Selection and Breakage functions of particles under Impact

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Introduction:
Size reduction processes of the particles are very common in different fields, such as: chemical, pharmaceutical and agricultural. Since the purpose of comminution systems is to produce a product in a specific size with minimum energy investment, the fundamental knowledge about the strength and size distribution of the breaking particles is crucial. Such knowledge can be achieved through either experimentation or modeling. Models of the complex breaking process during gas-particle flow are based on the population balance model (PBM). The widespread population balance models [1] are based on approximated equations for the selection function (SF) and breakage function (BF). Using these approximated functions in computer simulations could lead to incorrect description of gas-particle behavior according to breakage and interaction between particles. Hence, an extensive experimental research work that will give a clear insight into the relationship between particle characteristics and system behavior is required in order to optimize those systems. In the present work a new improved horizontal impact air-gun is introduced. Selection function which describes the probability of the particle to break under specific impact load was developed and compared with the existing functions found in the literature. Breakage function which describes the probability of the fragments (daughter particles) to be in a specific size interval was chosen with appropriate considerations.

Experimental:
Many types of impact test systems can be found in the literature: vertical [3], horizontal [4], air gun [5] etc. In the present study the horizontal impact system is introduced. This system is emphasized by the following advantages.
(1) Ability to change feed rate of the particles into acceleration tube.
(2) Ability to work with a wide particle size distribution.
(3) Ability to choose impact particle velocity.
(4) Ability to work with hazardous materials.
(5) Ability to perform experiments with different impact angels.
(6) Ability to handle big amounts of particles within a short time, while keeping experimental error at the sufficient rate.
(7) Ability to use different materials for the impact target.
(8) The system is easy to use and maintenance.

With all of these advantageous there are some drawbacks, such as neglecting the angular velocity of the particles, and secondary impacts with the walls of the collecting cage. By conducting impact experiments with this system there is an ability to determine the selection function and the breakage function from the collected experimental data.

Results and Discussion:
Population balance model (Eq.1) allows evaluations of dynamic changes in particle size distribution for size reduction processes. In such processes, the size of the original particles (mother fraction) will be continuously reduced toward more fine sizes (daughter fractions). The change of particles mass $m_i$ at the discrete size interval $i$ (while $i$ is the largest size interval and $i=N$ indicates the finest particles) per unit of time is given by mass that leaves the specific size interval as fragments
and mass which enters into the specific size interval as fragments of the larger particles, as described in Eq. 1.

$$\frac{dm_i}{dt} = \dot{m}_{i,in} - \dot{m}_{i,out} = \sum_{j=i+1}^{N} m_i b_{ij} S_j - m_i S_i$$

while $S_i$ is the function which represents percentage (or ratio) of the particles that were broken under specific conditions (SF) and $b_{ij}$ is the function which describes the ratio between the particles that transferred from size interval $i$ to $j$, due to the breakage to the total broken particles.

**Selection Function:**

Selection function or breakage probability indicates the fraction of the particles which were broken under some load. After literature review on this subject, it was found that there are three major distributions, that different researchers used in order to represent the breakage probability: Weibull [7], Logistic (Eq. 2) [8] and Lognormal [9].

$$S_i = 1 - \frac{1}{1 + \left( \frac{V}{V_{50}} \right)^{D_i}}$$

where $S_i$ is the particle breakage probability or selection function, $V$ is the impact velocity, $V_{50}$ is the median of the impact velocity, and $D_i$ is the distribution wideness. Usually, the selection function is presented as the chart of breakage probability versus some system variable, for instance, impact velocity [10] or specific impact energy [11]. In order to investigate the accuracy of the selection functions, they were fitted to the new experimental data. The comparison was performed on the basis of the coefficient of determination $R^2$ and found to be about the same. When one examines those functions as "candidates" to describe the particle breakage probability, mathematical simplicity and the statistical meaning of the model parameters are crucial. Therefore, the Logistic function was chosen to represent the percentage of the broken particles. $F_{50}$ and $D_i$ are empirical coefficients depending on the material and particle size. The following analysis was aimed to get a simple but comprehensive correlation even with a reasonable loss of accuracy. Based on preliminary tests, distribution parameter, $D_i$ was considered as a function of the material, but independent of the particle size. The median impact velocity, $V_{50}$, depends on the material properties and also on is the exponential function of the particle mean sieve diameter. Based on the above, the final selection function can be written in the following form:

$$S_i = 1 - \frac{1}{1 + \left( \frac{V}{A + B \cdot \exp(C \cdot d)} \right)^{D_i}}$$

In order to examine the Logistic function as the representative function of the impact breakage probability, Eq. 3 was fitted to the experimental data. Table 1 presents the values of the fitted parameters for the materials experimented upon.

**Table 1:** Logistic model parameters for some materials [6].
As an evaluation of the proposed model (Eq. 3), the experimental results are compared to the predicted ones by the comparison graph (Fig. 1). As can be seen from this figure, most of the results are within ±20% error, which is reasonable.

Particle breakage probability is also dependent on the impact angle, it was also investigated. Theoretically, as the impact angle decreases SF have to decrease, due to smaller normal stress applied on the particle.

### Breakage Function:

The Breakage function indicates the part of the particles reaching some size interval from a larger size interval as a consequence of breakage. There are many references in the literature for breakage functions [12,13]. Most of the researchers describe breakage function as a cumulative breakage probability versus sieve size of the particles. In order to examine and compare breakage models from the literature, they were fitted to the experimental data. Not all the models were appropriate. The choice of the suitable models that will represent daughter size probability was made on the basis of coefficients of determination $R^2$. The highest average $R^2$, for all materials, was upon Tavares model [13] (Eq. 4).

\[
B_{i,j} = 1 - \left(1 - t_{D}^{\alpha}ight)^{\frac{1}{\beta}}
\]

where $B_{i,j}$ is the cumulative breakage probability, $d_j$ is the geometrical average of the mother interval size, $D_i$ is the expected daughter size, and $t_{D}$ and $\alpha$ are model parameters. The validation of this model was done by means of comparison chart, Fig. 2.
Conclusions:
Two major functions were tested and their parameters were investigated for the different materials of various sizes. These functions will be integrated in model array, which will represent the comminution phenomena. By that over-all model, one can optimize any industrial process dealing with powder size reduction.

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