THE COST AND EFFECTIVENESS OF AERATION IN THE BRITISH CLIMATE

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ABSTRACT

Simple calculations based on meteorological records and biological data showed that 10 cu m/h/tonne was the minimum aeration rate required to prevent insect development in the British climate. It was estimated that grain could be cooled to 10 C by November at costs of 1.8 - 12 p/tonne, depending on grain depth.

In a farm scale experiment, aeration eliminated an infestation of 2.5 insects / Kg. in grain initially at 30 C, achieving 5 C by December.The cost was 3.1 p/ tonne when aeration was controlled with a differential thermostat with a 4 C setting and 8.1 p/ tonne when the differential was 2 C. The average cost of aeration in 19 commercial stores on 5 sites was 3.6 p/tonne.

A.INTRODUCTION

Cooling grain during storage using ambient air is a widely used technique in temperate and sub- tropical countries. The principle advantages of the technique include reducing biodeterioration and moisture migration caused by uneven temperatures within the bulk. However, its use is often restricted because of the inability of users to gain a clear picture of the potential advantages or an accurate calculation of the costs.

The purpose of this paper is to describe a simple method for calculating sufficient airflow rates to prevent insect breeding and to define what the cost of achieving this are likely to be. The theoretical approach is validated by practical results obtained in a farm scale experiment. An infestation was eliminated by aeration and hours of aeration and cooling times were compared with those of the theoretical study. The theoretical power costs were compared with those occuring in commercial stores.

B. CALCULATING THE EFFECTIVENESS OF AERATION

i.) Aeration rates

The minimum time required for a fan to pass enough air to cool a given volume of grain can be calculated assuming 1000 volumes of air are required to cool 1 of grain (Burrell and Laundon 1967). Assuming 1 tonne of grain occupies 1.4 cu. m (50 cu ft); the number of hours aeration for 5 commonly employed airflow rates was first calculated.

Table I. Hours of aeration required to pass each cooling front.

Airflow	3.4	6.8	10.2	13.6	17
- Cu m/tonne/h	3.4	6.8	10.2	13.6	17
- Cu ft/min/ton	2	4	6	8	10
h aeration	417	208	139	104	83

ii) Meteorological considerations

Weather is a notorious variable, so a series of calculations of actual cooling times have been made using meteorological data for two widely separated regions in England and based on 20 yr average, a hot autumn and a mild winter at each location. Records were acquired which show the hours spent each day below 15 and 10 C . Thus to calculate how long it would take to pass a 15 C front through grain, for a given start date, it was merely necessary to add up the hours below 15 C until the number of hours indicated for a particular airflow was exceeded. This calculation gave the date of the cooling front and therefore how many days were taken to achieve it.

Two sequential cooling fronts were considered in this manner; cooling the grain to 15 and 10 C. Four dates of starting aeration were selected; 1 July, 1 August, 1 September and 1 October.

Table II. Date at which 15 C was achieved.

Start date	Airflow - Cu m/tonne/h 3.4	6.8	10.2	13.6	17
1.7	4-18.8	14-24.7	8-16.7	6-12.7	5- 9.7
1.8	5-12.9	19-25.8	11-17.8	9-13.8	7-11.8
1.9	24-30.9	11-17.9	7-12.9	6- 9.9	5- 7.9
1.10	18-21.10	9-12.10	6-8.10	5-6.10	4-5.10

Table III. Date at which 10 C was achieved.

Start date	Airflow - Cu m/tonne/h 3.4	6.8	10.2	13.6	17
1.7	9.10-20.11	28.9-11.10	19-29.9	9.9-21.9	17.8-21.9
1.8	15.10-26.11	30.9- 4.10	25.9-9.10	23.9-3.10	18-22.9
1.9	11.10-28.11	1.10-7.11	27.9-14.10	25.9-9.10	23.9-3.10
1.10	6.11- 2.12	19.10-15.11	13.10-9.11	10.10-3.11	8-30.10

The range in dates at which the cooling fronts passed through the grain represents the maximum variation caused by geographic and seasonal factors. For all these calculations it was assumed that the aeration start date coincided with the filling of the store.

iii) Biological considerations

a) Cooling fronts.

In order to predict the effects of cooling on insects, the following assumptions have been made;-

1. That the temperature of grain drops sharply stepwise, as each cooling front passes through the warmest area. Thus initially,the warmest grain would be at 30 - 35 C and optimal for reproduction of the 3 commonest British grain beetles; Sitophilus granarius L., Oryzaephilus surinamensis L. and Cryptolestes ferrugineus Steph.

2. The temperature would then drop to 15 C, at which only one species; S.granarius can complete its life cycle. The second cooling front would reduce the temperature to 10 C.

b) 15 C front

While the first cooling front passes through the grain, the insects will be reproducing rapidly at an optimum rate and the calculations are based on the maximum infestation in the slowest cooling areas resulting from the activities of a gravid female. Thus it was necessary to compile the data on life cycle times, oviposition rates and pre-oviposition times for the three species.

Table IV. Life history details of 3 beetle species.

	S.granarius.	O.surinamensis.	C.ferrugineus
t (days)	26	17	21
t2 (days)	144	-	-
p (days)	3-8	5	2
e	1	7	6

Given;

t = optimal time (days) for development from egg to adult
t2 = time (days) for development from egg to adult at 15 C
p = adult maturation time (pre - oviposition)
e = no. of eggs laid per female per day

Sources;-

Eastham and Segrove,(1947);Eastham and McCully (1943);Richards (1947)-S.granarius
Howe,(1956);Back and Cotton (1926) - O.surinamensis
Smith (1963);Smith (1965);Rillett (1949) - C.ferrugineus

Thus, knowing the days available for rapid breeding at optimum temperatures until the cooling front arrives, it is possible to calculate if the insects can complete their development in this time and if so,how many progeny will be produced.

Table V. Estimates of insects developing during the 15 C front.

Species and start date	Airflow - Cu m/tonne/h 3.4	6.8	10.2	13.6	17
S.granarius					
1.7	9- 22	-	-	-	-
1.8	10- 16	-	-	-	-
1.9	0- 4	-	-	-	-
1.10	-	-	-	-	-
O.surinamensis					
1.7	126- 1319	0- 49	-	-	-
1.8	133- 322	7- 56	-	-	-
1.9	49- 91	-	-	-	-
1.10	7- 28	-	-	-	-
C. ferrugineus					
1.7	84-342	0- 18	-	-	-
1.8	90- 126	0- 24	-	-	-
1.9	18- 54	-	-	-	-
1.10	-	-	-	-	-

The consequences of the calculated cooling times were that no development of S.granarius could occur in theory, during progress of the first front, at airflows of 6.8 cu m/h/T and above in any year or either location. Burges and Burrell's (1964) prediction that S.granarius would only develop at airflows of less than 4 cfm/T (6.8 cu m/h/T) was confirmed. In fact this species failed to develop at 3.4 cu m/h/T, providing aeration was started in October.

However, the calculations suggested that O.surinamensis and C.ferrugineus were often able to develop at 6.8 cu m/h/T, when aeration was started in July or August, although only the former developed at 3.4 cu m/h/T, when aeration was started in October.

c) 10 C front

When the temperature is reduced to 15 C, only S.granarius can continue to complete its development. Therefore, it is necessary to add the numbers of this species developing at 15 C, during the passage of the 10 C front, to those that already developed under optimum conditions during the 15 C front.

Table VI. Sitophilus granarius developing during the 15 C and 10C cooling fronts.

Start Date	Airflow - Cu m/tonne/h 3.4	6.8	10.2	13.6	17
1.7	21-46	3-12	0-3	-	-
1.8	16-26	0-8	-	-	-
1.9	1-13	-	-	-	-
1.10	0-1	-	-	-	-

The calculations suggested additional S. granarius could complete their development at 3.4 cu m/T/h regardless of start date. It was predicted that smaller numbers could also also develop at 6.8 cu m/T/h when aeration was started in July or August and even at 10.2 cu m/T/h when starting cooling in July.

iv) Calculation of power requirements and costs

The power in watts (w) was calculated from:- w = [airflow(cu m/sec/tonne) x total pressure (N/sq.m)] /fan efficiency (ratio) The resulting temperature rise (t) was given by: t = w/tonne/ [1.2 x airflow]

The velocity pressure was taken as 135 N/sq.m = 15 m/sec and the efficiency as 65% in all cases. Static pressures were estimated using relations developed by Matthies and Petersen (1974) for the pressure loss through the crop and duct work resistances based on ASHRAE. The duct layout assumed was:-

Duct;	centres	width	depth	cover free area
3m deep	3.0	0.3	0.3	5%
10 m deep	4.0	0.45	0.5	5%

The crop parameters were:- density; 1.3 cu m / tonne, resistance coefficient; 2.2, void volume ratio; 0.39 and particle equivilent diameter; 3.9.

The costs required to pass each cooling front through the grain were achieved by multiplying aeration hours required for the 5 rates, by Kw required for 2 grain depths; 3m, typical of farm stores and 10m, appropriate for commercial stores. The costs per Kwh were taken as 6p for fan operation during the day and night. However if day/night tarrifs were adopted, these costs would drop by two thirds, to only 2p/Kwh.

Table VII. The cost of aeration.

	Grain depth	Airflow - Cu m/tonne/h 3.4	6.8	10.2	13.6	17
w/tonne	3m	0.24	0.59	1.07	1.68	2.68
	10m	0.57	2.00	4.73	8.19	12.74
t rise C	3m	0.21	0.25	0.31	0.36	0.43
	10m	0.5	0.9	1.4	1.8	2.2
cost/T/front	3m	0.6	0.74	0.89	1.05	1.23
at 6p	10m	1.43	2.50	3.94	5.11	6.34

C. FARM SCALE EXPERIMENT

i) Methods

One hundred and twenty tonnes of wheat at 30 C was divided between six bins each of 3x3x3 m. in September. Seven days after filling the bins, adult _S.granarius_, _O.surinamensis_ and _C.ferrugineus_ were added to the grain at the combined rate of 2.5 insects /Kg.

Ten days after the insects were inserted, aeration was commenced.

Fans of output 20 W (30 W input) have been found sufficient for these bins. Each bin was cooled at 9.9 - 13.3 cu m/ h / t (mean 11.1) by a fan connected to a differential thermostat. Three of these switched on the fans when the temperature at the centre of the bins exceeded ambient by 4 C and three used a differential of 2 C. Airflows were measured using a pitot tube and inclined micromanometer according to BS 1042 and 848. Hours of aeration were also recorded.

Grain temperatures were recorded on data loggers using copper constantan thermocouples. These were placed in 2 columns; 0.5 m from the corner of each bin and at the center. They were placed at depths of 0.5, 1, 1.5 and 2.0 m.

The insect numbers were monitored using 16 pitfall traps (Cogan and Wakefield 1987) per bin and 27 probe traps (Burkholder, 1984) at 3 depths. Insects around the outside of the bins were monitored using 50 bait bags (Pinniger 1975). Conventional gravity spear samples were withdrawn after 28 weeks from the 27 probe trap positions in each bin. At the end of the test, samples of 1 Kg. were taken every quarter hour as the grain was unloaded at 14 T/h. In addition 8 samples of 0.25 Kg. were collected according to BS 4510 from every lorry.

ii) Results

a. Temperatures and hours of aeration

There was little difference between the speed of cooling of the 2 sets of bins which were lower than those calculated. The hours run by fans controlled using the 4 C differential were usually lower than those calculated and showed considerable savings over those run by the fans controlled by the 2 C differential. At the end of the test, in July, the 2C differential had allowed 820 h aeration at a cost of 8.1 p/T compared to the 309 h at 3.1 p /T of the 4 C differential.

Table VIII. Time taken (days) and fan hours required to pass 3 cooling fronts through 3 bins of wheat cooled using a 2 C differential thermostat and 3 bins using a 4 C thermostat.

	Days		Hours	
Differential	4C	2C	4C	2C
15C	3-15	2-7	42-57	34-86
10C	49-63	42-63	93-139	207-423
5/6C	70-77	70-161	181-188	489-734

b. Insect numbers

Large numbers of insects were caught initially in the traps and there was some indication that O.surinamensis and C.ferrugineus migrated upward. However, the numbers caught declined rapidly. The probe traps recorded only single insects of O.surinamensis, S.granarius and C.ferrugineus in each bin after 31.3, 10.12 and 4.2 respectively while the pitfall traps caught no insects of these species after 7.4, 4.2 and 4.2 respectively.
No live insects were found as a result of the 28 week sampling or the final sampling during unloading of the bins.

D. THE COST OF AERATING COMMERCIAL STORES

i) Selection of stores

A number of sites were located with grain stored in heaps on the floor and nearly identical aeration systems, all intended to deliver 10 cu m/h/t. The fans were switched on and off manually.

ii) Collection of data

Daily records of fan running hours were acquired from 19 stores on 5 sites during 1984 and 1989. Sometimes these just noted the number of hours run, but often also included the time at which the fans were switched on and off. Details were also collected of the capacity of the store, either potential or exact; the total Kw of the fans and the depth of the grain.

The number of hours of fan operation between August and April each year were calculated, this being the normal storage season, as was the number of watts required to aerate each tonne of grain and the Kwh used for each tonne.

iii) Results

The stores needed between 0.9 (E4) and 3.8 (D1, 2, 3) w/t to deliver 10 cu m/h/t through grain depths of 6.5 - 10 m. These figures compare with estimates given earlier of 2 - 4.7 w/t to pass 7 - 10 cu m/h/t through 10 m of grain.

The hours of aeration in one "storage season" varied between 79 and 555. This compares with the estimate of 139 h to pass 1 cooling front through the grain or 417 to pass 3 fronts through, when using 10 cu m/h/t.

The power required to aerate the grain bulks can be calculated at between 0.17 and 1.29 kw x h/T (mean 0.4) for a "storage season". At 6p/Kwh, allowing for the fans having a nominal efficiency of 66 %, the cost would be about 1.6 - 11.7 p/T (Mean 3.6p/t)

Table IX. A comparison of average seasonal energy costs of aerating 19 stores on 5 sites in Britain at 10 cu m /h /t.

Site	store	date	h	t x1000	ht. (m)	Kw	w/t	Kwh/t
A	1-4	10.87-11.88	192	11	10	22.4	2.04	0.39
	5	10.87-11.88	126	5.5	10	11.2	2.04	0.26
B	1-2	9.87-2.89	121	18	10	28.2	1.5	0.19
C	1-5	10.87- 3.89	136	9	8-9	30.9	3.3	0.45
D	1-3	9.84-1.89	146	9	7.9	34.2	3.8	0.57
E	4	9.88-4.89	463	7	6.5	7.4	1.1	0.49

E. DISCUSSION AND CONCLUSIONS

The calculations showed that airflows above 10 cu m/T/h were adequate to prevent the development of stored product beetles in Britain, and that 10 C should be achieved by early November. The cost of this would be 1.8 -2.4 p/T for farm stores with 3m grain depth or 8 -12 p/T for commercial stores with 10 m grain depth.

The farm scale experiment showed that the calculations of required hours of aeration and time to cool the grain were not over- optimistic. The experiment was a very severe test of aeration with warm, infested grain and a delayed start to aeration, yet no live insects remained by the Spring. Therefore aeration may offer economic benefits in terms of reducing or eliminating the costs of pesticide treatments. The use of differential thermostats allowed temperatures near 5 C to be achieved and the use of a 4 C differential at 3.1 p /T offered considerable savings over that of the 2 C setting costing 8.1 p/T.

The estimates of costs in commercial stores with manually controlled aeration showed a wide variation between sites, suggesting there is scope for standardising the means of aeration control. The costs of aerating these stores averaged 3.6 p/T and were comparable with those estimated in the calculations.

In future the simple principles used in the calculations could be used to predict rates of airflow required to achieve specific biological targets and the costs of this estimated. Given access to the appropriate meteorological data, similar calculations could be conducted for different parts of the world. It is likely that this would allow aeration to be more widely used and could reduce the cost of storage and the use of pesticides.

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REFERENCES

Back, E. A. and Cotton, R. T. (1926) Biology of the saw toothed grain beetle <u>Oryzaephilus</u> <u>surinamensis</u> Linne. <u>J. Agric. Res.</u> 33, 435-451

Burrell, N.J. and Laundon (1967) Grain cooling studies I. observations during a large scale refrigeration test on damp grain. <u>J. stored Prod. Res.</u> 3, 125 -144

Burges, H. D. and Burrell, N. J. (1964) Cooling bulk grain in the British climate to control storage insects and improve keeping quality. <u>J. Sci. Fd. Agric.</u> 15, 32-50

Burkholder, W.E. (1984) Stored product insect behaviour and pheremone studies : Keys to succesful monitoring and trapping. Proc. 3rd. Int. Working Conf. Stored Prod. Entomol., Manhattan, Kansas, U.S.A. 1984, 20 - 33.

Cogan, P.M. and Wakefield, M. E. (1987) Further developments in traps used to detect low level infestations of beetle pests in stored grain. Brit. Crop prot. Council Monograph 37, 161-168 (Ed.T.J.Lawson)

Eastham, L. E. S. and McCully, S. B. (1943) The oviposition responses of Calandra granaria Linn. J. Exp. Biol. 20, 35-42.

Eastham, L. E. S. and Seagrove, F. (1947) The influence of temperature and humidity on instar length in Calandra granaria Linn. J. Exp. Biol 24, 79-94.

Howe, R. W. (1956). The biology of the two common storage species of Oryzaephilus (Coleoptera, Cucujidae). Ann. Appl. Biol. 44, 341-355.

Matthies, H. J. and Petersen, H. 1974. New data for calculating the resistance to airflow of stored granular materials. Trans. A.S.A.E. 7, 1144-1149.

Pinniger, D. B. (1975) The use of bait traps for assesment of stored product insect populations. U.S.D.A Cooperative Economic Report 25, 907- 909.

Richards, O. W. (1947). Observations on grain weevils, Calandra (Col.curculonidae) 1. General biology and oviposition. Proc. zool. Soc. 117, 1-43.

Rillett, R. O. 1949. The biology of Laemophloeus ferrugineus (Steph.) Can. J. Res. D, 27, 112-148.

Smith, L. B. (1963). The effect of temperature and humidity on the oviposition of the rusty grain beetle, Cryptolestes ferrugineus (Steph.) Proc. North Central Branch-E.S.A., 18, 74-76

Smith, L. B. (1965). The intrinsic rate of natural increase of Cryptolestes ferrugineus (Stephens) (Coleoptera, Cucujidae) J. Stored Prod. Res. 1, 35-49.