The solar tent

An effective method to disinfest museum objects using solar generated heat

Heat disinfestation

Disinfestation of museum objects has undergone a significant change in the past decade. Due to health and environmental concerns many museums have switched from chemical treatments to non-toxic pest control methods such as exposure to low oxygen concentrations (nitrogen fumigation), exposure to high carbon dioxide concentrations (CO_2 fumigation) and exposure to low temperatures (freezing). Beside these methods there is a demand for a cheap and fast alternative: heat disinfestation. Exposure to temperatures above 45°C effectively kills insects in all developmental stages within several hours. The higher the temperature, the faster total mortality occurs. Yet, for the sake of the objects, the temperature should not be too high. An acceptable compromise is 55°C, at which temperature an exposure time of 1 hour is required to reach total mortality in museum pests (fig. 1).[1, 2]

Solarisation

Solarisation is the use of solar radiation to increase the temperature of (dark) materials covered by a transparent plastic film or glass. The method is based on the fact that solar radiation (280 to 2500 nm) passes through the transparent layer, reaching the dark surface where it converts into convective heat and radiant heat of lower wavelength. Because the transparent film is much less permeable to long wavelength thermal radiation, the heat is contained within the system, increasing the temperature of the enclosed air volume.

The best known application of solarisation is in disinfesting soil.[3] Soil solarisation is a hydrothermal process that occurs in moist soil that is covered by a transparent plastic film and is exposed to sunlight during the warm summer months. Temperatures can be achieved which are lethal to many plant pathogens and pests. Solarisation for disinfesting crops and stored products has been used occasionally in tropical countries.[4, 5] Other applications of solarisation are drying of stored products[6, 7, 8] and timber.[9] Solarisation as a means to disinfest museum objects, was introduced in the conservation field by Strang[10, 11] and Brokerhof[12].

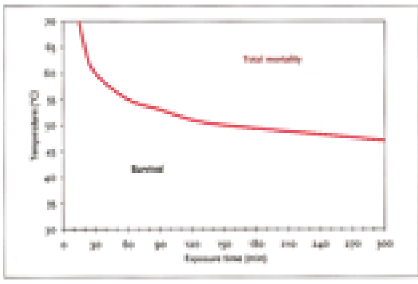

Figure 1. *Time-temperature-mortality relationship for insects exposed to heat; above the line mortality is 100%*

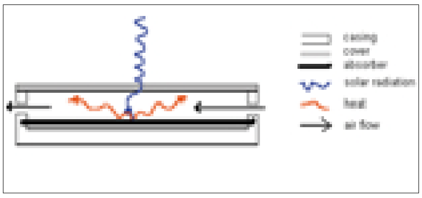

Figure 2. *Single Front Pass principle*

The solar tent

For effective, yet low cost, disinfestation of museum objects the Solar Tent has been designed.[13] A tent has the advantage that the object is never directly exposed to solar radiation and an even temperature distribution inside the tent can be achieved. The Solar Tent is based on the 'single front pass' principle (fig. 2). A black inner tent of cardboard or polyethylene converts the solar radiation into heat. Openings are left at the top and at both bottom sides. An outer roof of two layers of clear polyethylene sheet, large enough to enclose the entire tent, contains the heat. The air between inner and outer tent heats up and rises to the top, enters the tent and mixes with the cooler air. At the bottom cool air is drawn into the air layer where it warms up and rises. A pattern of white vertical stripes on the black surface improves the circulation by differential absorption. The tent is placed on an insulated black floorboard to avoid heat loss by conduction. The frame of the tent is placed on black bricks or stones. In this way the black floorboard converts additional incident solar radiation into heat, providing extra heat at the bottom of the tent. The blocks also serve as heat storage, slowing down the cooling of the tent overnight. The objects are placed on a grill, raised above the floor of the tent to allow heating from all sides. With this design it is possible to create temperatures inside the Solar Tent ranging from 75°C in the top, 66°C in the middle, to 55°C at the floor (fig. 4).

Figure 3. *The Solar Tent on a pallet that can be moved with fork lift*

To facilitate transportation of the tent, the whole structure can be placed on a pallet, which can be rolled with a fork lift into the sun in the morning and back inside at the end of the day (fig. 3). Alternatively one can fit two wheels to one side of the pallet or to an insulated floorboard structure and two handlebars to the other side, making a wheelbarrow-like construction.

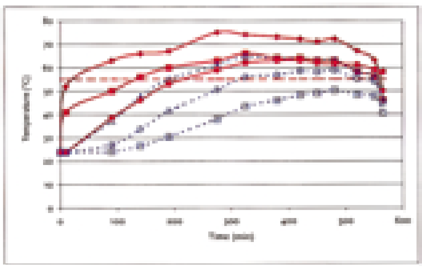

Figure 4. *Temperatures measured in top (◆) and middle (■) of solar tent and in core of wooden cylinder with radius 5 cm (●) and temperatures calculated for the core of wooden cylinders with radius 5 cm (△), 7.5 cm (○) and 10 cm (□).*

Caution with materials

Any heat treatment can have side effects on the materials of museum objects. These may not be adverse per se, but changes have been observed, such as the movement of resins in pine and softening of varnishes and waxes. One should take care with materials that have a melting point below 75°C.

Constructing a solar tent

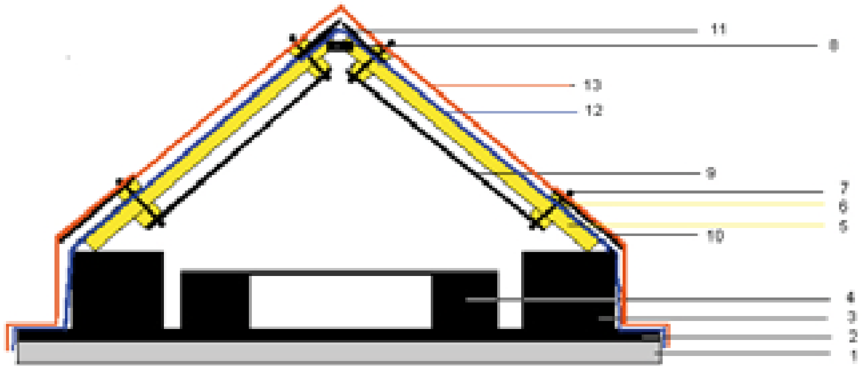

Figure 5. Solar Tent design, front view.

Materials to build a tent (shopping list)

1 Ground insulation (120 x 120 cm): polystyrene, old newspaper, fibre, rock wool
2 Floorboard: matt black (125 x 125 cm) plywood, boards
3 Corner block (brick, stone) wrapped in black plastic, raising the frame, circa 16 cm high (4x)
4 Support block (brick, stone) wrapped in black plastic, circa 12 cm high (4x), with a metal grill, for example refrigerator shelves
5 Timber post: matt black (70 x 7 x 3.5 cm)(4x)
6 Timber cross support: matt black (100 x 4 x 2 cm)(8x)
7 Bolt and nut (8 x 100 mm) with washers, to attach cross supports to posts (8x)
8 Plate mending or hinges, to connect posts (2x)
9 Cardboard inner roof (54 x 100 cm) painted matt black, with 3 vertical white stripes of 10 cm width (2x)
10 Cardboard bottom flap (17 x 100 cm), painted matt black with 3 vertical white stripes of 10 cm width (2x)
11 Cardboard top flap (12 x 100 cm), painted matt black with 3 vertical white stripes of 10 cm width (2x)
12 Clear outer roof: first layer polyethylene sheet, 0.10 mm thick (3 x 3 m)
13 Clear outer roof: second layer polyethylene sheet, 0.10 mm thick (3 x 3 m)

- Cardboard triangle (110 x 55 cm), painted matt black with 3 vertical white stripes of 10 cm width
- Scotch tape
- Clips to attach outer tent to floorboard
- Optional: Pallet with wheels to move tent

Instructions

- Drill 9-mm holes in timber posts (5): in the centre, 7 cm from the top and 14 cm from the bottom.
- Drill 9-mm holes in timber cross supports (6): in the centre, 3.5 cm from both ends.
- Attach timber posts (5) in pairs at their tops at an angle of circa 100° with a metal or cardboard plate (8)(fixed) or with hinges, cardboard or leather strips attached to the inside of the timber posts (flexible). In the flexible construction the timber posts are tied together with string or rope to keep the right angle (fig. 7).
- Make holes at 4 corners of the 2 cardboard inner roofs (9), corresponding with the holes in the cross supports (6) when they are lined up with the long sides of the roof.
- Push the bolts (7) from the back through each hole in the cardboard inner roof (9) and through the holes in the cross supports (6)(fig. 8).
- Attach inner roofs and cross supports with bolts from the inside out to the timber posts, with the cardboard roofs at the innermost side, black and white stripes facing out (fig. 9).
- Pull the first layer of clear outer roof (12) over the entire structure, with the middle lined up with the top of the tent. To avoid tearing of the plastic, stick pieces of Scotch tape on the plastic before cutting small holes in tape and plastic (fig. 10). Slide the plastic film over the bolts, while pulling the outer roof tight from top to bottom.
- Make holes in two corners of cardboard top flaps (11) corresponding with holes in cross supports (6). Slide cardboard top flaps over upper bolts, pointing up, and place cross supports over the flaps. The two flaps stand up, left and right at the top, held in position between cross support and timber post, resting on top of the first layer of clear outer roof (fig. 11).
- Make holes in two corners of cardboard bottom flaps (10) corresponding with holes in cross supports. Place the remaining 2 cross supports (6) left and right over the lower bolts. Slide cardboard bottom flaps over lower bolts, pointing down. The two

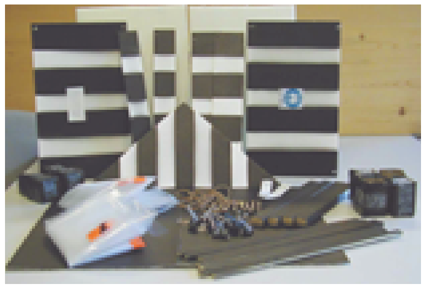

Figure 6. Construction parts of the Solar Tent

Figure 7. Attaching timber posts with cardboard. Strip, keeping an 100° angle with string

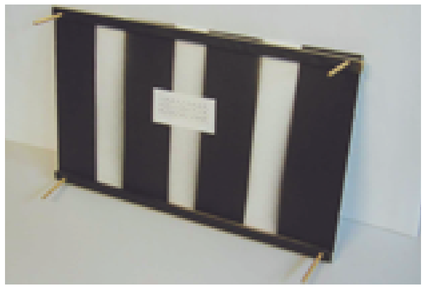

Figure 8. Lining up cross supports with inner roof

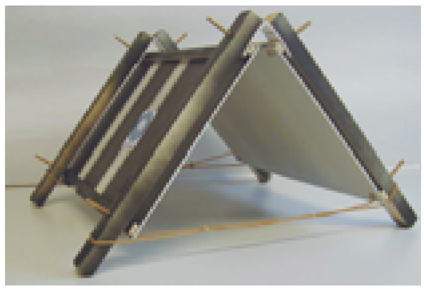

Figure 9. Inner roof attached to timber stands

Figure 10. Scotch tape on plastic to avoid tearing before cutting

flaps hang down, left and right, on the outside of the lower cross supports attached to the timber posts (fig. 11).

- Pull the second layer of clear outer roof (13) over the entire structure, similar to the first layer. Reinforce the holes with Scotch tape and slide the plastic film over the bolts, while pulling the outer roof tight from top to bottom. The four cardboard flaps (10, 11) act as spacers between the two layers of clear outer roof, while warming up the air layer in between the layers thus counteracting the heat loss by wind cooling.
- Slide washers over bolts and screw on the nuts.
- Prepare the insulated floorboard (1)+(2), preferably on a moveable structure.
- Place the four black corner blocks (3) on the corners of the black floorboard (2) and place the tent on top with the posts resting on the corner blocks (fig. 12).
- Clip the double outer roof along the two sides to the floorboard (or tie, staple, nail).
- Place the four support blocks (4) inside the tent and place the grill on top of them. This will carry the objects.
- Once the Solar Tent is filled with objects, the opening receiving most sunshine will be closed with the triangular cardboard, which rests on two of the corner blocks that carry the tent (fig. 11 and 12).

Figure 11. Outer cross supports with extra surface

Preparing the objects

To avoid changes in moisture content of the materials during treatment, the objects need to be wrapped in common polyethylene bags sealed with tape. When the surface is fragile, the object should first be wrapped in tissue paper.

Figure 12. Solar Tent placed on blocks with outer tent clipped to floorboard.

Performing a treatment

Set up the Solar Tent in a place where it is sheltered from the wind. Position the tent with its opening in the North-South direction so that the solar radiation falls upon one side during the morning, is above the tent at midday and falls on the other side during the afternoon (fig. 13).

The objects are placed on the grill, so that warm air has access from all sides. The top of the Solar Tent is the warmest, so the objects should be placed as high as possible, at least 12 cm above the floor. To ensure optimal heating, the objects should have maximum contact with the warm air. Objects should not touch each other. If possible, panel-shaped objects should stand upright on their side rather than lying flat. Objects with the shape of short cylinders and oblong blocks should stand upright. Objects shaped like long cylinders and thin objects can lie flat. The Solar Tent should be filled to a maximum of 50% of its volume.

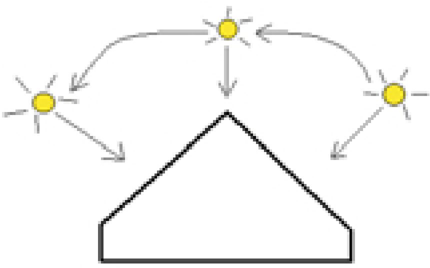

Figure 13. Positioning the Solar Tent

After the objects are placed on the grill, the opening facing the equator is closed with the cardboard triangle, which rests on two corner blocks. The outer roof is closed clamping it to the floorboard.

At the end of the day the objects are left inside the tent to cool down slowly together with the whole structure. Next morning, when the objects have reached the same temperature as their surroundings, they can be taken out and unwrapped. This is to avoid formation of condense inside the wrapping as a result of a large temperature difference between the warm object and the faster cooling plastic bag.

Modifications to the design

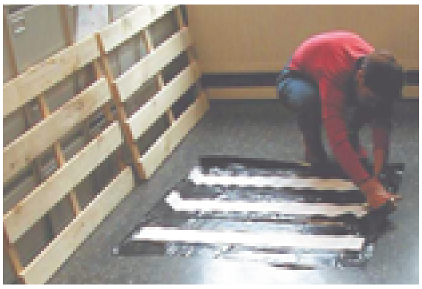

Figure 14. Modification: stapling paper strips to plastic inner roof

In hot and sunny locations the black cardboard inner roof generates enough heat without creating unnecessarily high temperatures in the tent. In moderate climates the cardboard can be replaced by black polyethylene, which generates more heat as it requires less energy to warm up its own mass.

- Take two sheets of black polyethylene plastic (100 x 100 cm, 0.1 mm thick).
- Staple three white paper strips (10 cm wide, 100 cm long) with 15 cm in between to the black plastic (fig. 14).
- Wind the black plastic around the cross supports, push the bolts (7) through the plastic, through the holes in the cross support and attach them to the inside of the timber posts (fig. 15).

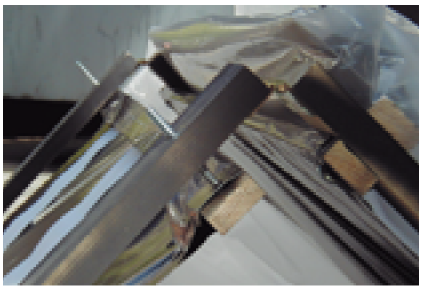

Figure 15. Modification: winding plastic inner roof around cross support and attaching to timber posts

In locations with much wind or too low an outside air temperature, the insulating performance of the outer roof can be improved by using thicker polyethylene film or even polyester or Plexiglas (less transparent to infrared radiation). Glass is a good alternative for the clear plastic, but it is heavy and fragile. The Solar Tent described here has a floor surface of approximately 1 m^2. Obviously, this restricts the size and the number of objects that can be placed inside. The tent can be made longer to fit long objects or a larger number of small to medium sized objects.

Temperatures and heat diffusion

The objects warm up through heat diffusion. The rate of heating depends on the difference between the temperature inside and outside the object, the thermal diffusivity of the material, and the volume of the object. To heat up objects in a few hours, the surface must be exposed to higher temperatures than the target temperature in the core. The maximum temperature in the tent determines the size of the objects that can be treated successfully. At temperatures of 75°C in the top and 66°C in the middle of the tent, wooden objects similar to a cylinder with 7.5 cm radius and paper objects the size of a phonebook can be heated to 55°C in the core, and kept for 1 hour, during a 1-day exposure (fig. 4). Larger objects require longer exposure or higher temperatures. A larger tent does not generate higher temperatures. Temperatures depend on the power of the solar radiation, the outside air temperature and the insulation of the tent.

Required conditions

To reach the required temperatures inside the tent, the amount of solar radiation and the weather conditions are important. The tent has proved to be effective with a maximum instantaneous solar irradiance (ISI) of 950-1100 Wm^{-2} and a total radiation dose of at least 18MJ during the day. The total dose can be calculated by multiplying the average ISI with the exposure time. ISI values can be obtained from the national weather bureau, often published on Internet.
In the tropics and subtropics these energy values can be obtained on a sunny day with a maximum of 25% cloud cover. In moderate climates the requirements can be met on clear sunny days in summer. The ISI is higher in the first part of the morning than in the last part of the afternoon, thus an early start provides more energy than a late finish.
Since the main loss of heat takes place through wind cooling, the outside air temperature needs to be at least 28°C. Exposure to wind should be minimised.
Under the required conditions the Solar Tent performs well. If one wants to monitor the performance, temperatures around the objects can be measured at the top (should be 75°C) and the bottom (should be 55°C) of the tent by sticking a thermometer through the clear outer roof into the tent.

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