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Sieve Analysis of As-Mined Galena and Predictability of Quantified Particle Passing Based on Sieve Size and Retained Weight

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Abstract: Sieve analysis of as-mined galena particles were carried out using an assembly of sieves of sizes S: 9.5, 5.6, 4.0, 2.8 and 2.36 mm. The ranges of Percent Galena Particle Passing (PGPP) and Percent Galena Retained Weight (PGRW) recorded during the sieving process were 30.14 – 75.0 and 2.98 – 25.01 respectively. A critical evaluation of the relationship between PGPP and a consortium of factorials; sieve size and retained weight was carried out using a derived two-factorial empirical model. Results of the sieve analysis show that PGPP and PGRW increase with increased S. The validity of derived model; $\xi = 13.1935 \ln\gamma + 0.0001\gamma + 13.4865e^{0.0349\vartheta} + 2.4581$ is rooted on the core expression $\xi - 0.0001\gamma = 13.1935 \ln\gamma + 13.4865e^{0.0349\vartheta} + 2.4581$ where both sides of the expression are correspondingly close. The model validity was verified through comparative evaluation of the PGPP per unit S & PGRW using experimental, derived and regression model-predicted results. These were 6.63, 7.49 and 6.25 %/ mm & 1.32, 1.49 and 1.24 which are in proximate agreement respectively. Comparative analysis of the correlations between PGPP and S & PGRW as obtained from experiment, derived and regression model-predicted results were all > 0.8. Deviation of model-predicted PGPP from experimental results increased with increase in sieve size and was maximum (14.08%) at the largest sieve size. The derived model predicted PGPP values was very close to experimental results at a sieve size range 2.36 – 5.6 mm (2.36, 2.8, 4.0 and 5.6 mm); corresponding to a deviation of less 8%. This invariably translated into over 92% operational confidence level for the derived model as well as over 0.92 dependency coefficients of PGPP on S and PGRW within a sieve size range: 2.36 – 5.6 mm.

Key words: Sieve analysis · Galena · Particle passing · Sieve size · Retained weight

INTRODUCTION

It has been shown [1] that sample preparation, technique used for the analysis and the particle shape all affects the accuracy of particle size data derived. Currently, the techniques frequently used are electrical sensing microscopy, sedimentation, laser diffraction, sieving and light intensity fluctuation. Comparative analysis of results [2] generated from application of sedimentation analysis and electrical sensing technique in determining size distribution of clay suspension indicates that the earlier is more precise and sensitive than the later.

Previous research [3] has shown that during application of electrical sensing techniques, resistance pulse for a stream of dispersed particle passing through the orifice are converted into the voltage pulse, amplified, scaled and counted electronically. This occurs when the resistance of an electrolyte current path through a narrow orifice between two electrode increases as ceramic particle passes through the orifice.

Characterization of particle size distribution has been widely carried out by sedimentation of particles in a fluid. During sedimentation analysis using hydrometer method, the velocity and time of settling are ascertained when spherical particles with a particular density and diameter are released into a viscous fluid. However, during gravitational sedimentation, sedimentation analysis relies on the relationship that existing between settling velocity and particle diameter. Settling velocity is related to the diameter of a spherical particle. The force acting downward on each particle due to its weight in water is given by [4]:

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$$F_{down} = 4/3\ \pi(X^3/8)(\rho_s - \rho_1)\ g \quad (1)$$

where X is the particle diameter, g is the acceleration due to gravity, ρ_1 is the liquid density and ρ_s is the particle density.

$$\nu = [g(\rho_s - \rho_1)X^2]/18h \quad (2)$$

Equation (2) is known as *Stokes' Law*. The basic assumptions [4] used in applying Stokes' Law to sediment particle suspensions are that: (I) There is no interaction between individual particles in the solution. (ii) Particles are smooth and spherical (iii) Terminal velocity is attained as soon as settling begins. (iv) Resistance to settling is entirely due to viscosity of the fluid. Stokes`s law [5] has since been used to determine an unknown distribution of spherical particle size by measuring the time required for the particles to settle at a known distance in a fluid of known viscosity and density.

It has been shown [6] that Stoke`s law does not accurately describe the sedimentation process if the Reynolds number for the system becomes too high. The Reynolds number increases with larger particles, faster sedimentation rate and lower fluid viscosity. Based on the foregoing, sedimentation analyses are run at low Reynolds number ((< 0.02), where the deviation from Stokes`s law is less than 0.5%.

Report [6] has shown that the rate of sedimentation for small particles is too low to give a practical analysis time and so Brownian motion of small particles becomes too large to allow effective settling. This therefore, limitsgravitational sedimentation to particles of relatively large size. The research indicated that very small particles (< 0.1 microns) never settle by gravity unless they are extremely dense. This implies that very small particles cannot be measured by gravitational sedimentation.

Centrifugal sedimentation involves much smaller particles [6]. Sedimentation can be either gravitational (1g- force), or centrifugal (many g- forces). The research shows that when a centrifuge is used, Stokes`s law must be modified to account for the variation in g-force with distance from the center rotation. High g-force makes sedimentation of small particles much faster than Brownian diffusion, even for very small particles. The study revealed that all the parameters except time are constant during centrifugal sedimentation analysis where a centrifuge is running at constant speed and temperature.

Sedimentation analysis has been classified into two: integral and differential [6]. The differential method was first reported in 1930 [7] as a viable means of measuring particle sizes. It was reported [8] that differential sedimentation involves sedimentation instability or streaming when there is bulk settling of particles. The researcher concluded that all information about the particle size distribution could be lost if streaming takes place.

Similar findings [9-11] have revealed several methods developed to eliminate streaming. Each of these methods was found to be effective because, prior to analyses, a slight density gradient is formed within the fluid column.

Research [12] has shown that proper selection and blending of raw materials with different initial characteristics and by subsequent crushing, grinding, dispersion, classification and granulation basically enables processing systems with distribution of particle sizes and shape. Packing has been observed to be mostly in an orthorhombic arrangement and packing density of 62.5% following studies [13] carried out on the packing of coarse (0.37 mm) mono size spherical particles using axial vibration. Results of the investigation clearly reveals that colloidal size of silica and aluminamono sized spherical particles packed by filter pressing deflocculated slurry is about 60-65%.

The present work is sieve analysis of as-mined galena and predictability of quantified particle passing based on sieve size and retained weight.

MATERIALS AND METHODS

Sieving Process: Size analysis carried out involved a fundamental part of laboratory testing procedures employed in the examination of the quality of crushing or/and grinding. Passing a known weight of the ground ore successively through finer sieves and weighing the amount retained on each sieve to determine the percentage weight in each size fraction passing the sieve accomplished sieve analysis.

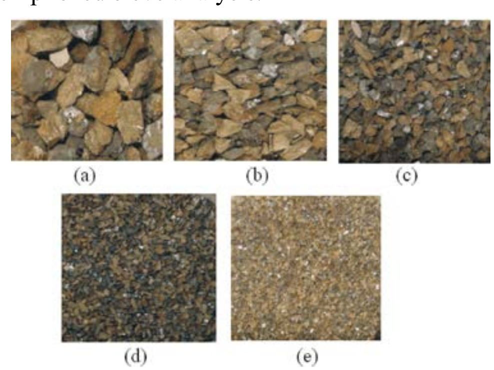

Fig. 1: Galena particles from sieve analysis (a) 9 mm (b) 5.6 mm © 4 mm (d) 2.8 mm (e) 2.36 mm

Apparatus: Jaw crusher, weighing balance (Mettle 4900), sieve shaker (Eijkelkamp), sieve of different apertures (Prufsieb), pulverized raw ore (Pb-Zn ore). The sieves were nested successively from the coarest sieve to the least on top of collecting pan and the analysis carried out at the Institute of Erosion, Federal University of Technology, Owerri (FUTO).

RESULTS AND DISCUSSIONS

Model Formulation: Computational analysis of the experimental data shown in Table 1, gave rise to Table 2 which indicate that;

$$\xi - \text{Ƅ}\gamma = K \ln\gamma + Se^{0.03499} + N \quad (3)$$

Introducing the values of Ƅ, N, K, C and S into equation (3)

$$\xi - 0.0001\gamma = 13.1935 \ \ln\gamma + 13.4865e^{0.0349\vartheta} + 2.4581 \quad (4)$$

$$\xi = 13.1935 \ \ln\gamma + 0.0001\gamma + 13.4865e^{0.0349\vartheta} + 2.4581 \quad (5)$$

where
(ξ) = Quantified particle passing (%)
(γ) = Sieve size (mm)
(ϑ) = Retained weight (%)
N, K, S, Ƅ and C are equalizing constants with values 2.4581, 13.1935 and 13.4865, 0.0001 and 0.0349 respectively (determined using C- NIKBRAN [14])

Boundary and Initial Condition: Sieve analysis of the mined galena was carried out according to the conventional procedure (BS1377:1975, Test 6(B)). The ranges of percent galena particle passing (PGPP), percent retained weight (PGRW) and sieve sizes considered were 30.14 – 75.0, 2.98 – 25.01 and 2.36 – 9.5 respectively. Details of the experimental technique and other process conditions are as presented in the experiment.

Model Validation: The validity of the model is strongly rooted on equation (4) where both sides of the equation are correspondingly close. Table 2 also agrees with equation (4) following the values of ξ - 0.0001γ and $13.1935 \ \ln\gamma + 13.4865e^{0.0349\vartheta} + 2.4581$ evaluated from the experimental results in Table 1. Furthermore, the derived model was validated by comparing the PGPP predicted by the model and that obtained from the experiment. This was done using various analytical techniques.

Table 1: Results of Sieve Analysis

Sieve size (mm)	Retained weight (%)	Passing (%)
9.5	25.01	75.00
5.6	23.34	51.68
4.0	9.32	42.36
2.8	9.25	33.12
2.36	2.98	30.14

Table 2: Variation of ξ - 0.0001γ with $13.1935\ln\gamma + 13.4865e^{0.0349\vartheta} + 2.4581$

ξ - 0.0001γ	$13.1935\ln\gamma + 13.4865e^{0.0349\vartheta} + 2.4581$
74.9991	64.9989
51.6794	55.6426
42.3596	39.4189
33.1197	34.6676
30.1398	28.7516

Computational Analysis: Computational analysis of the experimental and model-predicted PGPP was carried out to ascertain the degree of validity of the derived model. This was done by comparing the PGPP obtained by calculations involving experimental results with the model-predicted results.

Percent galena particle passing PGPP per unit sieve size S was calculated from the equation;

$$PGPP_S = \Delta PGPP / \Delta S \quad (6)$$

Equation (6) is detailed as:

$$PGPP_S = PGPP_2 - PGPP_1 / S_2 - S_1 \quad (7)$$

where
ΔPGPP = Change in the values of the percent galena particle passing $PGPP_2$, $PGPP_1$ through a range of sieve sizes: S_1- S_2.

ΔS = Change in the values of the sieve sizes S_2, S_1.

Therefore, a plot of the PGPP against S as in Figures 2 and 3 using experimental results in Table 1 and substitution of points (5.6, 51.68) & (2.8, 33.12), (5.6, 55.6426) & (2.8, 34.6676) and (5.6, 51.1329) & (2.8, 33.6407) for (S_1, $PGPP_1$) & (S_2, $PGPP_2$) into the mathematical expression in equation (7) gives ≈ 6.63, 7.49 and 6.25%/ mm as PGPP per unit sieve size for experimental, derived and regression model-predicted results respectively.

Similarly, Percent galena particle passing PGPP per unit retained weight R was calculated from the equation;

$$PGPP_S = \Delta PGPP / \Delta R \quad (8)$$

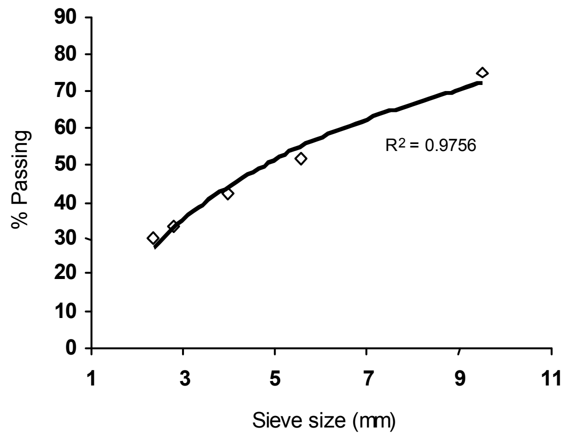

Fig. 2: Coefficient of determination between PGPP and sieve size as obtained from the experiment

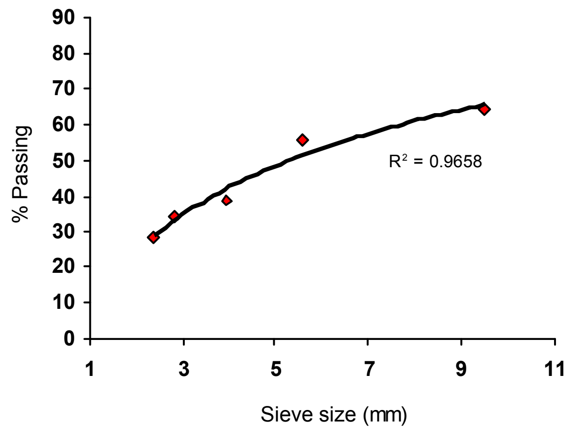

Fig. 3: Coefficient of determination between PGPP and sieve size as obtained from the derived model-prediction

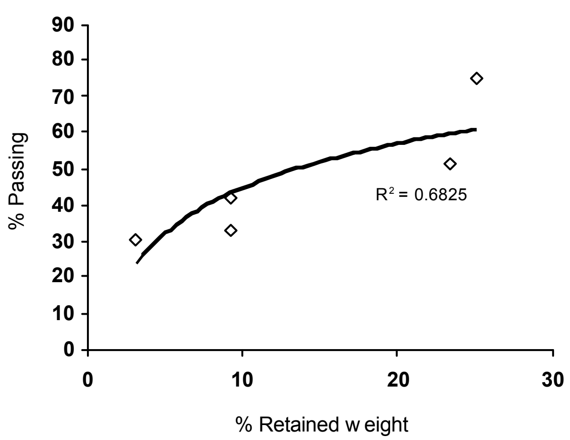

Fig. 4: Coefficient of determination between PGPP and retained weight as obtained from experiment

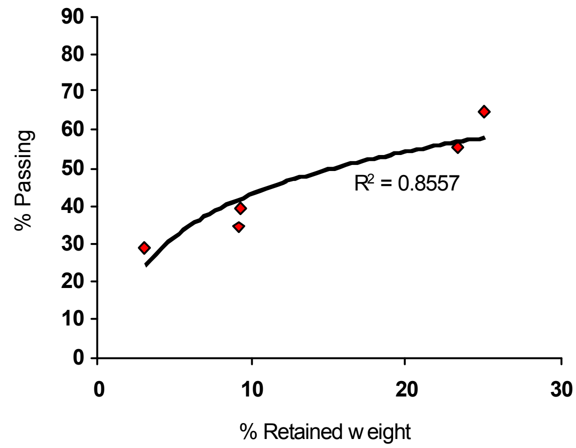

Fig. 5: Coefficient of determination between PGPP and retained weight as obtained from the derived model-prediction

Equation (8) is detailed as;

$$PGPP_S = PGPP_2 - PGPP_1 / R_2 - R_1 \qquad (9)$$

where
ΔR = Change in the values of the retained weight R_2, R_1.

Therefore, a plot of the PGPP against R as in Figure 3 using experimental results in Table 1, derived and regression model- predicted results and substitution of points (23.34, 51.68) & (9.25, 33.12), (23.34, 55.6426) & (9.25, 34.6676) and (23.34, 51.1329) & (9.25, 33.6407) and for (R_1, PGPP) & (R_2, PGPP) into the mathematical expression in equation (9) gives ≈ 1.32, 1.49 and 1.24 as PGPP per unit retained weight for experimental, derived and regression model-predicted results respectively.

Graphical Analysis: Comparative graphical analysis of Figures 6 and 7 shows very close alignment of the curves from model-predicted PGPP and that of the experiment.

The degree of alignment of these curves is indicative of the proximate agreement between both experimental and model-predicted PGPP.

Comparison of Derived Model with Standard Model: The validity of the derived model was further verified through application of the regression model (Reg) (Least Square Method using Excel version 2003) in predicting the trend of the experimental results. Comparative analysis of Figures 8 and 9 shows very close alignment of curves and significantly similar trend of data

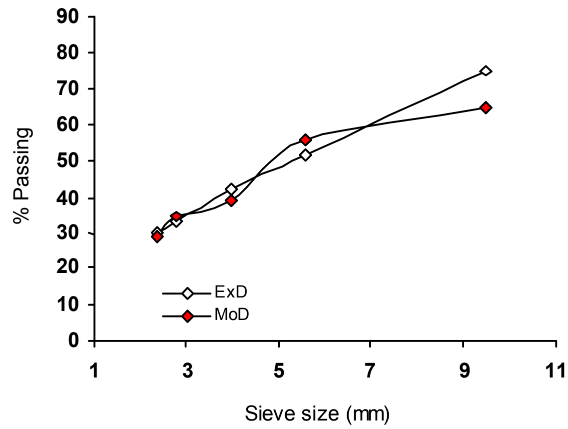

Fig. 6: Comparison of PGPPs (relative to sieve size) as obtained from experiment and derived model prediction

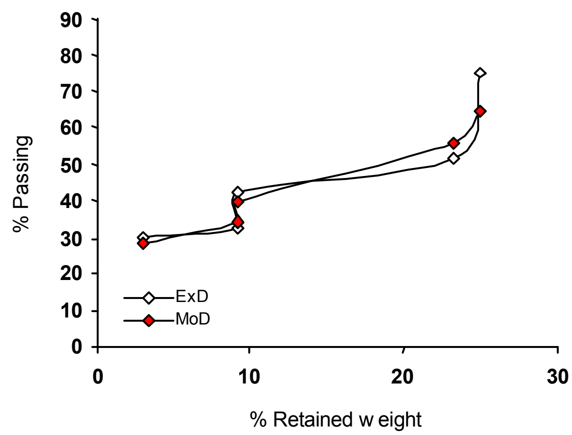

Fig. 7: Comparison of PGPPs (relative to retained weight) as obtained from experiment and derived model prediction

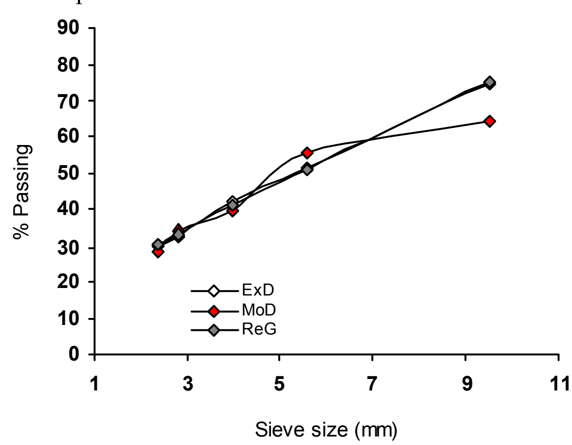

Fig. 8: Comparison of PGPPs (relative to sieve size) as obtained from experiment, derived andregression model prediction

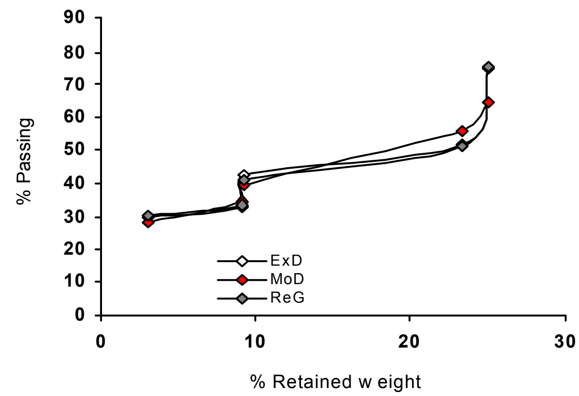

Fig. 9: Comparison of PGPPs (relative to retained weight) as obtained from experiment, derived and regression model prediction

point's distribution for experimental (ExD) and derived model-predicted (MoD) results of PGPP. Figures 8 and 9 show that the calculated correlations between PGPP and sieve size & retained weight for results obtained from regression model gives 1.000 and 0.8131 respectively. The PGPP per unit sieve size and retained weight as obtained from regression model are 6.25% / mm and 1.24 respectively. These values are in proximate agreement with both experimental and derived model-predicted results.

Deviational Analysis: Comparative analysis of PGPP from experiment and derived model revealed deviations on the part of the model-predicted values relative to values obtained from the experiment. This is attributed to the fact that the surface properties of the galena particles which played vital roles during the sieving process were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted PGPP to those of the corresponding experimental values.

Deviation (Dv) of model-predicted PGPP from that of the experiment is given by;

$$Dv = \left(\frac{P_D - E_D}{E_D}\right) x\ 100 \qquad (10)$$

Deviation of model-predicted PGPP from experimental results increased with increase in sieve size and was maximum (14.08%) at the largest sieve size (Figures 10 and 11). The derived model predicted PGPP values were very close to experimental results at a sieve size range 2.36 – 5.6 mm (2.36, 2.8, 4.0 and 5.6 mm); corresponding to a deviation of less 8%.

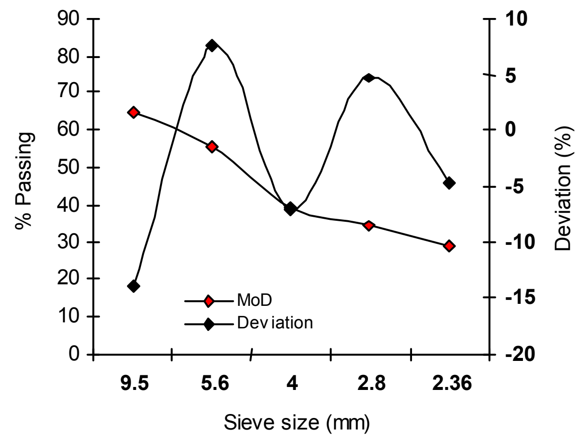

Fig. 10: Variation of model-predicted PGPP (relative to sieve size) with associated deviation from experimental results

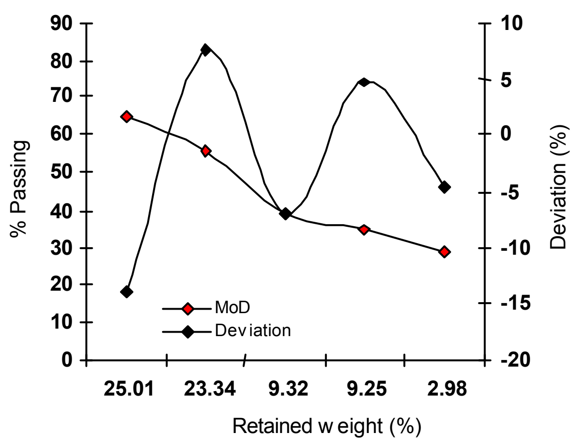

Fig. 11: Variation of model-predicted PGPP (relative to retained weight) with associated deviation from experimental results

Table 3: Variation of model-predicted PGPP with associated correction factor

Sieve size (mm)	Retained weight (%)	Cr (%)
9.5	25.01	+ 14.08
5.6	23.34	- 7.67
4.0	9.32	+ 6.94
2.8	9.25	- 4.67
2.36	2.98	+ 4.61

Correction factor (Cr) is the negative of the deviation i.e

$$Cr = - Dv \qquad (11)$$

Therefore

$$Cr = -\left(\frac{P^D - E^D}{E^D}\right) x\,100 \qquad (12)$$

where
P^D = Model-predicted PGPP(%)
E^D = PGPP from experiment (%)
Cr = Correction factor (%)
Dv = Deviation (%)

Introduction of the corresponding values of Cr from equation (12) into the model gives exactly the corresponding experimental PGPP.

Comparative analysis of Figures 10, 11 and Table 3 indicate that correction factor is the negative of the deviation as shown in equations (10) and (12). It is believed that the correction factor takes care of the effects of the surface properties of the galena particles which played vital roles during the sieving process, but were not considered during the model formulation. Values of correction factor < 8% realize the experimental results if added to the model-predicted PGPP within sieve size range 2.36 - 5.6mm (2.36, 2.8, 4.0 and 5.6 mm).

It is important to state that the deviation of model predicted results from that of the experiment is just the magnitude of the value. The associated sign preceding the value signifies if the deviation is deficit (negative sign) or surplus (positive sign).

CONCLUSIONS

Sieve analysis of mined galena particles carried out using an assembly of sieves of sizes S; 9.5, 5.6, 4.0, 2.8 and 2.36 mm shows that Percent Galena Particle Passing (PGPP) is a function of sieve size and Percent Galena Retained Weight (PGRW) as predicted by a derived and validated two-factorial empirical model. PGPP and PGRW increase with increased S. The validity of derived model; $\xi = 13.1935 \ln\gamma + 0.0001\gamma$ $13.4865e^{0.0349\vartheta} + 2.4581$ is rooted on the core expression $\xi - 0.0001\gamma = 13.1935 \ln\gamma + 13.4865e^{0.0349\vartheta} + 2.4581$ where both sides of the expression are correspondingly close. PGPP per unit S & PGRW using experimental, derived and regression model-predicted results gives 6.63, 7.49 and 6.25 %/ mm & 1.32, 1.49 and 1.24 which are in proximate agreement respectively. Correlations between PGPP and S & PGRW as obtained from experiment, derived and regression model-predicted results were all > 0.8. Deviation of model-predicted PGPP from experimental results increased with increase in sieve size and was maximum (14.08%) at the largest sieve size. The derived model predicted PGPP values was very close to experimental results at a sieve size range 2.36 – 5.6mm (2.36, 2.8, 4.0 and 5.6 mm); corresponding to a deviation of less 8%. This invariably translated into over 92%

operational confidence level for the derived model as well as over 0.92 dependency coefficients of PGPP on S and PGRW within a sieve size range: 2.36 – 5.6mm.

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