FACTORS AFFECTING THE PERFORMANCE OF THE BETA BACKSCATTER EGGSHELL MEASUREMENT*

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INTRODUCTION

The Beta backscatter technique for estimating eggshell strength first described by James and Retzer (2) and James *et al.* (3) is the only method published to date in which the egg is not tested mechanically or immersed in salt solutions. If the technique estimates shell thickness, one of the factors controlling shell strength, it may find application in commercial grading because it is feasible to automate this method. The radiation backscattered by the shell was found highly correlated with shell strength determined by impact from a falling steel ball (2, 3, 6). These data, however, were biased because the height from which the ball dropped was pre-estimated from the backscatter reading. Backscatter readings were also significantly correlated with shell thickness.

Later work (1, 5) indicated that backscatter readings estimated shell strength, as measured by destructive and non-destructive quasi-static compression tests, with only limited precision. The estimate of thickness however was comparable to that obtained from the specific gravity of the egg.

The purpose of the work here was to further investigate the backscatter technique and examine some of the factors affecting its performance.

APPARATUS AND METHODS

The Beta backscatter apparatus (Figure 1) was a modification of the system described by James and Retzer (2). A 10 microcurie point source of ruthenium 106 - rhodium 106 was suspended in a holder below the egg. A Geiger-Mueller tube (GMT) below the source detected radiation backscattered from the shell. The output of the GMT was recorded on a scaler (Model 123B, Baird-Atomic Ltd.). The GMT high voltage supply was monitored by a digital voltmeter and maintained at the plateau of the GMT characteristic curve (850 volts). Radiation backscattered was recorded for 60 sec. in all the tests. An electronic timer, based on the line voltage frequency, was used to automatically stop the scaler after precisely this time.

The performance of the system was improved by placing lead shielding below the tungsten radiation source holder to reduce direct radiation from the source to the GMT. This zero or background error was previously found to be constant at about 10% of the radiation backscattered from the egg (5). To eliminate this from the data the reading without a specimen above the source was subtracted from each specimen reading. The background was recorded throughout the experiment and the correction adjusted accordingly. The distances between the GMT, the source and the specimen were also adjusted to reduce the radiation backscattered. This reduced the counting rate to about 500/sec. which was assumed to prevent saturation of the GMT (Model 731 LND Inc., Oceanside, Long Island, N.Y. 11572) which had a dead time of 40 μ sec.

To determine the contribution of the shell, shell membranes, yolk and albumen to the radiation backscattered 50 eggs free from cracks were selected. A point was selected at random on the equator of each egg and marked. Beta backscatter (BB) readings were then taken at these points. A small hole was then drilled in each pole of the egg, the contents evacuated and BB recorded at the same point. The shell was then cut in half along the major axis using a thin carborundum cutting wheel. The half shells containing the marked points were washed, dried and BB again recorded. The shell membranes were then removed by boiling the half shells in a 5% solution of NaOH and the shells washed, dried and BB again recorded. Throughout this procedure care was taken to ensure that the egg or half shell was oriented the same way above the radioactive source.

To determine the effect of the depth of yolk and albumen (i.e., egg diameter) on the radiation backscattered, a graduated acrylic tube closed at the bottom by "Saran Wrap" was placed above the source (Figure 2). A BB reading was taken with the tube empty and this background used to correct the readings. The tube was filled with albumen to a depth of 0.2 cm and the BB noted. This was repeated at albumen depths of 0.4, 0.6, 0.8, 1.0, 2.0, 3.0, 4.0 and 5.0 cm. This procedure was repeated three times and then repeated using yolk. The BB reading for each depth was then expressed as a percentage of the maximum reading.

The effect of changes in shell thickness was also determined using 50 crack-free eggs. A point was selected at random on the equator, marked and the BB reading noted. A 2.54 cm diameter area about this point was then sanded with 150 grit paper to reduce its thickness an unknown

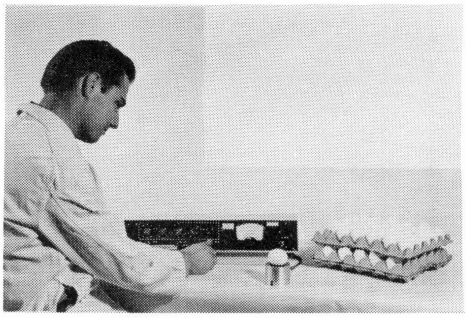

Figure 1. The apparatus

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*Contribution No. 176 from Engineering Research Service.

RECEIVED FOR PUBLICATION
MAY 14, 1969

amount and the BB reading again noted. The shell was then broken and the contents discarded. Thickness of the shell at the sanded area was measured within ± 0.001 mm by a dial gauge comparitor (5). Shell thickness was then measured at three equispaced points around the equator that had not been sanded. The mean of these three readings was assumed to be the shell thickness around the equator prior to sanding.

To compare the interchangeability of data between two instruments a second BB apparatus was constructed using a 12.6 microcurie strontium 90 radiation source and a surface barrier type detector capable of higher counting rates than the GMT. Readings were then taken at the same point on 21 eggs in the following sequence.

1. Egg-Strontium 90 source.
2. Egg less yolk and albumen-Strontium 90 source.
3. Egg less yolk and albumen dried naturally overnight-Strontium 90 source.
4. Egg less yolk and albumen oven dried-Strontium 90 source.
5. As in 4-ruthenium-rhodium source.
6. Half shell - ruthenium - rhodium source.
7. Half shell less membranes-ruthenium-rhodium source.
8. Shell thickness at measured point mm.

RESULTS AND DISCUSSION

Removal of the yolk and albumen, half of the shell and the shell membranes affected the amount of radiation backscattered. Each component reduced the reading and the greatest reduction was caused by removal of the membranes (Table I). However, the coefficient of variation between eggs was practically constant regardless of which component was removed. This may indicate that the effect of the yolk, albumen and membrane is consistent or that errors of measurement are constant. The total contribution of the yolk, albumen, top half of the shell and the shell membranes was 26% of the reading for the whole egg. Of this the largest portion was due to the shell membranes. It is thus most likely that any radiation penetrating the shell that is reflected, may be reflected by the membrane. The yolk and albumen had only a small effect (5%).

This behaviour can be explained by the fact that BB is proportional to $Z^{0.5}$ where Z is the atomic number. The shell consists primarily of calcium carbonate ($CaCO_3$) and the contents are water (H_2O) (87% in albumen and 48% in yolk) together with proteins and fat made up of C, H, O and N. The atomic numbers of these components are: Ca = 20, C = 6, H = 1, N = 7 and O = 8. Thus it can be assumed that the majority of radiation is backscattered by the shell. The data indicates that of the radiation penetrating the shell the majority is backscattered by the membranes.

The depth of yolk or albumen had only a small effect on the amount of radiation backscattered (Table II). The data indicated that the minimum practical test depth (0.2 cm) reflected at least 87% of the radiation re-

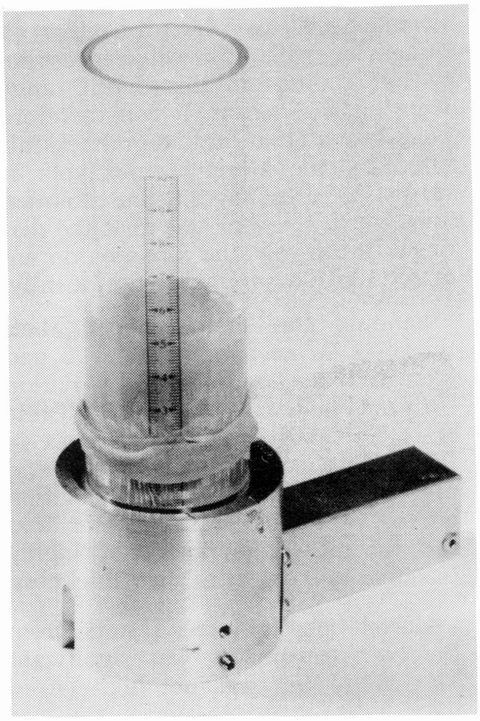

Figure 2. Measurement of yolk and albumen

TABLE I. RADIATION BACKSCATTERED BY EGG COMPONENTS

	Mean BB Reading[1] 1000 Counts	Coefficient of Variation %	Reduction of Reading 1000 Counts
Egg	30	3.2	-
Shell With Membranes	28	3.2	1.6
Half Shell With Membranes	26	3.2	2.8
Half Shell Less Membranes	22	3.2	3.3

[1] 50 eggs.

TABLE II. RADIATION BACKSCATTERED BY ALBUMEN AND YOLK

Depth cm	Percentage of B B Assuming the Maximum Reading = 100 %					
	Yolk			Albumen		
Test	1	2	3	1	2	3
0.2	86.6	98.4	99.3	94.4	93.5	89.7
0.4	99.4	98.9	97.3	97.9	96.4	96.9
0.6	99.3	98.5	97.3	97.1	96.2	97.5
0.8	97.4	99.2	100.0	99.6	94.6	93.4
1.0	97.3	100.0	98.9	99.2	96.3	98.9
2.0	98.0	99.5	97.5	98.0	94.0	100.0
3.0	97.9	99.8	98.3	98.8	97.2	95.8
4.0	99.0	98.2	97.1	98.1	96.0	98.4
5.0	100.0	96.4	98.0	100.0	100.0	99.8

flected by 0.4 to 5.0 cm of either albumen or yolk. The differences between readings in this depth range were not significant. It can therefore be assumed that radiation backscattered by the albumen and yolk is caused by a thin layer of the albumen adjacent to the shell and that the diameter of the yolk and albumen do not affect the measurement significantly.

Sanding the shell reduced their thickness by an average of 27% and increased the coefficient of variation between shells from 9 to 21% (Table III). The corresponding changes in BB reading were a reduction 8% and practically no change in the coefficient of variation. This indicates that the BB measurement is not highly sensitive to changes in shell thickness.

Correlation between results from the two instruments was significant ($P \leq 0.01$) but was not high ($r = 0.677$ Table IV). Correlation between BB and shell thickness covered a wide range and depended on the condition of the egg. The correlation appeared to be improved by cutting the shell in half and drying the shell. It would thus appear that the thin layer of albumen left in the shell when it is evacuated influences the result. This was verified in a second experiment using the Strontium-90 source with 27 avacuated and dried shells where the correlation between BB and mean shell thickness ($r = 0.875$) was higher than for measurements on whole eggs ($r = 0.609$, Table 4). This again indicates that the contents influence the measurement. For the dried shells the linear regression between shell thickness in mm (y) and BB in 1000 counts (x) was $y = 0.314 + 0.0044x$ (Figure 3).

CONCLUSION

Backscattered radiation is commonly used as a means of measuring thickness of materials superimposed on another material (4). Ideally changes in the base material should not affect the measurement. To measure thickness some of the radiation must pass through the material to the base which in the case of eggshells is the shell membranes, the albumen and yolk. The data indicate that these base materials influence the amount of radiation backscattered. Since the degree of penetration is governed by the energy of the particles emitted to the shell selection of the radioactive source and its distance from the shell must be assumed to be critical.

In its present form the BB apparatus gives results significantly correlated with shell thickness and can be used to determine biologically significant changes in this source of shell strength. However, it is concluded that before the technique can be used for precise measurements of shell

TABLE III. EFFECT OF CHANGES IN SHELL THICKNESS ON RADIATION BACKSCATTERED

		Mean[2]	Coefficient of Variation
BB before sanding	1000 counts	33	3.8
BB after sanding	1000 counts	30	4.1
Change in counts due to sanding	%	8.5	44.5
Shell thickness[1]	mm	0.333	9.0
Sanded shell thickness	mm	0.289	21.0
Thickness change due to sanding	%	26.9	40.1

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[1] 3 measurements per egg.

[2] 50 eggs.

TABLE IV. MEANS, COEFFICIENTS OF VARIATION AND CORRELATION COEFFICIENTS OF BB READINGS FROM TWO INSTRUMENTS

Variable No.[1]		1[3]	2[3]	3[3]	4[3]	5[3]	6[3]	7[3]	8[4]
Mean[2]		1891	1831	1719	1714	30	29	29	0.372
Coefficient of Variation	%	1.5	3.5	3.1	3.0	3.9	4.3	4.7	8.0
	2	0.666	-						
	3	0.589	0.415	-					
	4	0.792	0.411	0.630	-				
	5	0.450	0.248	0.601	0.677	-			
	6	0.447	0.022	0.393	0.829	0.623	-		
	7	0.625	0.195	0.547	0.852	0.706	0.888	-	
	8	0.609	0.212	0.601	0.876	0.658	0.898	0.883	

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[1] See text.

[2] 21 samples.

[3] 1000 counts.

[4] mm.

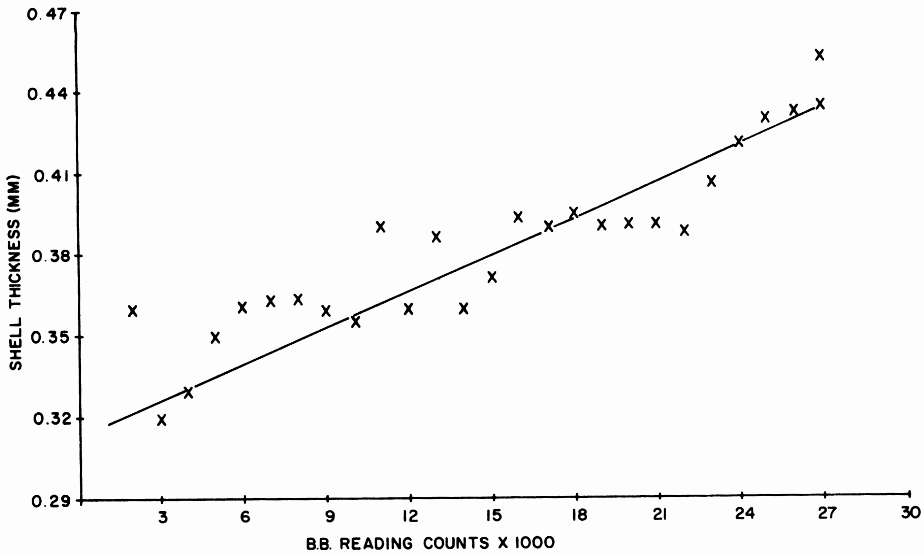

Figure 3. Relationship between shell thickness and BB for dried shells

thickness extensive additional research is required to determine the optimum radioactive source and the errors inherent in the measurement. Since the measurement is based on a statistical distribution of backscattered radiation improvements may be achieved through the use of solid state detectors capable of higher counting rates.

REFERENCES

1. Hunton, P. (1969). The measurement of eggshell strength a comparison of four methods. Brit. Poul. Sci. 10: 281-289.
2. James, P. E. and Retzer, H. J. (1967). Measuring eggshell strength by Beta backscatter technique. Poul. Sci. 46: 1200-1203.
3. James, P. E. Retzer, H. J. and Pressly, R. S. (1967). Beta backscatter method of measuring eggshell strength. Pap. 67-887. Pres. Amer. Soc. Agric. Eng. Detroit.
4. Nydegger, R. R. (1967). Applications of backscattered radiation. Progress in applied materials research. 7. Chemical Rubber Co. Press. Cleveland, Ohio. p. 135.
5. Voisey, P. W., Hunt, J. R. and James, P. E. (1969). A comparison of the Beta backscatter and quasi-static compression methods of measuring eggshell strength. Can. J. Animal Sci. 49: 157-168.
6. Wilson, S. P., Marks, H. L. and James, P. E. (1968). Associations among Beta backscatter and other measures of eggshell strength. Poul. Sci. 47: 232-237.

ACKNOWLEDGEMENT

The authors wish to acknowledge the contribution of G. D. Robertson, Engineering Research Service, for his technical assistance.

OPTIMUM COMBINING . . .

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Weather Dependent Operations", Can. Agric. Eng. 8: 26-28.

4. MacHardy, F. V. 1964. "An Investigation of the Application of Programming Techniques to Farm Management Problems." Unpublished Ph.D. Thesis, Faculty of Science, University of Edinburgh.
5. MacHardy, F. V. 1968. "Product Terms in Mathematical Programming," Can. Agric. Eng. 10: 51-52 and 56.
6. Russell, D. G. 1969. "Optimum Field Machinery Sizes For Alberta Farms." Unpublished M.Sc. Thesis, Faculty of Agriculture, University of Alberta. Pages 23-44.

CREDIT TO GIVE FOR RAIN . . .

continued from page 37

tion. Can. Jour. Plant Sci. 44: 439-445.

3. Wilcox, J. C., 1967. Credit to Give for Rain When Scheduling Irrigations. Can. Agr. Eng. 9: 103-107, 125.
4. Wilcox, J. C., 1967. Effects of soil Texture, Net Evapotranspiration and Other Factors on Irrigation Requirements of Orchards as Determined by a Scheduling Procedure. Can. Jour. Soil Sci. 47: 149-156.
5. Wilcox, J. C., 1967. A Simple Evaporimeter for Use in Cold Areas. Water Resources Res. 3: 433-436.