce 4,500 GW of electricity. The coal fuel for the combustion process should be in powder form in order to produce a complete combustion. Generally, a crusher is used to produce coal chunks, and then a grinder is needed to bring the chunks to powder form. By using a linear momentum mathematical model, the coal breaking pattern can be predicted. From this study, the state of coal throughout the transformation process could be classified into 3 stages; initial state, static impact and momentum effect. The above studies would influence the mathematical modeling of the breaking pattern, and the transformation process in coal physical collision. Therefore, to produce coal in the form of powder can be carried out with an impact system, not only a system of grinding such as in the grinding process.

Keywords*: Break pattern; Physical collision; Coal; Mathematical model, Linear momentum*

I. INTRODUCTION

Indonesia is one of the largest coal producing countries after Australia [1] with coal reserves of more than 25,000 million tones [2] while the demand is estimated to continue to rise to more than twice in 2030. The International Energy Agency estimated that more than 4,500 Giga Watts of new energy plants will be required in the same year [3]. Similarly, the results of the analysis of the "Asia-Pacific Economies Work" showed that it will continue to increase until the year 2035 [4] where the portion of coal use currently in the global power plants is more than 40% [5]. One of the use of the product related to the size of the material is coal which is used as boiler fuel to drive the turbine power plants where the coal particle size affect the combustion process in the boiler, the smaller the coal size the easier it will be burned out [6], and the combustion process will become more perfect. Apart from that, the rest of the burning results will be easily released in the air [7, 8]. Carbon monoxide produced in coal combusion process with larger particle size will be higher than the smaller size particles [9]. The effect of particle size of the simulation result "Computitional Fluid Dynamic" indicates that the particles tend to flow more easily because it is smaller and has a better distribution in the coal combustion process [10]. The theory of brittle fracture of material is quite extensive, but is still regarded as a basis for fracture and fragmentation process which uses modeling of kinetic energy impact on coal, and this process is considered as transformation of kinetic energy impact. Another process to produce coal powder is to use crusher instead of impact process [11, 12 and 13]. And in general, the process for producing coal into powder form at this time is to use grinding or non-impact processes [14, 15 and 16]. In this research, we will apply mathematical modeling of linear momentum impact processes to get the size of coal into powder. The kinetic energy given will be absorbed by coal, causing static and dynamic impact so that the coal will be fractured.

1.1 Physics of Collisions

Fracture mechanic affects the particle size distribution produced. Different methods of fragmentation produce different product sizes, based on the amount of input energy and the loading process. The perception of particle size distribution expected result can be determined only by the physic collisions [17]. In physic, the collision between two objects is classified into the effect of a linear central impact, the central angle impact and the eccentric impact. The important collision parameters between the two objects are velocity and mass dimension, impact intensity and impact area [18].

1.2 Linear momentum

Momentum $\vec{p}$ is a vector quantity that is related to the motion of an object. The amount is mass and the time of the velocity, in the direction of movement in units kgm/s. whereas impulse I is a vector quantity related to force, this is an integral part of the force during the duration of time. Usually, the duration of time is very short, as in the collision between two objects, where the unit is equal to momentum. For $\overrightarrow{\Delta p} = I$ is the effect of impulses on the body as momentum changes (vector size). And $\overrightarrow{P_B} + \vec{I} = \overrightarrow{P_A}$ is the momentum before and after the impulse. Impulses and momentum in a single particle for the body are acted on several forces; that strength can be summed up by allied vectors, giving one resultant force. This result in acceleration towards the resultant force, and then Newton's Second Law can be used:

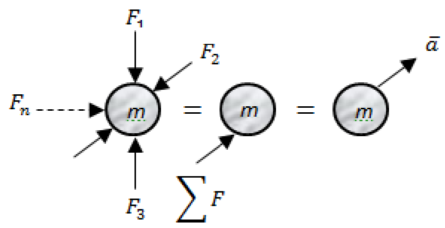

Figure 1. Force and Acceleration resultant

In figure 1, the equation $\sum_{\vec{F_i}} = m\vec{a} = m\,\frac{d\vec{v}}{dt}$, multiplied by d_t yields $\sum_{\vec{F_i}} d_t = md\vec{v}$, then the equation of the integration is as follows:

$$\sum \int_{t_1}^{t_2} \vec{F_i}\,dt = \int_{v_1}^{v_2} d\vec{v} = m\vec{v_2} - m\vec{v_1} \qquad (1)$$

Where: $\vec{v_1}$ is the velocity at t_1, for one particle, with the impulse we have $P_1 + I = P_2$ this can also be written is:

$$m\vec{v_1} + \sum \int_{t_1}^{t_2} \vec{F_i}\,dt = m\vec{v_2} \qquad (2)$$

By using the principle of impulse and momentum, vector relationships will be obtained:

$$mv_1 + \int_{t_1}^{t_2} F\,dt = mv_2, \text{ or } mv_1 + F\Delta t = mv_2 \qquad (3)$$

For linear momentum L is mass multiplied by velocity or L=mv where $F = L$ [19].

1.3 Kinetic Energy

Kinetic energy is influenced by velocity [20] and material thickness [21] at the time collision occurs. Energy produced from these two materials is influenced by the angle [22] and shape as well as its size where at the center of impact of linear momentum the material is the center of collision energy [23]; Force F is the cause of mass of accelerated material kg/s^2. Work W is the amount of work force on an object so that it experiences displacement [24]. Power P is the velocity or rate of doing work or work effort of objects per unit of time while Energy E is the ability to do work in watt hour [25]. Potential energy is the energy possessed by an object because of its position in the magnetic field or that the system has the effect of configuring its parts, and the kinetic energy of an object is the energy it possesses because of its motion [26]. And mathematically these equations can be written as follows:

$$W = F\,S \quad (4)$$

Where: W is the work joule; S is the displacement m; and F is force N. If work makes an angle then $W = FS\,Cos\emptyset$, the kinetic energy equation is as follows:

$$KE = \frac{1}{2}mv^2 \quad (5)$$

Where: KE is kinetic energy joule ; m is the mass of the object kg; v is the velocity of the object m/s. According to Choi and Lee (2015), the base of Newton Law can be written as the following relationship:

$$\vec{F} = m.\vec{a} \quad (6)$$

Where: $\vec{F}$ is the force acting on the body lb and N is the mass of the body lbf. $\frac{\mathrm{sec}^2}{\mathrm{ft}}$ is the acceleration experienced by the body, $\frac{\mathrm{ft}}{\mathrm{s}^2}$ or $\frac{\mathrm{m}}{\mathrm{s}^2}$ and g is gravity which is 33.2 $\frac{\mathrm{ft}}{\mathrm{s}^2}$ or 9.81 $\frac{\mathrm{m}}{\mathrm{s}^2}$. Weight is the strength of the mass that is given when the ground is followed up by gravity acceleration ($W = mg$), so we can divide each side of this equation with gravity to get mass in terms of weight and the equation of gravity:($m = \frac{W}{g}$). Acceleration can be defined as a change in velocity. If F work on an object then the object will move equally accelerated so that the equation applies as follows:

$$v_t = v_0 + 2as \text{ or } S = \frac{v_t^2 - v_0^2}{2a} \quad (7)$$

Acceleration is the change in velocity in a given unit of time, namely$a = \frac{F}{m}, \frac{m}{s^2}$, so that the equation for the effort in the body can be written as follows:

$$W = ma\left(\frac{v_t^2 - v_0^2}{2a}\right) \text{ or } W = \frac{1}{2}mv_t^2 - \frac{1}{2}mv_0^2 \quad (8)$$

And the equation of the relationship between work-kinetic energy will be as follows:

$$W = EK_t - EK_0 \quad (9)$$

So the equation for work carried out by force on changes in kinetic energy of particles is as follows:

$$W = \Delta EK$$
$$(Work - Kinetic\ Energy\ Theorem) \quad (10)$$

For the graphical potential energy equation the energy possessed by an object due to the influence of its position or height is as follows:

$$EP = mgh \quad (11)$$

Where: m is the mass object kg, g is the gravity m/s^2, h is the height of the object m and EP is the potential of gravitational energy joule [27, 28].

II. METHODOLOGY

The physical mechanism of collisions for kinetic energy is based on Newton's second Law and the principle of linear momentum. The linear momentum method (figure 2) aims to focus the impact energy of coal on the ground.

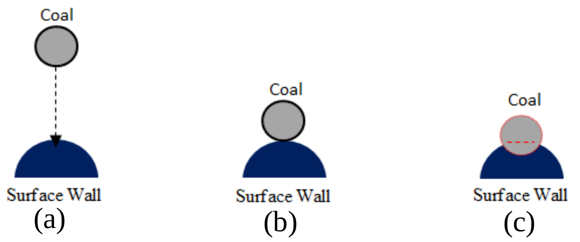

Figure 2. a), Coal before impact, b) Coal impact, c) Coal after impact

Physic of collisions with Newton's second Law and linear momentum are the main parameters [90] of material fracture processes. Effects that occur in coal after a physical process of collisions based on the theory of crushing for brittle materials, in several stages, namely kinetic energy impact condition, kinetic energy impact condition and kinetic energy impact condition (figure 3), are the process of mathematical coal fracture.

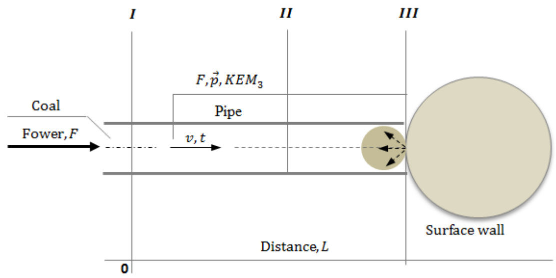

Figure 3. Schematic condition III of kinetic energy impact system

III. RESULTS AND DISSCUSION

3.1 Kinetic energy impact condition I (KEI_1)

Kinetic energy impact condition I (KEI_1) in the system is a condition of stationary system. This condition is a parameter for conditions II and III. The equations for power F, kinetic energy KE dan momentum $\vec{p}$ are as follows:

$$F = m\,.\,a \quad (12)$$

Where: F is the force kgm/s^2, m is the mass kg and a is the acceleration m/s^{-2}. By connecting Newton's II Law to equation 12 in system condition I, it can be expressed as follows:

$$F_1 = m_i.\,a_1 \quad (13)$$

And $a_1 = \frac{\Delta v_1}{\Delta t_1} = 0, \Delta v_1 = v_{f1} - v_{i1} = 0, \Delta t_1 = t_{f1} - t_{i1} = 0$

Where: F_1 is the force of 10 mm coal in diameter, m_i is the mass of 10 mm coal in diameter, a_1 is the acceleration, Δv_1 is the acceleration change, v_{i1} is the initial velocity, v_{f1} is the final velocity , Δt_1 is the change of time, t_{i1} is the initial time and t_{f1} is the final time of the coal. For the linear momentum equation of condition I in the system according to the principle momentum equation defined as:

$$\vec{p} = m\,.\,v \quad (14)$$

Where: $\vec{p}$ is the momentum kgm/s, m is the mass of coal kg and v is the velocity m/s. By connecting the linear momentum equation to system condition I, the equation becomes:

$$\overrightarrow{p_1} = m_i \cdot v_1 \quad (15)$$

Where: $\overrightarrow{p_1} = m_i \cdot v_1$ is the linear momentum in the condition I of 10 mm coal in diameter. By connecting the equation of Newton's second Law and the linear momentum equation; when coal moves in linear momentum $\underset{p}{\rightarrow}$, then breaks on the wall and is divided into three different parts, so the linear momentum eventually becomes $\underset{p_1}{\rightarrow}$, $\underset{p_2}{\rightarrow}$, $\underset{p_3'}{\rightarrow}$. And it is classified as a collision process, which is an impact made by coal against the ground wall. For the amount of linear momentum that occurs in the system condition I am:

$$\underset{p}{\rightarrow} = \underset{p'}{\rightarrow} \quad (16)$$

Where: $\underset{p}{\rightarrow}$ is the initial linear momentum and $\underset{p'}{\rightarrow}$ is the final linear momentum, a mixture of $\underset{p_1'}{\rightarrow} + \underset{p_2'}{\rightarrow} + \underset{p_3'}{\rightarrow}$. By connecting the linear momentum equation to the condition system I, the equation becomes:

$$\underset{p1_{mi}}{\longrightarrow} = \underset{p1'_{mi'}}{\longrightarrow} + \underset{p2'_{mi''}}{\longrightarrow} + \underset{p3'_{mi'''}}{\longrightarrow} \quad (17)$$

Where: $\underset{p1_{m1c1}}{\longrightarrow}$ is the initial linear momentums of 10 mm coal in diameter in conditions I and $\underset{p1'_{mi'}}{\longrightarrow} + \underset{p2'_{mi''}}{\longrightarrow} + \underset{p3'_{mi'''}}{\longrightarrow}$ is the final linear momentum of coal at the size of 10 mm in diameter. The amount of change in linear momentum is the total energy given to the system, namely coal that fits the size. With the statement that conservation of momentum is the amount of momentum interactions which is the total momentum before the interaction; connecting Newton's second Law to linear momentum and acceleration can be defined as:

$$F = m \cdot a = m\frac{dv}{dt} = \frac{d\,(m \cdot v)}{dt} = \frac{\overrightarrow{dp}}{dt} \quad (18)$$

Where: F is the force kgm/s^2, m is the mass kg, a is the acceleration m/s^2, dv is the velocity change, dt is the time change and dp is the change momentum. But since the velocity of the momentum changes from the system to the condition I is static, so the equation connect Newton Law to linear momentum and acceleration is:

$$F_1 = m_i \cdot a_1 = m_i\frac{dv_1}{dt_1} = \frac{d\,(m_i \cdot v_1)}{dt_1} = \frac{\overrightarrow{dp_1}}{dt_1} \quad (19)$$

Where: $F_1 = m_i \cdot a_1 = m_i\frac{dv_1}{dt_1} = \frac{d\,(m_i \cdot v_1)}{dt_1} = \frac{\overrightarrow{dp_1}}{dt_1} = 0$ is the power connects for linear momentum and acceleration at condition I of 10 mm coal in diameter. And connect the principle of kinetic energy to linear momentum [26, 27] which can be written as follows:

$$KE = \frac{1}{2}m \cdot v^2 = \frac{(m \cdot v)^2}{2 \cdot m} = \frac{\overrightarrow{p^2}}{2 \cdot m} \quad (20)$$

Where: KE is the kinetic energy joule, m is the mass kg, v is the velocity m/s and $\vec{p}$ is the momentum kgm/s. And to connect between the kinetic energy of the impact process expressed as the impact of kinetic energy and the linear momentum of condition I while the system in static condition can be written as:

$$KEI_1 = \frac{1}{2}m_i \cdot v_1^2 = \frac{(m_i \cdot v_1)^2}{2 \cdot m_i} = \frac{\overrightarrow{p_1^2}}{2 \cdot m_i} \quad (21)$$

Where: $KEI_1 = \frac{1}{2}m_i \cdot v_1^2 = \frac{(m_i \cdot v_1)^2}{2 \cdot m_i} = \frac{p_1^2}{2 \cdot m_i} = 0$ is the impact of kinetic energy on condition I of 10 mm coal in diameter. The distance and altitude parameters are to complete the system under condition I. The equation of 21 illustrates that if all parameters are given a certain value then it will produce kinetic energy which equal to zero 0 or equal to potential energy which means the position of coal in static condition.

3.2 Kinetic Energy Impact Condition II ($\mathrm{KEI_2}$)

Kinetic energy Impact condition II ($\mathrm{KEI_2}$) is a condition where the system has worked. The collision between the two solids is known as an impact. Time relationship determines the impact analysis. When the time relationship is large enough then there is a significant change in the system configuration and is considered to be an applicable impact [28]. So the change in condition I to condition II in the system is defined as follows:

$$F_2 = m_i \cdot a_1 \quad (22)$$

$$a_1 = \frac{\Delta v_1}{\Delta t_1} \quad (23)$$

$$\Delta v_1 = v_{f1} - v_{i1} \quad (24)$$

$$\Delta t_1 = t_{f1} - t_{i1} \quad (25)$$

Where: F_2 is the power of the system at condition II, m_i is the mass of coal 10 mm in diameter, a_1 is the acceleration of coal, Δv_1 is the change of coal velocity, v_{i1} is the initial velocity of coal, v_{f1} is the final velocity of coal, Δt_1 is the change of coal time, t_{i1} is the initial period of coal and t_{f1} is the final end of the coal at condition II. And the equation for the linear momentum that occurs in condition II is:

$$\overrightarrow{p_2} = m_i \cdot v_1 \quad (26)$$

Where: $\overrightarrow{p_2} = m_i \cdot v_1$ is the linear momentum of coal 10 mm in diameter at condition II. By connecting equations 12 and equation 16, the linear momentum changes to:

$$\underset{\overrightarrow{p_2}_{mi}}{\longrightarrow} = \underset{\overrightarrow{p_2}'_{mi'}}{\longrightarrow} + \underset{\overrightarrow{p_2}'_{mi''}}{\longrightarrow} + \underset{\overrightarrow{p_2}'_{mi'''}}{\longrightarrow} \quad (27)$$

Where $\underset{p2_{mi}}{\longrightarrow}$ the initial linear momentum of 10 mm is coal in diameter, and $\underset{\overrightarrow{p_2}_{mi}}{\longrightarrow} = \underset{\overrightarrow{p_2}'_{mi'}}{\longrightarrow} + \underset{\overrightarrow{p_2}'_{mi''}}{\longrightarrow} + \underset{\overrightarrow{p_2}'_{mi'''}}{\longrightarrow}$ is the final linear momentum of coal in condition II. For the equation of the total change of linear momentum are:

$$F_2 = m_i \, . \, a_1 = m_i \frac{dv_1}{dt_1} = \frac{d\,(m_i . v_1)}{dt_1} = \frac{\overrightarrow{dp_2}}{dt_1} \quad (28)$$

Where: $F_2 = m_i \, . \, a_1 = m_i \frac{dv_1}{dt_1} = \frac{d\,(m_i . v_1)}{dt_1} = \frac{\overrightarrow{dp_2}}{dt_1}$ is the relationship between linear momentum power and acceleration coal at condition II. And the relationship between kinetic energy with the linear momentum of the system in condition II is:

$$KEI_2 = \frac{1}{2} m_i \, . \, v_1^2 = \frac{(m_i . v_1)^2}{2.m_i} = \frac{\overrightarrow{p_2^2}}{2.m_i} \quad (29)$$

Where: $KEI_2 = \frac{1}{2} m_{1c1} \, . \, v_1^2 = \frac{(m_{1c1} . v_1)^2}{2.m_{1c1}} = \frac{\overrightarrow{p_2^2}}{2.m_{1c1}}$ is Kinetic energy system suppression in the condition II coal 10 mm in diameter. This condition is expressed as static initial impact of coal against the wall. The equation of 29 illustrates that if given a force value with a certain value then coal will have a certain kinetic energy value which means that the coal position moves with a certain velocity as far as the path to the breaking wall as an impact point where in this condition the coal experiences static impact. In the II coal condition there has not been a change in form A because the linear momentum generated is very small.

3.3 Kinetic Energy Impact Condition III (KEI_3)

For systems in condition III, the Newton II Law equation is stated as follows:

$$F_3 = m_I . a_1 \quad (30)$$

$$a_1 = \frac{\Delta v_1}{\Delta t_1} \quad (31)$$

$$\Delta v_1 = v_{f1} - v_{i1} \quad (32)$$

$$\Delta t_1 = t_{f1} - t_{i1} \quad (33)$$

Where: : F_3 is the III coal power system condition, m_i is the beginning of coal, Δv_1 is a change in velocity, v_{i1} is the initial rate, v_{f1} is the final system, Δt_1 is a period change, t_{i1} is the initial period and t_{f1} is the final period of system condition III. While for the linear momentum equation the system in condition III is stated as follows:

$$\overrightarrow{p_3} = m_i \, . \, v_1 \quad (34)$$

Where: $\overrightarrow{p_3} = m_i \, . \, v_1$ is the momentum of linear system condition III of mm coal 10 in diameter. And for velocity system condition III, the linear momentum equation becomes:

$$\underset{\overrightarrow{p_3}_{mi}}{\longrightarrow} = \underset{\overrightarrow{p_3}'_{,mi'}}{\longrightarrow} + \underset{\overrightarrow{p_3}'_{mi''}}{\longrightarrow} + \underset{\overrightarrow{p_3}'_{mi'''}}{\longrightarrow} \quad (35)$$

Where: $\overrightarrow{p_3}_{mi}$ is linear momentum starting from coal 10 mm in system diameter conditions III, and $\underset{\overrightarrow{p_3}_{mi}}{\longrightarrow} = \underset{\overrightarrow{p_3}'_{,mi'}}{\longrightarrow} + \underset{\overrightarrow{p_3}'_{mi''}}{\longrightarrow} + \underset{\overrightarrow{p_3}'_{mi'''}}{\longrightarrow}$ is the final momentum of condition III of coal system. So the relationship between Newton II Law, linear momentum and system fracture in condition III are:

$$F_3 = m_i \, . \, a_1 = m_i \frac{dv_1}{dt_1} = \frac{d\,(m_i . v_1)}{dt_1} = \frac{\overrightarrow{dp_3}}{dt_1} \quad (36)$$

Where: $F_3 = m_i \, . \, a_1 = m_i \frac{dv_1}{dt_1} = \frac{d\,(m_i . v_1)}{dt_1} = \frac{\overrightarrow{dp_3}}{dt_1}$ is the power relationship in linear momentum and fracture system condition III of coal 10 mm in diameter. Whereas the relationship of kinetic energy to the linear momentum of system condition III is:

$$KEI_3 = \frac{1}{2} m_i \, . \, v_1^2 = \frac{(m_i . v_1)^2}{2.m_i} = \frac{\overrightarrow{p_3^2}}{2.m_i} \quad (37)$$

Where: $KEI_3 = \frac{1}{2} m_i \, . \, v_1^2 = \frac{(m_i . v_1)^2}{2.m_i} = \frac{\overrightarrow{p_3^2}}{2.m_i}$ is the kinetic energy system condition III of coal 10 mm in diameter. And this condition is expressed as a split starting, because it has experienced an impact process, according to changes in force equations, linear momentum and kinetic energy impact. The equation of 37 illustrates that coal has experienced static impact. So that the kinetic energy absorbed by coal at the point of impact will cause coal to experience dynamic impact. In this condition the coal changes its shape or breaks. The coal fracture is caused by kinetic energy received by coal is greater than its energy density.

CONCLUSION

The application of this mathematical model can predict coal fracture patterns. The coal fracture patterns can be predicted with three conditions, namely coal in static conditions, coal experiencing static impact and the coal experienced dynamic impact that caused by kinetic energy absorption.

ACKNOWLEDGMENT

The author would like to express thanks to Rokan Hulu State Government and University Selangor for assisting him in term of finding scholarship, material sources and facilities during conducting research.

REFERENCES

[1] Direktorat Jendral Mineral dan Batubara Kementerian Energi dan Sumber Daya Mineral (2017). *Laporan Kinerja 2017*. Jakarta: Kementerian ESDM Indonesia.

[2] Mehmet Melikoglu (2018). *Clean coal technologies: A global to local review for Turkey*. Energy Strategy Reviews. Volume 22: 313-319.

[3] Pusat Data dan Teknologi Informasi Energi dan Sumber Daya Mineral Kementerian Energi dan Sumber Daya Mineral Indonesia (2017). *Kajian Supply Demand Energy*. Jakarta: Kementerian ESDM Indonesia.

[4] Asia-Pacific Economic Cooperation: (2016). *Energy Demand and Supply Outlook – 6th Edition*: *Volume II Economy Reviews*. Japan: Asia Pacific Energy Research Centre (APERC).

[5] World Energy Council (2016). *World Energy Resources Coal*. World Energy Council. London: World Energy Council.

[6] Tian xing Hou, Qiang Xu and Jia-wen Zhou (2015). *Size Distribution, Morphology and Fractal Characteristics of Brittle Rock Fragmentations by the Impact Loading Effect.* Springer: Acta Mech 226: 3623 – 3637.

[7] Fatemeh Saeidi et all (2017). *Investigating the Effect of Applied Strain Rate in a Single Breakage Event*. Minerals Engineering, Volume 100: 211 – 222.

[8] Horiba Scientific (2016). *A Guidebook to Particle Size Analysis.* Horiba instruments Inc. 9755. Research Drive Irvine: CA 92618 USA 1 – 800 – 4 Horiba.

[9] Marina Davydova et all (2014). *Scaling Law of Quasi Brittle Fragmentation*. Procedia Materials Science. Volume 3: 580 – 585.

[10] Wei-GangShen (2017). *Analysis of impact-induced rock fragmentation using a discrete element approach.* International Journal of Rock Mechanics and Mining Sciences. Volume 98: 33 – 38.

[11] Junfang Shan (2018). *Dynamic breakage of glass sphere subjected to impact loading*. Powder Technology. Volume 330: 317 – 329.

[12] Pascal Forquin et al (2018). *Microstructure influence on the fragmentation properties of dense silicon carbides under impact*. Mechanics of Materials. Volume 123: 59 – 76.

[13] Junfang Shan et all (2018). *Dynamic Breakage of Glass Sphere Subjected to Impact Loading*. Powder Technology. Volume 330: 317 – 329.

[14] Miguel Alvarez, Richard E. Kreeger and Jose Palacios (2019). *Experimental evaluation of the impact behavior of partially melted ice particles.* International Journal of Impact Engineering. Volume 123: 70 – 76.

[15] Tielin Chen et all (2017). *Numerical simulation of compression breakage of spherical particle.* Chemical Engineering Science. Volume 173: 443 – 454.

[16] Bankim Mahanta et all (2017). *Effects of strain rate on fracture toughness and energy release rate of gas shales.* Engineering Geology. Volume 218: 39 – 49.

17] Lucas M. Alves et all (2016). *Analytical fractal model for rugged fracture surface of brittle materials.* Engineering Fracture Mechanics. Volume 162: 232 – 255.

[18] Ying Zhang et all (2016). *Effects of Stone Size on the Comminution Process and Efficiency in Shock Wave Lithotripsy*. Ultrasound in Medicine and Biology. Volume 42: 2662 – 2675.

[19] Matthew Huang (2002). *Vehicle Crash Mechanics*. International Standard Book. Number 0-8493-0104-1, CRC Press LLC.

[20] Gulhan Ozbayoglu (2018). *Energy Production from Coal, Comprehensive Energy Systems.* Elsevier, Volume 3: 788 – 821.

[21] Kedar Kirane,Yewang Su and Zdenek P. Bazant (2015). *Strain-Rate-Dependent Micro Plane Model for High-Rate Comminution of Concrete under Impact Based on Kinetic Energy Release Theory*: Royal Society Publishing.

[22] Eleni Iacovidou et all (2018). *Technical Properties of Biomass and Solid Recovered Fuel (SRF) Co-Fired with Coal: Impact on Multi-Dimensional Resource Recovery Value*. Waste Management. Volume 73: 535 – 545.

[23] Marek Pronobis et all (2017). *Optimization of Coal Fineness in Pulverized-Fuel Boilers Energy*. CPOTE, Gliwice Poland, Volume 139: 655 – 666.

[24] Robert H. Perry and Don W. Green (1998). *Perry's Chemical engineers Handbook*. Seventh Edition. United States of America: R. R. Donnelley & Sons Company.

[25] Tobias Hoertha et all (2015). *Momentum Transfer in Hypervelocity Impact Experiments on Rock Targets.* Procardia Engineering. Volume 103: 197 – 204.

[26] Min Seok Choi and Jin Won Lee (2015). *Characteristics of Kinetic Energy Transfer in Collisions between a Fragile Nano-Particle and a Rigid Particle on a Surface.* Journal of Aerosol Science. Volume 84: 1–8.

[27] Zhang Dongmei (2017). *Study on collision of threaded connection during impact.* International Journal of Impact Engineering. Volume 106: 133 – 145.

[28] C. Z. Tan (2018). *Wave equation for the energy and the momentum of a moving particle.* Optik. Volume 168: 864 – 872.