Comparison of Explosion Characteristics of Autolyzed Yeast Extract Measured in a 1.23 Liter Cylindrical Hartmann Bomb and a 190 Liter Spherical Bomb

F. S. Lai and D. W. Garrett
U.S. Department of Agriculture
U.S. Grain Marketing Research Laboratory
Manhattan, KS 66502

L. T. Fan
Department of Chemical Engineering

R. S. Lee
Department of Physics
Kansas State University
Manhattan, KS 66506

A dust explosion consists of two major phases, an ignition phase and a propagation phase. Three parameters that characterize the propagation phase are maximum explosion pressure, maximum rate of pressure rise, and average rate of pressure rise. The magnitude of these quantities determines the extent of damage produced by the explosion of a dust cloud. The pressure history of a dust sample is the value of each of these parameters expressed as a function of dust concentration. This note presents a comparison of dust explosion characteristics of autolyzed yeast extract (AYE) in a 1.23 L cylindrical Hartmann bomb and 190 L spherical bomb.

Autolyzed yeast extract is produced by spray-drying, which involves injection of liquid droplets into a hot air stream at 150°C. As droplets pass through a drying chamber, the liquid evaporates, creating dried powder. The powder is then sent through the base of the drying chamber on a fluidized bed which serves as both conveyor and cooling chamber. Spray-drying to produce AYE is a relatively low-risk operation; however, both fires and explosions have occurred during the drying process. Explosions, usually the result of fires, have occurred in the drying chamber and in downstream units consisting of cyclones, blenders, hoppers, and dust collection systems. Because the incidence of explosions in the spray-drying process has established the explosible nature of AYE, we chose this material as the test dust for deriving comparable explosibility data with the Hartmann bomb and the spherical bomb. Both the precision and the accuracy of the two instruments were compared.

Materials and Procedure

The maximum explosion pressure, maximum rate of pressure rise, and average rate of pressure rise were measured for AYE in a 1.23 L cylindrical Hartmann bomb and a 190 L spherical bomb.

The pressure inside the Hartmann chamber was measured with a Bell & Howell pressure transducer, model no. CEC-402. The transducer was connected to a Bell & Howell 8-115 Signal Conditioner that produced an output electrical voltage proportional to the pressure in the explosion chamber.

A Tetronix 5112 dual beam oscilloscope was employed to measure the output voltage from the signal conditioner as a function of time. The signal trace on the oscilloscope screen was photographed with a Tetronix series 125 camera.

Explosion tests were performed on the AYE sample at five specific dust concentrations: 0.1, 0.2, 0.5, 1.0, and 2.0 kg/m^3. The number of replications at each concentration ranged from one to four. The concentration of a dust cloud is defined as the total mass of dust placed in the explosion chamber divided by the chamber volume; the concentrations mentioned above are those regularly used when obtaining the pressure history of a dust sample by means of a Hartmann bomb.

Explosions performed with the 190 L spherical bomb were conducted by Fenwal, Inc. (Ashland, MA), using an experimental procedure similar to that for the Hartmann bomb. Dust clouds of AYE at various concentrations were exploded and the pressure was recorded for each test. Maximum and average rates of pressure rise were determined from oscillograph charts.

A typical trace of pressure as a function of time in a dust explosion is shown in Figure 1. Maximum explosion pressure is defined as the difference between maximum pressure attained, B, and the pressure rise resulting from dispersion of air, A, (Dorsett et al., 1960). The maximum rate of pressure rise is defined as the largest slope of the line tangent to the pressure vs. time trace. This slope is shown as D/E in Figure 1 and was obtained graphically. The average rate of pressure rise is defined as maximum explosion pressure divided by the estimated time between ignition of the explosion and attainment of maximum pressure. This is shown as B/C in Figure 1.

Results and Discussion

The dust concentration, P_{max}, $(dP/dt)_{max}$, and $(dP/dt)_{avg}$ obtained in the explosion of AYE are presented in Table 1 for both the Hartmann bomb and the spherical bomb.

Maximum explosion pressure

The pooled standard deviation between trials was 0.435×10^5 Pa for data derived from the Hartmann bomb, and 0.554×10^5 Pa for data from the 190 L spherical bomb. A two-tailed F-test was performed to examine equality of the variances from both instruments. The F value of 1.62 was not significant even for $\alpha = 0.50$; the larger variance contained eight degrees of freedom and the smaller variance contained six degrees of freedom. Figure 2 presents the coefficients of variability of P_{max} between trials plotted against the concentration of dust in each bomb. The coefficients of variability for the 190 L spherical bomb are larger than those for the Hartmann bomb, except at concentrations of 0.5 and 1.1 kg/m^3.

In Figure 2 the average maximum explosion pressures from both instruments and the coefficient of variability between them are plotted against the dust cloud concentration. The values of the coefficient of variability are less than 10%, except at a dust concentration of 0.3 kg/m^3, where it is 17%. To statistically

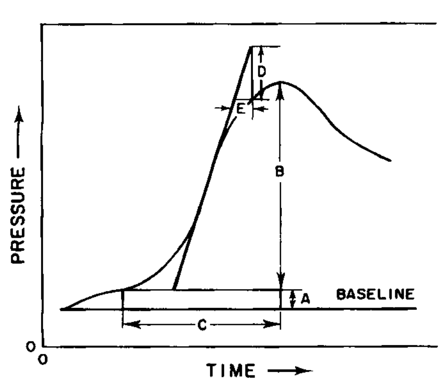

Figure 1. Pressure characteristics P_{max}, $(dP/dt)_{max}$, and $(dP/dt)_{avg}$.

Table 1. Comparison of Data from Explosion Tests

Apparatus	Replication	Concentration kg/m^3	Max. Explosion Press. 10^5 Pa	Max., Rate Press. Rise 10^5 Pa/s	Avge., Rate Press. Rise 10^5 Pa/s
Cylindrical	2	0.3	5.1	89	35
1.23L	2	0.5	5.5	118	54
Hartmann	2	0.6	6.1	140	66
bomb	2	0.7	7.5	146	71
	2	0.9	7.0	104	54
	2	1.1	6.8	97	46
Spherical	1	0.3	4.0	11	5
190 Liter	2	0.5	5.8	36	18
bomb	2	0.6	6.8	75	27
	4	0.7	7.6	77	29
	3	0.9	7.4	66	24
	2	1.1	7.4	48	21

determine if a significant difference existed between maximum pressures obtained from the two instruments, an analysis of variance for a 2 × 2 factorial experiment with two replications per treatment combination was performed. The treatments were the type of apparatus (the Hartmann and the 190 L bombs) and the levels of dust concentration. If a level of dust concentration contained more than two replications (see Table 1), two replications were selected at random. The results of analysis, Table 2, indicate that no significant differences exist between the two instruments at the 1% level of significance; the interactions are also insignificant. However, the effect of dust cloud concentration is significant at the 1% level.

To compare values of $(dP/dt)_{max}$ derived from each instrument, we utilized the cubic law. The empirical relationship between $(dP/dt)_{max}$ and volume of the explosion chamber is given according to the cubic law as (Bartknecht, 1981): $K_{st} = (dP/dt)\ V^{1/3}$. Figure 3 presents the coefficient of variability between replications of K_{st} for each apparatus plotted against

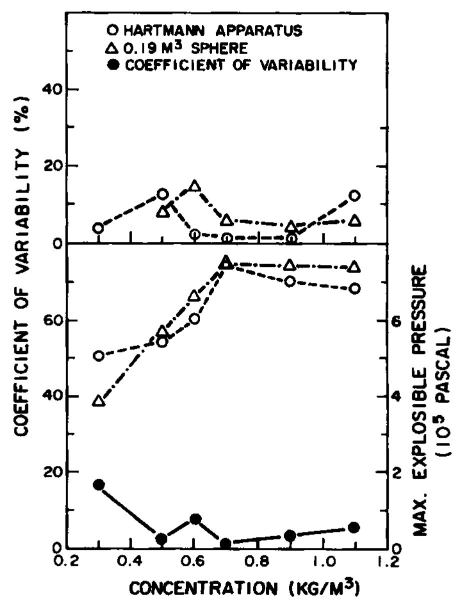

Figure 2. Coefficient of variability and maximum explosion pressure as affected by concentration for Hartmann bomb and 190 L spherical bomb.

Table 2. Analysis of Variance of Maximum Explosion Pressure Data

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment			
Concentration, C	4	2.28	6.61*
Apparatus, A	1	0.85	2.46
Interactions			
$C \times A$	4	0.09	0.25
Error	10	0.35	—
Total	19	—	—

*Significant at the 1% level.

dust concentration. The coefficients of variability for the 190 L spherical bomb are consistently higher than those for the Hartmann bomb, except at a dust concentration of 1.1 kg/m³. The two highest coefficients of variability for the Hartmann bomb are 23 and 27%; for the 190 L spherical bomb, three of the coefficients of variability are greater than or equal to 40%.

The values of K_{st} for the Hartmann bomb are plotted against those for the 190 L spherical bomb in Figure 4. If the two instruments yielded the same K_{st} values for a given concentration, all points would lie around the line of "consistency of measured values" with a slope of 1; however, the regression line for the experimental data has a slope of 0.356 ($r^2 = 0.909$). This slope is significantly different from 1 at the 95% confidence level. The 95% confidence interval ranged from -0.026 to 0.756, which does not contain 1. Bartknecht (1981) demonstrated experimentally that the Hartmann bomb consistently yields values of K_{st} lower than those from instruments having an explosion chamber volume of 20 L or larger. The slope of the regression line he obtained was 0.35 instead of 1. This value falls within the 95% confidence interval of our data.

The value for K_{st} is assumed to be constant in the definition of cubic law regardless of the apparatus. This constant should be obtained when the maximum pressure was obtained for an optional concentration. In other words, for a small or large apparatus the optimal concentration for maximum pressure may be

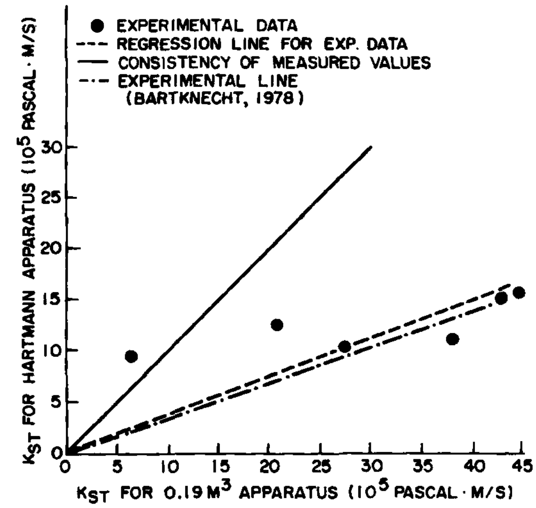

Figure 4. Comparison of K_{st} values from Hartmann bomb with those from the 190 L spherical bomb.

different, but the K_{st} value should be constant, within experimental repeatability. In reality, K_{st} is constant only for a given apparatus. Bartknecht suggested that a volume >16 L would result in a constant K_{st} regardless of apparatus.

Average Rate of Pressure Rise

To compare the average rates of pressure rise, a quantity similar to K_{st} is defined by the following equation: $K_{st} = (dP/dt)$ avg $V^{1/3}$. Figure 5 presents the coefficients of variability between trials of $K_{st,avg}$ for each instrument plotted against the dust concentration. Again, the coefficients of variability for the Hartmann bomb are consistently lower than those for the 190 L spherical bomb.

Figure 6 presents the value of $K_{st,avg}$ plotted in the same format as those of the K_{st} in Figure 4. The regression line through the experimental data has a slope of 0.458 ($r^2 = 0.963$). The 95% confidence interval for this value of the slope ranges from 0.103

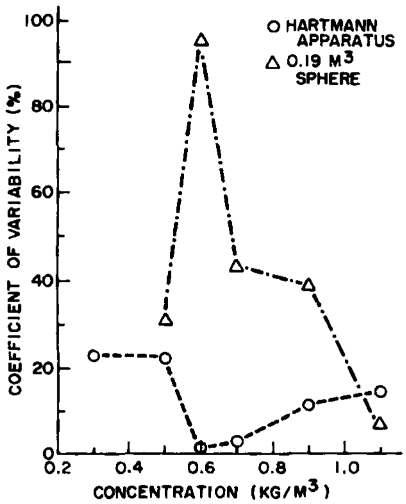

Figure 3. Coefficients of variability between repetitions of K_{st} values as affected by concentration for both bombs.

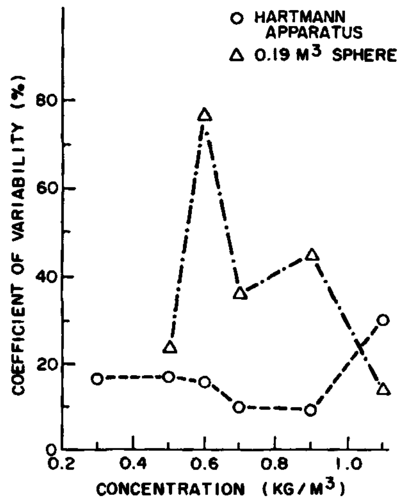

Figure 5. Coefficients of variability between repetitions of $K_{st,avg}$ values as affected by concentration for both bombs.

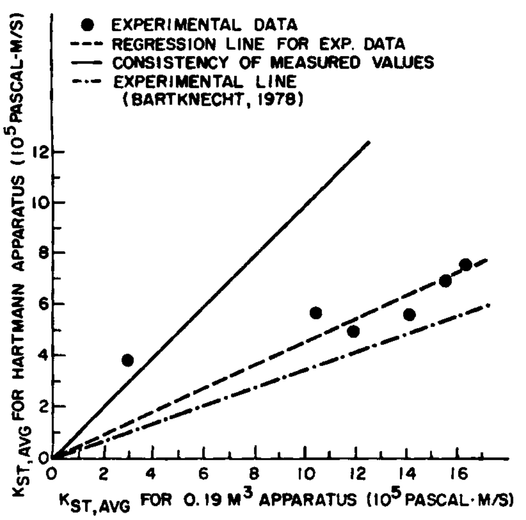

Figure 6. Comparison of $K_{st,avg}$ values from Hartmann bomb with those from 190 L spherical bomb.

to 0.813, which contains 0.35 (the value of the slope reported by Bartknecht).

The maximum pressure for an explosion is obtained with mixtures of approximate stoichiometric composition; lower values are observed when concentrations are changed toward the lower or upper explosion limit. The rate of pressure rise is a yardstick of the speed of flame propagation and hence the violence of an explosion. In this study, we found that the maximum pressures reached about the same for both the Hartmann bomb and the 190 L bomb, but there was a substantial difference in the rate of pressure rise. This observation led us to conclude that the 190 L spherical bomb provided more turbulence in the course of an explosion and that bombs were tested at the right stoichiometric composition of dust and air (oxygen).

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Notation

K_{st} = constant, Eqs. 1 and 2, Pa · m/s
dp/dt = rate of pressure rise, Pa/s
V = volume of the explosion chamber, m^3

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