Heat-transmitting membrane : volume 1

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HEAT-TRANSMITTING MEMBRANE

VOLUME 1

ARNO PRONK[*], TIM DE HAAS[†],MARK COX[†]

Eindhoven University of Technology
(TU/e)
P.O. Box 513 5600 MB The Netherlands
e-mail: a.d.c.Pronk@tue.nl , info@timdehaas.com or m.g.d.m.cox@tue.nl

Key words: Distance fabric, Climate control, Vacuum injection.

Summary: Multilayer membranes filled with a heat-transmitting substance/material make it possible to heat up or cool down a space by radiation. When a fluid is used, the principle of vacuum-injection can be used to make a heat-transmitting membrane with the capacity of 500W/m2.K The working of the heat-transmitting membrane can be improved by a proper use of the fluid dynamics. Extra membranes could increase the effects, because they filter the radiation of the sun and insulate the construction. Applications of this heat-transmitting membrane can be found in the climate control of inflatables, tents and buildings.

1 INTRODUCTION

In 2003 an Art Pavilion[1] was built at the Eindhoven University of Technology, with a mould of PVC coated polyester membrane.
The inflatable mould of the Art Pavilion was re-used as the base of an igloo that was made one year later. Making an igloo in September in the Netherlands is quite a challenge, because the average outside temperature is 18°C. Since the exhibition was inside a building, there were two options for creating ice:
(1) to cool the air of an insulated room,
(2) to cool down the surface of the igloo directly.

Figure 1 - Igloo

Option 1 is the most commonly used. But to insulate the exhibition space was difficult and expensive. An other argument for the researchers to look at the second option was that air has a limited cooling capacity compared

	Heat capacity J / kg * K	Heat transportation W / (m * K)
Ice	2.2 x 1000	2.1
Air	1.0 x 1000	
Water	4.2 x 1000	
Ice->water	345 x 1000	
Glycol	2.4 x 1000	

Table 1 - Thermo energy

to water and ice. The phase change of water into ice is an energy consuming process. This phase change costs approximately 150 times more energy as the heating or cooling of ice by 1 degree. There fore the most direct process is favorable. Water has a much better heat capacity than air; the heat capacity of 2330 dm3 air is equal to 1 dm3 water. Therefore the researchers choose the second option. In practice it seems an easy process if you can cool a surface below zero and spray the surface with water so that ice can develop on the surface of the igloo. From a theoretical point of view the process is very complicated and hard to calculate due to the non-linearity's of the phase change (water-ice), the outside conditions (solar energy) and the time-dependency of the igloo construction.
To show the reader in full detail the complexity of the occurring phenomena would take a full course on turbulent flows, finite element methods, time-dependent non linear solutions of the mathematical model of such an igloo and so on.
Some detailed studies have been done on the different topics and one of the conclusions is that with an integral approach the time and effort to build an igloo can be reduced significantly. The theoretical approach can help to optimize the balance between time-dependent energy flows and ice formation at the surface. For example: to cool water 1 degree will cost about 4.18 KJ/kgK. To produce ice will cost approx. 334 KJ/kg. Question: Would it help to cool the water (that is sprayed on the igloo during formation of the igloo) from 11C -> 1C? The amount of energy needed to produce ice (0C) from water (0C) is 8 times greater than the energy needed to water 1 degrees. From this point of view, pre-cooling the water seems not to be very effective.
One important item has been jumped over: TIME. Time plays an important role in the whole process of making an igloo. Taking time into account, the pre-cooling is effective for the time needed to produce ice. After comparing the practical production time of the igloo with the theoretical computations of the production time, the authors concluded that the time needed tot produce a certain igloo can be reduced by a factor 2 when accurate theoretical calculations are used to design the igloo cooling system. The leads to advantages in several fields, like reduction of labor cost, less energy consumption, better understanding of the physics of the process, etc.

The igloo was built similar as an ice-skating ring, with ducts around the mould of the Pavilion. The structure was sprayed with water and after 3 days with 5 people the igloo got into final shape. Evaluating this project, we can conclude that there is a lot of labor in it (5 people x 3 days x 8 hours = 120 hours) and is not very easy to construct.
In search of an easier way to construct this igloo, a new mould was constructed. The result was an igloo-shaped double membrane within a fiber layer (30mm). Between the layers a fluid can be injected as a cooling layer.

2 VACUUM INJECTION

By using a vacuum injection technique, it is possible to have a flat surface without bumps. This technique is used by making objects from

Figure 2 - Vacuum injection

(fiberglass reinforced) polyester like (sailing) ships. By shipbuilding it also used to get the right proportion of resin in the fiberglass (not too much). Vacuum injection is a method in which a thermo set resin is injected between two surfaces. First a fabric is placed between two surfaces. In the end the fiber is just for reinforcement of the polymer. After closing the surfaces a pressure differential is applied that impregnates the fabric with resin. The pressure differential is obtained by means of a vacuum. The injection has to take place within the cure time of a resin. The different pressures arising on the mould are bound to limits. More in detail we have the following relevant pressures on the mould:

- air pressure (ca 1 bar)
- pressure difference between inside (water) and outside (air) which is depending on position at the surface. This depends on factors like bend/yield force in the surface material and on the velocity of the fluid between the layers.

As the fluid acts on the bottom surface by gravitational forces we can see that the height of the fluid column plays an important role in the force balance acting on the surface of the mould. By using the direction of the fluid flow and the average under or overpressure of the system compared to the atmospherical pressure we can decrease or optimize the pressures on the mould. This can be used to optimize the cooling down time for the mould.

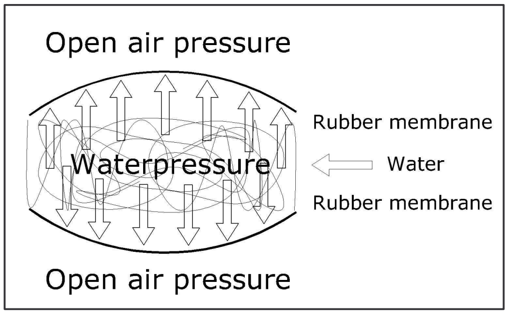

Figure 1 –With over pressure

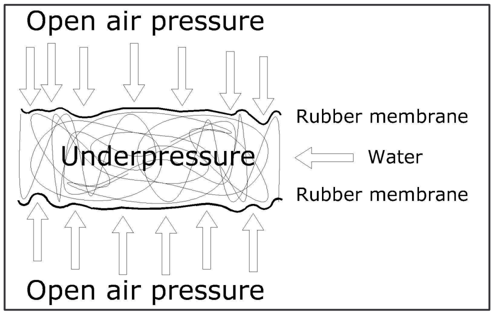

Figure 2 - With vacuum

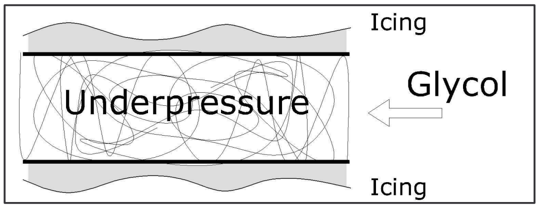

Figure 3 – Ice membrane

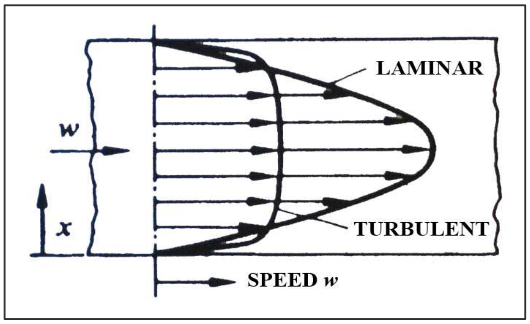

Figure 4 - Laminar-turbulent

3 HEAT ADAPTING MEMBRANE

To make a heat-adapting membrane the resin is replaced by water. The volume between the two layers is put into under-pressure. To keep space between the layers drainage (fiber) material is used. Through this space it is possible to transport water. When glycol is added to the water, the water can be cooled below 0C. In this way it is possible to make ice on the surface of the membrane. Also warm water can be used to use the membrane as a radiator.

Also important for cooling down and heating up fluids are the hydrodynamics, when a fluid is pumped through a surface there is an amount of flow. The Reynolds figure[2] is the most important figure in hydrodynamics. It determines if the flow is turbulent ($R_{ed} > 3500$) or laminar ($R_{ed} < 2300$). When the flow is turbulent, the fluid can give more energy to the surface it is flowing through. This is due to the effective mixing of the fluid. For laminar flow the coefficient of transition is of the order of 500 W/m2K and for turbulent flow approximately 1500-2000 W/m2K. The membrane in fig 2 turned out to be laminar.

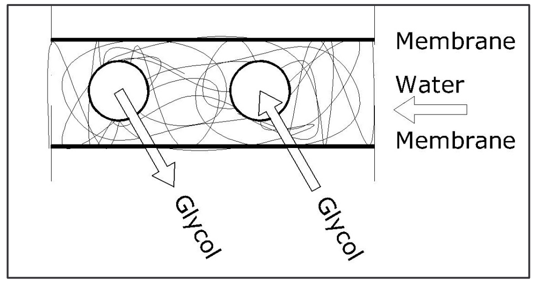

Figure 5 - Membrane with tubes

The system works as long as the membranes are 100% fluid closed. If there comes air in the system the fluid pumps will turn down. The amount of seams increases if the form of the object becomes more complex. It is hard to make a 100% fluid closed envelope out of a polyester reinforced membrane in a complex form with a lot of seams. The problem of the leakage and the other problem of turbulent flow were solved by an improved design. In this design the heating/cooling fluid is pumped through a tube; this tube lays within the fiber. The fiber is filled with water and has underpressure compared to the atmosphere. Therefore only water can leak from the membranes and the flow of the heating/cooling liquid is turbulent. Important parameters for the design are the tube diameter, distance between the tubes, fluid speed and temperature, glycol/water ratio, layer thickness, coefficients of transition and the surrounding temperatures.

4 EXPERIMENT

To determine if the previous written design works, some tests are done.[3] Four different sample pieces were made:

1. A distance fabric with a rough surface which is connected by short rope - every square centimeter was used. Thickness ± 13 millimeter, material PVC coated textile fiber.
2. Two membranes filled with a fiber (drainage mat). Thickness ± 3,5 millimeter, material PVC foil and PVC drainage fiber.
3. A bigger and wider vision of piece nr. 2. Thickness ± 13.5millimeter, material PVS foil and PVC drainage fiber.
4. A double membrane filled with tubes and fiber, therefore divided in two different compartments. One, the tubes for example filled with glycol, two, the fiber filled with water. Thickness 30 millimeter, material EPDM foil, fiber reinforced tubes and PVC drainage fiber.

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VOLUME 2

ARNO PRONK[*], TIM DE HAAS[†],MARK COX[†]

Eindhoven University of Technology
(TU/e)
P.O. Box 513 5600 MB The Netherlands
e-mail: a.d.c.Pronk@tue.nl , info@timdehaas.com or m.g.d.m.cox@tue.nl

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The main objective of this test was to determine the Reynolds figure. The test setup/arrangement measured the following things: water flow, amount of vacuum and pressure difference between the water input and exit. Since piece 1 has connected membranes, this piece was not vacuumed. After two test cycles, a problem appeared with piece 1, the connected short ropes collapsed. Therefore there are no results of this piece, decomposing of the ropes is probably the main cause of this failure. The test results show us that the main target; $R_{ed} > 3500$, is only succeeded with the 4th piece because there is a tube in the membrane. The results also show us that the earlier decision not to go on with only fiber filling but with the separate system is the right one.

Figure 6 - 4 sample pieces

5 SIMULATIONS

To get more information about the heating or cooling capacities and to optimize the design there are some simulations done. First a simple model is made with only two membranes, fiber and a tube (Figure 7 - Simple setup). Different situations must be regarded:

- heating/cooling of a space by a heated or cooled membrane (no phase change (water->ice) present *and* no solar radiation)
- the system used to make the igloo (phase change present *but* no solar radiation present)
- systems including phase change *and* solar radiation

Designing well-functioning systems is very difficult when phase changes have to be taken into account. Systems without phase changes can be calculated rather easily with commonly used numerical methods.
Depending on the purpose of the membrane some layers of fabric can be added. When this membrane is used as a roof structure, energy losses due to solar radiation can be prevented by adding an insulating layer. This space can be filled with glass wool or with air (**Error! Reference source not found.**).
When the membrane is used in a hot climate with a lot of sun it's better to use a double membrane. The first layer will absorb the heat of the sun and when ventilated, the hot air can be removed. The second layer is an insulating layer. The third layer is the cooling layer (Figure 8 - double top layer).
To improve properties and reduce failure, the water layer can be replaced with an aluminum foil. This foil must have enough thickness to transport the energy from the pipes effectively to the space underneath the roof. In the simulation a double 0.1 millimeter aluminum foil is used, which does not make the membrane lose its flexibility and makes it able to roll (Figure 9 - With aluminum foil). At the moment we are researching the lay-up of the complete structure, after that we start testing.

Applications for this way of heat transmitting are:
Tents:
Emergency tents (for example near a battlefield)
Red Cross tents (after a nature disaster)
Temporary accommodation (shops, festivals, etc)
Buildings:
Roof structures (courtyards, double curved roofs, seasonal roofs, etc.)
Wall structures (seasonal separations/walls, double curved walls, etc.)
Second skin façades (more in chapter "6 Water façade)

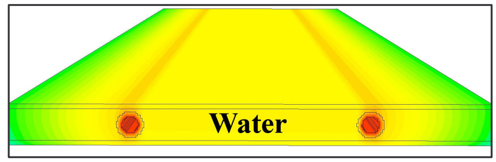

Figure 7 - Simple setup

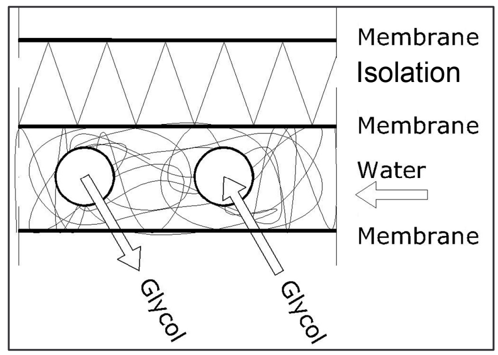

Figure 8 - With isolation

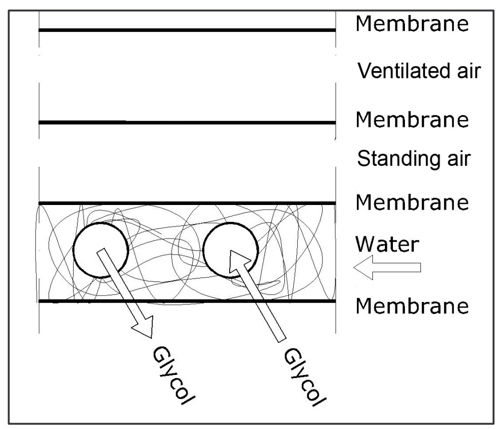

Figure 8 - double top layer

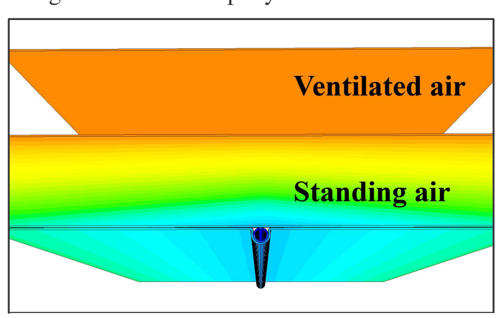

Figure 9 - With aluminum foil

6 WATER FAÇADE

One of the most promising applications for this heat-transmitting membrane is the use as a second skin façade for the renovation of existing buildings. In this way it is possible to modernise the appearance of an old building in combination with the improvement of the claimed control just by adding a second skin to the existing façade.
The water façade is a second skin façade with a heat-transmitting membrane.

The purpose of this second skin façade is to insulate the building, as a sunscreen and as a solar boiler. The lay-up of the façade is similar to the one used by the climate membrane, two layers of ETFE foil, a permeable PVC layer (15 millimetres) and a water-glycol solution. To keep a nice flat surface there is underpressure between the layers. The membrane fits into a frame that is fixed to the existing façade, between the two façades there's space for maintenance. In the prototype an inflatable sleeve is applied to stretch the membrane within the frame. The sun heats up the water-glycol solution in between the layer of foil, when this solution is pumped away it can be used to heat up the building. When a heat exchanger is put in between there is a possibility to cool the building, but also heat storage in the bottom makes it possible to heat up the building in wintertime. Chemical additives like dyes can significantly improve the absorption of solar energy.

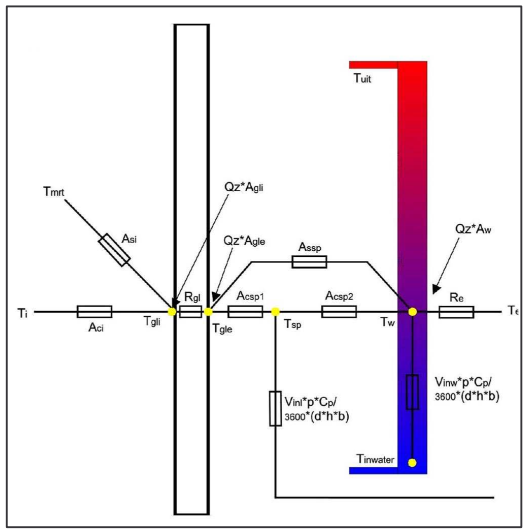

Figure 10 - Simulation water façade

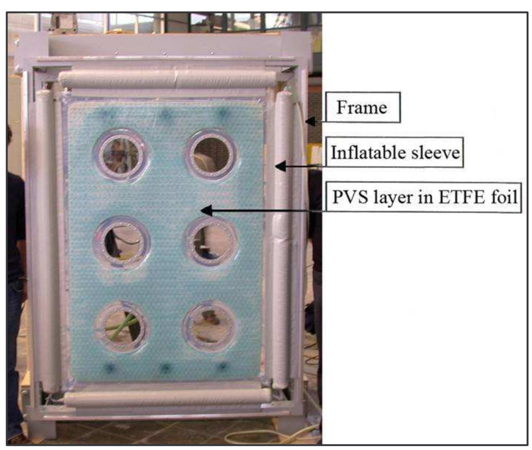

Figure 11 - Prototype water façade

7 CONCLUSIONS

By using (flexible) multilayer membranes filled with a fluid or an energy-transmitting layer, it is possible to heat up or cool down a space. Applications of the heat-transmitting membrane can be found in front of an existing façade to collect energy en reuse that energy in the building itself. When fluid is used, vacuum injection provides a flat surface of the membrane and therefore the membranes are suitable for roofs and (second skin façade) walls. If there are some extra layers added on the top of the fluid filled membrane, it can filter the radiation from the sun and work as an insulation layer. This membrane can for example be used as a roof structure.

REFERENCE

[1] Pronk, A.D.C., Osinga, D.R. "*Making Igloo's in September*", paper (2005)
[2] Recknagel, Sprenger, Schramek: *"Heizung+klima technik"*,(1997/98) 68e ed.
[3] De Haas, T.C.A., "*Toepassen van textiele warmte plafonds*",research(2006)