Agriculture Canada

REPORT NUMBER:
7322-598

Engineering Research Service

March 1976

Notes on the Measurement of Egg Specific Gravity to Estimate Egg Shell Quality

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Contribution No. 598 from Engineering Research Service, Research Branch, Agriculture Canada, Ottawa, Ontario, K1A 0C6.

NOTES ON THE MEASUREMENT OF EGG SPECIFIC GRAVITY TO ESTIMATE SHELL QUALITY

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1. SUMMARY

Specific gravity (S.G.) of any material is temperature dependent. The hydrometers used to measure the S.G. of the saline solutions for estimating eggshell quality, by the specific gravity method, are normally calibrated at a reference temperature of 60°F (15.56°C). However, it is not usual to control the temperature of the saline solutions. Experiments were conducted to determine the effect of saline solution temperature and other factors on the accuracy in determining egg S.G.

The theoretical change in solution and, therefore, egg S.G. readings with temperature was calculated to be 0.00045/°C. The observed change in egg S.G. was 0.00033/°C. Although not in close agreement, the experimental value confirms that egg S.G. readings are temperature dependent. A maximum difference of 0.0015 was found between the mean egg S.G. readings from uncontrolled (69.5 - 72.2°F) and controlled (60°F) temperature facilities. This closely agreed with a calculated difference (0.0022) based on the experimentally determined value of the temperature induced changes (0.00033/°C) and the maximum temperature difference (6.8°C) between the two sets of solutions. This would not have a serious effect on egg S.G. results providing the solution temperatures did not deviate further from the calibrated standard.

A maximum of 0.0018 was observed between the S.G. of saline solutions measured gravimetrically and with a hydrometer. Hairline cracks

in the shells of eggs were found to have a small (0.001) effect on mean group S.G. but could affect some eggs as much as 0.004. A maximum difference of 0.006 was found between a "reference" hydrometer and hydrometers which spanned different S.G. ranges. Under routine conditions, hydrometers cannot be read to much better than ±0.001 because the meniscus is not viewed horizontally. When approximately 900 eggs which had been stored at 55°C overnight, were passed through saline solutions ranging in S.G. from 1.062 to 1.102, in increments of 0.004, a temperature change of -2.9°C was observed in the 1.062 solution and only a change of ±0.056°C in solutions with an S.G. > 1.094. A practical method to reduce this temperature change, in particular, of the first saline solution would be to pass the eggs through several (3 - 4) containers of water at room temperature prior to the first saline solution.

In general, all the errors were small but it appears that egg S.G. readings can only be considered realiable to within ±0.004 or ±1 increment when using a 0.004 incremental difference between solutions. A number of methods of alleviating this situation are recommended.

2. INTRODUCTION

The measurement of specific gravity (S.G.) of the whole egg is a technique used to predict shell quality (Mussehl and Halbersleben, 1923; Hays and Sumbardo, 1926; Harrossowitz, 1934). The S.G. of an egg provides an estimate of the amount of shell (Olsson, 1934), and as this increases, the larger amount of shell tends to increase shell strength. It has been found significantly correlated with shell strength by a number of workers. Egg S.G. is obviously affected by variation of density in the shell and the egg contents. Carter (1968) reported that shell density was homogeneous among strains, whereas that of the contents was significantly different. Egg specific gravity is also affected by time of oviposition (Roland and Harms, 1974; Chipera, 1976). The size of the air pocket in the egg affects the S.G. measurement because it changes with time after laying. Eggs must be tested either at a constant preselected time after laying, or after sufficient time has elapsed for the air size to stabilize. The effect of cracked shells on egg S.G. is not documented, but is assumed to occur so cracked shells are not normally tested. Thus, it is readily apparent that a number of factors affect egg S.G. which must influence the precision with which it can predict shell strength.

The floatation technique is a simple method of measuring S.G. and is used by many workers (e.g. Olsson, 1936; Munro, 1940, 1942; Marks and Kinney, 1964; Gaisford, 1965; Hunt and Chancey, 1970). A series of plastic garbage pails filled with saline solutions in ascending concentrations can be used to ascertain the S.G. of eggs. The degree of resolution is limited only by the number of pails used and the accuracy with which the S.G. of the solutions can be measured and controlled. It is quite practical to use S.G. increments of 0.002 (e.g. Hunt and Voisey, 1966; Voisey et al., 1969). However, to reduce the labour required most workers use larger increments, generally 0.005 (e.g. Voisey, 1975). Current practice at our laboratories is to use increments of 0.004.

The floatation method has the advantage that groups of eggs can be tested simultaneously by placing a layer of eggs in a wire basket and immersing the basket in each solution in turn removing those which just float at each stage. There is the disadvantage that the eggs must be washed and dried after testing. However, this is a widely accepted method of evaluating shell strength. It is less labour consuming than other non-destructive techniques, such as shell deformation measurements, where each egg must be tested individually. Another method of determining S.G. is a modification of the Archimedes method using a special hydrometer to determine the weight of the egg in water (Asmundson and Baker, 1940; Richards and Swanson, 1965). The S.G. is then calculated from

$$S.G. = \frac{\text{weight in air}}{\text{weight in air - weight in water}}$$

Carter (1975) has developed techniques and equations to extend this method for quickly determining flock mean shell thickness. Special calculators have been made to solve the above equation when determining the S.G. of potatoes (Young et al., 1964). Similar units could be designed for eggs.

As a predictor of shell strength, that is the resistance of the shell to fracture by an externally applied force, S.G. measurements do not achieve a high degree of precision. For example, the correlation coefficient with quasi static compression fracture force at the equator is typically 0.75 and 0.45 at the poles (Hunt and Voisey, 1966), or 0.73 at the equator (Voisey et al., 1967) and 0.49 (Voisey, 1975). Under impact conditions the correlation coefficient was 0.61 (Voisey and Hunt, 1976). Thus, it appears that S.G. readings can only account for less than 50% of the variation in shell strength. There is also the fact that within a group of eggs the variation of S.G. is much less than the variation of fracture force. In a typical experiment, Voisey and Hunt (1976) reported a mean S.G. for 1013 eggs of 1.083 with

a coefficient of variation of 0.7% whereas the mean impact fracture force was 5.16 kg with a coefficient of variation of 18.4%. The same kind of results are obtained with quasi static compression tests (e.g. 0.69% compared to 18.8%, Voisey et al. 1969). This points out that S.G. readings are not sensitive indicators of shell strength and that S.G. should be measured as precisely as possible to optimize the prediction. The use of S.G. to predict shell strength can be likened to looking at a scene through a pin hole camera in the wrong direction.

The accuracy of S.G. determinations are affected by a number of factors such as: a) as will be shown later, the temperature of the saline solutions; b) the accuracy of the hydrometer used to test the solutions; c) cracks in the shell; d) operator techniques, etc. The purpose of the work reported here was to examine some of these effects and determine the order of measurement accuracy that can be expected under presently applied methods. A number of these effects are well know but have not been examined systematically. An added objective was to determine if changes in procedure could be used to improve the accuracy of S.G. measurements. It was considered that even though S.G. is an imprecise predictor of shell strength, if S.G. is measured for this purpose, then it would be best to make the accuracy of the readings the best possible.

3. ANALYSIS OF THE EFFECT OF TEMPERATURE ON THE SPECIFIC GRAVITY OF SALINE SOLUTIONS

Specific gravity (S.G.) of a substance is the weight of a certain volume of that substance relative to the weight of an equal volume of water whose temperature is $4^{\circ}C$ (Harris and Hemmerling, 1955). The $4^{\circ}C$ temperature was originally chosen because this is the temperature at which water reaches its maximum density of 1.000 g/cc (Kell, 1967) (Fig. 1). Thus the S.G. of any substance is conveniently the ratio of its density at a specific temperature to unity. Thus to properly specify the properties of the substance both S.G. and its temperature must be cited. In industrial practice it is common to use a reference temperature of $60^{\circ}F$ ($15.56^{\circ}C$) because this is a more convenient temperature at which to make measurements (Considine, 1957). Thus the S.G. of the substance is based on the density of water at this temperature i.e. 1.00098792 g/cc, a value interpolated from the values given at 15 and $16^{\circ}C$ by Kell (1967).

A multitude of different S.G. scales have been developed for specific industrial applications such as the Balling for Brewing, the API for petroleum products, etc. (Considine, 1957). However, the hydrometers generally used for testing the saline solutions for egg S.G. measurements are calibrated in specific gravity units based on ratio of solution weight to weight of an equal volume of water at $60^{\circ}F$ ($15.56^{\circ}C$). The designation given is $60/60^{\circ}F$. Thus to be used accurately the solutions should be tested at $60^{\circ}F$. However this requires that the temperature of the solutions be controlled which is generally not attempted. Thus for example it is possible for the solution temperature to vary in Ottawa from about 22 to $34^{\circ}C$.

Generally for testing eggs, saline solutions ranging from about 1.06 to

1.10 S.G. units in increments of .004 or .005 are utilized. This requires sodium chloride (NaCl) concentrations ranging from about 9 to 15% (Table 1). The objective is to provide a range of S.G. solutions differing by fixed equal increments. To accomplish this at a constant temperature of 60^{o}F is a simple matter. However, if the temperature is uncontrolled the procedure becomes cumbersome as follows.

1. With the solution at some temperature T measure the S.G. with a hygrometer.
2. Determine the S.G. at 60^{o}F using a correction table.
3. Adjust the concentration until the correct S.G. (60^{o}F) is obtained.
4. During operation read the temperature of the solutions as it varies from T_1 to T_2 and correct the readings assigned to each egg to establish the S.G. of each egg at $60/60^{o}$F.

While at any given uniform temperature T the S.G. readings of individual eggs are comparable, temperature fluctuations of the saline solutions will affect the comparisons. This is evident when the variation of saline solution density with temperature is plotted from data given by Perry et al. (1963) (Fig. 2). From these data the variation of S.G. based on water at the same temperature can be calculated. Plots of these data (Fig. 3 and 4) show that the S.G. drops with increasing temperature to minimize at about 50^{o}C and then increases with temperature. The rate of change of S.G. with temperature for the solution concentrations used (say 8 to 15%) over the range of temperature changes expected (22 to 34^{o}C) ranged from 0.000093 to 0.000174 S.G. units/^{o}C. Or at most 0.0021 units for the maximum expected change in solution temperature. In the case of the solutions given (Table 1) about half an S.G. increment error. In view

of the other errors possible in the measurement this is negligible.

The above calculations are based on the S.G. as a ratio of the density of the saline solutions to the density of water at the same temperature. A more realistic estimate of the error should be provided by the ratio of the density of the saline solution at its temperature to the density of water at 60°F. This can be calculated from the data of Perry et al. (1963) and Kell (1967) and represents a measurement with one factor, the density of water, standardized. These data for 3 saline solution concentrations are given in Table 3. Plots of these data show that in the range of expected solution temperatures (22 to 34°C) the rate of change of solution S.G. with temperature that could be expected is in the range of 0.00045 S.G. units/°C. Thus a maximum error of 0.0054 S.G. units could be expected in the worst case due to uncontrolled solution temperature. This represents one S.G. increment in the experimental set-up used which must be considered significant.

Additional errors are introduced by temperature variation because this affects the volume of the egg, the density of the contents and shell and the volume of the air sac which all affect the S.G. of the egg. Generally eggs are collected and stored overnight in a cooler at 13°C (55°F). S.G. testing commences the following morning upon removal of the eggs from the cooler so that the first and last eggs tested are likely to be at different temperatures. Also, the cold eggs will cool the solutions by differing amounts. The temperature of the first S.G. solution will decrease the most because all eggs pass through this step, whereas only a small percentage of the eggs are passed through the final increment at the maximum S.G.

Table 1. Approximate sodium chloride (NaCl) concentrations required to provide a typical range of S.G. solutions for testing eggs.

S.G.	g of NaCl/litre
1.062	94.3
1.066	100.3
1.070	106.3
1.074	112.3
1.078	118.2
1.082	124.3
1.086	130.3
1.090	136.3
1.094	142.3
1.098	148.4
1.102	154.5

Table 2 - Density of sodium chloride (NaCl) and S.G. based on the ratio of saline solution density and density of water at the same temperature T/T°C.

Temperature	Density H_2O*	Concentration %									
		4		8		12		16		20	
°C	g/cc	ρ** g/cc	S.G.	ρ** g/cc	S.G.	ρ** g/cc	S.G.	ρ** g/cc	S.G.	ρ** g/cc	S.G.
0	0.999868	1.03038	1.03052	1.06121	1.06135	1.09244	1.09258	1.12419	1.124338	1.15663	1.156782
10	0.999728	1.02920	1.029335	1.05907	1.059209	1.089946	1.089603	1.12056	1.120707	1.15254	1.152692
25	0.997075	1.02530	1.028307	1.05412	1.057212	1.08365	1.086828	1.11401	1.117278	1.14533	1.148689
40	0.992247	1.01977	1.027738	1.04798	1.056168	1.07699	1.085405	1.10688	1.115528	1.13774	1.146629
60	0.983226	1.0103	1.027535	1.0381	1.05581	1.0667	1.084898	1.0962	1.114901	1.1268	1.146023
80	0.971819	0.9988	1.027763	1.0264	1.056163	1.0549	1.08549	1.0842	1.115639	1.1146	1.14692
100	0.958384	0.9855	1.028293	1.0134	1.057404	1.0420	1.087246	1.0713	1.117819	1.1017	1.149539

* From the data of Kell (1967)
** From the data of Perry et al. (1963)

Table 3 - S.G. of sodium chloride (NaCl) based on the ratio of the solution density at a given temperature* and the density of water at 60°F** (T/60°F).

Temperature °C	Concentration %	8		12		16	
		ρ g/cc	S.G.	ρ g/cc	S.G.	ρ g/cc	S.G.
0		1.06121	1.06016	1.09244	1.09136	1.12419	1.12308
10		1.05907	1.05802	1.08946	1.08839	1.12056	1.11946
25		1.05412	1.05308	1.08365	1.08258	1.11404	1.11294
40		1.04798	1.04695	1.07699	1.07593	1.10688	1.10579
60		1.0381	1.03708	1.0667	1.06565	1.0962	1.09512
80		1.0264	1.02539	1.0549	1.05386	1.0842	1.08313
100		1.0134	1.01240	1.0420	1.04097	1.0713	1.07024

* Taken from Perry et al. 1963.

** Extrapolated from data of Kell (1967) as a value of 1.00098792 g/cc.

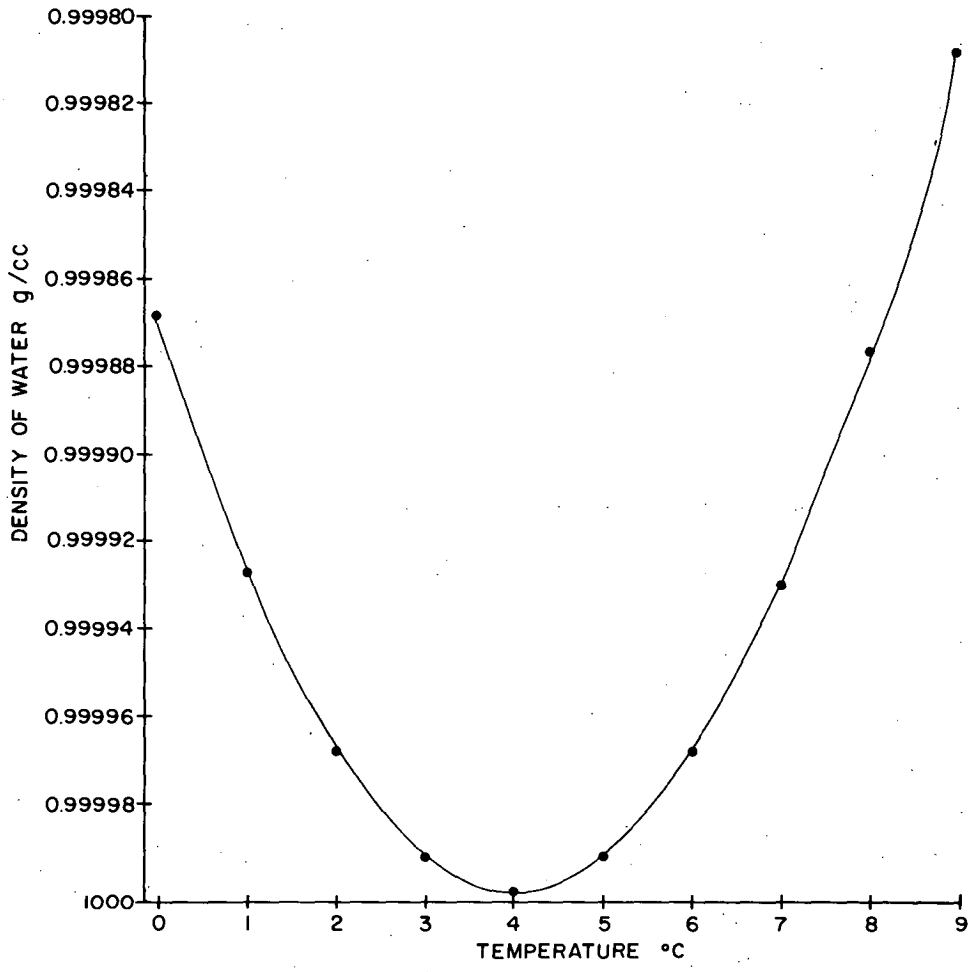

Fig. 1 - Density of water from 0 to 9°C showing maxima that occurs at 4°C. Plotted from the data of Kell (1967).

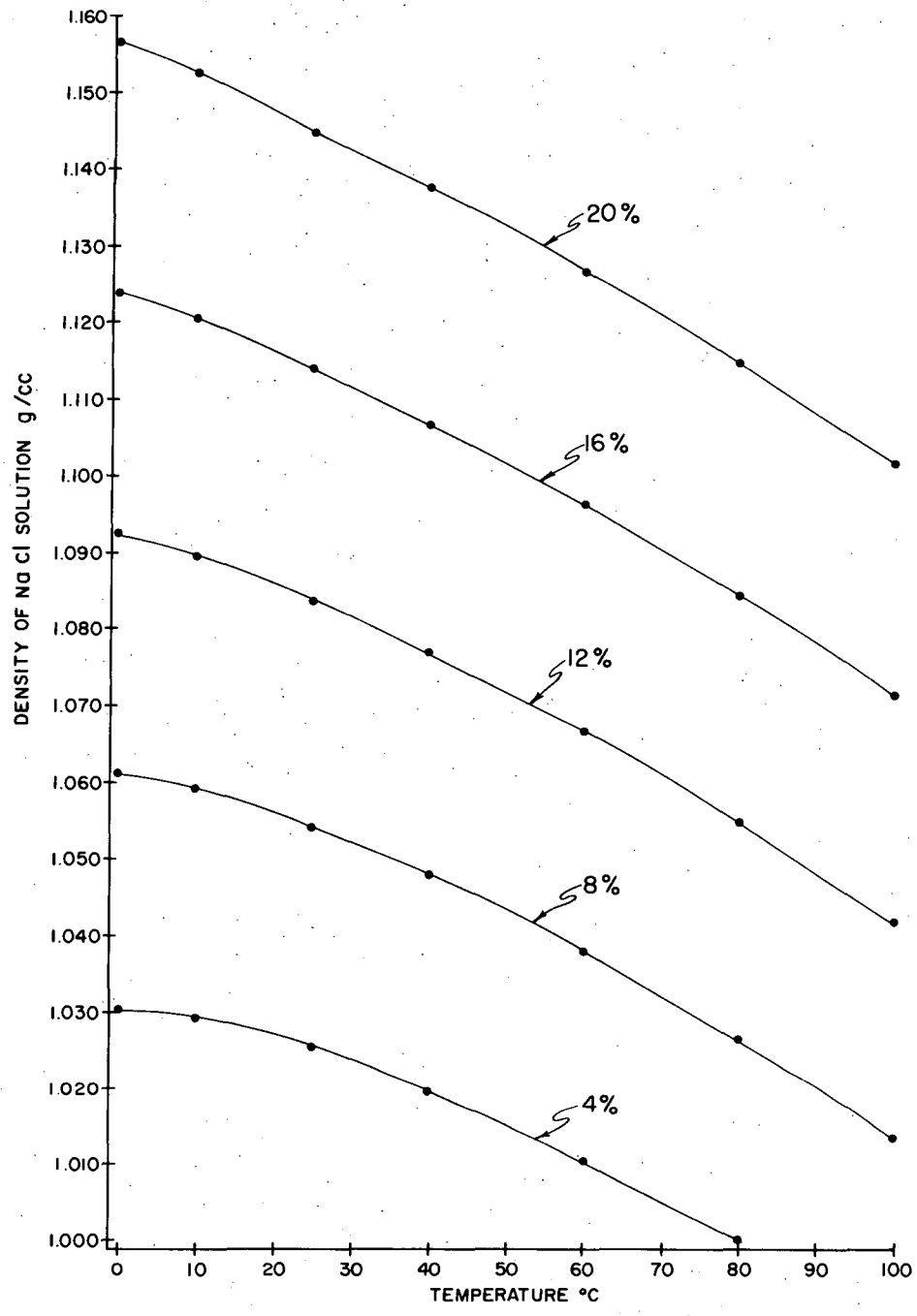

Fig. 2 - Variation of saline solution density with temperature. Plotted from the data of Perry et al. (1963).

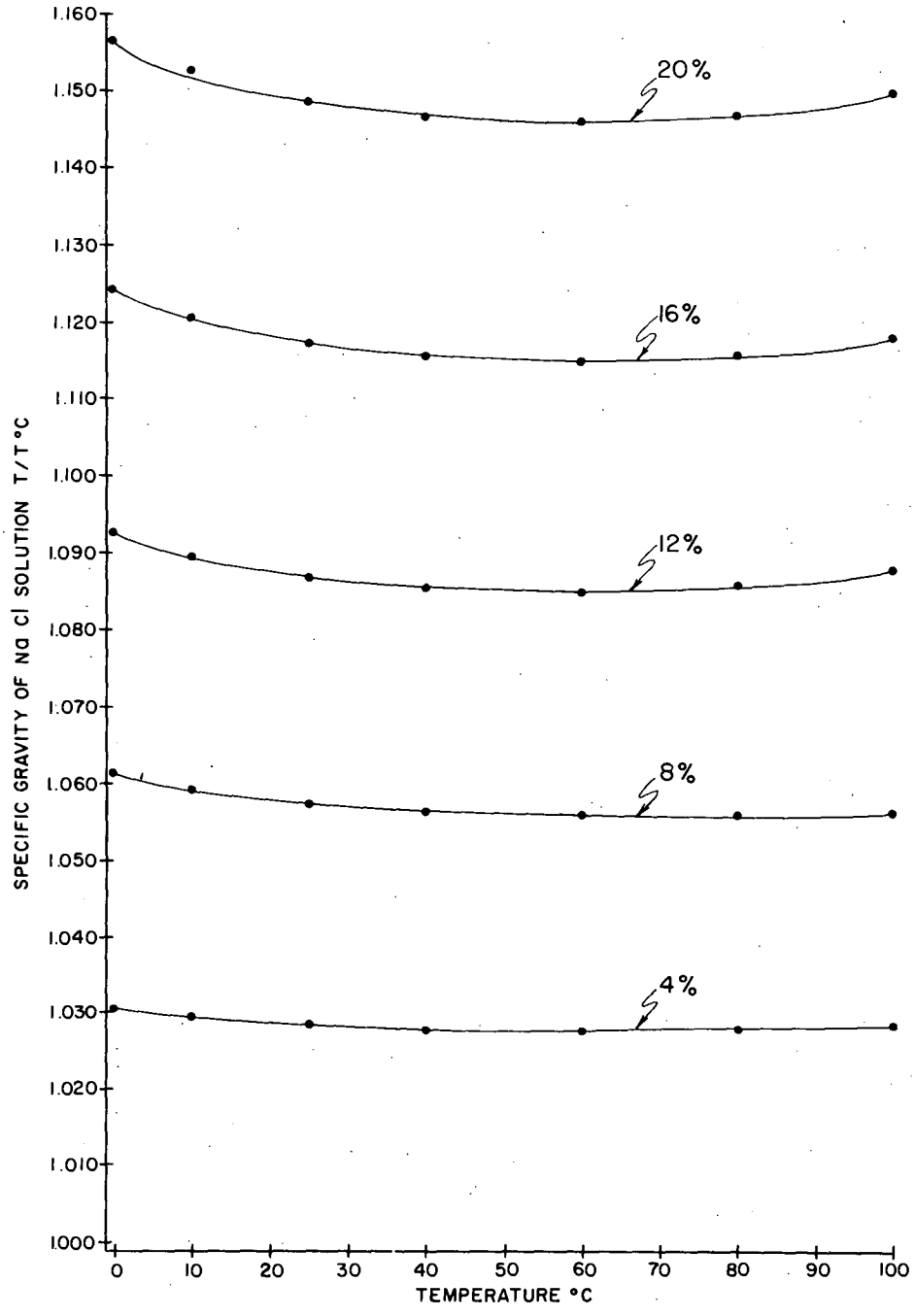

Fig. 3 - Plots of variation of S.G. of saline solutions of various concentrations with temperature. Based on the data of Kell (1967) and Perry et al. (1963). S.G. calculated from the ratio of the density of the solution and the density of water at the same temperature. ($T/T^{\circ}C$)

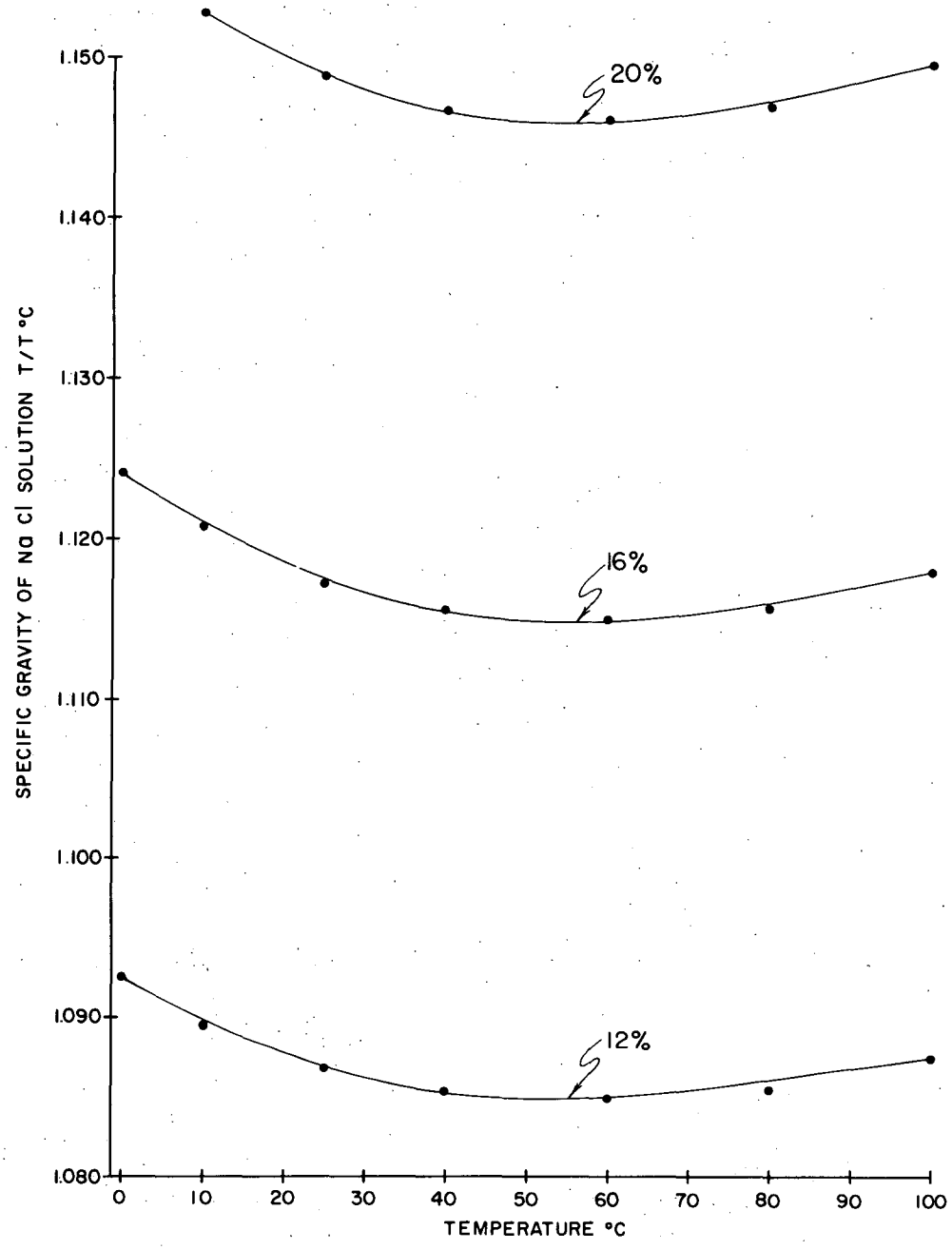

Fig. 4 - Plots of variation of S.G. of saline solutions of various concentrations with temperature. Based on the data of Kell (1967) and Perry et al. (1963). S.G. calculated from the ratio of the density of the solution and the density of water at the same temperature. ($T/T^{o}C$)

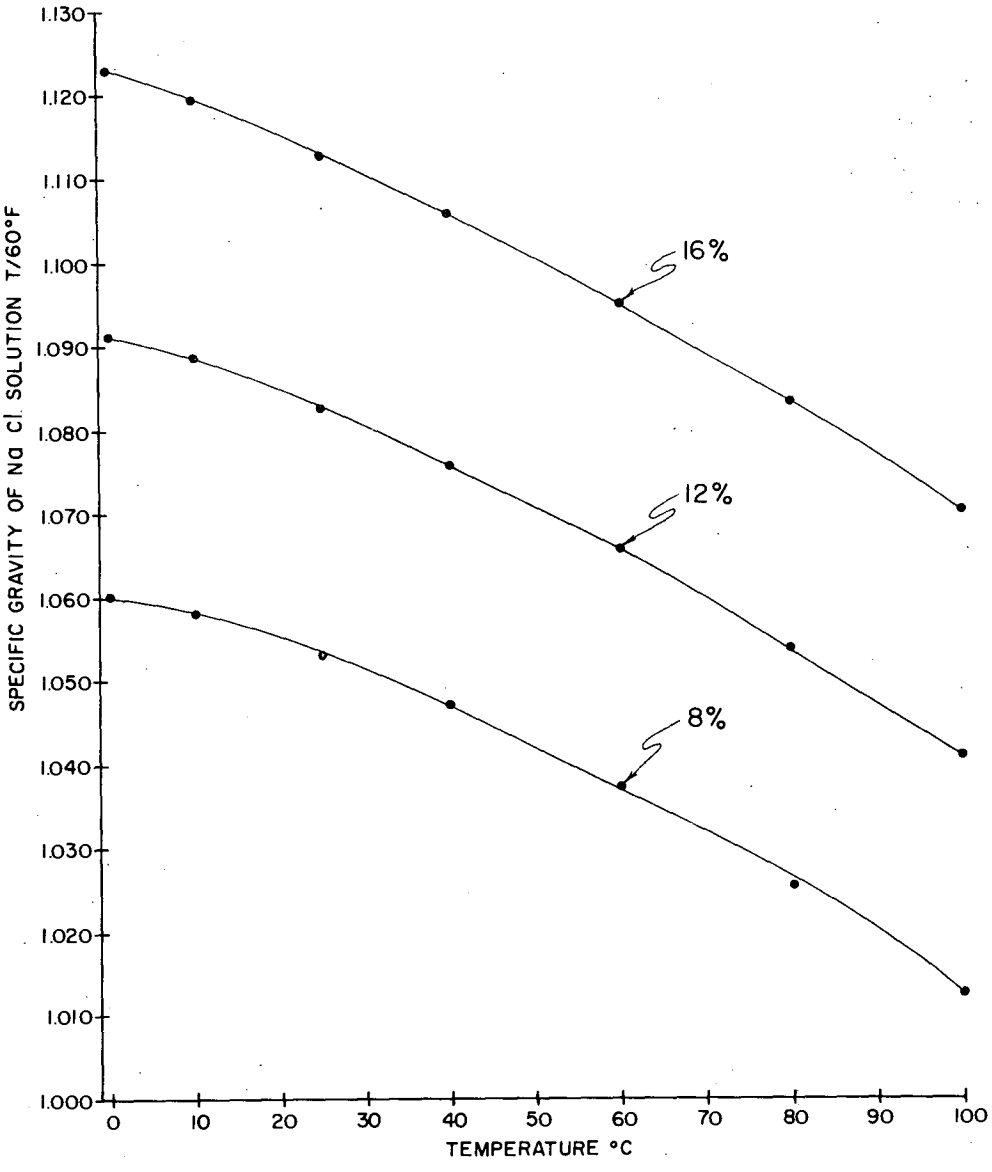

Fig. 5 - Plots of variation of S.G. with temperature for 3 saline solution concentrations where the S.G. is calculated as the ratio of the solution density at its temperature to the density of water at 60^{o}F using the data of Perry et al. (1963) and Kell (1967). T/60^{o}F.

4. GENERAL EXPERIMENTAL TECHNIQUES

4.1. Source of Eggs Tested

Eggs used in this experiment were collected from four flocks of White Leghorn hens. The flocks were selected so that the eggs used for the tests had a wide range of shell quality because of differences in age, diet and strains included in the flocks:

Flock A - Comprised of 110 birds, 264 days old at the start of the experiment and included 2 strains (07 Kentville control and Strain 10). The flock was maintained on the Ottawa Hatching Ration (1970) which contained 3.1% calcium.

Flock B - Comprised of 525 birds, 489 days old at the start of the experiment and included 8 strains (3 commercial; 07 Kentville control and four 2-way crosses). The birds were maintained on a 3.25% calcium laying diet.

Flock C - Comprised of 475 birds 489 days old at the start of the experiment and included the same strains as flock B. The flock was maintained on a low calcium diet:

Age	
0 to 144 days	- 0.51%
145 to 327 days	- 2.25%
328 to 504 days	- 3.25%

Flock D - Comprised of 550 birds 264 days old at the start of the experiment and included the same strains as flock A. This flock was maintained on a basal diet of the Ottawa Hatching Ration (1970) with groups of the birds receiving 3 different levels of ammonium sulphate.

The collection and testing of all the eggs in this experiment was completed in a period of 9 days.

4.2. Specific Gravity Measurement Facilities

Eleven saline solutions were prepared to provide S.G. increments of 0.004 (Table 1) and a range of 1.062 to 1.102. Two sets of solutions, designated X and Y were made up for the experiment. The solutions were made up in quantities of 35 l and each stored in a 40 l plastic garbage pail. When not in use the lids were installed on the pails.

The pails were kept in a large environmental chamber maintained at 60 ± 1°F and 72 ± 2% relative humidity for the duration of the experiment. The solutions were made up 3 days prior to commencing the experiment so that the temperature of the solutions was constant at 60°F. Before taking any egg S.G. readings the temperature and S.G. of each solution was measured at each phase of the different tests performed. This showed that the temperature and S.G. of each solution did not change measurably throughout the test.

4.3. Specific Gravity Standard for Solutions

The specific gravity of the solutions was measured with a single hydrometer which had a range of 1.060 to 1.130. This was designated as hydrometer number 1 and arbitrarily adopted as the standard of measurement for the experiments. The hydrometer was calibrated to read at 60/60°F. The National Bureau of Standards recommendations for reading the hydrometers was followed. Namely the reading was taken at a point where the liquid surface intersected the graduated stem, not at the top of the meniscus.

4.4. Method of Measuring Specific Gravity

The method currently used by the Animal Research Institute was adopted for all S.G. readings taken in the pails. About 30 eggs were placed in a wire basket to form a layer on the bottom. The

basket was then slowly immersed into the pail containing the lowest S.G. solution and gently rotated and raised up and down to eliminate any air bubbles adhering to the eggs. The basket was then allowed to rest at about two thirds of the solution depth where the diameter of the basket and the gradually tapering diameter of the pail were equal. Sufficient time was allowed to elapse for the solution to stabilize, to observe and remove those eggs that floated and broke the surface of the liquid. This procedure was repeated at each ascending increment of S.G. until the S.G. of all the eggs in the group was determined. The eggs were carefully drained between each determination to minimize the transfer of solution between pails.

5. DIFFERENCES IN READINGS BETWEEN HYDROMETERS

A possible source of error is the calibration of the hydrometer used and how accurately it is read. The latter depends on the skill of the operator and the range of the instrument since this affects the resolution.

The temperature of each solution in sets X and Y was checked and the S.G. verified as being correct at $60^{o}F$ using the standard hydrometer (No. 1). The S.G. of each solution in both sets was then read using 9 other $60/60^{o}F$ hydrometers having the same or different ranges to the standard. The difference between the standard reading and each reading was then calculated.

The results (Table 4) showed that the maximum difference between the hydrometers and the arbitrary standard was a 0.006 change in S.G. In general, the errors recorded were consistent within hydrometers and within the two solution sets. However, the errors were both positive and negative. Thus, within the group of hydrometers tested the average differences ranged from +0.003 to -0.005 for a total range of 0.008 specific gravity units. This represents two increments of S.G. used to test eggs.

An observation made during this test was that depending on the range of the hydrometer (i.e. resolution of its scale) it was difficult to estimate the reading to within ±0.00025 . Judgement was required because the solution surface was below the rim of the pail and it was difficult to observe the intersection of the surface and hydrometer scale. Parallax introduced errors particularly with hydrometers having a large range. With the hydrometers normally used which had a range of 1.060 to 1.130 it was considered that judgement introduced a maximum error of 0.0005 .

Thus, it must be concluded that errors in egg S.G. readings may arise from differences in the hydrometers used to test the solutions.

Table 4. Summary of differences observed between readings from different hydrometers in measuring the specific gravity of two sets of salt solutions using one hydrometer (No. 1) as the arbitrary standard. All hydrometers are calibrated at 60/60°F and all measurements were made at 60°F.

Hydrometer number		1*	2	3	4	5	6++	7	8	9	10
Range	Maximum	1.130	1.220	1.220	1.070	1.100	1.600	1.070	1.200	1.130	1.130
	Minimum	1.060	1.000	1.000	1.000	1.050	1.000	1.000	1.000	1.060	1.060

Solution set		Difference**																	
		X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
	1.062	+2	+2	+2	+2	0	0	-2	0	-3	-	+1	+1	-5	-3	0	-1	-1	-1
	1.066	+2	+2	+2	+2	0	0	-1	0	-4	-	+1	+1	-4	-4	0	-1	-1	-1
	1.070	+2	+4	+2	+2	0	0	-1	0	-5	-	+1	0	-2	-2	0	-1	-1	-1
	1.074	+2	+4	+2	+2	-	-	-1	+4	-6	-	-	-	-1	-1	0	-1	-1	-1
	1.078	+2	+4	+2	+2	-	-	-2	+4	-5	-	-	-	-2	-2	0	-1	-1	-1
	1.082	+2	+2	+2	+2	-	-	-2	+4	-5	-	-	-	-3	-1	-1	-1	-1	-1
	1.086	+2	+2	+2	+2	-	-	-2	-1	-4	-	-	-	-4	-1	-1	-1	-1	-1
	1.090	+2	+2	+2	+2	-	-	-2	-1	-6	-	-	-	-5	0	-1	-1	0	-1
	1.094	+2	+2	+2	+2	-	-	-3	-1	-	-	-	-	-4	-1	-1	-1	-1	-1
	1.098	+2	+4	+2	+4	-	-	-1	-1	-	-	-	-	-2	-2	-1	-1	0	-1
	1.102	+2	+2	+2	+2	-	-	-1	-1	-	-	-	-	-3	-3	-1	-1	-1	-1
Mean error+		+2	+3	+2	+2	0	0	-2	+1	-5	-	+1	+1	-3	-2	-1	-1	-1	-1

*This is the hydrometer used as the arbitrary standard for the experiment and solutions. X and Y were adjusted so that they were correct according to readings from this unit.

**Difference = Reading from No. 1 - Reading from test hydrometer. Differences are given in 0.001 units of specific gravity.

+Given to the nearest 0.001 units of specific gravity.

++This hydrometer was accidently broken during test.

6. CALIBRATION OF THE STANDARD HYDROMETER

An experiment was conducted to verify the calibration of the arbitrary standard hydrometer by comparing its readings with gravimetric determinations of the S.G. of the solutions. Again the entire experiment was conducted in the environmental chamber so that all solutions and test equipment were at 60^{o}F.

The temperature and S.G. of each solution in both sets X and Y was verified. The S.G. of each solution was then measured by gravimetric methods using a pyknometer (or specific gravity bottle) following the procedure outlined by Harris and Hemmerling (1955). The capacity of the S.G. bottle used was 100 cc. All weighings were done on a 160 g capacity balance reading to within 1 mg.

The detailed procedure was as follows:

1. Weigh the clean dry bottle (W_B).
2. Fill with double distilled water and reweigh (W_W).
3. Fill and flush with salt solution to be tested twice and reweigh filled with solution (W_{SG}).

For each measurement the exterior of the bottle was carefully dried and it was rinsed once with distilled water after each S.G. solution was tested. Each solution of both the X and Y sets was tested in this manner. Specific gravity was calculated from:

$$S.G. = \frac{W_{SG} - W_B}{W_W - W_B}$$

A comparison of the hydrometer readings and the gravimetric determinations (Table 5) showed that the maximum error in the hydrometer readings was 0.0018 S.G. units. and the minimum error was 0.0008. The hydrometer gave readings that were consistently lower than the S.G. according to gravimetric determinations in both sets of solutions. On the average the error appeared slightly larger (0.0003 S.G. units) for solution set Y compared to set X. This could not be explained and is probably insignificant. The errors did not appear to be related to the S.G. reading since their magnitude varied at random with level of the S.G. reading. Thus, it would appear that a typical hydrometer may give readings in error by as much as about half the S.G. increment between the solutions.

Table 5. Comparison of hydrometer readings (60/60°F) with gravimetric determinations of salt solution S.G.'s at 60°F for two sets of solutions (X & Y).

S.G. from hydrometer reading*	Specific gravity from gravimetric measurements			
	S.G. (X)	Difference**	S.G. (Y)	Difference**
1.062	1.0634	-0.0014	1.0637	-0.0017
1.066	1.0670	-0.0010	1.0671	-0.0011
1.070	1.0710	-0.0010	1.0708	-0.0008
1.074	1.0750	-0.0010	1.0752	-0.0012
1.078	1.0788	-0.0008	1.0791	-0.0011
1.082	1.0828	-0.0008	1.0830	-0.0010
1.086	1.0873	-0.0013	1.0877	-0.0017
1.090	1.0910	-0.0010	1.0914	-0.0014
1.094	1.0955	-0.0015	1.0958	-0.0018
1.098	1.0995	-0.0015	1.0998	-0.0018
1.102	1.1032	-0.0012	1.1038	-0.0018
Mean		-0.0011		-0.0014

*Solutions adjusted to give the correct reading at 60°F using hydrometer No. 1, the arbitrary standard.

**Difference = Hydrometer reading-gravimetric

7. COMPARISON OF S.G. READINGS AT TWO LOCATIONS, ONE WITHOUT TEMPERATURE CONTROL

A comparison was made between S.G. readings obtained in a facility used routinely for this purpose and the controlled temperature test facility. The routinely used facility was not equipped with temperature controls for either the saline solutions or the ambient temperature apart from the normal heating used in winter.

Eggs were collected from flocks A, B and C at the following times and in the quantities shown.

Flock	Time	Egg numbers
A	8:00 am	14-60
	10:30 am	1-13
B	8:15 am	145-160
	10:30 am	101-144
C	8:15 am	244-260
	10:30 am	201-243

The eggs were placed in storage at 11:00 am at a temperature of 55°F (13°C) wet bulb and stored overnight . The following morning the S.G. of the 11 solutions was measured with the hydrometer normally used in the routine facility and the arbitrary standard hydrometer for the experiment. The temperature of the solutions was also measured. The eggs were removed from storage at 9:20 am (i.e. 10.3 hr storage time) and candled. Any cracked shells were discarded. Their S.G. was determined in the period between 9:45 and 10:30 am. The air temperature during the tests was 76°F (24.5°C). The temperature of the solutions was then remeasured and the S.G. checked with the routinely used hydrometer. The eggs were rinsed with water and immediately transferred to the controlled environment chamber. Three hours were then allowed for the temperature of the eggs to stabilize at 60°F. The eggs

were candled and any with cracked shells discarded. The S.G. of the eggs was then determined on the two sets of solutions (X and Y) during the period 2:00 to 5:00 pm. The specific gravity of the solutions and their temperature were measured before and after the tests.

The results for the S.G. and temperature readings of the solutions at the routine facility (Table 6) showed that a) the S.G. readings were the same within 0.001 for the arbitrary standard and routine hydrometers; the S.G. of the solutions were stable within 0.0005 during the 45 minute operation; the temperature of the solutions were not changed by more than $0.5^{o}F$ by testing the 179 eggs. Thus, it would appear that for small quantities of eggs the cooling effect of the chilled eggs on the solution temperatures was negligible. Similarly in the controlled temperature test facility the temperature of the solutions was stable throughout the measurements. The S.G. of these solutions showed a maximum change of 0.001 after testing the 179 eggs. In the experimental and the routine facilities the observed S.G. changes occurred randomly throughout the S.G. range indicating that the source was quite likely errors in reading the hydrometers.

A summary of the results (Table 7) showed that the differences between the mean values of S.G. and the variation within flocks and within the experiment were insignificant. The maximum difference between any of the mean readings from the uncontrolled and controlled temperature facility including the two sets of solutions (X and Y) was 0.0015 units of S.G. This indicates that a temperature difference between the solutions of about $11^{o}F$ and between the air of about $16^{o}F$ and the unknown temperature differences between the eggs when tested at the two facilities did not seriously affect the over-all result. However, it should be noted that the temperature differences were less than those that can possibly occur.

On an individual egg basis there were differences observed between the readings obtained in the two measurement facilities. These were all within one increment (i.e. 0.004) of S.G. reading but were both positive and negative (Table 8). About the same number of eggs gave different readings in solution sets X and Y. For 53% of the eggs where a difference was observed, the same difference occurred in both sets of solutions X and Y. The remaining 47% showed a difference in only one of the solutions. Thus, it would appear that the differences in readings must be attributed to two sources a) a real difference in reading; b) differences introduced by judging the solution in which the egg floats.

Table 6. Comparison of solution S.G.'s as indicated by two hydrometers and temperature changes during testing 179 eggs in a facility without temperature controls

Hydrometer:	Standard (No. 1)	Routine		Solution temperature °F		
Time of measurement:	Before	Before	After	Before	After	Difference*
	1.0620	1.0620	1.0615	70.0	69.5	0.5
	1.0657	1.0655	1.0660	70.0	70.0	0.0
	1.0700	1.0695	1.0695	70.5	70.5	0.0
	1.0740	1.0735	1.0735	70.8	70.8	0.0
	1.0780	1.0780	1.0785	70.5	70.5	0.0
	1.0820	1.0820	1.0820	70.5	70.5	0.0
	1.0860	1.0860	1.0860	70.8	71.0	-0.2
	1.0900	1.0910	1.0905	71.0	71.0	0.0
	1.0940	1.0940	1.0940	71.0	71.2	-0.2
	1.0980	1.0980	1.0985	71.5	71.8	-0.3
	1.1020	1.1025	1.1025	72.0	72.2	-0.2
			Mean	70.8	70.8	

*Difference = Before - After

Table 7. Summary of results comparing egg S.G. readings obtained in a facility without temperature control used routinely to test eggs and the experimental facility where the temperature was controlled at 60°F.

Location at which measurements were taken			Routine facility without temperature control	Experimental facility controlled at 60°F	
Flock	No. of eggs	Trait		Solution set X	Solution set Y
A	60	Mean S.G.	1.0846	1.0836	1.0831
		S.D.	0.0056	0.0056	0.0055
		C.V. %	0.51	0.52	0.50
B	60	Mean S.G.	1.0811	1.0798	1.0795
		S.D.	0.0056	0.0062	0.0060
		C.V. %	0.52	0.57	0.56
C	59	Mean S.G.	1.0807	1.0798	1.0794
		S.D.	0.0069	0.0073	0.0072
		C.V. %	0.64	0.68	0.66
A,B and C pooled		Mean S.G.	1.0821	1.0811	1.0807
		S.D.	0.0074	0.0077	0.0076
		C.V. %	0.68	0.72	0.71

Table 8. Number of eggs for which the difference in S.G. indicated by the tests in the uncontrolled and controlled temperature measurement facilities was 0.004 S.G. units.

Flock	No. of eggs	Solution set X	Solution set Y
A	60	15	22
B	60	20	24
C	59	14	21
Pooled	179	49	67
Sign of differences		All positive	Positive and negative

8. SELECTION OF EGGS FOR TWO EXPERIMENTS

To obtain a wide range of eggshell quality with a uniform distribution of egg S.G. for two experiments, the following procedure was used.

Eggs were collected from flocks A, B, C and D that were laid between 1:00 am and 1:30 pm in the following quantities.

Flock	Eggs collected	Cracked eggs discarded
A	78	2
B	289	15
C	190	7
D	355	3
Total	912	27

The eggs were candled and those with cracked shells discarded. The remaining 885 were placed in the controlled environment chamber at 4:30 pm and stored for 63.5 hr. It was assumed that this period allowed the air sacs in the eggs to stabilize so that the egg S.G.'s also stabilized. The specific gravity of all the eggs was then determined for each flock (Table 9) in the period from 10:00 am to 3:00 pm.

Eggs were then selected according to specific gravity so that as far as was possible equal numbers from each flock and each increment of S.G. were collected to provide a composite sample of 115 eggs (Table 9). These eggs were used to examine the effect of saline solution temperature on egg specific gravity readings (see paragraph 10).

A similar procedure was used to select 116 eggs (Table 9) to examine the effect of cracked shells on egg specific gravity readings (see paragraph 9).

The results of these S.G. readings showed that the distribution of egg S.G.'s within flocks was different (Fig. 6). A

frequency diagram for all the eggs (Fig. 7) shows that it was possible to select almost equal numbers of eggs from each S.G. level for the two experiments. Exceptions were the two highest increments (1.098 and 1.102) where insufficient eggs were obtained. However, a wide spread of egg S.G. of almost uniform distribution was achieved for both expeirments.

Table 9. Eggs selected for two experiments showing total number of eggs of each S.G. collected by flocks, and the number of eggs selected from each flock at each S.G. to provide eggs for the experiments.

Specific gravity	1.062	1.066	1.070	1.074	1.078	1.082	1.086	1.090	1.094	1.098	1.102	Total
Flock A	1	1	0	8	20	21	16	8	1	0	0	76
Flock B	19	14	28	68	70	47	19	8	0	0	1	274
Flock C	12	7	29	37	50	27	17	4	0	0	0	183
Flock D	2	5	8	67	59	111	68	19	12	1	0	352
Total	34	27	65	180	199	206	120	39	13	1	1	885
Eggs selected to examine the effect of saline solution temperature on egg S.G.												
Flock A	1	1	0	4	3	3	3	3	1	0	0	19
Flock B	4	4	4	3	4	3	3	3	0	0	1	29
Flock C	4	4	4	4	4	3	3	3	0	0	0	29
Flock D	2	4	4	4	4	3	3	3	10	1	0	38
Total	11	13	12	15	15	12	12	12	11	1	1	115
Eggs selected to examine the effect of cracks in the shell on the egg S.G.												
Flock A	0	0	1	4	4	4	4	5	0	0	0	22
Flock B	5	5	4	4	4	4	4	5	0	0	0	35
Flock C	5	3	4	4	4	4	4	3	0	0	0	31
Flock D	0	2	4	4	4	4	4	4	2	0	0	28
Total	10	10	13	16	16	16	16	17	2	0	0	116

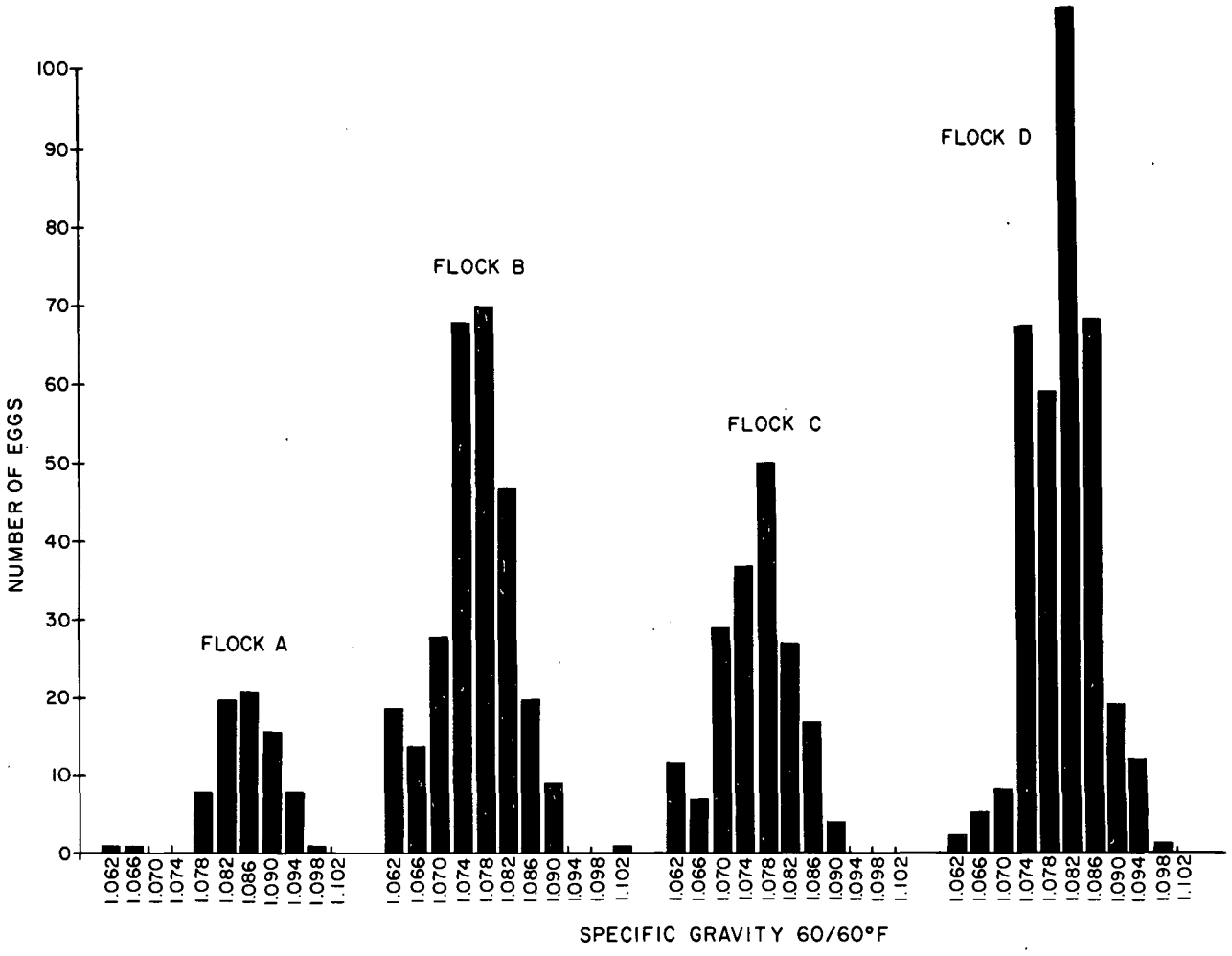

Figure 6. Distribution of egg S.G. by flocks for flock A, B, C and D.

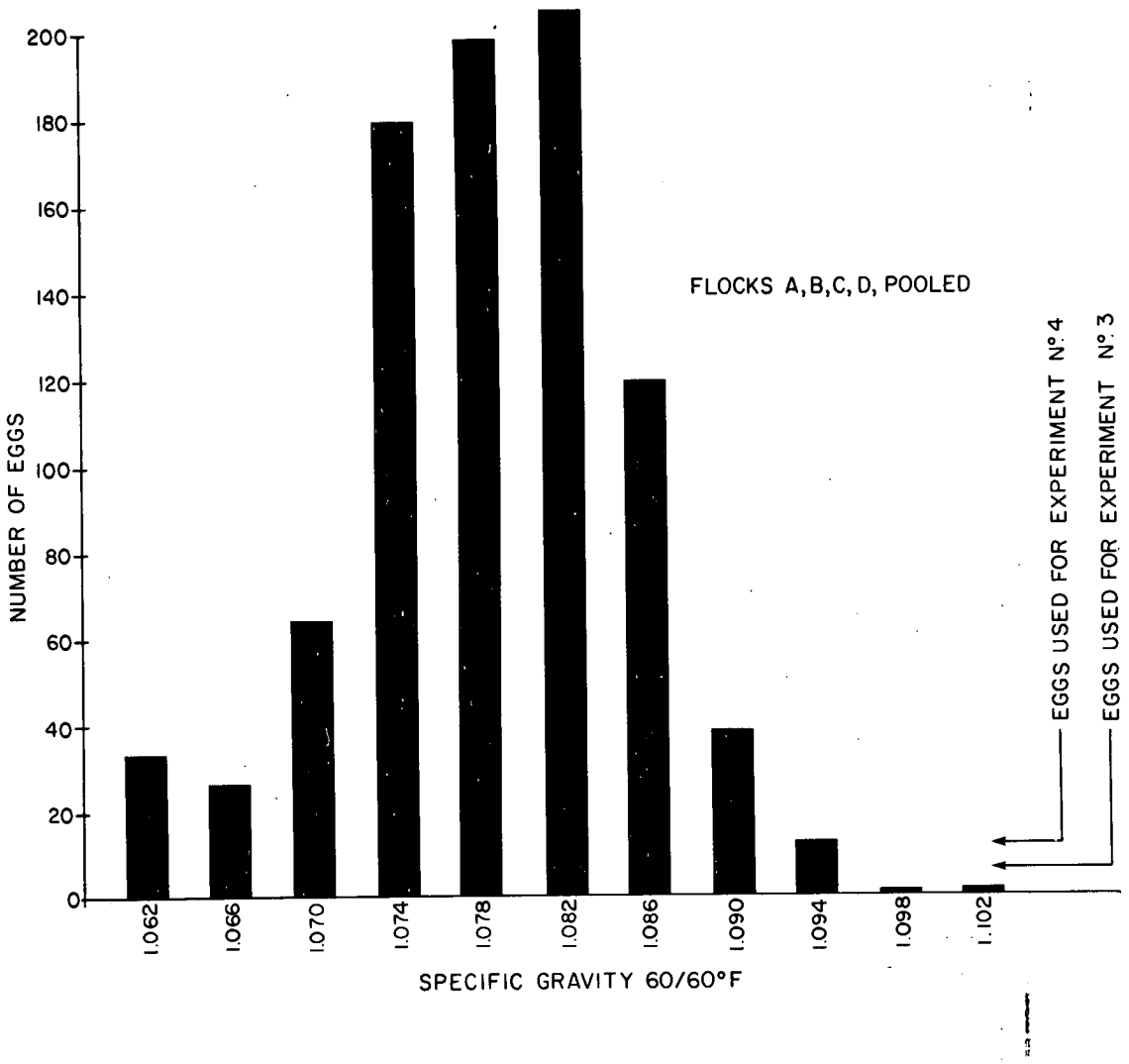

Figure 7. Distribution of egg S.G. for all the eggs from flocks A, B, C and D pooled.

9. THE EFFECT OF CRACKED SHELLS ON EGG SPECIFIC GRAVITY READING

It is customary to discard any eggs with cracked shells before taking shell quality measurements. Also, when measuring S.G. by floatation eggs are occasionly cracked as they are moved from solution to solution in the wire basket. An experiment was, therefore, conducted to examine the effect of shell cracks on egg S.G. Obviously, it would be an advantage, experimentally, to measure the S.G. of cracked as well as unbroken shells since cracked shells in all probability are the weak shells within a given group.

The 116 eggs selected as shown in paragraph 8 were utilized. Testing commenced 90.5 hr after the eggs were first stored in the controlled temperature chamber and the tests completed in a period of 4.5 hr.

The S.G. of the eggs was measured in one set of the solutions (X). A compression machine previously moved into the chamber to reach the test temperature ($60^{o}F$) was used to crack the shells under controlled conditions. Each egg was placed between ground stainless-steel flat, parallel surfaces and compressed at 5 cm min^{-1} at the equator. Immediately the shell cracked compression was stopped. Cracking was detected by the sound. This procedure produced a single hairline crack in the shell originating at one of the points of contact with the compression surfaces. The S.G. of the eggs was then again determined.

The results showed that the S.G. of 23% of the eggs after cracking decreased by one increment (0.004) (Table 10). However, the mean S.G. for the group of eggs was only reduced by an insignificant amount (0.001) and the variation within the group was unchanged. Thus, it would appear that the changes introduced by hairline cracks are small and possibly depended as much on the judgement exercised in selecting the eggs that floated in each solution as on the effect of the crack. It was concluded that it was reasonable to test cracked eggs and expect accurate S.G. readings.

However, it should be noted that the immersion times in the solutions during the experiment were short (e.g. compared with the procedures used in the routine facility). It would be reasonable to expect reading errors to increase with immersion time.

Table 10. Effect of shell cracks on egg specific gravity based on readings for 116 eggs before and after cracking.

	S.G.	
	Before cracking	After cracking
Mean	1.077	1.076
S.D.	0.0095	0.0095
C.V. %	0.88	0.88
Maximum difference*		0.004
Number of eggs that changed 0.004 S.G. units after cracking		27

*S.G. before - S.G. after, 24 eggs reduced in S.G. by 0.004 after cracking

10. THE EFFECT OF SALINE SOLUTION TEMPERATURE ON EGG SPECIFIC GRAVITY READINGS

As discussed in paragraph 3 the temperature of the saline solutions affects the specific gravity reading. This was investigated using the 115 eggs selected as outlined in paragraph 8. The test was started 110.5 hours after the eggs were first stored in the controlled environment chamber. The entire test procedure was completed within a period of 57 hr.

It was not practical to change the temperature of the saline solutions in the pails rapidly enough to execute the experiment so an alternative method was used. Eleven 600 cc beakers were immersed in a controlled temperature water bath installed in the controlled environment chamber. About 500 cc of each of the S.G. solutions was placed in the set of beakers to provide a set of solutions that could have their temperatures changed rapidly. The solutions used in the beakers were taken from the pails making up solution set Y and the ordinary S.G. determinations at 60^{o}F were also taken in set Y. Thus, all measurements were taken in solutions from the same source. Plastic lids were installed on each beaker to prevent evaporation. To take readings in the beakers a wire loop formed into a cradle was used to lower and raise the egg in the solution. To minimize transfer of solution between beakers the egg and wire cradle were wiped between determinations.

The S.G. and temperature of the solutions in the pails was verified and then the set of beakers filled. The water bath temperature was set at 55^{o}F and sufficient time allowed to elapse for the solutions in the beakers to stabilize at 55^{o}F.

The eggs were numbered and their S.G. determined in solution set Y and these readings marked on each egg. The reading marked on the egg was used to minimize the transfer of solution between beakers and reduce the number of immersions required in both the pails and beakers. The egg was placed in the wire cradle and first immersed in the pail corresponding to the previously determined S.G. It was then verified that the egg did not float in the pail of solution one increment below this reading or, if necessary two or three increments less. A similar procedure was followed with the beakers. Each egg was tested individually first in the pails and immediately after in the beakers. Thus, for practical purposes the two readings were obtained simultaneously. When the 55°F test was complete, the solutions in the beakers were discarded and a fresh set installed in the controlled temperature water bath. This entire procedure was repeated with the solutions in the beakers stabilized at 60, 65, 70, 75, 80 and 85°F. Finally the procedure was repeated at 60°F.

The temperature and S.G. of the solutions in the pails was verified at each increment of beaker solution temperature and adjusted if necessary.

The eggs were removed from the chamber and allowed 6 hours to warm up to room temperature. The shell strength was then measured by compressing the eggs at the equator at 2 cm min^{-1} between ground stainless steel parallel flat surfaces. The non-destructive deformation for a change in applied force of 0.1 to 1.1 kg and the fracture force were recorded electronically using techniques described by Voisey and Hunt (1973, 1974), Voisey (1975) and Voisey and Hamilton (1976). These measurements were known to be precise within at least 1%. A piece of shell was then removed

from the shell membranes at the point of contact where the fracture initiated and its thickness measured within 0.00025 mm with a dial guage comparitor (Voisey and Hunt 1973, 1974).

A summary of the S.G. readings (Table 11) showed that there was no difference between the means and standard deviations determined in the pails and beakers when the solutions they contained were all at $60^{o}F$. This was observed at the start of the test and at the completion. Thus, it is reasonable to assume that any differences between the readings from the pails and beakers, when the beakers were at temperatures different from $60^{o}F$, could be attributed to a change of solution temperature, particularly as the readings were effectively taken simultaneously.

The difference between the mean S.G. reading at $60^{o}F$ and the S.G. at other temperatures increased as the temperature difference between the solutions increased (Table 12). The maximum difference of 0.0037 S.G. units occurred at $80^{o}F$ or almost one increment in the set of solutions. As the temperature of the saline solutions increased, the egg S.G. readings increased (Fig. 8A). From a plot of the data (Fig. 8A) it appeared that the error was linearly related to temperature with a slope of 0.00019 S.G. units per ^{o}F (i.e. 0.00033 units/^{o}C). This is in reasonable agreement with the rate of 0.00045 units/^{o}C calculated from the theoretical analysis in paragraph 3. Thus, the experimental results confirmed the analysis and support the contention that temperature of the saline solutions affeets the egg S.G. readings.

Variation of S.G. within the group of eggs was virtually constant each time the S.G. was determined in either the pails or beakers and was virtually the same for pail and beaker determinations (Table 11).

The mean S.G. of the group of eggs increased during the experimental period (Table 12, Fig. 8B). This was verified by comparing readings made in the pails at the start of the test and the final determination (Fig. 8). Thus, the eggs changed with time. However, this did not affect the comparison of the S.G.'s at the different temperatures since these were made effectively in zero time.

Table 11. Comparison of specific gravity determined in garbage pails with the saline solution at 60°F and in beakers at selected temperatures. Means and standard deviations for 115 eggs.

Measurement	S.G. determined in the pails at 60°F		S.G. determined in beakers at temperatures specified		
	Mean	S.D.	Mean	S.D.	Temperature °F
First determination*	1.0766	0.0102	-	-	-
Varying beaker temp.**	1.0765	0.0103	1.0764	0.0102	55
	1.0766	0.0102	1.0766	0.0102	60
	1.0762	0.0103	1.0771	0.0105	65
	1.0749	0.0100	1.0767	0.0107	70
	1.0747	0.0101	1.0774	0.0107	75
	1.0745	0.0101	1.0782	0.0107	80
	1.0743	0.0101	1.0787	0.0111	85
Final determination+	1.0735	0.0100	1.0735	0.0100	60

*First determination made to mark S.G. on eggs 110.5 hr after the eggs were placed in storage.

**Determinations made first in the pails at 60°F and then in the beakers at the temperatures shown.

+Final determination made 167.5 hr after the eggs were placed in storage.

Table 12. Changes in mean egg S.G. during the experiment and differences between mean S.G. at 60°F in the pails and at temperatures ranging from 55 to 85°F in the beakers for 115 eggs.

Beaker temperature	Difference in S.G. readings*	Change in egg S.G. at 60°F*
55	+0.0001	0.0000
60	0.0000	+0.0001
65	-0.0009	-0.0003
70	-0.0018	-0.0016
75	-0.0027	-0.0018
80	-0.0037	-0.0020
85	-0.0034	-0.0022
60	0.0000	-0.0020

*Difference = S.G. at 60°F in pail - S.G. at temperature in beaker.

**Difference = S.G. at 60°F in pail (first determination) - S.G. at 60°F in pail (determinations made at time of beaker readings at temperature selected).

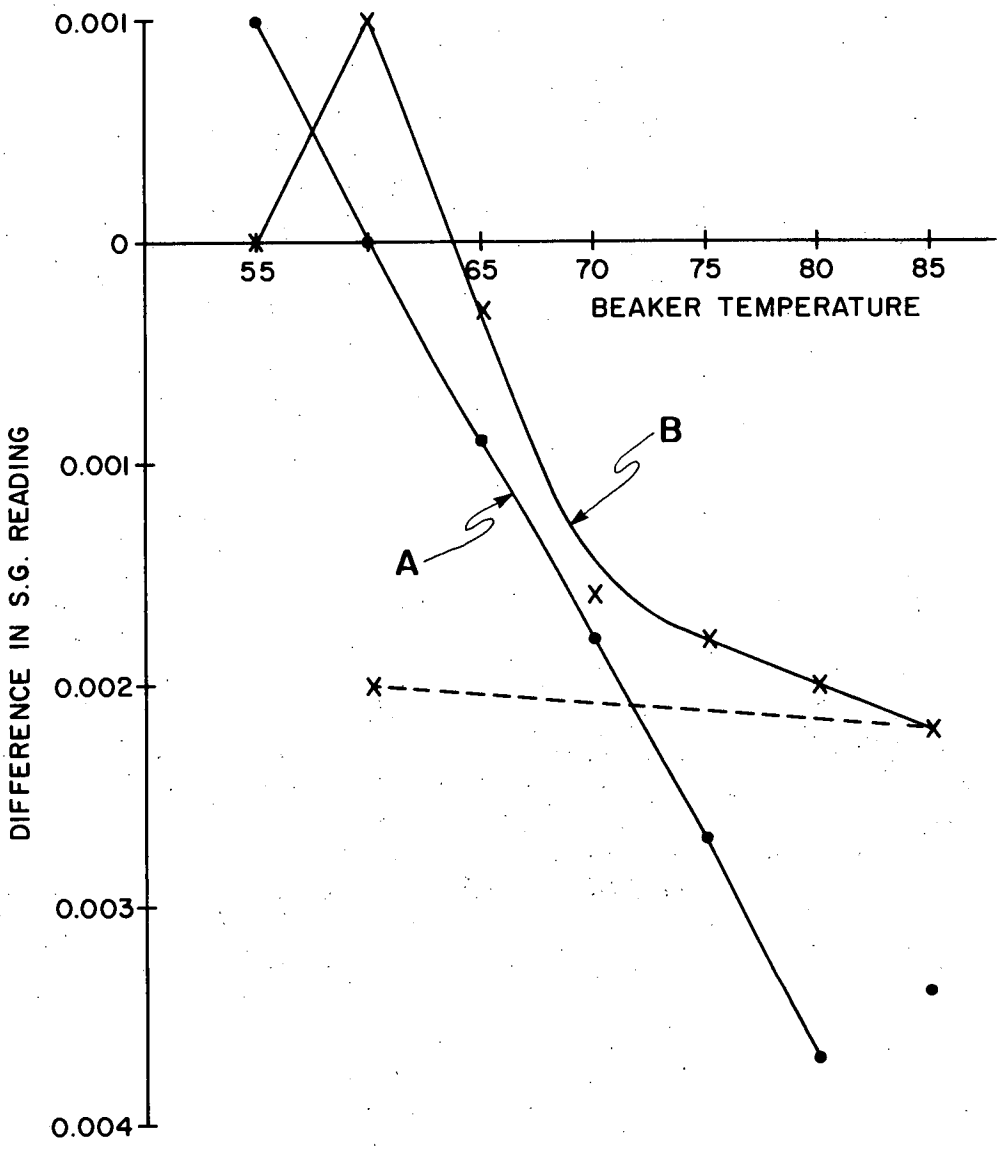

Figure 8. A. Difference between S.G. determined in the pails at 60°F and in the beakers at temperatures ranging from 55 to 85°F, note that the point at 60°F represents two comparisons: one at the beginning of the series of temperature increase increments and the second at the end; B. Change of egg S.G. during the experiment. Each point represents the mean of 115 eggs.

10.1. Comparison of S.G., Deformation, Shell Thickness and Fracture Force

A summary of the readings for the first and final S.G. readings (in the pails at 60°F) shell deformation, fracture force and shell thickness (Table 13) indicated that the variation of S.G. within the experimental group of eggs was higher than normal (C.V. 0.92 and 0.94% c.f. 0.6% observed in previous experiments). Thus, the method of egg selection provided a wider than normal range of shell quality. Even so the variation and range of S.G. readings was insignificant compared to the variation of fracture force (C.V. = 23%). On the other hand the variation of deformation readings (C.V. = 29%) was higher than that of fracture force. Variation of shell thickness (C.V. = 13%) was, however, at a lower level. These characteristics were also reflected in the ranges of the readings and agree with previous results.

Correlation among the traits were significant ($P < 0.01$) and were generally higher than observed in previous experiments (Table 14). Based on these statistics the precision with which fracture force is predicted by S.G. (Fig. 9), shell deformation (Fig. 10) and shell thickness (Fig. 11) can be compared. Based on the correlation coefficients and scatter diagrams (Figs. 9, 10 & 11) it appears that shell deformation ($r = -0.847$) had the strongest relationship with fracture force. The relationship is curvilinear (Fig. 10) and it is known from previous work that the correlation is improved when a quadratic relationship is assumed. Thus, it appeared that up to 72% of the variation in shell strength could be explained by the deformation readings as opposed to 63% by the S.G. values. It can be argued that such an increase in prediction accuracy (14%), from a non-destructive test, may justify the higher labour requirements to perform deformation measurements compared to S.G. determinations. Obviously, if prediction accuracy is improved, the over-all efficiency of experimental operations is increased. This may more than offset the increased cost caused by deformation measurements.

Table 13. Summary of data for 113 eggs showing mean, S.D. and coefficient of variation of specific gravity at the start and finish of the test, non-destructive deformation, fracture force and shell thickness

Trait	Mean	S.D.	C.V. (%)	Maximum	Minimum	Range %+
S.G. first determination*	1.0764	0.0102	0.94	1.098	1.062	3.34
S.G. final determination**	1.0738	0.0098	0.92	1.098	1.062	3.35
Deformation mm	0.0682 (75)	0.0075 (29)	29	0.1527	0.0377	168.62
Fracture force g	3478	786	23	5455	1510	113.43
Shell thickness mm	0.3329	0.0438	13	0.4248	0.2333	57.53

*Measured 110.5 hours after the eggs were placed in the 60°F controlled environment chamber using pails at 60°F.

**Measured 57 hours later at end of experiment using pails at 60°F.

$^{+}\text{Range} = \frac{\text{maximum - minimum}}{\text{mean}}$

Note 2 eggs were damaged and the data discarded.

Table 14. Correlation coefficients among S.G., non-destructive deformation, fracture force and shell thickness for 113 eggs,

Trait	1st S.G.	Final S.G.	Deformation	Fracture force	Shell thickness
1st S.G.	-	0.941	-0.841	0.794	0.849
Final S.G.		-	-0.796	0.782	0.818
Deformation				-0.847	-0.839
Fracture force					0.798

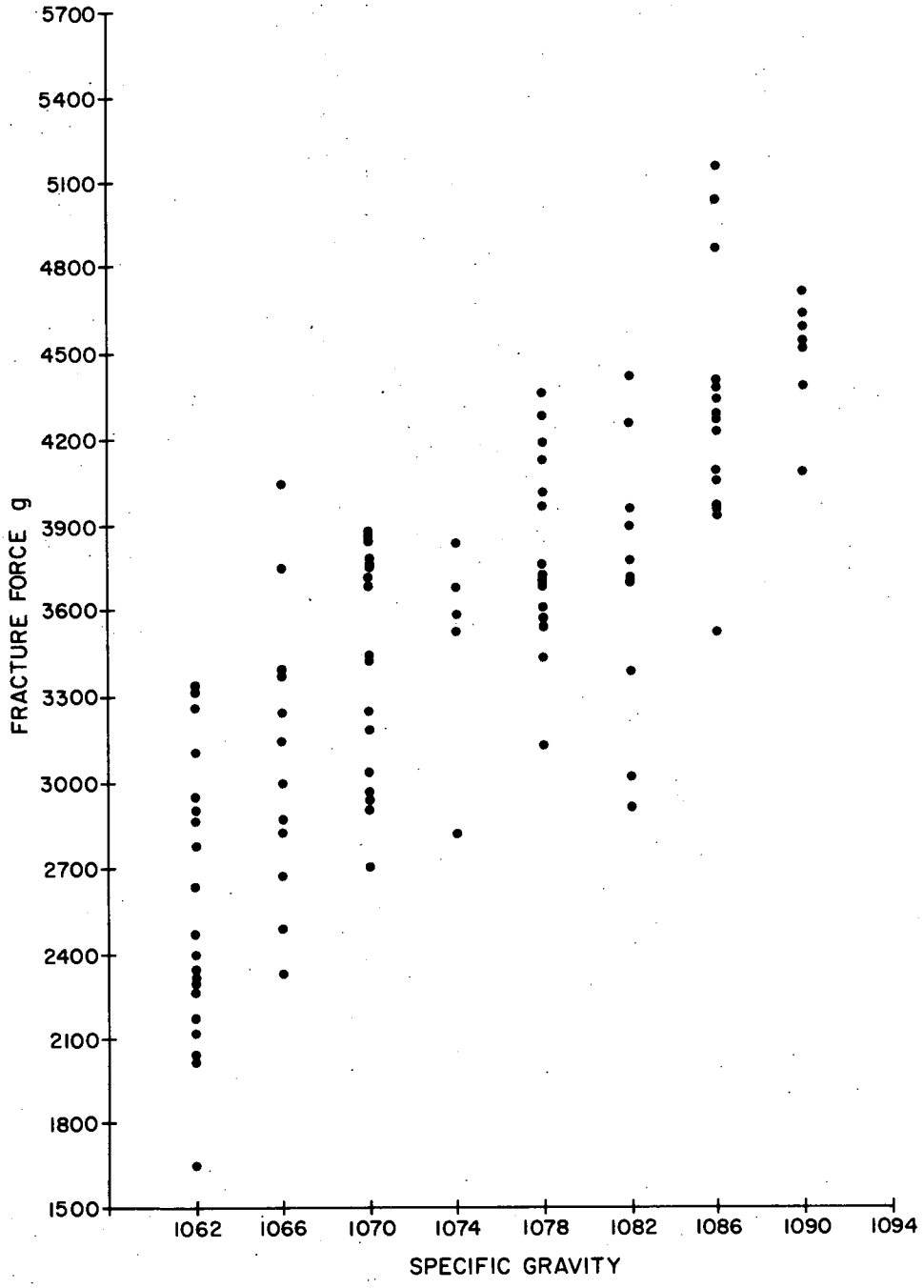

Figure 9. Scatter diagram fracture force against specific gravity for 113 eggs.

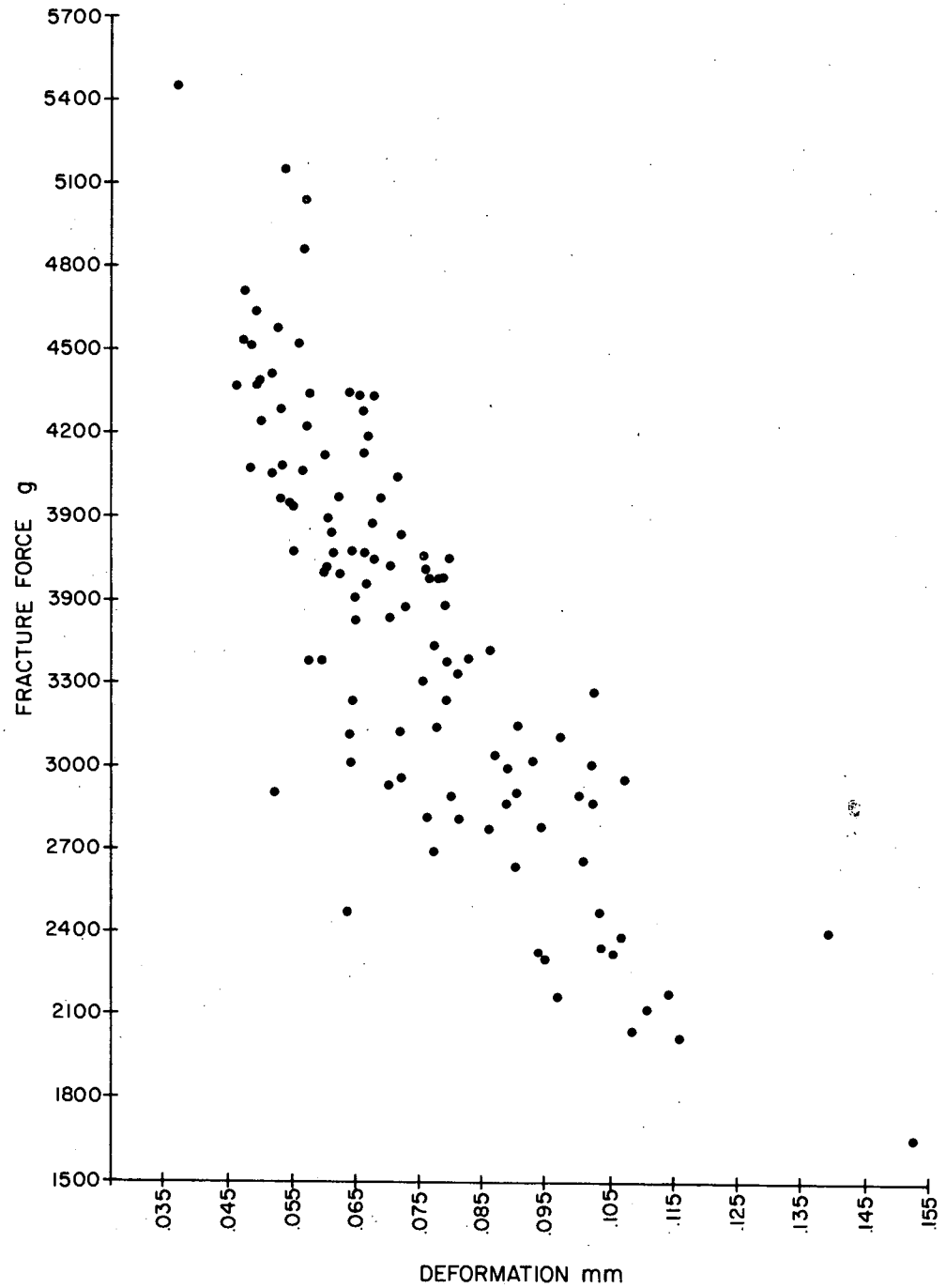

Figure 10. Scatter diagram fracture force against shell deformation for 113 eggs.

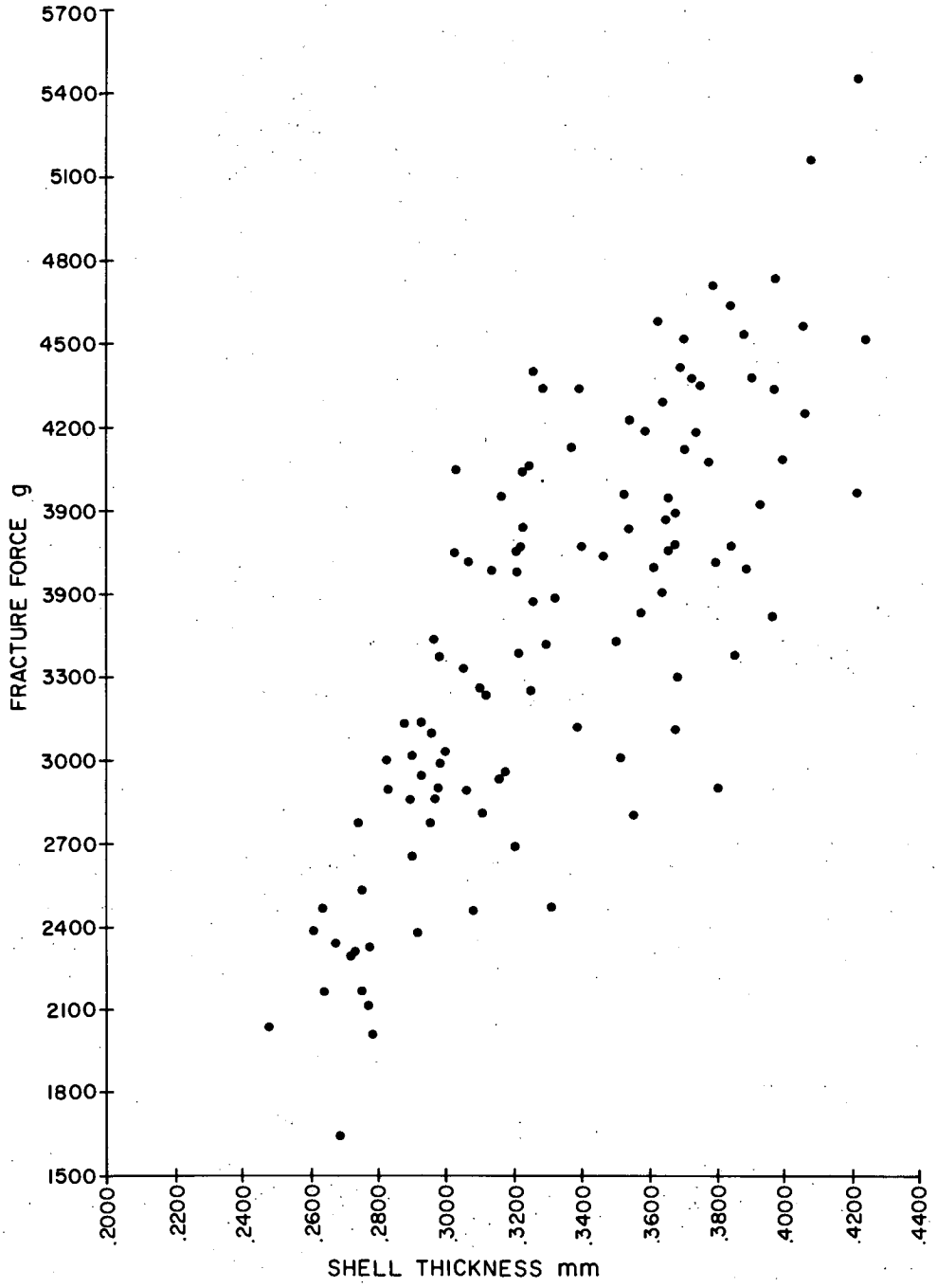

Figure 11. Scatter diagram fracture force against shell thickness for 113 eggs.

11. CHANGES IN SALINE SOLUTION TEMPERATURE DURING ROUTINE S.G. DETERMINATIONS

To determine the order of temperature change that occurred, the temperatures of the saline solutions were monitored during normal operation in the facility used routinely (previously used to compare readings obtained in the temperature controlled facility, paragraph 7). The routine procedure was to store the eggs overnight in a cooler at 55°F, remove them the following morning and immediately start determining the S.G. of the eggs. The same 11 increments (each of 0.004 S.G. units) were used as in the experiments reported above. The plastic garbage pails containing the solutions had a capacity of 17 litres and contained approximately twice the amount of solution contained by the pails used in the controlled temperature facility.

The sequence of events used in testing the eggs was as follows:

1. Fill a wire basket with about 60 eggs .
2. Immerse it in the first increment of the solutions (1.062).
3. Allow time for the eggs to stabilize in the solution.
4. Fill a second basket.
5. Remove eggs that float in the first solution increment and transfer the first basket to the second increment.
6. Install the second basket in the first increment.
7. Continue loading and transferring baskets until all the eggs are tested.

Using this procedure it is estimated that up to 5000 eggs can be tested per 8 hr day. However, it is obvious that the eggs spend considerable time immersed in the solutions. During this period heat was transferred between the egg and solutions efficiently (c.f. the egg immersed in air). Thus, the eggs were heated by the solutions

and the solutions cooled by the eggs. Thus, both the egg and solution temperatures were changing during the test. Since all the eggs had to pass through the first increment, this solution should change the greatest amount. Few eggs passed through the eleventh increment (1.102) so its temperature should be unaffected particularly since the eggs had by then been heated by the solutions for the longest time. There is thus the combined effect on egg S.G. of solution and egg temperature changes.

The solutions were in a room where the temperature was about 72°F. The tests were performed in the early spring when the room heating system was in operation so the temperature was relatively stable.

The temperature of the solutions was measured before the S.G. determinations commenced and then again when the days batch of eggs had passed through the solutions. This was done for 5 days during which an average of 906 eggs were tested per day. The S.G. determinations were completed in an average of about 1 hr.

The results (Table 15) showed that the temperature changes for about the same number of eggs varied from day to day. The maximum change of 7.5°F occurred at the first solution in the series. In general the temperature of the solutions was decreased by passage of the eggs. Exceptions occurred only at the 1.094 and 1.098 increments on two days where the temperature increased 0.3 to 0.5°F. On the average the decrease in solution temperature decreased with ascending S.G. increments due to the decreasing number of eggs tested at each successive step. So few eggs passed through the final increment that the temperature of this solution was unchanged. This is illustrated by a plot of the results (Fig. 12).

The results clearly show that the first and last eggs to pass through the solutions are tested at different solution temperatures and the difference depends on the S.G. of the egg. Obviously, larger changes in solution temperatures must be expected when larger numbers of eggs are tested.

The effect of the temperature changes on egg S.G. readings can be calculated from the results given in paragraph 10 which showed that the egg S.G. changed at 0.00019 S.G. units per ^{o}F. Consider the maximum temperature change of $7.5^{o}F$ that was observed.

Change in egg S.G. = 0.00019 x 7.5

= 0.0014

Thus, errors up to a quarter of an S.G. increment were introduced. However, this does not include the unknown effect of egg temperature changes. Also, the room temperature during this period was stable which cannot be guaranteed throughout the year.

Thus, it was concluded that when eggs are stored in a cooler and tested immediately upon removal, errors in S.G. readings are introduced. These errors change from the beginning to the end of a batch of eggs and increase as the number of eggs in the batch increases.

Table 15. Observed temperature changes, in saline solutions when batches of eggs were tested after removal from a 55°F storage. Given to nearest 0.1°F.

No. of eggs tested	S.G.:	Temperature Change °F*										
		1.062	1.066	1.070	1.074	1.078	1.082	1.086	1.090	1.094	1.098	1.102
918		-3.5	-3.0	-2.5	-1.5	-1.0	-1.0	-0.5	-0.3	0	0	0
898		-5.8	-2.3	-2.3	-1.8	-1.3	-0.8	-0.3	0	-0.3	-0.3	0
910		-4.5	-2.8	-2.0	-1.8	-1.0	-0.5	-0.5	-0.3	0	0	0
885		-7.5	-4.5	-3.3	-2.5	-2.3	-1.5	-1.3	-0.5	-0.5	-0.3	0
920		-5.0	-2.8	-2.0	-13.	-1.0	0	0	+0.3	+0.5	+0.25	0
Average 906		-5.3	-3.1	-2.4	-1.8	-1.3	-0.8	-0.5	-0.2	-0.1	+0.1	0

*Temperature at start - Temperature at finish

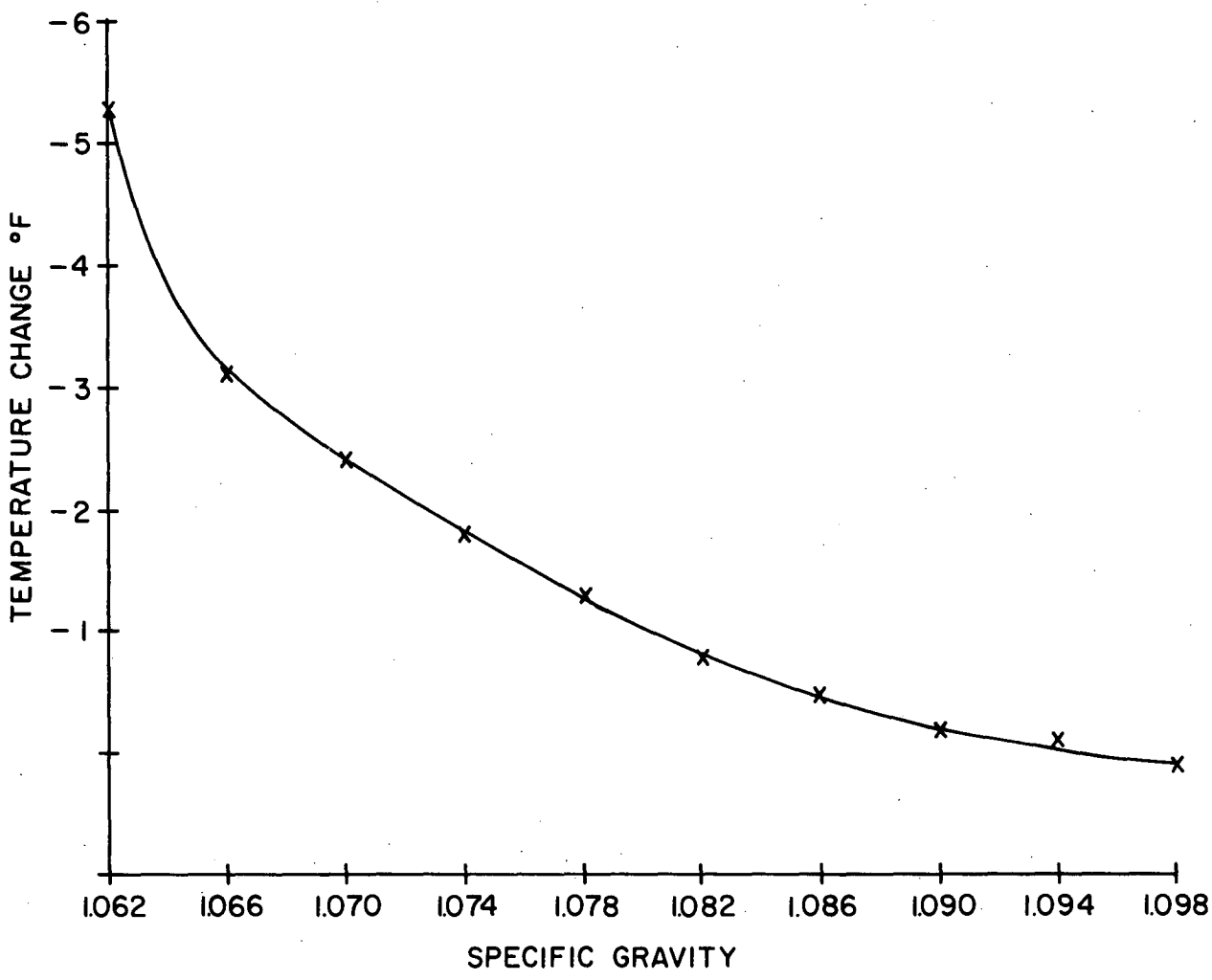

Figure 12. Observed temperature changes in S.G. solutions in testing an average of 906 eggs. Each point represents the average of 5 runs.

12. GENERAL OBSERVATIONS

In the controlled environment chamber the temperature of the solutions was observed to be absolutely stable even during a test involving 912 eggs. This was because the chamber and, therefore, solution temperature were controlled and the eggs were at the same temperature as the solutions. Specific gravity of the solutions was changed slightly by transfer of solution between pails by the eggs and basket. This was corrected by frequent checks and adjustments when observable changes (0.00025) were noted. When testing small numbers of eggs (e.g. 115), measurable changes of S.G. were not observed when the batch of eggs passed through the solution once.

Temperature changes in the pails before testing were extremely slow. The mass of the water "damps out" temperature changes and since the pails are immersed in air, heat transfer between the air and water is inefficient. For example, when making up the solutions using tap water at 43°F three days were required in the 60°F chamber for the solution temperatures to stabilize at 60°F. Obviously as the temperature difference between the solution and air decreases, the rate of heat transfer to the solution decreases thus prolonging the stabilization time.

It was observed that in a number of cases additional S.G. increments (1.058 and 1.106) were needed to verify that certain eggs had S.G.'s of 1.062 or 1.102. The frequency of this need was small and perhaps would not justify the extra work for most experiments.

The routine facility was an efficient operation since large numbers of eggs were immersed simultaneously in the pails and a number of baskets progressively passed through the series of solutions. Thus, there was

sufficient time for the eggs to stabilize or float in the solutions. There is the problem that the time of immersion increases the temperature changes of the solutions. Also, the mass of egg clustered together in the solution may prevent eggs that should float from floating. As the S.G. of the egg approaches that of the solution, the bouyancy force acting on the egg increases in opposition to the gravitational force. The technique used is to collect only those eggs that float to the surface in a particular solution, i.e. that have a positive bouyancy force, not neutral, which would be the requirement to match the egg and solution S.G. Even so at the stage where some of the eggs float they, in theory, have a range of 0.004 S.G. units, e.g. > 1.062 < 1.066. Thus, the eggs with S.G.'s at the highest end of the increment range will be subjected to a larger bouyancy force than those at the lowest end. An egg at the lowest end is thus easily trapped and prevented from floating by other eggs. This phenomenon is easily observed by the various speeds at which different eggs float to the surface. The behaviour of the eggs thus requires a certain amount of judgement to pick off eggs at the lowest end of the S.G. increment. It is reasonable to assume that a percentage of the eggs are assigned S.G. readings that are one increment higher than the increment that is closest to the egg S.G. The effect of judgement in this respect can be reduced by using smaller increments (e.g. 0.002).

When testing small batches of eggs in the experimental facility and attempting to achieve a high measurement accuracy, the procedure became quite tedious. It required time for the eggs to stabilize and utilize judgement to examine (individually) borderline cases. The efficiency compared to other techniques which test each egg individually,

such as deformation measurements, was not as high as might be expected. This was because even though the eggs were tested in groups of say 30 the group had to be tested in effect 11 times. For certain experiments the additional labour required for individual egg tests may be justified and by utilizing appropriate automatic electronic equipment the additional test time need not be excessive.

13. DISCUSSION

The results show that there are a number of sources of error in egg specific gravity determinations. These are summarized below. A fact that is not known is if the errors combine or tend to cancel each other. Evidence from the comparison between uncontrolled and controlled temperature conditions suggests that they dont combine since the difference in readings did not exceed plus or minus one S.G. increment (0.004).

Sources of Error

1. Transfer of solutions between pails by the eggs and baskets. This is not a serious problem providing the S.G. of the solutions is checked and corrected regularly. The maximum observed error in this work was 0.005 S.G. units after testing 900 eggs. Obviously it is important to monitor the first increments in the series more frequently than the last.
2. The temperature of the solutions affects their S.G. In theory this is 0.00045 S.G. units/^{o}C. Under ambient conditions at Ottawa, for example, this could give rise to an error of 0.0054 S.G. units. Experimental results are in agreement (0.00033 S.G. units/^{o}C). Testing at an uncontrolled ambient (e.g. 70^{o}F) compared to a controlled temperature of 60^{o}F for which the hydrometers are calibrated introduces an inherent error in the reading of true egg S.G. of 0.0033 and this increases as the ambient temperature increases.
3. There are differences in readings between hydrometers which, depending on their range, span up to 0.008 S.G. units. It is also difficult to estimate the hydrometer reading to an accuracy better than 0.001 because it is not possible to view the meniscus horizontally.

4. The accuracy of hydrometers is not better than 0.0018 S.G. units depending on their range.
5. The judgement required to decide if an egg floats introduces an error of 0.004 S.G. units particularly with borderline eggs.
6. Cracked shells introduce small errors (0.001) which may range up to 0.004.
7. Eggs stored in a cooler before testing changed the solution temperature up to 7.5°F, thereby introducing an S.G. error of 0.0014 and the error varies across the range of solutions.
8. When the egg and solution are at different temperatures, the temperature of the eggs is changed an unknown amount which depends on the number of immersions required to reach the egg S.G.

In general all the errors are small but it appears that the egg S.G. readings can only be considered reliable within ± 0.004 S.G. units or ± 1 increment when using 0.004 increments. If smaller increments are used (e.g. 0.002) then the uncertainty of the increment increases (e.g. ± 2). The effect of this on the statistical analysis of egg quality data may be significant as the stepped S.G. determination is compared to continuous readings of the other traits. This suggests that a technique for providing egg S.G. readings on a continuous scale might improve the usefulness of this trait as an index of shell strength. Certainly smaller S.G. increments between solutions would improve the present situation. The observed errors represent up to ± 6.7% of the measurement range.

14. RECOMMENDATIONS

There are a number of sources of error in determining the S.G. readings of eggs. These can be eliminated by a number of changes in the procedure and equipment used. A number of these can be instituted with a minimum of effort while others require additional cost as follows:

1. Use larger pails (e.g. 4 times the volume) to reduce the temperature changes through immersion of cooled eggs. This would also minimize the effect of solution being transferred between pails and changing the solution S.G.
2. Allow the eggs to warm up to room temperature before taking readings. This could be done in air or quicker by immersion in water at room temperature. For example, several pails of water could be placed ahead of the saline solutions. The eggs could be immersed in say a series of 4 water pails each for 5 minutes. Once the procedure was started this would not introduce extra time and the total test time would only be increased 20 minutes.
3. Use smaller increments (e.g. 0.002) so that the effect of the errors could be in effect halved.
4. Install immersion heaters in the solution pails to maintain a constant temperature slightly above ambient. In this way the measuring facility would be in a constant condition during and between batches of eggs.
5. Determine S.G. of the solutions by taking a sample in a glass cylinder so that the intersection of the meniscus and hydrometer scale can be viewed horizontally.
6. The ideal situtation would be to control the temperature of the solutions, eggs and ambient at $60^{o}F$ so that all readings obtained were comparable

to the temperature used as a reference for the hydrometers. Unfortunately this is an uncomfortable working environment particularly if a high humidity is maintained. Personnel must wear heavy clothing.

7. Where operational requirements permit do not store the eggs overnight in the cooler. Store them in the room where the S.G. measurements are taken.

15. CONCLUSIONS

It is concluded that there are a number of sources of error in determining the S.G. of eggs using a practical experimental facility. The results of the test indicate that egg readings can only be considered reliable within ± 0.004 S.G. units (i.e. ± one increment). This is particularly true from the viewpoint of long term experiments or inter-laboratory comparisons. However, the errors are probably smaller within a single laboratory following a consistent procedure, using one hydrometer as the only standard and a single well trained operator. Long term comparisons may not be important as most of the comparisons in nutrition and genetic experiments are made at intervals and comparisons are made within intervals not between. For example, eggs may be tested at intervals of a flock's production where the measurement period spans 5 days. Because of the experimental design it is not legitimate to compare the data from one interval with another.

It is feasible to eliminate or reduce a number of sources of error by simple changes of procedure and modest expenditures for equipment that could be considered for implementation. An ideal egg S.G. testing facility would probably increase costs, labour and be an uncomfortable work station. This would detract from the practicality and efficiency of this simple shell quality determination method.

16 REFERENCES

Anon. 1967. Handbook of Fundamentals. Amer. Soc. Heating Refrigerating and Air Conditioning Eng. New York. pp. 225-229.

Asmundson, V.S., Baker, G.A. 1940. Percentage Shell as a Function of Shell Thickness, Egg Volume, and Egg Shape. Poul. Sci. 19,227.

Carter, T.C. 1968. The Hen's Egg: Density of Egg Shell and Egg Contents. Br. Poul. Sci. 9, 265.

Carter, T.C. 1975. The Hen's Egg: A Rapid Method for Routine Estimation of Flock Mean Shell Thickness. Brit. Poul. Sci. 16: 131-143.

Considine, D.M. (ed.) 1957. Process Instruments and Controls Handbook. McGraw-Hill, New York. pp. 7-54-7-59.

Gaisford, M.J. 1965. The Application of Shell Strength Measurements in Eggshell Quality Determination. Br. Poul. Sci. 6, 193.

Harris, N.C. and Hemmerling, E.M. 1955. Introductory Applied Physics. McGraw-Hill, New York. pp. 77-80.

Harrassowitz, M.O. 1934. Studies on the Specific Gravity of Hens' Eggs. A New Method for Determining the Percentage of Shell in Hens' Eggs. Forlagakteebolgets i Malno Boktrycheri (Sweden), pp. 1.

Hayes, F.A. and Sumbards, A.H. 1926. Physical Characters of Eggs in Relation to Hatchability. Poul. Sci. 5.

Hunt, J.R. and Voisey, P.W. 1966. Physical Properties of Egg Shells. 1. Relationship of Resistance of Compression and Force at Failure of Egg Shells. Poul. Sci. 45, 1398.

Hunt, J.R., Chancey, H.W.R. 1970. Influence of Dietary Phosphorus on Shell Quality. Br. Poul. Sci. 11, 259.

Chipera, J.D. 1976. Effect of Oviposition Time and Storage Conditions on the Specific Gravities of Eggs. Poul. Sci. 55:1132-1134.

Jennings, B.H. (ed.) 1951. Refrigeration Fundamentals, 7th Ed. Amer. Soc. Refrigerating Eng. New York. p. 215.

Kell, G.S. 1967. In Handbook of Chemistry and Physics, ed. Weast, R.C. The Chemical Rubber Co., Cleveland, Ohio. p. F-5.

Marks, H.L., Kinney Jr., T.B. 1964. Measures of Egg Shell Quality. Poul. Sci. 43, 469.

Munro, S.S. 1940. The Relation of Specific Gravity to Hatching Power in Eggs of the Domestic Fowl. Sci. Agr. 21, 53.

Munro, S.S. 1942. Further Data on the Relation Between Shell Strength, Hatchability and Chick Viability in the Fowl. Sci. Agr. 22, 698.

Musseh1, F.E. and Halbersleben, D.L. 1923. Influence of Specific Gravity of Hen's Eggs on Fertility, Hatching Power and Growth of Chicks. J. Agr. Res. 23.

Olsson, N. 1934. Studies on Specific Gravity of Hen's Eggs. A New Method for Determining the Percentage of Shell on Hen's Eggs. Agric. School, Hammenhog, Sweden. Ed. Harrassowitz, O. Leipzig, p. 1.

Olsson, N. 1936. Studies on Some Physical and Physiological Characters in Hens' Eggs. Proc. 6th World Poul. Cong., Berlin-Leipzig 1, 310.

Perry, J.H., Chilton, C.H. and Kirkpatrick. (ed.) 1963. Chemical Engineers Handbook. McGraw-Hill, New York. p. 3-77.

Richards, J.F., Swanson, M.H. 1965. The Relationship of Egg Shape to Shell Strength. Poul. Sci. 44, 1555.

Roland, D.A. and Harms, R.H. 1974. Specific Gravity of Eggs in Relation to Egg Weight and Time of Oviposition. Poult. Sci. 53: 1494-1498.

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.

Voisey, P.W. and Hunt, J.R. 1973. Apparatus and Techniques for Measuring Eggshell Strength and other quality factors. Eng. Spec. 6176. Eng. Res. Service, Agriculture Canada, Ottawa.

Voisey, P.W. and Hunt, J.R. 1974. Measurement of Eggshell Strength. J. Texture Studies 5, 135-182.

Voisey, P.W. 1975. Field Comparison of Two Instruments for Measuring Shell Deformation to Estimate Egg Shell Strength. Poul. Sci. 54, 190-194.

Voisey, P.W. and Hamilton, R.M.G. 1976. Factors Affecting the Non-destructive and Destructive Methods of Measuring Eggshell Strength by the Quasi-Static Compression Test. Brit. J. Poul. Sci. 17, 103-124.

Voisey, P.W. and Hunt, J.R. 1976. Comparison of Several Eggshell Characteristics with Impact Resistance. Can. J. Animal Sci. (in press).

Young, D.A., Voisey, P.W. and Dixon, N. 1964. A Specific Gravity Calculator for Potatoes. Amer. Potato J. 41, 401.

17. ACKNOWLEDGEMENTS

The authors wish to acknowledge the contribution of D.C. MacDonald and A. Burnett of Engineering Research Service who conducted the experiments, and B.F. McCleary of the Animal Research Institute who monitored the temperature of the saline solution during a routine Egg Quality test.