Super-heated steam drying in Dutch operations

W.F. Gard[1], M. Riepen[2]

Delft University of Technology,
[1] Timber Structures & Wood Technology, Delft, The Netherlands
[2] Wood-Drying-Centre Europe, Delft, Netherlands
[1] W.F.Gard@tudelft.nl

ABSTRACT

Reducing processing times and energy wastage being accompanied by a high drying quality are important objectives of the timber drying industry. The present investigation shows that super-heated steam drying under atmospheric pressure contributes significantly to the goal of the industry needs. Since several years a number of drying operations work on this principle with success in the Netherlands. At least the drying time can be decreased by 50% and the energy consumption can be reduced up to 20% retaining the same drying quality. The effect of steam drying on the colour of the timber depends of the type of wood species. The colour of the wood is slightly darker. But in some cases it is even desirable getting the timber through and through slightly or even severe coloured, especially hardwoods.

INTRODUCTION

Since centuries the Dutch timber market is characterised by trading, processing and using tropical timber. Also European hardwood species have played an important role. Beech and oak are two of the most important and valuable hardwood species in Europe. The high value of beech is based on the aesthetic appearance of the surface structure, the good machining and bending properties. It is used for furniture, doors, plywood and parquet flooring. Huge volumes of oak are currently used for parquet flooring and furniture. For centuries beech and oak were used for structural applications but have mostly been displaced by softwood. Nowadays both wood species are considered to be also used for structural application such as glued laminated timber. A number of other European, Asian and Latin America hardwoods have entered the commercial European market such as maple, sapupira, jatoba, robinia, chestnut, poplar, and meranti. Dimensions vary from thin boards 25mm x 100mm to beams 100mm x 130mm.

From the drying point of view most hardwood species suffers normally under extensive drying times in comparison to softwood. From this follows that also the energy consumption gradually increases per cubic metre timber.

The use of hardwoods in a wide field of applications is mirrored in the diversity of drying quality requirements. Beside distortions, moisture content distribution and fissures, the colour and discolouration are major issues for hardwoods. In the furniture and parquet industry most of the problems with hardwood entailed in the appearance of the surface. In this case high quality requirements concerning the colour balance of the surface decides if the timber is accepted or not.

In order to keep the colour of natural light-coloured wood species, conventional drying schedules, consisting of very low dry-bulb temperatures (30°C - 40°C), are applied.
Due to the characteristics of super-heated steam drying (e.g. temperature >100°C), schedules are not able to maintain the natural colour of light-coloured wood species. It has been shown that super-heated steam drying schedules are able to achieve homogenous colour throughout the cross section of the timber.
This paper presents the procedure and process how super-heated steam drying benefits the customer by reducing drying time and obtaining homogenous colour, applied on hardwood.

DRYING PROCESS

The Super-heated steam drying process is different from conventional convective drying. The drying process with super-heated steam takes place above 100**°C** in a steam medium.

Principle of convective drying

In a regular convection drying kiln for sawn timber the drying process is performed with heated air blown through a stack of boards. The hot air heats up the boards at the start of the process and supplies thereafter the heat needed for the evaporation process. The water evaporated from the wood will mix with the air flow and is removed from the stack.
The temperature and relative humidity (RH) are the key parameters, which determine the progress of the drying process.
If air is blown through a channel between two boards with a very high moisture content above fibre saturation point (FSP), then the boards will get a steady state temperature close to the, so called, wet-bulb temperature (T_{wet}). At this wet-bulb temperature all convective energy supplied by the air flow is used for evaporation of water from the surface of the boards. If the RH of the drying air is increased then the evaporation rate will decrease (at RH=100% no evaporation will occur).
As a consequence the energy balance is disturbed. Not all energy supplied by the air flow is now used for evaporation of water and therefore the boards will be heated up until a new balance will be found at a higher wet-bulb temperature.
To maintain the wet-bulb temperature at the surface of the boards the internal transport of water in the board towards the surface should be as high as the evaporation rate. In practice the internal moisture transport, driven by water diffusion, is slow and forms the limiting factor in the drying process. If there is not enough water available for evaporation at the surface of the boards, the energy balance is disturbed and the temperature of the boards will increase until a new balance is achieved. So the temperature of the boards in normal drying practice will have a value between T_{wet} and dry-bulb temperature (T_{dry}), even if the moisture content of the boards is above FSP.

Principle of super-heated steam drying

<u>**Steam condensation**</u>

Steam is injected in the drying kiln during the warming-up phase to heat the wood and keep the relative humidity (RH) high. An increase of the RH implies an increase of the so called dew-point temperature of the drying air Fig. 1. The dew-point temperature is the temperature at which condensation will occur, which means that mist will be formed if the air is cooled down below the dew-point temperature. It means that on all objects a kiln with a temperature below the dew-point temperature condensation will be formed. If the water vapour condensates into water, the latent heat of evaporation will be generated and applied to the cold surface. The latent heat of evaporation is for example 2337 kJ/kg water at a temperature of 70°C, which is a considerable heat source.

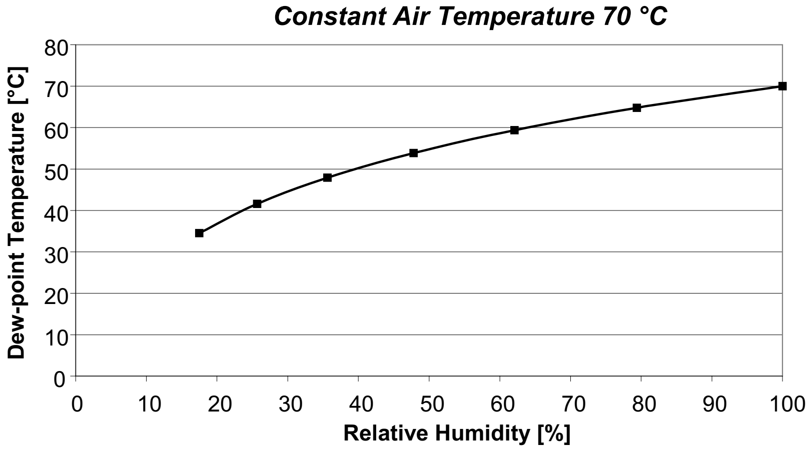

Figure 1: Dew-point temperature as function of relative humidity

To heat 1 m^3 wood (density of 450kg/m^3), with moisture content (MC) =35% by1°C requires for example 0.35 kWh (1260 kJ). So, with 1 kg steam it is possible to heat 2 m^3 wood by 1°C if it condensates completely on the wood surface.
The advantage of condensation heat transfer is that it will occur at all places were cold surfaces are in contact with the drying medium regardless of the air velocity.
However the condensate may form a film layer on the surface of the boards, which causes insulation, limiting the condensation process. This effect can be reduced if the air velocities during the warming-up phase are high enough to disturb the condensate layer (in practice above 3 m/s). The condensation rate is also limited by the internal heat transport in the boards. Once the surface of a board is heated up to the dew-point temperature, the condensation will stop, until the surface temperature will decrease again below the dew point temperature.

Super-heated steam drying
Super heated steam is water vapour with a temperature above 100°C. During the warming-up phase all air, which is initially present in the kiln, will be replaced by steam. The relative humidity of the air is during the warming-up phase kept at a maximum level close to 100 % but at least the T_{wet} at the temperature of the timber. If the temperature of the drying medium approaches 100°C and the relative humidity is equal to RH=100% the climate has changed into saturated steam. No drying occurred yet, because the wet-bulb depression was zero during the warming-up phase.

If the saturated steam is further heated by the heating coils in the kiln, the steam will become super heated. The overpressure valve will keep the pressure in the kiln at atmospheric conditions. At atmospheric conditions water boils at 100 °C, i.e. T_{wet} = 100 °C.
The temperature difference between the steam and the boards will increase and the boards start to dry. Since the evaporation now occurs at the boiling point the internal moisture transport inside the board towards the surface is no longer driven by diffusion, but is now forced by an internal overpressure greater than the atmospheric pressure. As a consequence the internal

transport coefficient is highly increased in comparison with the normal water diffusion coefficient.
Therefore the internal efficiency factor E in equation (1) will remain E=1, as long as the moisture content of the boards is above fibre saturation point (FSP).

$$drying\_rate = \frac{2h \cdot E(T_{dry} - T_{wet})}{H_{vap} \cdot \rho_w \cdot D} 360 \quad [\%MC/h] \qquad (1)$$

with:

h	convective heat transfer coefficient [W/m^{2}K]
T_{dry}	dry-bulb air temperature [°C]
T_{wet}	wet-bulb temperature [°C]
H_{vap}	latent heat of evaporation [kJ/kg]
ρ_W	density of the wood species [kg/m^3]
D	thickness of the boards [m]
E	internal transport efficiency = $(T_{dry} - T_{board})/(T_{dry} - T_{wet})$

The process can be compared with boiling water in a kettle. As long as the water temperature is below 100°C, some evaporation takes place, but most energy is used to heat the water. At the moment the temperature becomes 100°C the lit will be pushed off the kettle by an overpressure and the temperature of the water will no longer increase.
Below 100°C, water vapour can be added to a system of air and vapour until the partial saturated vapour pressure is reached. Fig. 2 shows that if the temperature is 70°C and the wet-bulb depression is 20°C, (T_{wet} = 50°C), that the partial vapour pressure is 0.11 bar. If vapour is added this vapour pressure will increase to a maximum value of 0.31 bar. If more vapour is supplied to this system condensation will occur (mist will be formed).

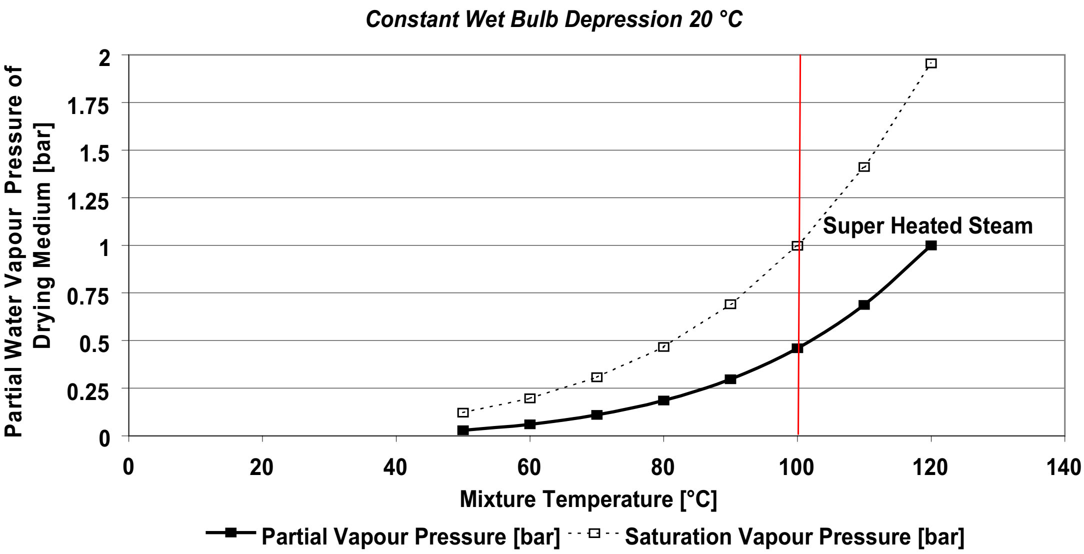

Figure 2: Water vapour pressure of drying medium (air-steam)

DRYING TRIALS

Drying trials were carried out on semi-industrial and industrial scale for oak, beech and different tropical wood species (e.g. iroko, sapupira, afromosia). The cases following deal with drying schedules beech and oak (steamed and non-steamed).

Drying schedule

The starting point for developing drying schedules was the high temperature schedule for softwood, which have been used in industrial operations for a long time.
From practice and research (Gard et al, 1994) it is known that the level of temperature and moisture content combined with a certain time interval determine the colour.
In order to keep the colour as bright as possible the steaming period has to be short and drying process has to be started as soon as possible. The high temperature drying phase starts when the wood temperature of 100°C is reached.
The basic drying schedules are divided in the following phases

- Warming up the timber. This phase also can be combined with a steaming phase.
- Steaming, if desired, it depends on the colour
- Drying with temperatures above 100°C
- Cooling down towards below 100° and drying with temperatures below 100°C
- Conditioning
- Cooling down

A principle drying schedule for super-heated steam drying is given in the Fig. 3.

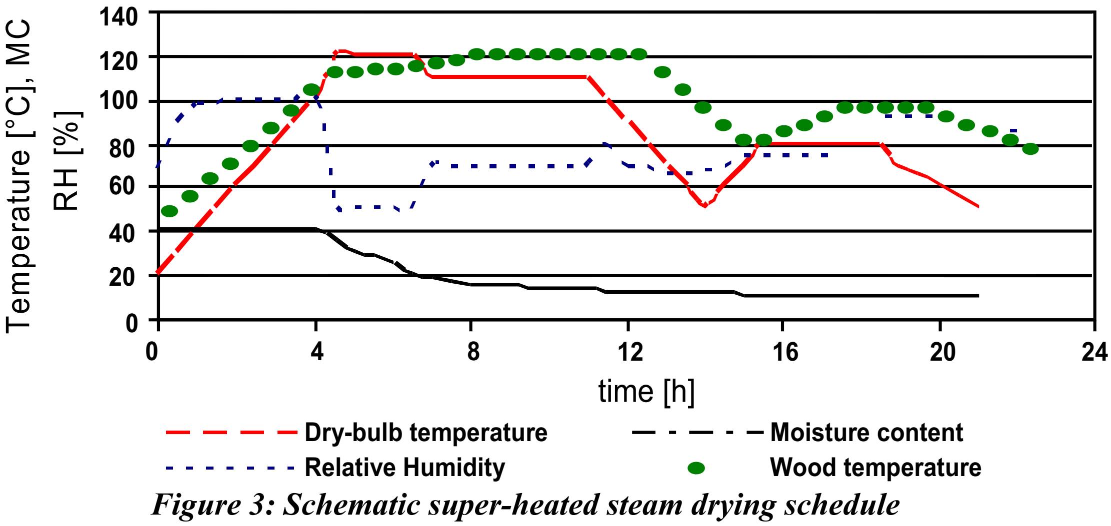

Figure 3: Schematic super-heated steam drying schedule

Depending on the requirements of the drying quality and the dimension of the timber, the schedules were adjusted. In a few cases a steam phase was inserted in order to determine the colour of the wood surface.

Kiln and sensors

Drying runs in a semi industrial kiln were intended to develop and optimise the drying schedules. On in industrial scale, the trials were carried out in special designed kilns for super-heated steam drying (Fig. 4). The stack volumes of the industrial kilns are about 80m^3. The industrial kiln was equipped with a jet-burner system, a steam supply, a spraying system for cold water, RH-sensors, moisture content (MC) sensors and temperature sensors for both air and wood. The fans are reversible. The control system is able to monitor and control drying process conditions for super-heated steam processes.

Figure 4: Industrial kiln for super-heated steam drying

In order to avoid discolouration during storage, the timber (beech and oak) was immediately transported to the kiln after sawing. Thus the timber was green and had a wood moisture content of approximately 70%.
Great attention has to be paid to the sticking of the stack and the timber load distribution in the kiln.
Because of the high temperature and the high moisture content, the wood enters into the softening state. Consequentially the timber becomes more flexible and tends to bend between the sticks. The distance between the sticks depends on the thickness of the boards. For the 35mm thick boards a space of 0.30m was calculated.
Since the drying process is very fast, it has to be assured that the drying condition is even in all timber stacks. This can be guaranteed if the airflow distribution between the boards is even. Therefore the kilns need at least a high filling level with boards of the same thickness. If this is not possible, the drying schedule has to be adjusted to keep the drying rate low. Then super-heated drying does not gain.

RESULTS

Beech trials
The drying time for 28 mm Beech sawn wood could be reduced from 2 weeks to about 3 days obtaining the same drying quality according to the costumer. Maximum dry-bulb temperatures were applied at 110°C. In this case the colour of the surface was bright (not white) because there was no special steaming phase integrated into the drying schedule (Fig. 5).
The final moisture content spread was ±0.2% MC, caused by the long conditioning phase. No discolouration under the sticks (stick marks) occurred.

In order to get a darker wood colour, a steaming phase was inserted into the drying schedule (Fig. 6). Steam period of about 18 hours obtained a reddish colour of the wood from surface to the core. After this steaming period the accelerated drying period was started.
The results with regard to checks were about the same in comparison to conventional drying systems, distortions were less.

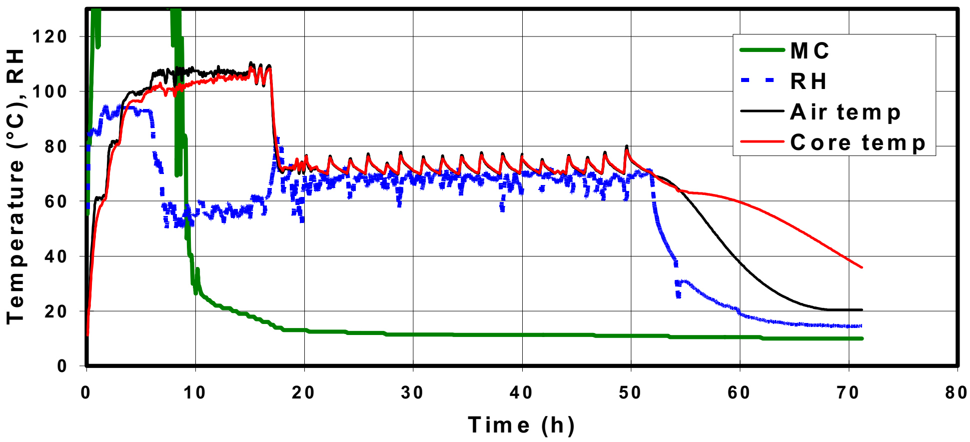

Figure 5 : Drying schedule without extra steaming phase

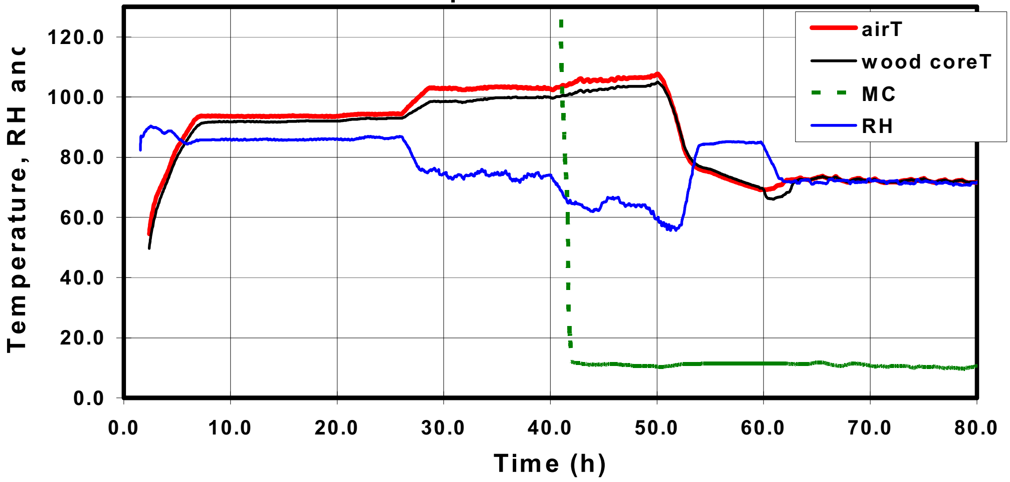

Figure 6: Drying schedule with an extra steaming phase

Oak trials

A few drying trials of oak were dedicated to obtain a slight dark colour. Because of the anatomical structure of oak it turned out that a combination of pre-drying and steaming was necessary to obtain the desirable drying quality (Fig. 7).

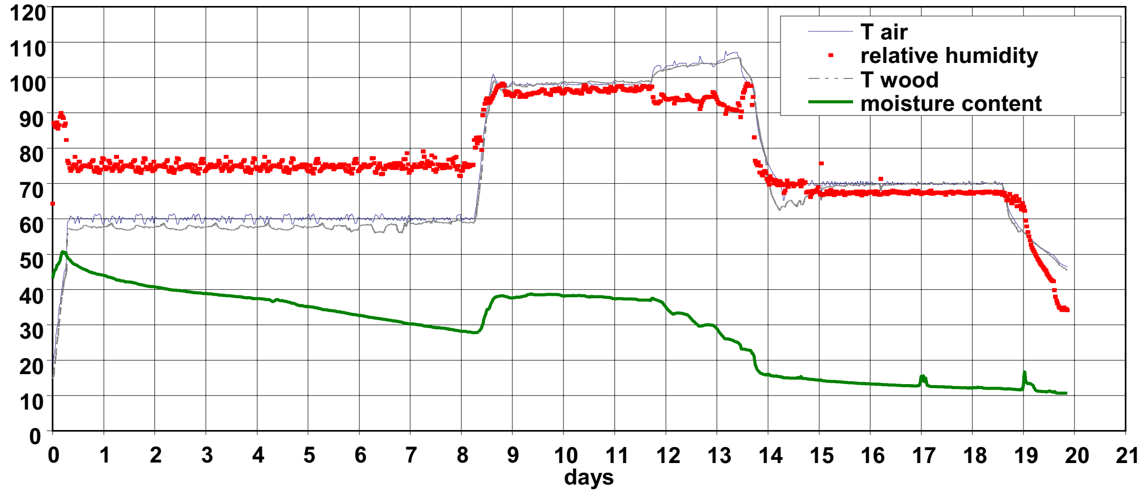

Figure 7: Drying schedule for oak

Figure 8: Steam dried oak

Energy consumption

Since the drying time is cut down significantly, the energy efficiency of high temperature kilns is better than of conventional kilns. The fans will operate shorter and also the transmission losses through the kiln walls are lower, although the kiln temperature is higher. Ventilation losses are minimal during the high temperature phases, because of the use of super-heated steam. Only the heat accumulation in the wood is higher in case of high temperature drying. The energy consumption of the combined steam-drying system is about 35% less than conventional systems. In addition the wood does not have to be specially warmed up for the drying process. Summarising an improvement of the kiln efficiency up to 20 % may be expected, depending on the specific situation. Fig. 7 indicates the energy consumption of conventional and super-heated steam drying operations.

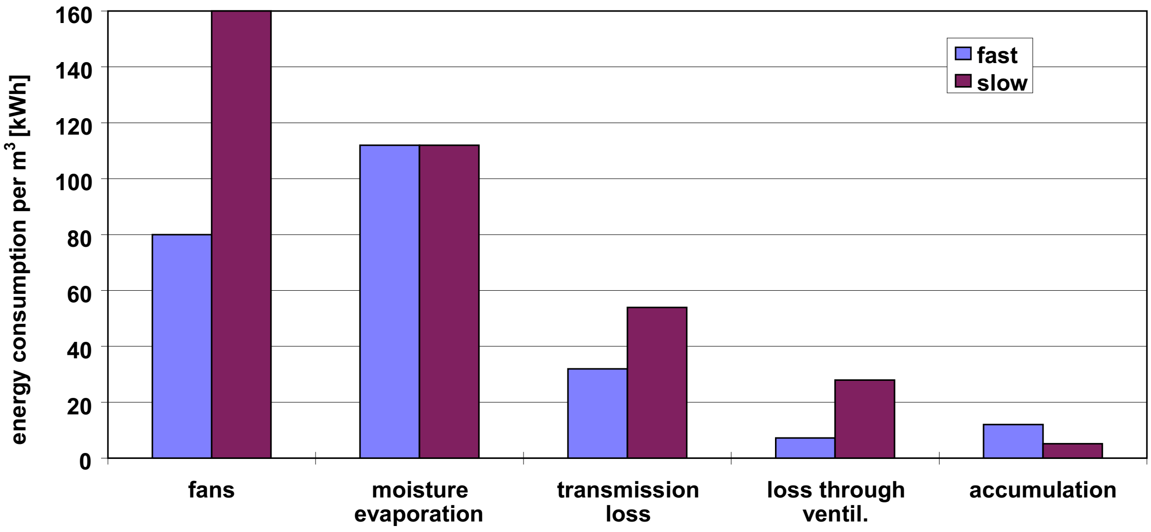

Figure 9: Indicative comparison between the energy consumption in a high temperature kiln and a conventional kiln

CONCLUSION

- Super-heated steam drying is a capable option for drying European and Latin American hardwood species.
- Drying time/rate can be accelerated by super-heated steam drying without quality decrease.
- The combination steaming and drying, results in shorter process times and less energy consumption.
- Depending on the required drying quality, drying time can be reduced up to 70% and energy consumption up to 20%.
- High flexibility in combining steam with low and high temperature in one drying process in an economical way.
- Moisture content control above 100°C dry-bulb temperature is still an important problem.

Future work will be focused on optimizing drying schedules for tropical timber, effects on mechanical properties of wood and sensor development for moisture content measurements above 100°C.

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