THE KILN-STERILIZATION OF TIMBER INFESTED BY *LYCTUS* POWDER-POST BEETLES

BY E. A. PARKIN

(Entomology Section, Forest Products Research Laboratory, Princes Risborough, Aylesbury, Bucks.)

THE *Lyctus* powder-post beetles are a group of wood-boring insects which attack the sapwood only of certain recently seasoned hardwoods and have for many years past been causing considerable losses to the hardwood-using industries in Great Britain and other countries. The life-history, habits, and economic importance of these insects, together with recommendations for the prevention and control of their attack, have been described in this country by Altson (1) and Munro (4) and, more recently, as a result of investigations at the Forest Products Research Laboratory, by Fisher (2, 3) and Parkin (5).

Very few hardwood timber firms take active steps to prevent *Lyctus* damage, but the majority are, at some time, compelled to consider methods of control: sterilization of infected timber in a steam-operated kiln is one of the most satisfactory.

Reference to previous research on kiln-sterilization in relation to *Lyctus* control reveals that three papers only are of special interest. Snyder (6), in some preliminary experiments, showed that a temperature of 180° F. in a dry kiln must be maintained for at least ½ hour in order to kill all stages of *Lyctus* in the wood. This temperature, however, was deleterious to the timber and impaired its strength. Snyder and St. George (7), therefore, carried out a series of experiments at lower temperatures in a saturated atmosphere, from which they concluded that 'Temperatures of 130° F. and upward, maintained for 1½ hours, or longer, are fatal to these insects if all parts of the wood infested by them have at the beginning of the exposure to these temperatures been brought to the minimum temperature of 130° F.' Fisher (2) has repeated and extended this work and lays particular stress on the time required to overcome the lag of penetration of heat into the timber after the kiln atmosphere has reached the desired temperature. He has determined that all stages of *Lyctus* can be killed in timber 1 inch in thickness by exposing the wood to a temperature of 130° F., at a relative humidity of 100 per cent., for 2½ hours, a proportionately longer time being necessary for greater thicknesses. This schedule has been generally accepted in this country as the standard and has been successfully employed commercially during the past 8 years. A number of firms, however, possess chambers in which the conditions mentioned cannot easily be attained, but which would be suitable for the sterilization of infested timber if slightly lower temperatures and humidities, held over a longer period, could be used. Fisher points out that there are indications from the results of his experiments that, provided the temperature does not fall below

120° F., prolonged treatment at 60–70 per cent. relative humidity would suffice to kill *Lyctus* and sterilize infested timber. A series of experiments was, therefore, planned to extend this work by determining what periods of exposure would be necessary to ensure sterilization of timber infested by *Lyctus* powder-post beetles at relatively low temperatures (105–125° F.) and humidities (60 and 80 per cent.). An account of these experiments is given in this paper.

MATERIAL.

American ash, infested probably by *Lyctus planicollis* Le C., was used when available, since this timber is easier to cut up for examination than English oak (attacked by *L. brunneus* Steph.) or French walnut (*L. brunneus*), which were utilized when the supplies of ash ran short. The dimensions of the samples were 6×3×1 in., but slightly larger pieces of the same thickness (1 in.) were used if the wood was not heavily infested.

The work has been carried out during the period December 1933 to January 1936 and has been confined to the winter months in order that half to fully grown larvae should be present in the samples. Larvae only have been used during these experiments since they are present in wood all the year round, whereas other stages are seasonal in occurrence. However, from earlier experiments (unpublished) it is known that eggs of *L. brunneus* and *L. linearis* are killed by exposure for 3 minutes to 130° F. and 95 per cent. relative humidity, and are therefore much less resistant than the larvae. Moreover, Fisher (2) indicates that conditions suitable for sterilizing timber containing larvae will also kill pupae and adults.

METHOD.

The experiments were carried out, with the co-operation of the Seasoning Section of the Laboratory, in a model kiln in which the desired conditions were held constant to within ±1° F. and ±2 per cent. relative humidity over long periods. The kiln was heated to the required conditions and the batch of samples then introduced on a rack. This rack consisted of a series of wires extending horizontally across a wooden framework in such a way that the samples could be laid upon the wires with sufficient space between to permit free circulation of air around them. During the run, the wet and dry bulb temperatures were read every 3 hours or less according to the period of exposure. This period was timed from the moment the samples were placed in the kiln, and therefore includes the time required for the wood to attain a temperature equal to that of the surrounding atmosphere.

Sets of 3 samples were withdrawn at predetermined intervals throughout the run. The samples were removed to the laboratory, where 2 of each set were chopped up for examination as soon as possible after treatment: the third was kept for about a month before examination in case the larvae might be able to recover more satisfactorily when left in the wood.

Larvae cut out of the samples were kept in corked tubes in the laboratory

and examined periodically until they could be classified as alive or dead. A larva was considered to be alive if it was able to perform any muscular movement, however slight, although in many cases the insects would probably never have recovered sufficiently to resume feeding and development. Partial recovery was usually evident within a week of treatment, but in a few cases signs of life were not detected for 2 to 4 weeks. Larvae could not be classified as dead until signs of post-mortem changes were apparent, and it was often necessary to keep the insects under observation for several weeks before such changes were discernible.

Control samples from the same supply of wood as the experimental specimens were cut up from time to time in order to ensure that living larvae were present before treatment.

RESULTS.

In Table I the results of all the experiments have been combined in such a way as to show the percentage kill of larvae for different periods of exposure to various temperatures and relative humidities.

From the results given in Table I, the approximate minimum lethal periods for the various combinations of temperature and relative humidity may be extracted (Table II).

It will be seen that a reduction in relative humidity necessitates an increase in the period of exposure in order to achieve a 100 per cent. kill. This holds for all temperatures except 110° F., where the lethal period at 60 per cent. R.H. is less than at 80 per cent. R.H. If the lethal periods are plotted against the corresponding temperatures for the two relative humidities, it is found that a smooth curve can be drawn through the points obtained at 80 per cent. R.H. and a curve of similar shape will pass through 4 of the 5 points obtained at 60 per cent. R.H. According to the curve, the lethal period at a temperature of 110° F. and 60 per cent. R.H. should be about 102 hours, instead of 84 hours as recorded. No reason can be advanced to account for this anomalous result, which has been checked by a second series of experiments.

Although samples were sterilized successfully at 105° F., the period of exposure is rather long for commercial practice and there is a danger that the variation in temperature in a kiln might allow part of a load to pass through without reaching a lethal temperature. The use of a temperature as low as 105° F. is, therefore, not recommended, nor, owing to the anomaly in the results, is 110° F.

Effective sterilization may be carried out at temperatures of 115–25° F., provided that an adequate margin of safety is allowed on the periods of exposure given in Table II.

As mentioned earlier, during the experimental kiln runs the samples were introduced into the chamber after it had attained the desired conditions. This is not possible in commercial practice owing to the time required to load the kiln, so that the period of exposure must be calculated from the time at which the atmosphere in the loaded kiln reaches the required temperature and

TABLE I. *Percentage kill of* Lyctus *larvae in timber after exposure to different kiln-sterilization treatments.*

A. Results of experiments at 80 per cent. relative humidity.

Temperature, ° *F.*	*Period of exposure, hrs.*	*Number of experiments.*	*Number of larvae.*		*Mortality per cent.*
			Dead.	*Alive.*	
105	24	1	3	32	8·6
	48	1	16	38	29·6
	72	1	37	37	50·0
	96	1	76	4	95·0
	120	1	68	1	98·6
	144	2	80	0	100·0
	168	1	71	0	100·0
110	12	1	4	36	10·0
	18	1	64	16	80·0
	24	3	85	34	71·5
	30	2	51	28	64·6
	36	3	97	44	68·8
	48	3	252	5	98·1
	60	4	305	7	97·8
	66	1	112	0	100·0
	72	2	174	3	98·3
	78	1	99	0	100·0
	84	2	96	4	96·0
	90	1	68	0	100·0
	96	1	50	0	100·0
	108	1	56	0	100·0
115	6	1	46	22	67·7
	9	1	41	3	93·3
	12	3	79	78	50·3
	18	3	99	8	92·5
	24	3	99	2	98·0
	30	2	52	0	100·0
	36	1	37	0	100·0
	42	1	42	0	100·0
120	2	1	53	2	96·4
	4	1	30	1	96·8
	5	1	34	2	94·5
	6	1	39	0	100·0
	8	1	41	0	100·0
125	1	1	46	16	74·2
	1·5	1	26	3	89·7
	2	1	25	0	100·0
	4	1	40	0	100·0
	8	1	47	0	100·0

B. Results of experiments at 60 per cent. relative humidity.

Temperature, ° *F.*	*Period of exposure, hrs.*	*Number of experiments.*	*Number of larvae.*		*Mortality per cent.*
			Dead.	*Alive.*	
105	96	2	61	11	84·7
	120	2	68	14	82·9
	144	2	51	2	96·3
	168	2	78	0	100·0
	192	1	16	0	100·0
110	18	1	4	16	20·0
	24	1	12	15	44·4
	30	1	49	12	80·3
	36	1	24	15	61·5
	48	1	27	3	90·0
	60	2	77	5	93·9
	72	1	35	2	94·7
	84	2	128	0	100·0
	90	1	107	0	100·0
	96	1	120	0	100·0
	102	1	134	0	100·0
	108	1	79	0	100·0
	114	1	61	0	100·0
115	9	1	0	20	0·0
	12	1	21	12	63·6
	18	1	33	17	66·0
	24	2	77	7	91·7
	30	1	34	1	97·2
	36	2	53	0	100·0
	42	1	27	0	100·0
120	3	1	17	6	73·9
	5	1	52	7	88·2
	6	1	24	12	66·7
	7	1	73	0	100·0
	10	1	45	0	100·0
125	1	1	16	31	34·1
	2	1	42	39	51·8
	3	1	31	1	96·8
	4	1	47	0	100·0
	8	1	36	0	100·0

humidity. An allowance must be made for the time necessary for the heat to penetrate to the centre of the boards after the surface has come into approximate equilibrium with the kiln atmosphere. During the experimental work this allowance was included in the lethal period, but, because oft he smallness of the samples, the lag in penetration would probably not be so great as in the case of commercial stock. In order to be quite safe, therefore, there should be

added to the lethal period the full allowances (time required to overcome lag) given by Fisher (2) in his table, which shows the periods of exposure necessary for the destruction of all stages of *Lyctus* powder-post beetles in timber 1–3 in. thick at a temperature of 130° F. and relative humidity of 100 per cent. and which is reprinted below with very slight modifications (Table III).

TABLE II. *Approximate lethal periods for* Lyctus *larvae in timber at various temperatures and relative humidities.*

Relative humidity.	*Temperature, ° F.*	*Lethal period, hours.*
80 per cent.	105	144
	110	90
	115	30
	120	6
	125	2
60 „	105	168
	110	84
	115	36
	120	7
	125	4

TABLE III. *Periods of exposure necessary for sterilization of* Lyctus*-infested timber of different thicknesses at* 130° F. *and* 100 *per cent. R.H.*

Thickness of timber, inches.	*Time required to overcome lag, hours.*	*Lethal period, hours.*	*Safety factor, hours.*	*Total period of exposure after kiln has attained required conditions, hours.*
1	½	1½	½	2½
2	2	1½	½	4
2½	3½	1½	½	5½
3	4½	1½	½	6½

For the treatment of 1-inch boards, the periods of exposure in the kiln for temperatures of 115° F., 120° F., and 125° F., and relative humidities of 80 per cent. and 60 per cent., are shown in Table IV. The safety factor has been arbitrarily fixed at 25 per cent. of the experimentally determined lethal period for the larvae.

For timber less than 1 inch in thickness the same treatment as for 1 inch should be given. When the load contains boards more than 1 inch thick, the time required to overcome the lag in penetration of heat into the wood must be increased in accordance with the figures shown in Table III. Thus the total sterilization period which should elapse after the kiln has reached conditions of, for example, 120° F. and 80 per cent. relative humidity for boards 3 inches thick would be $4\frac{1}{2}+6+1\frac{1}{2} = 12$ hours.

Although the use of a relative humidity of 100 per cent. helps to bring about the more rapid death of *Lyctus* larvae in wood, kiln-sterilization at relative humidities less than 100 per cent. is advantageous in that, providing a suitable humidity is chosen, the timber does not change its moisture content by any appreciable amount even during long periods of exposure, nor does it suffer from surface wetting due to condensation.

TABLE IV. *Periods of exposure necessary for sterilization of* Lyctus-*infested timber* 1 *inch in thickness.*

Relative humidity, per cent.	*Temperature, ° F.*	*Time required to overcome lag, hours.*	*Lethal period, hours.*	*Safety factor, hours.*	*Total period of exposure after kiln has attained required conditions, hours.*
80	115	½	30	7½	38
80	120	½	6	1½	8
80	125	½	2	½	3
60	115	½	36	9	45½
60	120	½	7	2	9½
60	125	½	4	1	5½

It must be emphasized that kiln-sterilization does not render timber immune from subsequent reinfestation, and, since there is at present no commercially practicable method of achieving this, kiln-sterilized stock should be segregated or, preferably, should be utilized with as little delay as possible, for the finished article is usually protected to some extent against infestation by the polish or varnish. Apart from its application to stocks of converted timber, the treatment can also be utilized for the control of *Lyctus* in manufactured articles, whether constructed of solid wood or plywood, although care must be taken to adjust the humidity of the kiln atmosphere so that the change in moisture content of the furniture, panelling, &c., is kept at a minimum. Care must also be taken to ensure that joints do not fail because of softening of the glue.

SUMMARY.

The results of this investigation show that it is possible to use lower temperatures and relative humidities than have hitherto been recommended for the sterilization of timber infested by *Lyctus* powder-post beetles. Timber can be sterilized at a temperature as low as 105° F. and a relative humidity of 60 per cent., but it is recommended that, in practice, a temperature not lower than 115° F. should be employed.

Tables are included showing the periods of exposure which are necessary to kill *Lyctus* larvae in timber of different thicknesses at temperatures between 115° F. and 130° F. and relative humidities between 60 per cent. and 100 per cent.

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