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Investigations into the causes and prevention of heating and discoloration ('Stackburn') in bag stored maize

Report No.4: A study of the effect of bag material on the development of stackburn in sacks of maize

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A STUDY OF THE EFFECT OF BAG MATERIAL ON THE DEVELOPMENT OF STACKBURN IN SACKS OF MAIZE

INTRODUCTION

History of stackburn

1. Grain storage in sacks remains the major method of storage in many parts of the developing world. Sacks of grain are well-suited to procurement from small-scale farmers and transport by multi-purpose trucks. The main method of storage in many parts of Africa is in bag stacks in small and large warehouses, or, in drier regions of the Sahel and southern Africa, stacks may be kept outdoors for many months if protected under tarpaulins.

2. Stored grain heating is a well-known phenomenon that is commonly associated with excessive grain moisture. Insufficiently dried grain will heat rapidly, through the growth of moulds and other micro-organisms. Similarly, grain that becomes wetted by rain or condensation will heat. One consequence of insect infestation in grain is heating which may arise in either moist or dry grain.

3. In Zimbabwe, maize has been successfully stored outdoors in modular 5,000-tonne stacks. These are built on a simple dunnage of poles and are sheeted over with tarpaulins. Until recently, the maize was placed into jute sacks of 90 kg capacity, but for economy and convenience of handling, the switch has been made to polypropylene sacks of 90 kg. Stacks are built after harvest with maize dried to below 12.5% moisture content (wet basis).

4. The stacks are constructed by laying sacks lengthways then widthways on alternate layers in order

to form a stable structure. Voids tend to occur between the sacks with the result that the volume of a stack of grain in sacks is greater than the volume of an equivalent amount of grain in bulk. The voids can join together to form airways both horizontally and vertically into a stack. The size and extent of these airways will depend on how easily the sacks deform and fill the voids between them and how the stack is built, i.e. how closely packed the sacks are. These airways may well affect the physical conditions within a stack during storage but their precise effects are not fully understood.

5. A heating cycle has been observed in stacks in Zimbabwe in which the internal temperature rises sharply and much of the maize changes in colour from cream to a light or dark shade of brown. This colour change is commonly referred to as stackburn. After heating, the maize is less suitable for milling and is nutritionally degraded, reducing its value as a food or feed component. Although this colour change occurred when jute sacks were used the frequency and intensity of stackburn has increased following the switch from jute to woven polypropylene.

Possible cause of stackburn

6. The precise cause of stackburn is unknown, but information on the changes that are occurring is being accumulated from monitoring the conditions (temperature, moisture and infestation levels) within stacks. This is leading to the conclusion that grain moisture is not a significant factor in the initiation of the heating cycle. Grain respiration seems unlikely to have led to the degree of escalation in grain temperature experienced.

7. Despite fumigation of the grain, infestation by insect pests remains the most likely cause of stackburn. Large stacks situated out-of-doors require particular care in fumigation to achieve total disinfestation, and there is growing evidence that fumigations may have been inadequate so that a residual population of live insect infestation may have survived. It is possible that the respiratory heat from these insects would disperse by air convection more quickly from jute compared to polypropylene sacks. This would militate against an accumulation of heat in a jute sack. Another potentially important factor is that convective heat loss from stacks of the two kinds of sacks may be different due to the configuration and size of the voids between the sacks in the stacks.

OBJECTIVES

General objective

8. To establish if the development of stackburn in sacks of maize is influenced by the physical properties of the sack material.

Specific objectives

9. To determine the difference in heat loss from single jute and polypropylene bags.

10. To determine the difference in heat loss from jute and polypropylene sacks due to convection, with particular emphasis on the importance of voids within the stacks.

11. To devise changes in operational procedures for polypropylene sacks to minimise the development of stackburn.

METHODOLOGY

To examine the effect of stack geometry on the heat loss from sacks three situations were looked at:

a) single sacks;
b) single columns of sacks;
c) small stacks (9.6 and 6.6 tonnes).

For the small stack trials a procedure was followed which fundamentally consisted of:

1- Set a controlled temperature and humidity (CTH) room 40°C;
2- Lay out all sacks of maize individually in the CTH room;
3- Allow the sacks to equilibate to 40°C;
4- Build and instrument the stack at 40°C;
5- Insulate the stack sides;
7- Reduce the CTH room temperature 15°C.

The procedure for the single sacks and single columns of sacks was similar but less complex. The CTH room ambient relative humidity was fixed at 60% throughout all the trials.

The temperatures in the CTH room and in the sacks of maize were recorded using thermocouples connected to a Delta-T data logger.

Jute or woven polypropylene (wpp) sacks containing 50 kg of French yellow shelled maize were used for the trials. The empty sack dimensions were 600 mm by 1000 mm. They were made loosely filled by sewing 30-50 mm from the mouth, or tightly filled by sewing as closely as possible to the product, about 200-240 mm from the mouth, the excess material being rolled and stitched.

The maize was initially fumigated under tight control conditions to avoid the possible development of insect populations. This fumigation was carried out with methyl bromide for the appropriate concentration and exposure period.

Single sack trials

The objective of these trials was to compare cooling rates in single, tightly filled sacks with unrestricted and totally restricted air flow allowed through the sack material. Four trials were conducted as follows:

- trial 1 - jute sack lined internally with polyethylene film;
- trial 2 - wpp sack lined internally with polyethylene film;
- trial 3 - jute sack (not lined);
- trial 4 - wpp sack (not lined).

For each trial sacks were placed horizontally on a mesh grid suspended approximately 1.1 m above the floor to allow free air movement around the sacks. Temperature sensors were placed in the centre of each sack and in the central middle airspace among the sacks. The sacks were allowed to cool for two weeks.

Single column trials

The objective of these trials was to simulate the cooling of a stack of jute and wpp sacks with infinite voids. Trials were conducted with columns of single tightly filled sacks as follows:

- trial 5 - jute sacks;
- trial 6 - wpp sacks.

For each trial six sacks were built into a column on dunnage then cooled. A temperature sensor was placed underneath the fabric on the top of the third sack from the floor. The columns were allowed to cool for three weeks.

Stack trials

These trials were conducted in stacks designed to simulate a segment of a larger stack of the same height. The objective was to compare cooling in stacks of jute and wpp with differing proportions of voids between sacks. Eight trials were conducted as shown in Table 1. The quantity of maize used was 9.6 t in trials 7 and 8 and 6.6 t in trials 9 to 14.

Trial number	Sack material	Degree of sack filling	Stack type *	Bulk density* (kg/m^3)	Dimensions of stack (m) L	W	H
7	jute	loose	restricted	687	2.48	2.20	2.56
8	wpp	loose	restricted	761	2.48	2.27	2.30
9	jute	tight	open	605	2.20	2.00	2.53
10	jute	tight	open	648	2.14	1.99	2.39
11	wpp	tight	open	636	2.16	2.02	2.38
12	wpp	tight	open	672	2.13	1.98	2.33
13	jute	tight	very open	599	2.26	2.12	2.30
14	wpp	tight	very open	623	2.15	2.17	2.27

* (see text)

Table 1. Trials carried out with stacks, with indication of sack material, degree of sack filling, stack type, bulk density and dimensions of each stack. Trials 10 and 12 were repetitions of trials 9 and 11.

The "stack type" in Table 1 refers to the degree of voids between sacks. Loosely filled sacks tend to deform and fill any voids and thus result in a stack with "restricted airways" (trials 7 and 8). Tightly filled sacks tend to retain their curved shape and create voids, resulting in an "open airways" stack (trials 9 to 12). The "very open" stacks (trials 13 and 14) were made this way by using tightly filled sacks placed further apart than normal and by orienting the sacks, which were slightly asymmetrical, to give the largest possible voids.

The "bulk density" in table 1 was calculated by dividing the mass of the stack by the volume. This was used to estimate the voids in each stack.

Each stack was built on dunnage, comprising pallets with deck-boards spaced 55 and 120 mm apart. The sacks were laid out according to a previously defined pattern, shown in Figure 1. Each layer was repeated by rotating the pattern by 180 degrees.

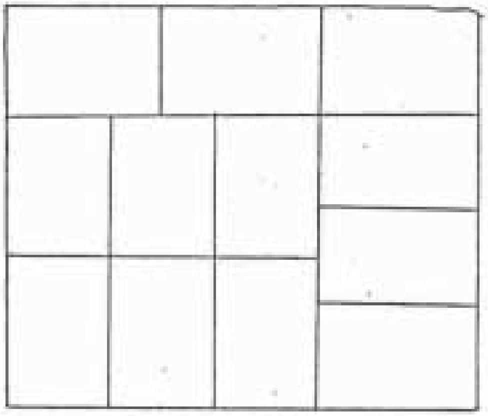


Figure 1. Pattern of layout of sacks used on each of the stack trials.

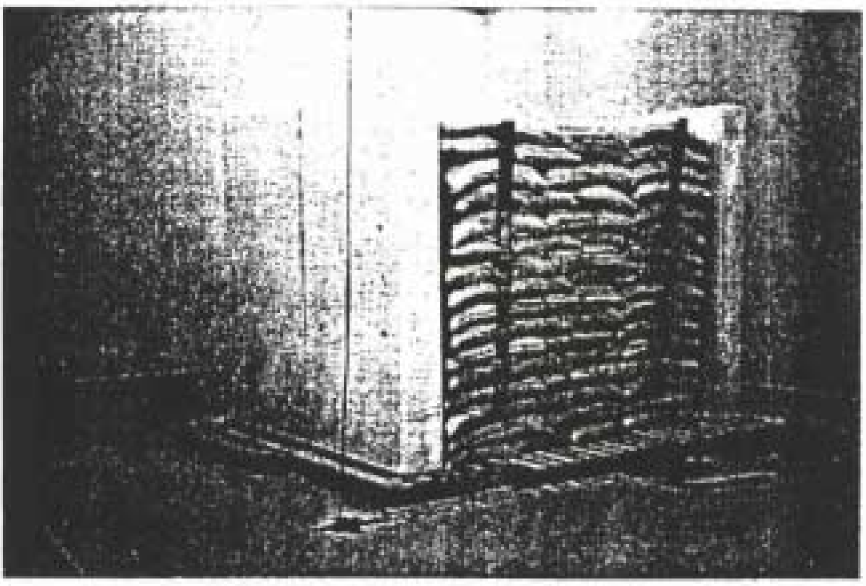


Figure 2. Stack of polypropylene sacks, loosely filled, before placing the final sheets of thermal insulation -polystyrene sheets- on one of the sides.

After constructing the stacks, the sides were covered with polyethylene film to prevent lateral airflows between the stack and the ambient air. To reduce lateral heat losses, and hence simulate a full sized stack, the stack sides were insulated with 30 cm thick expanded polystyrene sheets, as shown in Figure 2.

As the sides were not perfect plane surfaces any gaps between the polyethylene film and the polystyrene sheets were filled with insulation material.

The temperature measuring positions throughout each stack were located along five different levels across the two vertical axial planes of the stack, as shown in Figure 3.

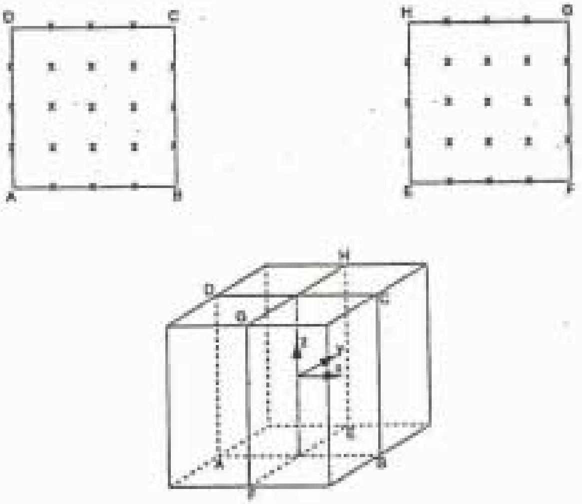


Figure 3. Distribution of the temperature sensors in the bag stack.

Each of the thermocouples inside the stack was placed in the centre of the top or bottom surface of a sack immediately underneath the fabric of the sack.

Another six thermocouples were used to monitor the temperature in the CTH room. One was placed in the airspace between the floor and base of the stack. The remaining five thermocouples were located next to the stack in 60 cm steps from the floor to measure vertical temperature gradients.

Temperatures were recorded every half hour during the first 48-72 hours of each trial then hourly till the end of the trial.

In each experiment, observations were continued until the temperature at the stack centre had fallen at least to 20°C, i.e. 80% of the initial temperature difference.

RESULTS

General

It is possible to characterise the heat retention in the central vertical axis in each trial by the cooling rate (CR). This is the rate at which the temperature at the centre of a single bag, single column or stack declines in response to the cool surrounding air. It is virtually unaffected by a) the small differences between the sizes of each stack and b) the non-ideal condition of the stacks whereby conductive heat is lost from the sides of the stacks.
The cooling rate was determined in the manner described by Mohsenin (1980), i.e. by assuming Newtonian cooling and fitting the equation:

$$Y=A.e^{-Bx}, \qquad (1)$$

to the temperature vs. time curve for the trial, where B represents the cooling rate.

CR is more accurate than nominal cooling half-life because, in each trial, it utilises all the temperature data over the period when 80 % of the excess heat has been lost.

Air temperature

The time taken in the various trials for the CTH room temperature to fall from 40°C to a steady 15°C ± 1°C varied between 6 and 8 hours. The difference between the air temperature at the top and at the bottom levels of the stacks was less then 0.5°C.

The single bag trials (trials 1 to 4)

All four bags cooled at about the same rate (table 2), though the wpp sacks were slightly faster to cool.

After 9.3 to 10.6 hours and 34.9 to 38.1 hours they had lost about 30% and 80% of their excess heat respectively (see table 3). A more detailed study of the initial temperature data for the two jute bags, with and without polyethylene lining, showed no significant difference due to the warm air escaping from the unlined bag (see Table 4).

	Trial number	Sack material	Degree of sack filling	Sack/stack	Cooling Rate 10-3°C/°C day
Single sack					
	1	jute + polythene	tight	single sack lined	1,069
	2	wpp + polythene	tight	single sack lined	1,127
	3	jute	tight	single sack	1,045
	4	wpp	tight	single sack	1,140
Column					
	5	jute	tight	single column of sacks	539
	6	wpp	tight	single column of sacks	557
Stack					
	7	jute	loose	restricted stack	40
	8	wpp	loose	restricted stack	32
	9	jute	tight	open stack	86
	10	jute	tight	open stack	70
	11	wpp	tight	open stack	137
	12	wpp	tight	open stack	119
	13	jute	tight	very open stack	194
	14	wpp	tight	very open stack	286

Table 2. Cooling rates of the centres of single sacks, single columns or stacks during the trials. The sacks were tightly or loosely filled. The sacks were packed during stack building either a) restrictedly b) openly or c) very openly (see Methodology section).

		Time (hours) at which different percentages of cooling were attained				
Trial	Type of sack	25%	30%	50%	75%	80%
1	jute + polythene	9.0	10.6	17.9	32.8	37.8
2	wpp + polythene	8.8	10.4	17.3	31.3	36.1
3	jute	8.3	9.9	17.0	32.6	38.1
4	wpp	7.8	9.3	16.1	30.2	34.9

Table 3. Times at which different percentages of cooling were attained at the centres of single sacks of four types.

	Jute + Polythene		Jute	
Time (hours)	Temperature (°C)	Cooling (%)	Temperature (°C)	Cooling (%)
0	39.8	0	37.6	0
1	39.3	2	37.1	2
2	38.8	4	36.6	5
3	38.2	7	35.9	8
4	37.5	10	35.2	11
5	36.8	12	34.5	14
6	36.0	16	33.8	17
7	35.3	19	33.1	21
8	34.5	22	32.3	24
9	33.7	25	31.6	27
10	32.9	28	30.9	30
11	32.2	31	30.2	34
12	31.5	34	29.6	37
13	30.7	37	28.9	40
14	30.1	40	28.3	42
15	29.4	43	27.7	45
16	28.8	45	27.1	48
17	28.2	48	26.6	50
18	27.6	50	26.0	52
19	27.0	53	25.6	54
20	26.5	55	25.1	56
21	26.0	57	24.7	58
22	25.5	59	24.3	60
23	25.0	61	23.9	62
24	24.6	63	23.5	64

Table 4. Temperature and percentage cooling of two single jute sacks (one lined with polythene), after being submitted to a constant ambient of 15 °C.

The single column of sacks trials (trials 5 and 6)

The centres of the columns of jute and polypropylene bags cooled at about half the rate of the single bags (see Table 2). After 18.2 and 19.9 hours and 74.3 and 72.5 hours the columns had lost 30 and 80 % of their excess heat respectively for the jute and wpp sacks. The CR values (see Table 2) of the two columns are virtually the same. The pattern of cooling in both stacks during the first few hours of cooling are also very similar (Table 5).

	Jute		wpp	
Time (hours)	Temperature (°C)	Cooling (%)	Temperature (°C)	Cooling (%)
0	37.6	0	37.2	0
1	37.4	1	37.0	1
2	37.2	2	36.8	2
3	36.9	3	36.6	3
4	36.6	5	36.3	4
5	36.2	6	36.0	5
6	35.9	8	35.8	7
7	35.5	10	35.4	8
8	35.1	12	35.1	10
9	34.7	13	34.7	11
10	34.3	15	34.3	13
11	33.9	17	34.0	15
12	33.5	19	33.6	16
13	33.1	21	33.2	18
14	32.7	22	32.9	20
15	32.3	24	32.5	22
16	31.9	26	32.1	23
17	31.5	28	31.8	25
18	31.1	30	31.4	27
19	30.7	31	31.0	29
20	30.3	33	30.7	30
21	30.0	35	30.3	32
22	29.7	36	30.0	33
23	29.3	38	29.6	35
24	29.0	39	29.3	36

Table 5. Temperature and percentage cooling of the centre of two single columns of sacks, after being submitted to a constant ambient temperature of 15 °C.

The stack trials (trials 7 to 14)

Before cooling began the temperatures across the stacks were generally homogeneous - the largest temperature range was 1.9 degrees Celsius (see Table 6).

Trial number	Sack material	Degree of sack filling	Stack type	Temperature			
				Max	Min	Range	AVG
7	jute	loose	restricted	38.4	37.3	1.1	37.9
8	wpp	loose	restricted	38.5	37.5	1.0	38.0
9	jute	tight	open	38.5	36.6	1.9	37.5
10	jute	tight	open	39.4	37.9	1.5	38.6
11	wpp	tight	open	40.3	39.3	1.0	39.7
12	wpp	tight	open	40.8	40.4	0.4	40.6
13	jute	tight	very open	40.1	39.4	0.7	39.7
14	wpp	tight	very open	39.0	38.0	1.0	38.6

Table 6. Temperature, maximum, minimum, range and average, of the stacks before cooling.

Trials 7 and 8

The jute stack presented more voids than the wpp stack; this was reflected by the higher bulk density of the wpp stack though a small part of the difference in the bulk densities is due to the thickness of the jute fabric compared to the wpp fabric. This is due to the extra flexibility of the loosely filled wpp sacks compared to similarly sized and filled jute bags, i.e. the wpp sacks tended to fill the voids between sacks more readily then the jute sacks.

Both stacks cooled slowly; the cooling rates were 40 and 32 $\times 10^{-3}$ °C/°C day for jute and wpp respectively, i.e. the jute stack cooled faster than the wpp stack, as can be seen in Figure 4.

The patterns of cooling for the two trials also showed substantial differences. Figures 5 a and b show isotherms for the two stacks when the centres had reached similar temperatures of approximately 26.5°C, on days 21 and 30 for jute and wpp stack respectively. In the wpp stack the isotherms formed concentric circles around the centre of the stack, showing that the stack had cooled evenly from all sides. In the jute stack however the isotherms formed an inverted delta shape and the hottest part of the stack was near the top, suggesting that the stack cooled more rapidly in the bottom half. The isotherms were more closely spaced at the top of the stack then at the bottom.

Figures 6 a and b tend to confirm these results. In the jute stack the side cooled more rapidly at first and was always cooler than the top and the bottom while the bottom cooled more rapidly than the top and was always cooler than the top. In the wpp stack the side again cooled most rapidly at first and was always the coolest, but the top and the bottom were almost identical.

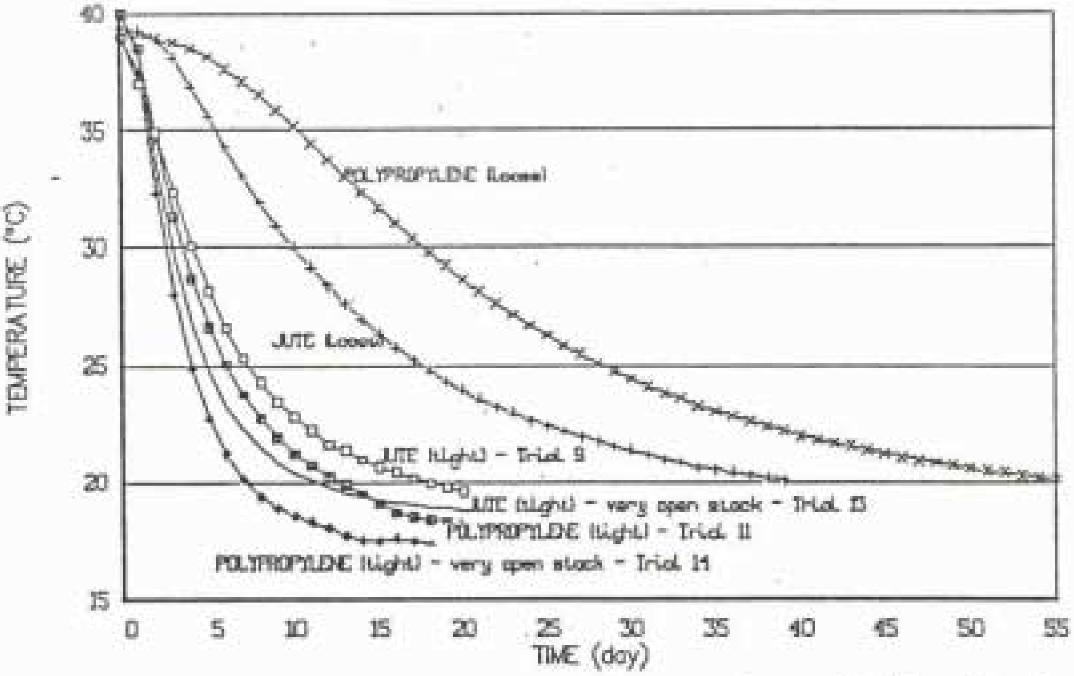


Figure 4. Cooling curves of the centres of the stacks.

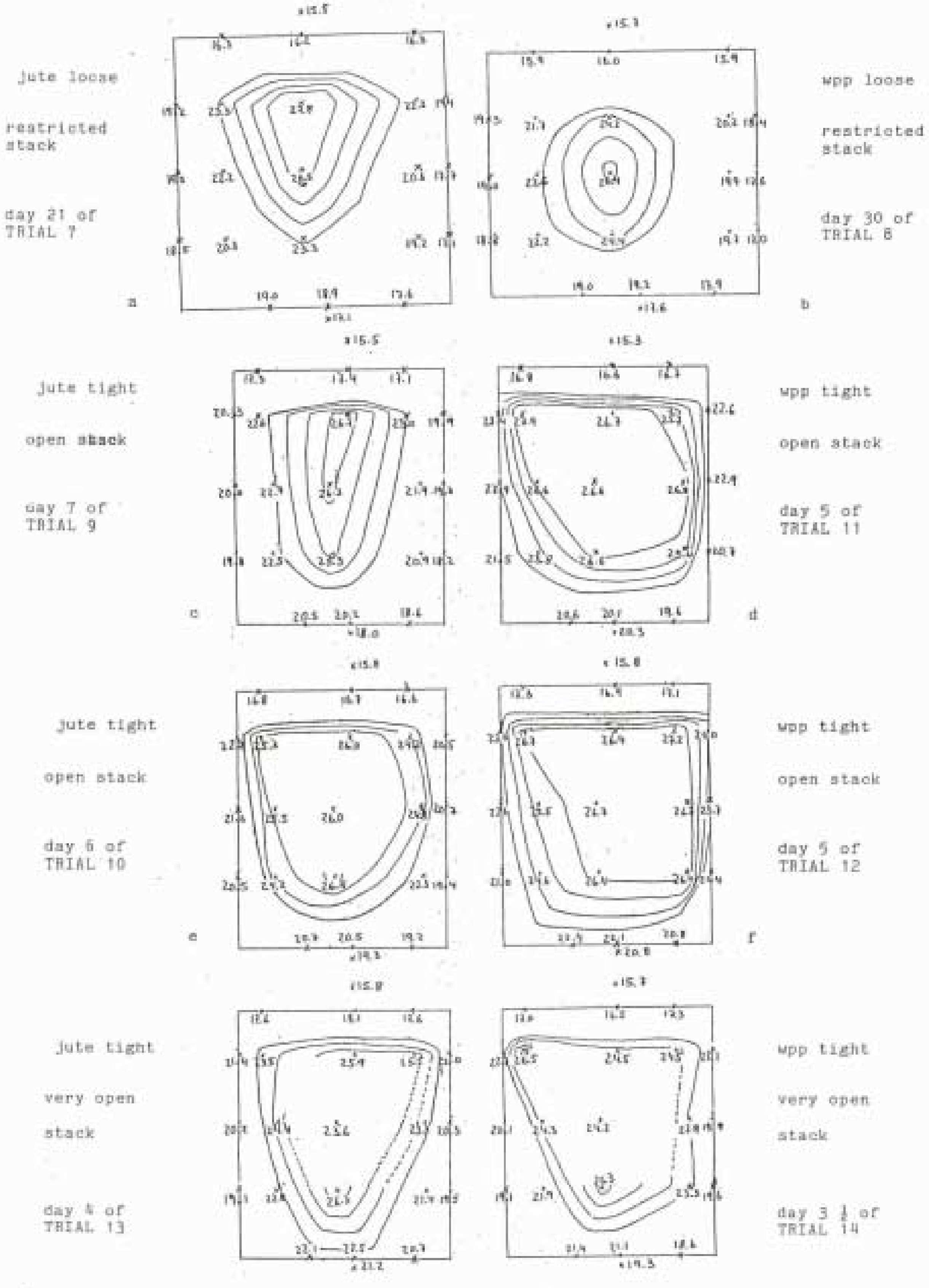


Figure 5. Isotherms of 23, 24, 25 and 26°C for the longest axial vertical plane of the various stacks.

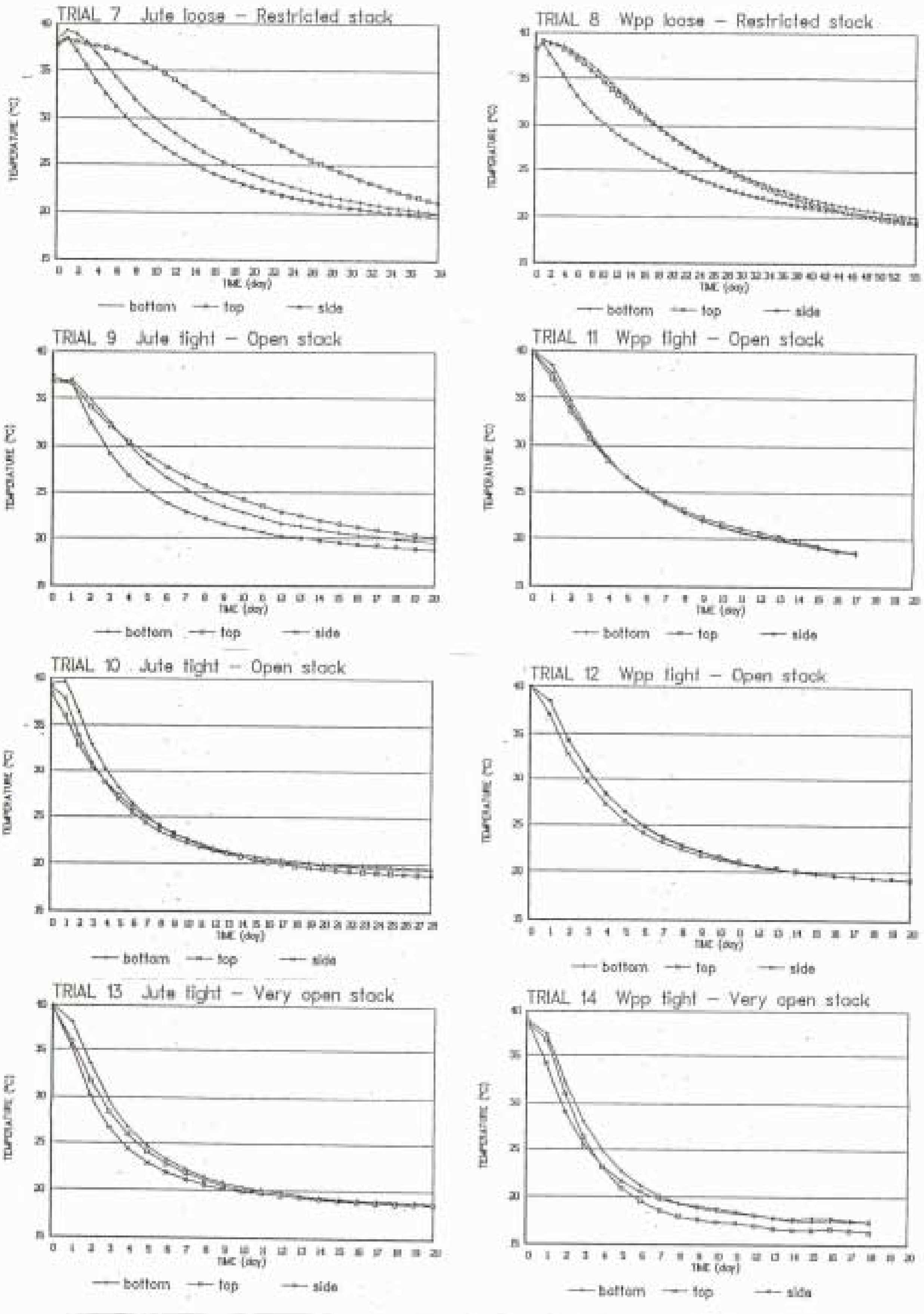


Figure 6. Cooling curves for the top, bottom and side region of the various stack trials.

Trials 9, 10, 11 and 12

The voids in each stack were higher in these trials than in trials 7 and 8 as shown by the lower bulk densities (see Table 1) which were also less different for the jute and wpp stacks.

The cooling rates were again significantly different for the jute and wpp stacks, 86 and 70 $\times 10^{-3}$ °C/°C day for the jute trials and 137 and 119 $\times 10^{-3}$ °C/°C day for the wpp. This time however the wpp was the fastest to cool. The cooling rates were much greater then those in trials 7 and 8, as shown in Figure 4.

Figures 5 c, d, e and f, show isotherms for these trials when the centre temperatures had fallen to approximately 26.5°C, around day 6. With the exception of trial 9, the isotherms showed that large areas in the centres of the stacks were at a more or less uniform temperature while there were sharp temperature gradients around the periphery of the stacks, particularly at the top. In the trials 9, 10 and 12 the hottest point was near the top.

Figures 6 c, d, e and f, confirm these results: in both the wpp and the jute stack there was little difference between the cooling curves for the top, bottom and sides of the stacks and no clear pattern as to which position was hottest.

Trials 13 and 14

The voids in these two trials were the highest of all the stack trials. The bulk densities (see Table 1) were slightly lower then those for trials 9 to 12 and again showed less difference between jute and wpp.

The cooling rates were 194 and 286 $\times 10^{-3}$ °C/°C day, again significantly different, with wpp cooling faster than jute. These cooling rates were the fastest of all the eight trials.

Figures 5 g and h, show isotherms for these trials when the central temperatures had fallen to approximately 26.5°C, around day 4. The pattern of these isotherms for jute and wpp was very similar to trials 10, 11 and 12 with a more or less uniform temperature in the central region and sharp temperature gradients around the periphery of the stacks, particularly at the top.

Figures 6 g and h, confirm these results: the cooling curves for the three positions, bottom, top and side, showed for the jute stack that there were small differences between the positions, with the bottom slightly hotter than the top. The wpp stack was very similar to the jute.

DISCUSSION

Calculation of cooling rates

The method used to calculate the cooling rates in the various trials is strictly speaking only applicable to homogeneous materials cooling only by conduction with negligible temperature gradients, conditions which did not hold for these trials. This is reflected in the imperfect fit of equation (1) to the data from the trials - see Appendix A . However the CR values did provide a good approximation of the cooling process in terms of time and temperature and were useful in comparing the various trials.

The single bag trials

The difference between the CR's and cooling patterns of the bags with and without the polyethylene lining was small. This indicates that heat loss by air movement through the fabric of either type of sack was not significant, and implies that the sacks cooled by convective air flow around their surfaces. The similarity between CR's for equivalent jute and wpp sacks suggests that there is little difference in heat loss from the two types of sack if they are allowed to cool in this manner, i.e. with unrestricted air flow allowed around the sack.

The single column trials

The single column trials confirm the above findings. The potential air flow around the sacks in the columns was more restricted, which explains the smaller CR's. The CR's were very similar again for jute and wpp sacks with the wpp sacks tending to cool slightly faster.

The stack trials

Trials 7 and 8 represent almost the opposite case to the single bag case, i.e. the potential air flow around the sacks was greatly restricted by the lack of voids in the stacks. The stacks took a very long time to cool. The isotherm pattern for the wpp stack suggests that there was little cooling by convective air flow. The isotherm pattern for the jute stack suggests that there was a degree of convective air flow in this stack and it is likely that this was the cause of its faster cooling rate. This difference in convective air flow between jute and wpp could be due to the tendency of the jute sacks to form larger stack voids than similar wpp sacks, which was reflected in the bulk densities of the two stacks. This suggests that the reason for the occurrence of stackburn after the adoption of wpp sacks was that the new wpp sacks formed less voids in stacks than jute sacks and thereby reduced the ability of the stacks to cool.

Trials 9 to 12 showed that the rate of cooling of each type of stack was increased dramatically by creating numerous voids in the stacks by filling the sacks tightly. In this situation, the wpp stacks cooled significantly more quickly than the jute stacks. The isotherm patterns for these trials, with sharp temperature gradients at the top and even temperatures in the middle of the stacks, show that convective air flow was an important component of the cooling of these stacks.

Trials 13 and 14 showed that cooling rates could be further increased by increasing the size and continuity of voids, with wpp again the fastest cooling stack. The the decrease in bulk density between these trials and trials 9 to 12 was approximately half of the decrease in bulk density between trials 9 to 12 and trials 7 and 8. However, the cooling rate was approximately doubled, suggesting that any relationship between the amount of voids as measured by bulk density and the cooling rate is not linear.

Overall, these trials show that the most important factor in the cooling of stacks is the degree of voids between sacks. Where there are numerous voids, convective air currents can flow around sacks, dramatically increasing the stack cooling rates and allowing wpp stacks to cool faster that jute stacks.

CONCLUSIONS

1. The cooling rate method (Mohsenin, 1980) is useful in quantifying the rate of heat loss from stacks of maize despite being somewhat inapplicable to this situation.

2. Air flow through the fabric of a sack of warm maize surrounded by cool air has an insignificant effect on the cooling rate of the sack. Cooling is therefore achieved by movement of air around the sack surface, i.e. by convective air flow.

3. The ability of a stack of maize sacks to cool rapidly depends most significantly on the degree of voids between sacks, as these allow the passage of convective air flows around the individual sacks.

4. Woven polypropylene sacks when loosely filled with an equal amount of maize as similarly sized jute sacks result in stacks with fewer and smaller voids which therefore cool more slowly.

5. Stack cooling rates are dramatically increased if the stacks are provided with numerous voids by tightly filling the sacks. Arranging the sacks with extra spaces between them further increases the cooling rate. Under these conditions woven polypropylene stacks cool faster than equivalent jute stacks.

6. The implications of these conclusions for stackburn are that:

a. the change from jute sacks to loosely filled woven polypropylene sacks would have impaired the ability of the stacks to lose internal heat;

b. the provision of voids in woven polypropylene stacks by tightly filling the sacks and/or specially arranging the stacking pattern could result in faster cooling rates for the stacks which are potentially greater than those in the original jute stacks.

APPENDIX A

To characterise the heat retention in the central vertical axis of each trial, cooling rates were determined in the manner described by Mohsenin (1980). The equation:

$$Y=A.e^{-Bx} ,$$

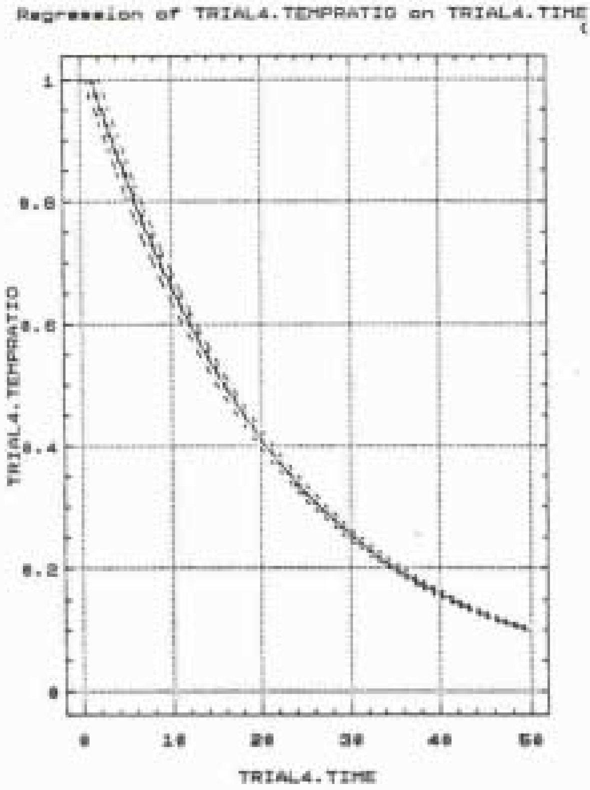
where Y is the temperature ratio, x the time and A the lag factor, was fitted to the cooling data of the various trials by simple regression.

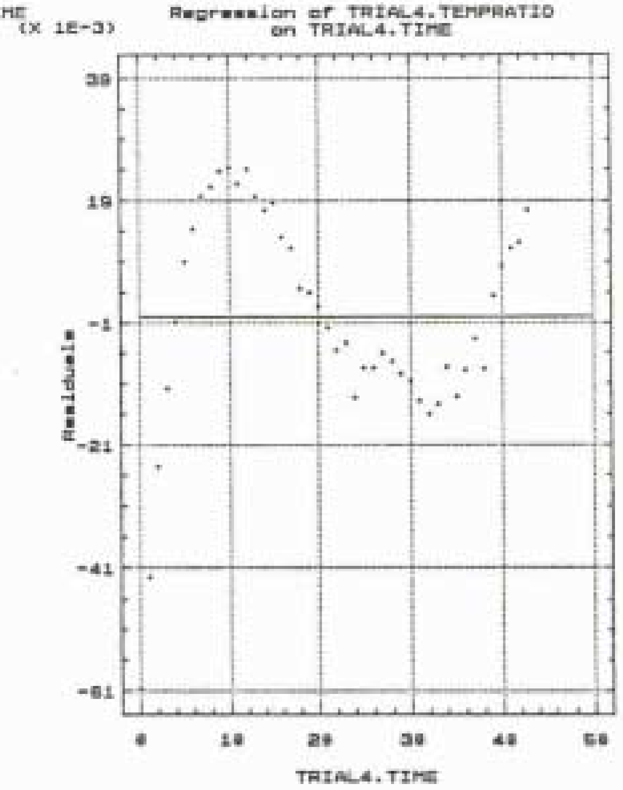
Plots of the residuals were not randomly distributed and showed a clear function for all the trials. Nevertheless although the equation did not fit totally to the cooling data it presented for all the trials good correlation coefficients and R^2 values.

The trial data was analysed using three different time intervals according to the cooling period: 1 hour for trials 1 to 6, 24 hours for trials 7 and 8 and 4 hours for trials 9 to 14. So estimates for the intercept (lag factor), and slope (cooling rate) were multiplied respectively by 24, 1 and 6 so that they may be all expressed in °C/°C day. Three examples, trials 4, 8 and 13 are shown overleaf.

TRIAL 4

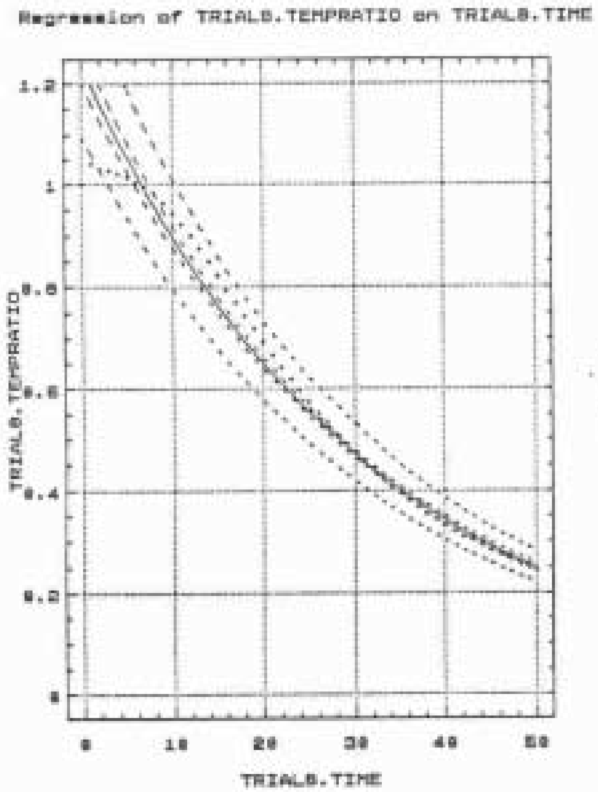
```
Regression Analysis - Exponential model: Y = exp(a+bX)
--------------------------------------------------------------------------------------
Dependent variable: TRIAL4.TEMPRATIO               Independent variable: TRIAL4.TI
--------------------------------------------------------------------------------------
                               Standard                T                 Prob.
Parameter        Estimate        Error               Value               Level
--------------------------------------------------------------------------------------
Intercept       0.0607172      5.2706E-3             11.52              .00000
Slope          -0.0475182      2.11077E-4          -225.122             .00000
--------------------------------------------------------------------------------------
                                 Analysis of Variance
--------------------------------------------------------------------------------------
Source                 Sum of Squares      Df  Mean Square      F-Ratio  Prob. Level
Model                          16.020       1       16.020     50679.95       .00000
Residual                      .013277      42      .000316
--------------------------------------------------------------------------------------
Total (Corr.)               16.033638      43
Correlation Coefficient = -0.999586               R-squared =  99.92 percent
Stnd. Error of Est. = 0.0177794
```

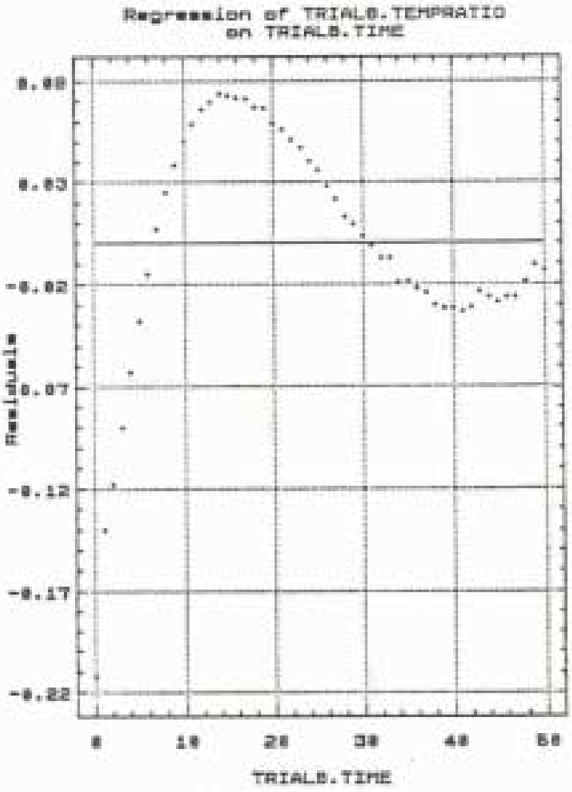




TRIAL 8

```
Regression Analysis - Exponential model: Y = exp(a+bX)
----------------------------------------------------------------------------------
Dependent variable: TRIAL8.TEMPRATIO              Independent variable: TRIAL8.TI
----------------------------------------------------------------------------------
                                  Standard              T               Prob.
Parameter          Estimate          Error            Value              Level
----------------------------------------------------------------------------------
Intercept          0.212203      0.0160919           13.187             .00000
Slope             -0.032038     5.54672E-4         -57.7603             .00000
----------------------------------------------------------------------------------
                              Analysis of Variance
----------------------------------------------------------------------------------
Source                   Sum of Squares      Df  Mean Square    F-Ratio  Prob. Level
Model                           11.3421       1      11.3421   3336.256       .00000
Residual                        .166583      49      .003400
----------------------------------------------------------------------------------
Total (Corr.)                 11.508694      50
Correlation Coefficient = -0.992736             R-squared =   98.55 percent
Stnd. Error of Est. = 0.0583065
```





TRIAL 13

```
Regression Analysis - Exponential model: Y = exp(a+bX)
------------------------------------------------------------------------------
Dependent variable: TRIAL13.TEMPRATIO          Independent variable: TRIAL13.TI
------------------------------------------------------------------------------
                                Standard              T              Prob.
Parameter          Estimate       Error             Value            Level
------------------------------------------------------------------------------
Intercept         -0.216934     0.0265297         -8.17701          .00000
Slope            -0.0323078     9.52361E-4        -33.9239          .00000
------------------------------------------------------------------------------
                            Analysis of Variance
------------------------------------------------------------------------------
Source              Sum of Squares     Df  Mean Square    F-Ratio  Prob. Level
Model                      10.2292      1      10.2292   1150.834       .00000
Residual                   .417760     47      .008889
------------------------------------------------------------------------------
Total (Corr.)            10.646953     48
Correlation Coefficient = -0.980185          R-squared =  96.08 percent
Stnd. Error of Est. = 0.0942789
```