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High temperature drying of UK Sitka spruce

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Executive Summary

This study, commissioned by the Forestry commission and Scottish Enterprise was undertaken to further investigate the high temperature drying of UK spruce. Previous trials on UK spruce by research organisations in France, Finland and the Netherlands showed that UK material could be dried to a moisture content of 18% in approximately 63 hours with a quality similar to, or better than that achieved using conventional drying methods.

Although the results from this previous work were very promising, several areas of high temperature drying still required further investigation before the UK industry could be confident that the system was commercially viable. These included:

- Investigate the possibility (using experimental trials) of further reducing drying times whilst retaining or improving final dried quality of UK material.
- Undertake a full scale industrial trial with the most promising kiln schedule developed in the experimental phase, and assess the drying time and wood quality.
- Provide an indication of the construction costs of an industrial size high temperature kiln and a full breakdown of the energy requirements to dry spruce in such a facility.
- Undertake a programme of bending and stiffness assessments on conventionally dried and high temperature dried spruce to clarify situation on possible strength reductions due to subjecting timber to high temperature.

To date four high temperature drying trials have been undertaken at the premises of HB Koeltechniek, in Almelo, Holland. The drying times recorded from these trials range from 76 hours to 56 hours. After some discussion, it was felt that the drying times could be further reduced, although the variation in final moisture content of the charge would be likely to increase.

During distortional characteristic assessments on high temperature dried material, the average twist values were found to be either very similar too or lower than those exhibited by conventionally dried material. In comparison, bow and spring values tended to be slightly variable, although in all instances well within acceptable limits.

Results from strength and stiffness assessments undertaken on material from each of the trials were found to be quite variable. Certain batches of material dried using high temperature showed large reductions in strength and stiffness, whilst others remained fairly stable, when compared to timber dried conventionally. These results indicate that the schedule type, and also possibly length, does have an influence on the structural properties of the timber being dried. Due to the variable strength and stiffness results recorded from the material dried in the Netherlands. It was decided that further strength and stiffness tests would be undertaken with material dried using high temperatures in the Windsor/Nardi project. This would clarify whether the reduction in the structural properties was due to the high temperatures used during the drying process (similar temperatures are reached by both systems) or whether the drying system itself is causing some of the reductions.

Data and written comments supplied by Michel Reipen of the TNO Institute in Holland indicate that high temperature drying is more energy efficient and therefore more economical to run that conventional drying kilns.

Further work will hopefully clarify the strength and stiffness issues which have been highlighted in this report and also provide a strategy for future work.

Contents

Introduction

This report presents the progress of the project since it's inception at the end of October 2005. The work is funded by the Forestry commission and Scottish Enterprise and complements work already undertaken in both government funded Partners in Innovation, and Forestry Commission projects. This report represents the first milestone of the contract, due at the end of March 2006.

During the last four years, BRE and 7 of the UK's largest softwood sawmillers have been involved with the European funded 'STRAIGHT' project. This project was initiated to investigate a number of new and novel drying techniques to improve softwood drying, reduce distortion and shorten drying times. Several of the techniques assessed within the project provided very encouraging results. One of the most promising methods of drying was high temperature drying. After a number of trials on UK spruce by research organisations in France, Finland and the Netherlands, UK material was finally dried to a moisture content of 18% in approximately 63 hours with a quality similar to, or better than that achieved using conventional drying methods.

Although the results from this work have been very promising, the work to reach this point has required extensive assessments. Before the UK softwood sawmilling industry can be confident that the system is commercially viable, several areas of high temperature drying still require further investigation. These include:

- Investigate the possibility (using experimental trials) of further reducing drying times whilst retaining or improving the final dried quality of UK material.
- Undertake a full scale industrial trial with the most promising kiln schedule developed in the experimental phase, and assess the drying time and wood quality.
- Provide an indication of the construction costs of an industrial size high temperature kiln and a full breakdown of the energy requirements to dry spruce in such a facility.
- Undertake a programme of bending and stiffness assessments on conventionally dried and high temperature dried spruce to clarify the situation on possible strength reductions due to subjecting timber to high temperature.

Description of the project

Initially, the project was organised into six work tasks (see below), although work has been undertaken simultaneously across all the tasks. Due to results from the structural testing, work within certain tasks has been curtailed. Descriptions of the original work tasks are shown below.

Task 1. Undertake eight experimental trials on UK material

8 packs of 50 x 100 x 4800 mm spruce battens will be selected from freshly processed material from participating sawmills. Each pack will be consecutively numbered, cut in half, a moisture content sample removed and the packs mixed to provide two identical packs. One pack will be dried by the participating sawmill and the other pack sent to the Netherlands to be dried in the experimental high temperature kiln in Almelo, Netherlands. After drying, both the experimental and control packs will be sent to BRE for quality assessment measurements.

Task 2. Analysis of results

Results from task 1 will be analysed and compiled for dissemination to the project partners. The results from the analysis (plus partner comments) should provide a suitable schedule for use in the next stage (industrial trial) of the work programme.

Task 3. Full scale industrial trial

Depending on the size of the industrial high temperature drying kiln a suitable volume of freshly processed UK spruce (50 m^3– 80m^3) of specific dimensions will be collected from the UK partners and transported to the Netherlands for high temperature drying. The load will be dried in the industrial unit using the schedule selected during trials in task 1. When drying is completed, the material will be transported back to BRE for quality assessment. A minimum of 500 battens will be selected from the returned material and measured for distortion and moisture content.

Task 4. Energy costs in high temperature drying

The first indications from the manufacturers of high temperature kilns is that the cost of drying is significantly less than that of drying using conventional kilns. This is mainly due to the ‘closed system’ and the speed of drying. In order to verify these statements, a detailed breakdown will be made of the costs of drying using an industrial high temperature kiln. Included in these costs will be the cost of construction of an industrial high temperature kiln, in comparison to a conventional kiln of the same dimension. This will provide further information to UK industry of the suitability of introducing such a system into the UK.

Task 5. Bending and stiffness assessments

It is well known that timber subjected to high temperature shows a small loss in strength. In this work task, battens subjected to high temperature drying will be assessed for reductions in strength and stiffness. Tests will be conducted on 50% of the control and experimental battens dried in task 1. This work task will investigate whether drying UK spruce under high temperature causes any significant loss in strength or stiffness, and if so, how this may affect machine grade settings.

Task 6. Dissemination

Results from task 1 will be in distributed in the form a short (no more than 4 pages) summary describing the high temperature schedule used in each trial and the wood quality results from both the conventionally dried and high temperature dried material. This will be distributed to the partners prior to task 3, the full scale industrial trial. Following the full scale industrial trial, a short report will produced describing the methods used in the project and a detailed set of results and conclusions. A trip will also be organised for the partners and funding bodies, to visit the Netherlands in order to view the industrial high temperature kiln as it discharges its load of UK material.

Findings

High temperature drying assessments on UK spruce

To date, four high temperature drying trials have been undertaken at the premises of HB Koeltechniek, in Almelo, Holland. Each of these high temperature trials was devised and supervised by Michel Reipen of the TNO Research Institute, Delft, The Netherlands. As this project is a continuation of the work first undertaken in the EU funded STRAIGHT project, the original coding for the trials has been continued on into this project. Therefore, the first high temperature trial within the project is suffixed 09, the second 10 and so on.

50 x 100 x 4800 mm spruce battens were selected from freshly processed material from two of the participating UK sawmills. Each pack was consecutively numbered, cut in half, a moisture content sample removed from the centre of each batten and the packs mixed to provide two identical packs. One pack was dried by the participating sawmill using a conventional drying schedule and the other pack sent to the Netherlands to be dried using high temperature. After drying, both the experimental (high temperature dried) and control packs (dried conventionally in the UK) were sent back to BRE for quality assessment measurements.

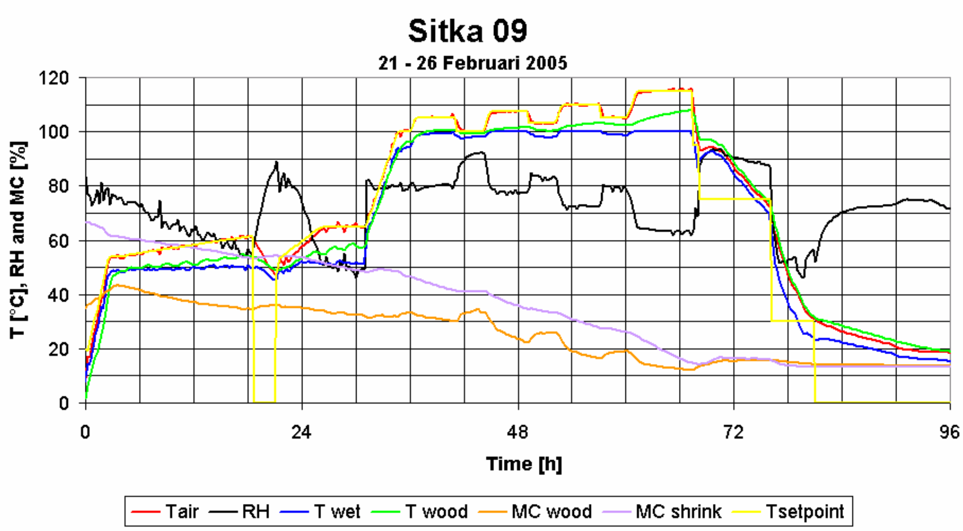

Figure 1. No 09 high temperature drying schedule (76 hours in length)

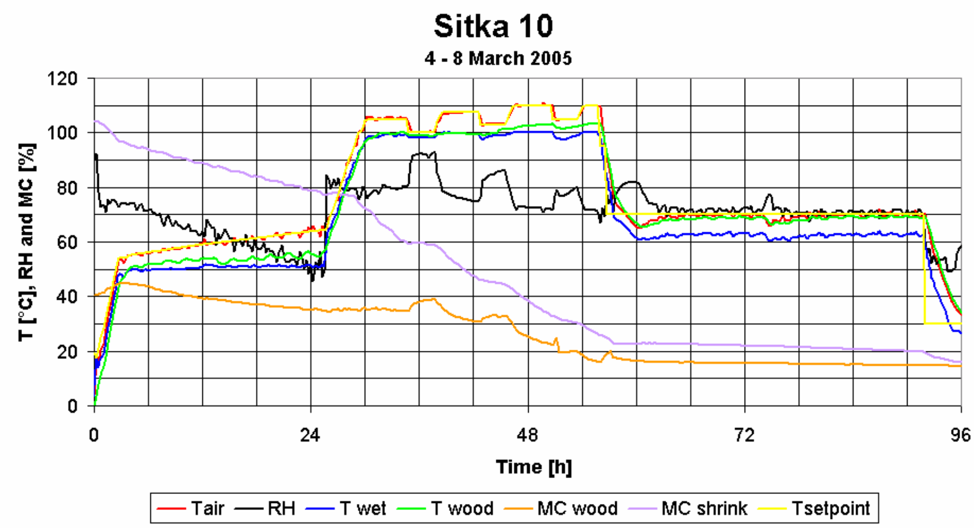

Figure 2. No 10 high temperature drying schedule (60 hours in length)

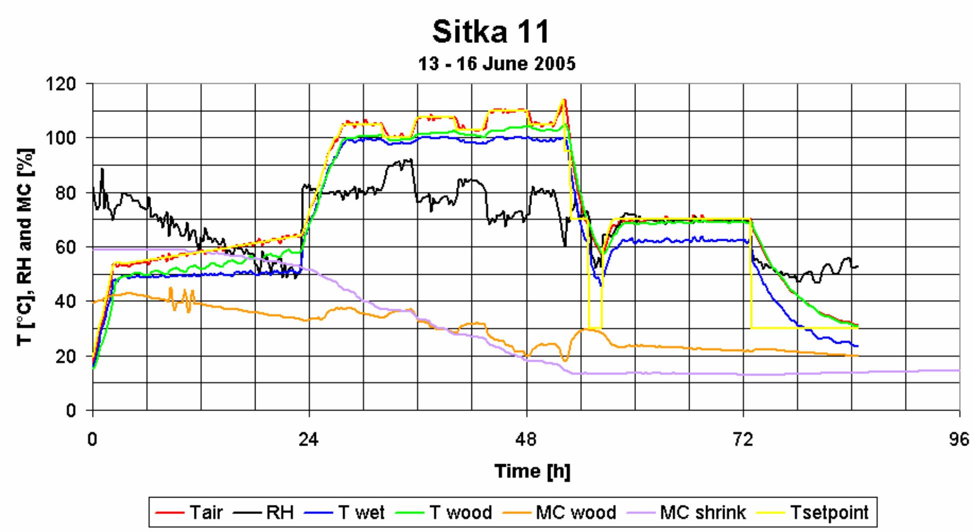

Figure 3. No 11 high temperature drying schedule (56 hours in length)

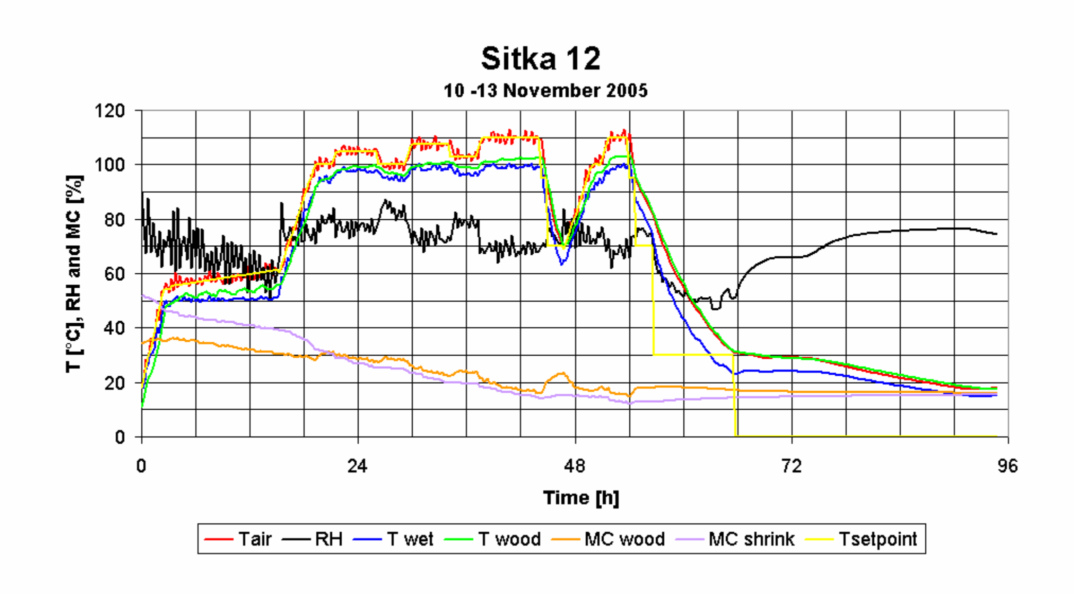

Figure 4. No 12 high temperature drying schedule (58 hours in length)

Figures 1, 2, 3 and 4 show the experimental high temperature schedules used to dry the first four batches of experimental material sourced from the UK. The drying times recorded from these trials ranged from 76 hours to 56 hours. The associated control material for trial 09 and 10 was dried in 98 hours using conventional drying technology at the sawmill of Adam Wilson & Sons Ltd of Troon, using a maximum dry bulb temperature of 68°C. The associated control material for trial 11 and 12 was dried in 165 hours using conventional drying technology by BSW Timber Plc at their Boat of Garten sawmill, Scotland, using a maximum dry bulb temperature of 60°C. In discussion with Michel Reipen of the TNO Institute in Delft, it was felt that the high temperature drying times could be further reduced, although the variation in final moisture content of the charge would also increase from those exhibited (table 1). In reality, even charges dried using conventional means still exhibit a fairly wide variation in final moisture content (table 1). In a high temperature charge, this could be reduced by elongating the equalising phase of the schedule.

Table 1. Final moisture content variation

Trial	Conventionally dried		High temperature dried	
	Average M/C (%)	Standard Deviation	Average M/C (%)	Standard Deviation
09	14.3	1.3	15.6	2.4
10	14.0	0.9	17.1	2.5
11	19.1	2.5	18.0	3.7
12	19.2	2.4	17.9	2.0

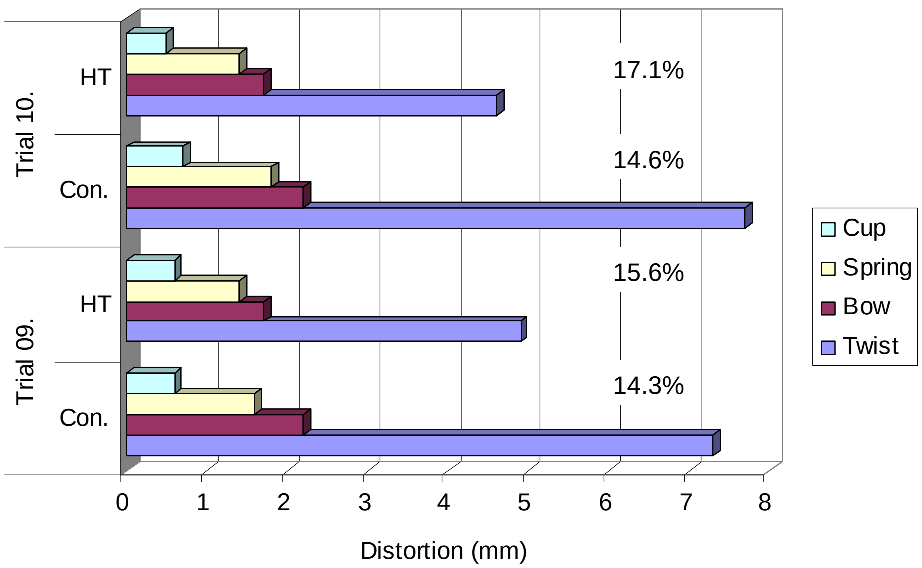

Figure 5. Average distortion & M/C values for experimental and control trials 09 & 10

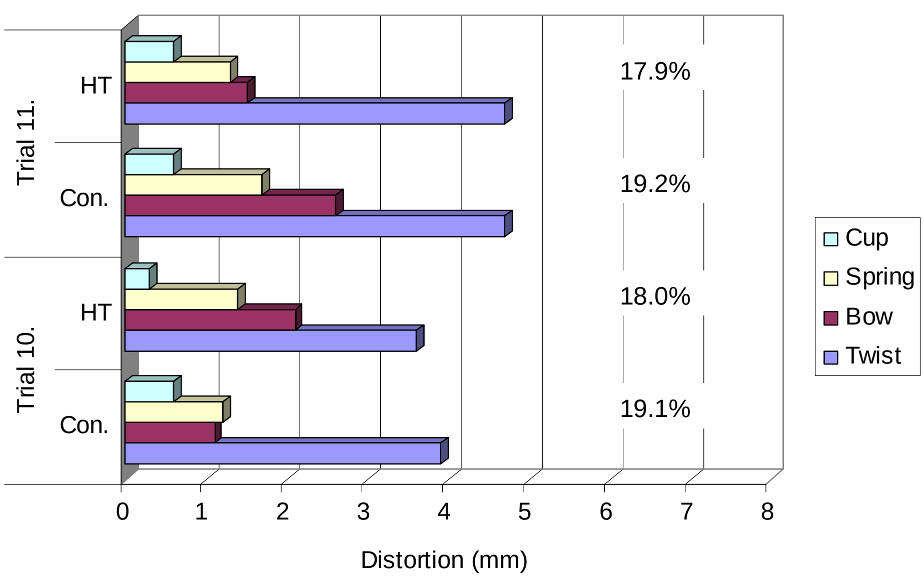

Figure 6. Average distortion & M/C values for experimental and control trials 11 & 12

Distortion assessments

Figures 5 and 6 indicate the average distortion values exhibited by each of the high temperature and associated control trials, with the average final moisture content of each batch shown to the left of each bar graph.

In all four instances, the average twist values of the high temperature dried material were either very similar, or lower than those exhibited by conventionally dried material. In comparison, bow and spring values tended to be slightly variable, although in all instances well within acceptable limits.

Attention is drawn to the final average moisture contents of conventionally dried material in trial 09 and 10. Due to a computer failure on the measuring rig, this material required re-measurement after the initial data had been lost. This resulted in further drying of the material, with an associated rise in distortion values. Even so, the average moisture contents are only differentiated by 1% in both sets of material within trial 09, although the twist values vary considerably.

The four trials completed to date provide additional evidence to previous work that UK grown spruce can be effectively dried using high temperatures in under 60 hours, with distortion levels similar or better than those achieved by conventional drying. As already mentioned, Michel Reipen of the TNO Institute in Delft, felt that these drying times could be further reduced, although final average moisture contents would become more variable. The variation exhibited (table 1) in final moisture contents in the latest trials is similar to that of conventionally dried material. It should be noted that if the final average moisture content is reduced, the actual variation between final moisture contents also reduce.

Strength and stiffness assessments on high temperature dried spruce

It has been documented in Swedish[1] and American[2] timber research literature that timber subjected to high temperatures (above 100°C) has shown small (5%) or no loss in strength or stiffness. Under task 5 of the project, battens dried using both high temperature and conventional drying schedules would be assessed for variations in strength and stiffness. This work task investigated whether drying UK spruce under high temperature causes any significant loss in strength or stiffness, and if so, how this may affect subsequent machine grade settings.

Material from all four high temperature and conventional drying trials were tested in four point bending in accordance with EN 408: 1995 (Timber Structures – structural timber and glue laminated timber – Determination of some physical and mechanical properties) for the calculation of both the modulus of rupture (strength) and modulus of elasticity (stiffness).

The battens were assessed using a medium capacity Avery strength testing machine located in the timber centre at BRE. A linear voltage displacement transducer (LVDT) was placed in a central position under each specimen to measure the deflection of the beam as the load was applied. Data from the LVDT and load cell were transferred to a PC via a data acquisition programme which recorded both the applied load and the specimen deflection at 1 second intervals up to a specified deflection. The specimen was then tested to failure. After the tests were completed, the results were standardised for strength to a common batten depth of 150 mm and for stiffness at a moisture content of 12%.

Table 2. Results for modulus of elasticity (MOE) and modulus of rupture (MOR) on conventional and high temperature dried spruce

Trial	Conventionally dried		High temperature dried	
	MOE (N/mm^2)	MOR (N/mm^2)	MOE (N/mm^2)	MOR (N/mm^2)
09	10723.3	23.6	8257.6	18.4
10	9466.3	23.2	8964.23	15.28
11	8575.6	21.1	8851.5	21.8
12	9101.5	23.0	10212.6	19.3

MOR values adjusted to 5^{th} percentile

Initial results from the strength and stiffness assessments on material dried using high temperature indicate that the results seem to be dependant on the type of high temperature schedule used to dry the charge. In trial 09, both strength and stiffness of the high temperature dried material was reduced by approximately 22% when compared to values recorded on conventionally dried material. In trial 10, stiffness was reduced by 6% and strength by 32%. In trial 11, stiffness slightly increased and strength remained almost constant when the two types of drying were compared. In trial 13, stiffness again increased, although strength was reduced (approx. 15%).

The results reported here seem to indicate that the schedule type, and possibly length, does have some influence on the structural properties of the timber being dried. Although, due to the relatively small statistical sample number which have been assessed, further work would be required to verify these results. On a plus point, further structural testing of high temperature dried material is planned for the coming months. These assessments will be undertaken on material dried in the Windsor/Nardi high temperature drying project. This material is at present being machine graded, before being returned to BRE for bending and stiffness testing. The time frame for this test work is covered later in the report under the heading 'Future work plan'.

Surface colour changes in high temperature dried material

The colour of freshly processed spruce is generally a bright creamy white; a colour retained even after (conventional) kiln drying at medium temperatures. This bright colour will darken naturally over time to a light tan colour. This will occur quite quickly if exposed to strong sunlight.

The colour differences between the timber dried using conventional, and high temperature schedules is marked. Drying spruce using high temperature darkens the timber to a similar hue as that of aged conventionally dried spruce.

This definite colour variation may cause some concern to producers, especially if this colour change affects the customer perception of timber dried using this form of technology.

Energy costs associated with high temperature drying

Kiln drying is a necessary part of producing UK softwoods for the construction industry. This process is often a bottleneck in the production chain and also a serious consumer of energy.

The cost of drying timber for the UK markets consists of four main elements, capital investment, raw material cost, energy consumption and labour (load and un-load the kiln). The energy requirements can be further split into four components to:

- Generate heat
- Generate airflow
- Run the control unit and associated switch gear
- Run the forced extraction fans (if fitted)

All four can utilise electricity, although most UK softwood sawmills use a combination of energy types including, electricity, fuel oil, gas and sawmill waste residues to run their kilns. Because of the different sources and the variability of dimensions and moisture contents required from the final product, it can be very difficult to place a specific price on the cost of drying per m^3 of softwood.

A conventional wood drying kiln (batch kiln) is basically an insulated box with the facility to produce heat and to humidify and circulate air. These three variables (heat, humidity and airflow) are essential elements of the drying process and are controlled via sensors within the kiln to optimise the removal of moisture from wet timber at a controlled rate.

Most UK softwood producers have relatively modern wood drying kilns which have the main fans and heat exchangers situated above the kiln load in the roof space, above a false ceiling. Top and side flaps or rubber partitions reduce the size of gaps around the parcels of timber, ensuring the heated air is directed through the load as efficiently as possible. Several types of kilns have forced air extraction units to remove moisture laden air, whilst vents introduce fresh air. Most of the modern kilns used in the UK softwood industry have their operation controlled by computer.

On the whole, conventional wood drying kilns (batch) are not efficient users of heat energy. Essentially, wet timber is placed into the kiln and the air within heated and circulated through the stacked timber by a number of fans. In order to regulate the loss of moisture from the drying timber (to prevent drying degrade), the atmospheric conditions are regulated by the introduction of moisture (steam or atomised spray) to prevent the timber drying too rapidly (to prevent distortional problems and various types of drying degrade). As the hot air is passed through the kiln, the wet timber absorbs heat, resulting in the movement of moisture to the surface where it is absorbed by the circulating air. When the circulating air becomes saturated with moisture, the vents, located on the kiln roof are opened and the saturated air is vented to the atmosphere. Fresh air is then drawn into the kiln, heated, and the wood drying process continues.

The high temperature drying system used in this project is better described as 'super heated steam drying', where the wet bulb temperature is set at 100°C and the dry bulb temperature may reach 120°C. This type of drying system uses the sealed chamber principle, whereby no exchange of air occurs between the atmosphere and drying charge during the drying cycle. Moisture given off from the timber during drying is vented as a natural overpressure from the system as drying occurs.

High temperature drying systems reduce drying times and have been calculated as being more energy efficient than conventional systems. The main reasons for this are:

- Drying occurs at a faster rate than with conventional systems (reducing energy consumption)
- High temperature kilns are sealed units and do not require an exchange of air with the atmosphere to expel the excessive moisture produced during the drying process

Table 3 provides a cost comparision[3] between a conventional batch kiln drying to a moisture content of 8%, a continuous kiln drying to 18%, and a high temperature (HT) kiln drying to both 8% and 18%. The table shows that HT-drying is most economical when drying to low moisture contents. Shorter drying schedules cut capital and energy costs. In this example, normal construction timber is dried in a continuous kiln, which are common in Nordic countries. The use of a heat exchanger on this example makes it more energy efficient. Savings are higher when construction timber is produced using HT-drying compared with low temperature batch kiln drying.

Table 3. Comparison between HT drying and conventional kiln drying (batch kiln for joinery timber and one stage continuous drying kiln for shipping dry timber).

Scots Pine 50 mm	batch kiln 8 %	HTD -kiln 8 %	contin.kiln 18 %	HTD -kiln 18 %
Initial data				
drying capasity, m^3 / a	7200	7000	14000	14000
kiln acquisition price, million euros	0,3	0,21	0,35	0,21
repayment period, a	12	12	12	12
interest rate, %	6	6	6	6
price of heat, €kWh	0,02	0,02	0,02	0,02
price of electricity, €kWh	0,04	0,04	0,04	0,04
timber value, €m^3	200	200	170	170
drying time, h	200	50	100	25
heat consumption, kWh/m^3	450	360	300	300
electricity consumption, kWh/m^3	40	50	25	35
labour and maintanace costs, €m^3	2	2	2	2
value loss due drying defects, %	5	5	5	5
Costs, €m^3				
capital costs, kiln	4,97	3,58	2,98	1,79
interest payable, timber during drying	0,27	0,07	0,12	0,03
energy	10,60	9,20	7,00	7,40
labour and maintenance	2,00	2,00	2,00	2,00
value loss due drying defects	10,00	10,00	8,50	8,50
Total	*27,84*	*24,85*	*20,60*	*19,72*
change LTD > HTD, %		-10,8		-4,3

Future work plan

At the dissemination meeting held at BRE on the 26th January 2006 and attended by project partners and funders, a number of difficulties were raised concerning the 'The high temperature drying of spruce' project. Firstly, the company (HB Koeltechniek) who have been drying the UK spruce using their experimental high temperature facility in Holland have 'lost interest in the project'. Michel Reipen who has been devising and overseeing the drying programme has, due to difficulties with the firm, severed working ties with HBK. This has resulted in the cessation of trials in the Netherlands.

This chain of events has since been overtaken by the results gained from strength and stiffness testing of the material which has already undergone high temperature drying. Results have indicated that a severe reduction in the strength and stiffness of UK spruce can occur when dried using high temperatures, using the methods employed by the drying method in Holland.

During the middle of last year, a project was undertaken with the Windsor/Nardi group (kiln manufacturers in New Zealand and Italy) on the high temperature drying of spruce. This company uses a slightly different form of drying technology, although the both technologies being trialled are similar. The Windsor/Nardi group has shown they are able to dry UK spruce in approximately 24 hours, whereas the shortest time achieved by the group in Holland was 58 hours. This reduction in drying time is impressive, although further work is required by Windsor to improve the distortional quality of the dried material, a quality not far removed from that achieved by conventional means.

At this moment in time, the Windsor/Nardi group are in the process of deciding what to do next. Among several ideas under discussion is to install a full size industrial unit at a sawmill in Scotland. This would allow further trials to be undertaken, although this would also require a considerable outlay for the company. I am in regular contact with Stephen Carr, regional sales manager for the company and will keep the industry informed of any decisions which may affect the UK.

Due to the poor strength and stiffness results of material dried in the Netherlands, it was decided that further strength and stiffness tests would be undertaken with the material dried using high temperatures in the Windsor/Nardi test work. This would clarify whether the reduction in the structural properties was due to the high temperatures used during the drying process (similar temperatures are reached by both systems) or whether the drying system itself is causing the reductions. Alternatively, UK spruce may not be best suited to this type of drying due to its specific cellular structure.

The future work plan (shown below) will hopefully clarify the strength and stiffness issues, and provide a strategy for future work on high temperature drying. The main tasks for the completion of the project will consist of:

1. Complete the strength and stiffness assessments of both control and high temperature dried material

2. Transport four packs of material (two experimental and two control packs) dried in the Windsor/Nardi project to James Jones in Aboyne to be graded using both the GoldenEye x-ray grader and a traditional bending type grading machine.

3. Return material to BRE to undergo structural testing
4. Analyse results of structural assessments
5. Disseminate results to partners and funders in a short letter format via e-mail
6. Arrange short meeting in Scotland to discuss results

The expected time frame for the completion of the above tasks is given in table 3.

Table 3. Time frame of future work plan

Task	March 06	April 06	May 06	June 06
1	√			
2	√			
3		√	√	
4			√	
5			√	
6				√

Conclusion and recommendations

This report presents the results from the project 'High temperature drying of UK spruce' since it's inception at the end of October 2005. To date, the work program has covered a number of work tasks including:

1. The completion of four drying (high temperature and associated conventional controls)
2. Distortion assessments of the above material
3. Structural testing of both high temperature dried and conventionally dried material
4. An assessment of the associated costs of high temperature drying
5. After unexpected structural test results and the withdrawal of HB Koeltechniek from the project, a revised work plan of the tasks planed for completion by June 2006 has been produced.

1. To date four high temperature drying trials have been undertaken at the premises of HB Koeltechniek, in Almelo, Holland. Each of these high temperature trials was devised and supervised by Michel Reipen of the TNO Research Institute, Delft, Holland. The drying times recorded from these trials ranged from 76 hours to 56 hours. The associated control material for trial 09 and 10 was dried in 98 hours using conventional drying technology at the sawmill of Adam Wilson & Sons Ltd of Troon, using a maximum dry bulb temperature of 68°C. The associated control material for trial 11 and 12 was dried in 165 hours using conventional drying technology by BSW Timber Plc at their Boat of Garten sawmill, using a maximum dry bulb temperature of 60°C. In discussion with Michel Reipen of the TNO Institute in Delft, it was felt that the high temperature drying times could be further reduced, although the variation in final moisture content of the charge would increase from those already exhibited

2. After an assessment for distortional characteristics, the average twist values of the high temperature dried material were either very similar, or lower than those exhibited by conventionally dried material. In comparison, bow and spring values tended to be slightly variable, although in all instances well within acceptable limits.

3. Material from all four high temperature and conventional drying trials were tested in four point bending in accordance with EN 408: 1995. In trial 09, both strength and stiffness of high temperature dried material was reduced by approximately 22% when compared to values recorded on conventionally dried material. In trial 10, stiffness was reduced by 6% and strength by 32%. In trial 11, stiffness was slightly increased and strength remained almost constant when the two types of drying were compared. In trial 13, stiffness again increased, although strength was reduced (approx. 15%). The results reported here seem to indicate that the schedule type, and possibly length, does have some influence on the structural properties of the timber being dried.

4. Due to the poor strength and stiffness results of material dried in the Netherlands, it was decided that further strength and stiffness tests would be undertaken with the material dried using high temperatures in the Windsor/Nardi test work. This would clarify whether the reduction in the structural properties was due

to the high temperatures used during the drying process (similar temperatures are reached by both systems) or whether the drying system itself is causing the reductions. Alternatively, UK spruce may not be best suited to this type of drying due to its specific cellular structure.

5. Data and literature supplied by Michel Reipen of the TNO Institute in Holland indicate that high temperature drying is more energy efficient and therefore more economical to run that conventional drying kilns.

The future work plan will hopefully clarify the strength and stiffness issues raised during the project and provide a strategy for future work on high temperature drying. The main tasks for the completion of the project will consist of:

- Complete the strength and stiffness assessments of both control material and material high temperature dried in the Netherlands
- Transport four packs of material (two experimental and two control packs) dried in the Windsor/Nardi project to James Jones in Aboyne to be graded using both the GoldenEye x-ray grader and a traditional bending type grading machine.
- Return this material to BRE to undergo structural testing
- Analyse results of structural assessments
- Disseminate results to partners and funders in a short letter format via e-mail
- Arrange short meeting in Scotland to discuss results

References

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2. Gerhards, C. C. (1986) High temperature drying of Southern pine 2 by 4's: effects on strength and load duration in bending. Wood science and technology vol 20, no 4, 349-360.
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Appendix A – Distortion measurement process

Twist

Twist measurements were recorded on a special rig using calibrated transducers. Each batten being measured over a distance of 2000 mm. The severity of twist exhibited by each piece was measured at a distance of 2000 mm from the clamped end, at a height or depth of 100 mm (fig. 1).

Bow

Bow measurements were recorded on a special rig using calibrated transducers. The central portion of each batten was clamped against the rig up-rights, 2000 mm apart. The deflection from parallel of the piece was measured at the central point, 1000 mm from either up-right (fig. 1).

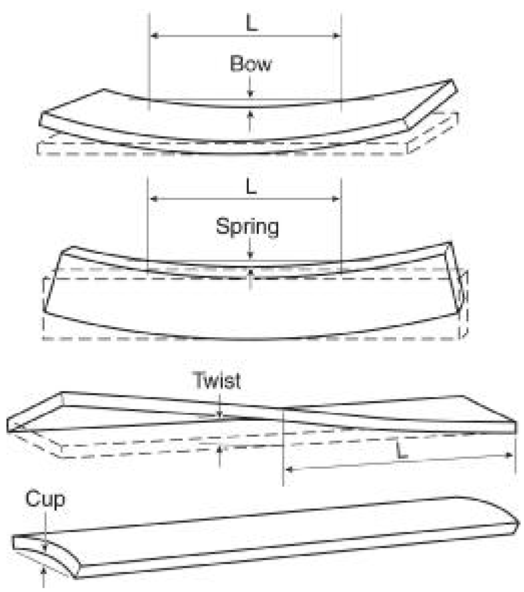

Figure 1. Distortion Types

Spring

The measurement of spring was similar to that of bow, except measurements were recorded on the narrow face only.

Cup

Cup was measured using a short straight edge and a digital dial gauge. The straight edge was positioned across the broad face of each piece, and the deflection of the piece from parallel measured in the centre of the section, in the centre portion of each batten.

Moisture Content Measurement

Moisture content was measured, using a calibrated electrical resistance type moisture meter at the central position of the board, a third in from one edge at a depth of 15 mm. The reading was calibrated against wood temperature at the time of measurement.