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Oil-heat-treatment of wood - process and properties

Postupak zagrijavanja drva uljem – proces i svojstva

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SUMMARY • *Modifying heat treatments can improve wood properties in different ways. This work describes an oil-heat-treatment process, developed and used in industrial scale in Germany. Vegetable oil serves at temperatures between 180°C and 220°C as medium to transport heat into wooden beams and to separate oxygen from the immersed wood. After several hours of deep-frying, the wood becomes modified with new properties: strongly increased dimensional stability, biological durability and brittleness. The new properties of the material are tested and described in detail. Additional information on the state of the art and on the industrial production in Germany is given.*
Key words: *oil-heat modification of wood, properties of modified wood*

SAŽETAK • *Modificirana toplinska obrada može poboljšati svojstva drva na različite načine. Ovaj rad opisuje toplinsku obradu drva uljem koja je razvijena i koja se koristi u industriji Njemačke. Biljno ulje, na temperaturi izmedju 180 °C i 220 °C, služi kao sredstvo koje prenosi toplinu u drvnu tvar i odvaja kisik iz natopljenog drva. Nakon nekoliko sati izloženosti toplini, drvo se modificira i dobija nova svojstva: izrazito pojačanu stabilnost dimenzija, biološku trajnost i krtost. Nova svojsta materijala su provjerena, te se detaljno opisuju u ovom radu. Najzad, daju se i dodatne informacije o stanju u ovom području, te o industrijskoj proizvodnji u Njemačkoj.*
Ključne riječi: *modifikacija drva zagrijanim uljem, svojstva modificiranog drva*

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Autori su znanstvenici u Institutu za biologiju i zaštitu drva njemačkog Saveznog centra za šumarstvo i šumske proizvode u Hamburgu. Dr Rapp je predavač kolegija *Zaštita drva* na Hamburškom sveučilištu. Rad je u neznatno izmijenjenom obliku predstavljen na konferenciji "Drvo u graditeljstvu – tradicija i budućnost" u Zagrebu, u travnju 2001.

1. INTRODUCTION
1. UVOD

Thermal wood improvement processes have been developed and optimised in various countries for a considerable time. Stamm *et al.* (1946) reported on the first systematic attempts to increase resistance to wood-destroying fungi in a hot metal bath. Buro (1954, 1955) studied the heat treatment of wood in different gaseous atmospheres and in molten baths. Other aspects of the thermal treatment of wood were pursued in subsequent years. Interest often focused on the drying characteristics (Schneider 1973) and the chemical changes of heat-treated wood (Sandermann and Augustin 1963a; Kollmann and Fengel 1965; Topf 1971; Tjeerdsma *et al.*1998a) as well as increased dimensional stability (Kollmann and Schneider 1963) and changes in strength (Schneider 1971, Rusche 1973). Burmester (1973) found improved wood characteristics on applying a thermal pressure treatment. Giebeler (1983) further developed this process. There have been continuing attempts to improve wood by thermal treatment for some years, especially in Finland, France and some other European countries (e.g. Dirol and Guyonnet 1993; Viitanen *et al.*1994;Troya and Navarette 1994; Boonstra *et al.* 1998; Tjeerdsma *et al.* 1998a; EC project BRE-CT-5006, 1998). The various wood improvement processes are documented in patent specifications (e.g. EP0018446, 1982; EP0612595, 1994; EP0623433, 1994; EP0622163, 1994; EP0759137, 1995; US5678324, 1997). In most of the publications on the heat treatment of wood, reference is made to improved dimensional stability and increased resistance to fungi, though also to negative changes in the wood's characteristics. The high temperatures during treatment increase the brittleness and the formation of cracks, in particular. Spotted surfaces due to exudation of resin and low UV resistance of the heat-related brown hue also prove to be problematic during practical use of the wood. More recent investigations point to a lower resistance to fungi of heat-treated wood in contact with soil than suggested by earlier findings (Jämsä and Viitaniemi 1998; Rapp *et al.* 2000). The aim of the procedural approach

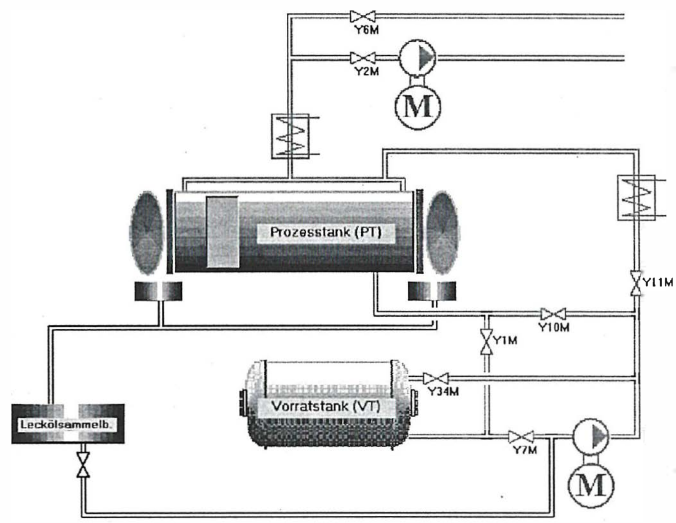


Fig. 1 *Principle design of the plant. Diagram: designed by MENZ HOLZ Germany. • Shema postrojenja za uljno zagrijavanje njemačke tvrtke MENZ HOLZ. Radni spremnik (PT), spremnik za pohranu (VT) i komora za pretičak ulja*

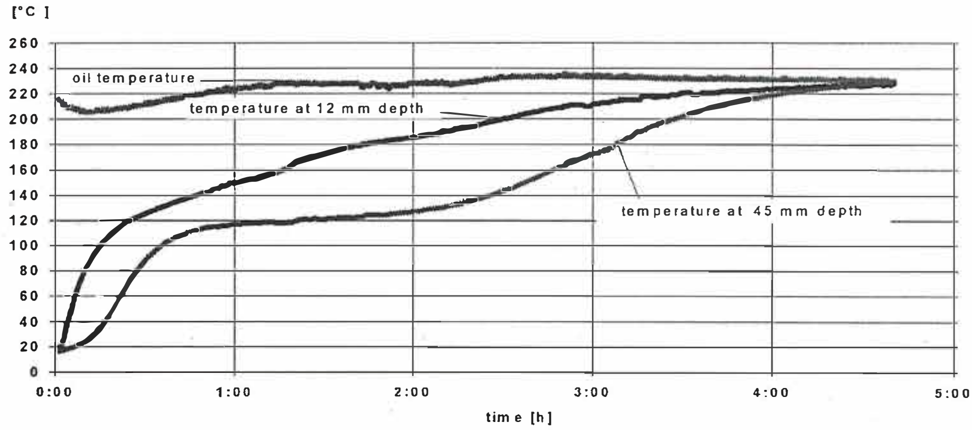


Fig. 2. *Course of temperature in the oil and wood during the phase of heating up. Picea abies L. Karst., with a cross section: 90 x 90 mm. • Promjene temperature ulja (gornja krivulja) i drva (na 12 i 45 mm od površine) smrekovine (Picea abies L. Karst.) u elementima poprečnog presjeka 90 x 90 mm.*

presented here, which is based on the heating of wood in hot oil, is to improve some of these critical characteristics.

Heat treatments usually take place in an inert gas atmosphere at temperatures between 180 and 260°C (Leithoff and Peek 1998). The boiling points of many natural oils and resins are higher than the temperature required for the heat treatment of wood. This opens up the option of the thermal treatment of **wood in a hot oil bath**. Improvements in various wood characteristics can be expected from the application of oil-heat treatment as compared with heat treatment in a gaseous atmosphere, due to the behaviour of oils in conjunction with the effect of heat.

2. EQUIPMENT AND PROCESS
2. OPREMA I POSTUPAK

2.1. The principle design of the plant
2.1. Osnovna načela projektiranja tvornice

The principle design of the plant can be seen from Fig. 1. The process is performed in a closed process vessel (PT). After loading the process vessel (PT) with wood, hot oil is pumped from the stock vessel (VT) into the process vessel (PT) where the hot oil is kept at high temperatures circulating around the wood. Before unloading the process vessel (PT) the hot oil is pumped back into the stock vessel (VT).

2.2. Temperatures and process times
2.2. Temperature i vremena procesa

For different degrees of upgrading, different temperatures are used.

To obtain maximum durability and minimum oil consumption the process is operated at 220°C. To obtain maximum durability and maximum strength temperatures between 180°C and 200°C are used plus a controlled oil uptake. It proved to be necessary to keep the desired process temperature (for example 220°C) for 2-4 hours in the middle of the wooden pieces to be treated. Additional time for heating up and cooling down is necessary, depending on the dimension of the wood. Fig. 2 gives an example of the a heating up phase for logs with a cross section of 90 mm by 90 mm.

Typical process duration for a whole treatment cycle (including heating up and cooling down) for logs with a cross section of 100 mm x 100 mm and length of 4 meters is 18 hours.

2.3. Heating medium
2.3. Sredstvo za zagrijavanje

The heating medium is crude vegetable oil. For example rape seed, linseed oil or sunflower oil. The oil serves for both,

- fast and equal transfer of heat to the wood, providing the same heat-conditions all over the whole vessel
- perfect separation of oxygen from wood

Natural plant oils lend themselves to the oil-heat improvement of wood from an environmental point of view and because of their physical and chemical properties. As renewable raw materials they are CO_2 neutral. The use of other plant oils, such as rape seed oil, sunflower oil, soybean oil or even tall oils or tall oil derivatives in addition to drying oils such as linseed oil, is also conceivable. Linseed oil proved to be unproblematic though the smell that develops during the heat treatment may be a drawback. The smoke point and the tendency to polymerisation are also important for the drying of the oil in the wood and for the stability of the respective oil batch. The ability of the oil to withstand heating to a minimum temperature of 230°C is a prerequisite. The consistency and colour of the oil change during heat treatment. The oil becomes thicker because volatile components evaporate; the products arising from decomposition of the wood accumulate in the oil and change its composition. This obviously leads to improved setting of the oils.

3. COSTS
3. TROŠKOVI

The investment for a capacity of 8500 m/a is 450.000 €, based on a 10 years period of use, 5.2 € /m are the calculated depreciation. The operation costs for treatment of spruce are 60 to 90 € /m, depending on the desired oil loading. The costs for 1 m of oil-heat-treated spruce are 265 to 295 €/m based on costs for untreated timber of 200 € /m.

4. WOOD PROPERTIES
4. SVOJSTVA DRVA

Before determining the properties, the material was treated as follows:

Fresh, untreated pine (*Pinus sylvestris* L.) and spruce (*Picea abies* L. Karst.) were used for the oil-heat treatment. The specimens with a wood moisture content of 6% were heated at three temperatures (180°C, 200°C and 220°C) unpressurised and with exclusion of oxygen in an oil bath of refined linseed oil. On the oil reaching the desired temperature, the wood specimens were immersed in it for 4.5 hours. Virtually no oil was absorbed during the actual heat treatment. To achieve the desired oil loading, the specimens cooled off in the oil bath for 15 minutes. Reference samples were also treated for 4.5 hours at corresponding temperatures in a drying chamber in an air atmosphere.

4.1. Biological durability
4.1. Biološka trajnost

The oil-heat treated specimens and specimens treated in a hot air atmosphere were tested for resistance to *Coniophora puteana* in accordance with DIN EN 113 (1996). This was done using spruce as well as pine sapwood because the oil loading was different, even though they were subjected to the same treatment, due to the different impregnability of the two types of wood. Treated specimens and untreated controls were incubated in a Kolle flask for 19 weeks. The percentage loss of mass was determined in relation to the pure wood mass after treatment. Untreated spruce controls showed 48% loss of mass and pine controls 40% loss of mass. The resistance of heat-treated spruce and pine to the brown rot fungus *C. puteana* was improved with increasing temperatures. Treatment of wood in hot air did not prevent an attack of *C. puteana*. An average mass loss of 11% was determined for Scots pine, 5.5 % for spruce (Tab. 1).

4.2. Strength properties
4.2. Svojstva čvrstoće

The MOE and MOR was determined in a three point bending test with medium force applied on 150x10x10 mm^3 treated and untreated wooden slats parallel to the grain on a universal testing machine. Tests of the impact bending strength provide information on the dynamic stability of wood specimens. They were performed using a Louis Schopper pendulum impact machine. The changes in the impact strength due to oil-heat or air-heat treatment were calculated in relation to untreated specimens of the same type of wood. The highest MOE of more than 11,000 N/mm^2 were achieved at 200°C in the case of oil-heat treated specimens (Fig. 3). There was no reduction in the values for the MOE compared to untreated wood with either heat treatment process.

The MOR of wood that was oil-heat-treated at 220°C was about 70% of the value of untreated controls. The impact bending strength is the most critical value for all kinds of heat treatments. It declines considerably and the wood becomes brittle. Oil-heat-treated wood achieved a 51% and air heat treated wood only 37 % of the impact bending strength of untreated controls as the treatment temperature increased (Fig. 4).

Table 1
Mass loss after 19 weeks exposition of heat treated specimens according to DIN EN 113 (Fungus: Coniophora puteana) • Gubitak mase (po DIN EN 113, djelovanjem gljive Coniophora puteana) grijanjem obrađenih uzoraka nakon 19 mjeseci izlaganja

	oil-heat-treatment				air-heat-treatment			
	pine sapwood		spruce		pine sapwood		spruce	
treatment	[g]	[%]	[g]	[%]	[g]	[%]	[g]	[%]
180°C	1,1	13,0	1,2	15,0	2,3	25,0	2,5	31,2
200°C	0,1	1,9	1,1	13,1	1,0	15,8	2,2	26,7
220°C	0,1	2,0	0,0	0,0	0,9	11,0	0,4	5,5

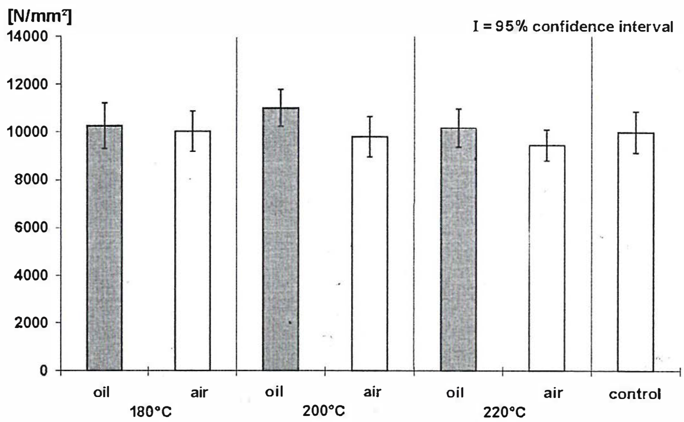
A noticeably lower loss of mass was determined for oil-heat treated specimens than for air-heat treated specimens. A loss of mass of less than 2% was found in the case of pine sapwood, when oil-heat treatment was applied at 200°C. With spruce, on the other hand, a decisive increase in resistance was only obtained at 220°C.

4.3. Dimensional stability
4.3. Dimenzijska stabilnost

If the oil-heat-treatment is performed for 4 hours at 22°C then the moisture content at fibre saturation was 14% whereas the moisture content of untreated controls was 29% under the same conditions.

Specimens for the examination of

Fig. 3.
Modulus of elasticity of Pinus sylvestris L. parallel to the fibres (150x10x10 mm) after treatment; n=15 • Modul elastičnosti bijele borovine (Pinus sylvestris L.) paralelno s vlakancinma mjeren na 15 uzoraka dimenzija 150x10x10 mm



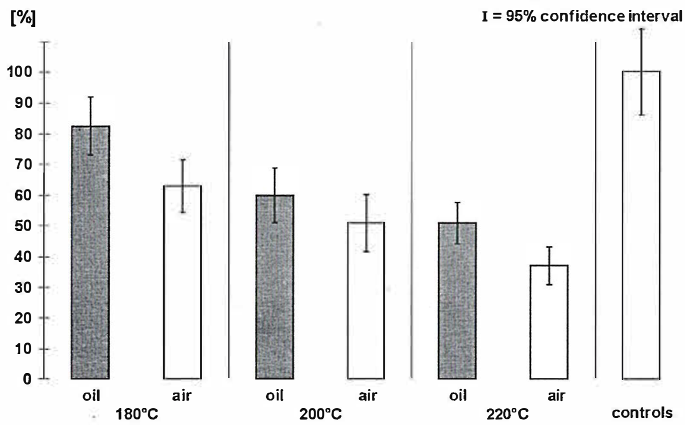


Fig. 4. Changes of the impact bending strength of Pinus sylvestris L. (150x10x10 mm) after treatment compared to untreated controls; n=15 • Promjene čvrstoće na udar bijele borovine (Pinus sylvestris L.) mjerene na 15 uzoraka dimenzija 150x10x10 mm bez obrade i nakon različitih postupaka toplinske obrade

swell and shrink improvement (ASE) were exposed to a temperature of 20°C and a relative humidity of 35%, 65% and 85% after the oil-heat treatment. The dimensions of the specimens subjected to the above climatic conditions were determined after their masses becoming constant. The ASE was calculated from the ratio of the percentage volumetric change of the treated specimens in relation to the volumetric change of untreated wood specimens.

The improvement in the ASE of specimens that were treated at 220°C was similar for both types of treatment, at about 40%. The degree of improvement in this case depended on the relative humidity. When humidity was increased, the ASE became lower, with less difference in the specimens treated at higher temperatures than in those treated at lower temperatures (Fig. 5 to Fig. 7).

In Anglo-Saxon literature the term ASE (anti-swell efficiency or anti-shrink efficiency), coined by Stamm (1964) to describe the reduced swell or shrink of treated wood compared to untreated controls, has become established. In this case the swell or shrink characteristic of wood is determined under laboratory conditions with appropriate climatic conditions. However, it is not yet possible to make a statement on dimensional stability under open land conditions on the basis of these values because experience shows that the behaviour of samples subject to the multi-faceted stresses of open land is different from their behaviour under laboratory conditions. But since the ASE is easy to determine, it is often ascertained and therefore offers a good means for comparison of the various wood improvement processes. It is expected that the dimensional stability of oil-heat-treated samples will prove to be better in open land than that of wood that has undergone conventional heat-treatment in an oxygen-free gas atmosphere, due to the additional water-repellent effect of the oil component. Among other things this should have a beneficial effect on the stability of surface treatments, and on reduced crack formation during weathering. On the whole, the ASE values are consistent with the findings of Seborg *et al.* (1953) and Tjeerdsma *et al.* (1998b).

4.4. Other technical properties
4.4. Ostala tehnička svojstva

At the end of the treatment cycle the wood absorbed the oil remaining on the surface of the wood very quickly during the cooling down of the specimens so that a dry wood **surface** appeared a few minutes after treatment. The surfaces were light brown in

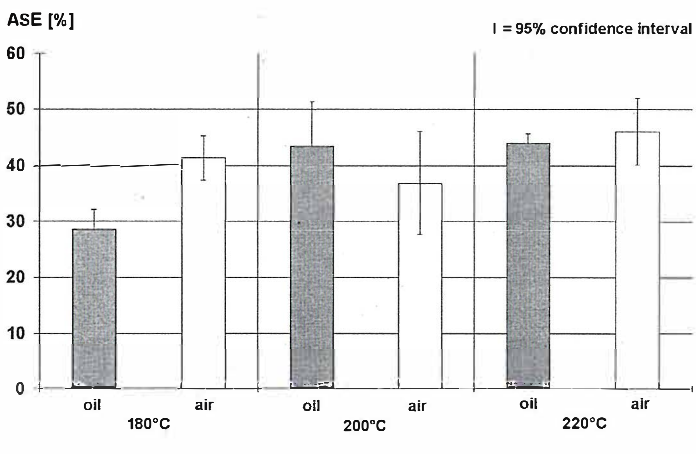


Fig. 5. ASE anti-shrink efficiency between 0 and 35% relative humidity of treated Pinus sylvestris L. (10x20x20 mm), n=4 • Vrijednosti ASE (učinkovitosti smanjenja utezanja) u rasponu rel. vlažnosti od 0 do 35 % toplinski obrađenih uzoraka bijele borovine Pinus sylvestris L. (10x20x20 mm), n=4

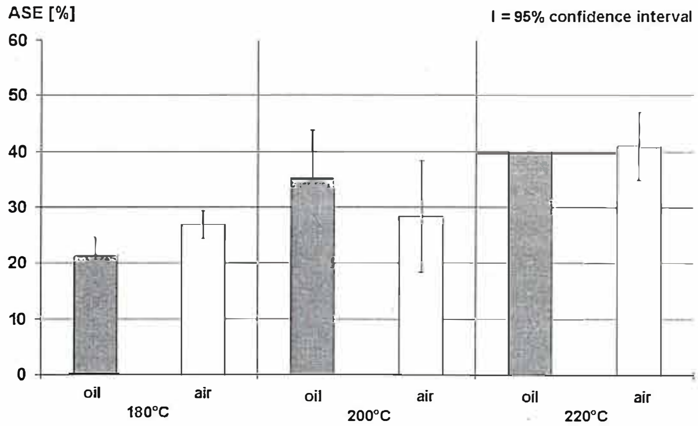


Fig. 6. *ASE between 0 and 65% relative humidity of treated Pinus sylvestris L. (10x20x20 mm), n=4 • Vrijednosti ASE (učinkovitosti smanjenja utezanja) u rasponu rel. vlažnosti od 0 do 65 % toplinski obrađenih uzoraka bijele borovine Pinus sylvestris L. (10x20x20 mm), n=4*

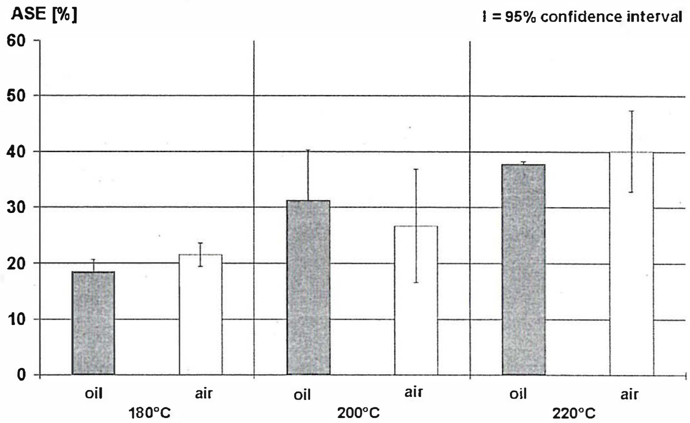


Fig. 7. *ASE between 0 and 85% relative humidity of treated Pinus sylvestris L. (10x20x20 mm), n=4 • Vrijednosti ASE (učinkovitosti smanjenja utezanja) u rasponu rel. vlažnosti od 0 do 85 % toplinski obrađenih uzoraka bijele borovine Pinus sylvestris L. (10x20x20 mm), n=4*

colour at lower treatment temperatures and dark brown at higher treatment temperatures. Unlike the air-heat treated specimens, no spotted discoloration due to the uneven distribution of exudated resin was found on oil-heat treated specimens. For heat-treated softwoods its typical initial **brownish colour** is not UV-stable without surface treatments. After a half year of weathering in the field the colour of oil-heat-treated spruce came close to that of weathered untreated larch heartwood.

The **paintability** of oil-heat-treated wood with acrylic water based paints as well as with alkyd solvent-based systems proved to be good during two years of weathering. Surprisingly after two years the adhesion of the paints and varnishes on the oil-heat-treated wood was even better than on gas-heat-treated wood. Initial tests to assess the **gluability** have been made with the following results: After planing of oil-heat-treated spruce, gluing was no problem. However for oil-heat-treated pine with higher oil uptake, only modified glues lead to good results.

Like all heat-treated woods also oil-heat-treated wood has that initially typical **smoky smell**. This could lead to limitations in use in internal areas, though this smell evaporates after some time. In any case this should hardly be a problem outdoors.

5. WOOD SPECIES AND COMMODITIES
5. UTJECAJ VRSTE DRVA

5.1. Suitable wood species
5.1. Pogodne vrste drva

Unlike wood impregnation processes in which protective substances are introduced into the wood, even larger-dimensioned wood of types that are difficult to impregnate can be protected right into the inner areas of the log by oil-heat improvement. This applies in particular to spruce, which is available in large quantities at favourable prices. The whole chain from basic research, standard testing to process optimisation was done for spruce (*Picea abies*) and pine (*Pinus sylvestris*).

5.2. Adoption of process parameters for different wood species
5.2. Prilagodba parametara postupaka za različite vrste drva

The use of the refractory spruce and the permeable pine sapwood allows varying the oil uptake within a wide range. The process can be run with spruce with minimum oil uptake (20 to 60 kg/m depending on the dimension) when no pressure is applied. If high durability and high strength properties are desired, then pine can be used at lower temperatures but with higher oil uptakes (see Table 1). By application of pressure in the process the desired uptake can easily be adjusted.

5.3. Influence of wood species on durability
5.3. Utjecaj vrsta drva na trajnost

The combination of vegetable oils and heat treatment led to greater improvement in the resistance of wood to *Coniophora puteana* than heat treatment in air. Besides the pure thermal modification at high temperatures the oil uptake contributes to the durability (see Table 1). It is conceivable to use oil-heat treated wood with a higher oil loading under more sever conditions in European hazard class 3. In European hazard class 4, high oil loading extends the service life of oil-heat-treated wood, compared to heat-treated wood with no oil uptake.

5.4. Suitable commodities and applications
5.4. Prikladna uporaba i primjena

The main applications of heat treated wood is most probably in out of ground contact situations. Suitable commodities are claddings, pergolas, exterior joinery, garden furniture, decks, fencing and noise barriers. This applications and further research will show within the next years if oil heat-treated wood is also suitable for some load bearing constructions.

6. INDUSTRIAL PRODUCTION
6. INDUSTRIJSKA PROIZVODNJA

There is currently one plant in commercial use in Germany. The plant (Fig. 8) is operated since August 2000 by MENZ HOLZ in Reulbach, 30 km east of the city of Fulda. MENZ is intending to cover the German marked segment of oil-heat-treated wood for garden furniture and wood for gardening. The company is interested to find partners for licensed production of oil-heat-treatment wood for different market segments in all European countries. The existing vessel has a capacity of 2900 m/a. The future vessels planned by MENZ have typical capacities of 8500 m/a.

7. RECENT RESEARCH AND DEVELOPMENT
7. DOSADAŠNJA ISTRAŽIVANJA I RAZVOJ

BFH is currently running comparative assessment of properties of heat-treated wood produced after 4 different processes in different countries. BFH has together with Swedish University of Agricultural Sciences Uppsala (SLU) and Chalmers University on-going field tests to assess the long-term performance of heat-treated wood. Recent results are published (Sailer *et al.* 2000a; Sailer *et al.* 2000b).

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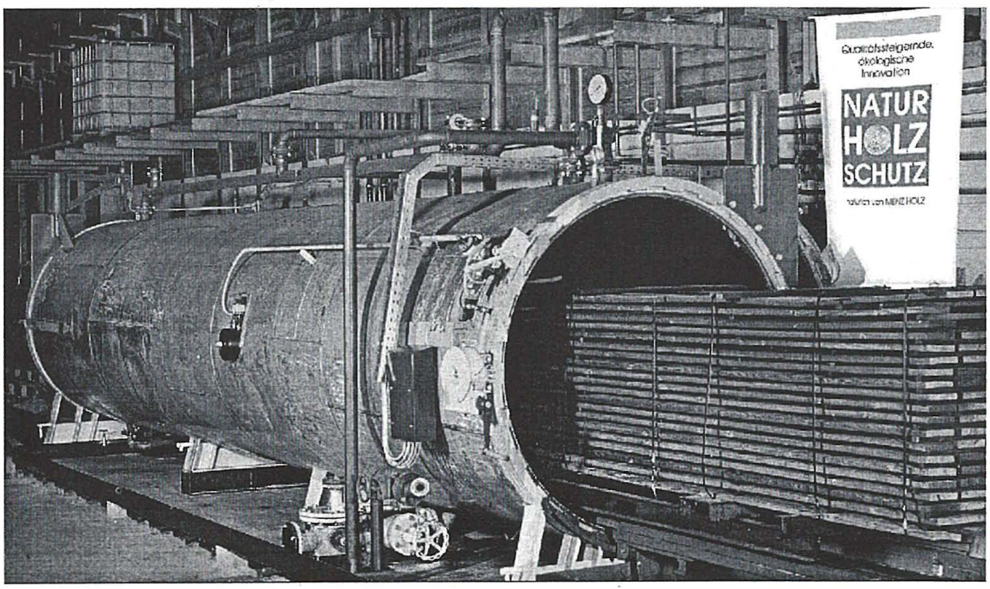

Fig. 8: *Process vessel for the oil-heat-treatment in Reulbach. (Foto: MENZ HOLZ, Germany).* • *Radni spremnik postrojenja za zagrijavanje uljem u Reulbachu, (Foto: tvrtka MENZ HOLZ), Njemačka.*

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