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SolarFrost: The Icebook

The Icebook is a completely new type of cooling machine. It is revolutionary by its new patented cooling cycle, which allows ammonia absorption cooling under temperature conditions that were impossible until recently. Even more surprising is the construction principle and its shape. Contrary to conventional cooling systems which are made of a number of heat exchangers connected by a rather complicated network of bent tubes and fittings, the Icebook is simply built as a block of sheets of different materials (see picture below) like a book or even better, like a microchip.

Fig. 1
Assembly of the Icebook

For the moment our prototypes – built individually, partly by hand – have a specific volume of 5 – 10 litres per KW of cooling power. This is by a factor of 30 better than conventional ammonia absorption cooling machines.

It is noteworthy to state that the Icebook in its actual size and built basically by hand in our small workshop has a payback time for the investment (calculating the price of the saved electric energy) of about 3 years.

To start an industrial mass production SolarFrost is planning to organise a group of companies to prepare the last necessary steps.

In order to make the Icebook work, SolarFrost in a 10 years research work has invented, developed and patented a series of new thermodynamic cycles. To make clear what we are talking about, we have to go a little bit into thermodynamic theory:

Cooling with Ammonia-Water Absorption

By Gerhard Kunze (ph.D.)

1) The Conventional Absorption Cycle

Evaporation of liquid ammonia (=NH3) extracts heat from its surrounding media, thus cooling it to a lower temperature. In order to establish a continuous process it is necessary to re-liquefy the resulting NH3 vapour. Compression cooling achieves this by means of a compression engine which runs driven by electricity or by a diesel engine. By compressing a vapour one obtains first a hot gas. When this gas is cooled back to the ambient temperature (the so called **“back-cooling”**) maintaining the same high pressure, the vapour condenses and becomes liquid. If this pressure is reduced significantly, for example by passing this liquid through a throttle into another vessel, it can evaporate again, repeating the cooling process.

The absorption engine uses a different physical principle: NH3-vapour can be absorbed easily by cold water and low pressure. This solution is heated in a vessel connected to a condenser at ambient temperature. Heating up the vapour pressure of NH3 over the solution is rising until it achieves the necessary pressure when condensation at ambient pressure can take place. Now the NH3 escapes from the solution in form of vapour bubbles (“generator process”), it moves into the condenser where it becomes liquid. The liquid NH3 passes through a throttle into an evaporator vessel, in contact with water at ambient temperature (the so called “absorber”), which attracts the evaporating NH3 thus producing cold. It is noteworthy that the energy that is invested into the generator process is very closely the same as the energy created during the absorption, though the latter is produced with a lower temperature.

Fig. 2 shows the typical temperatures and pressures for an ammonia water absorption cooling machine as designed for an air-conditioning process driven by solar heat. Note that for the part of the cycle where the solution heats up, rising its pressure simultaneously, you still need a pump, though the required power is smaller than in the case of a compression cooler.

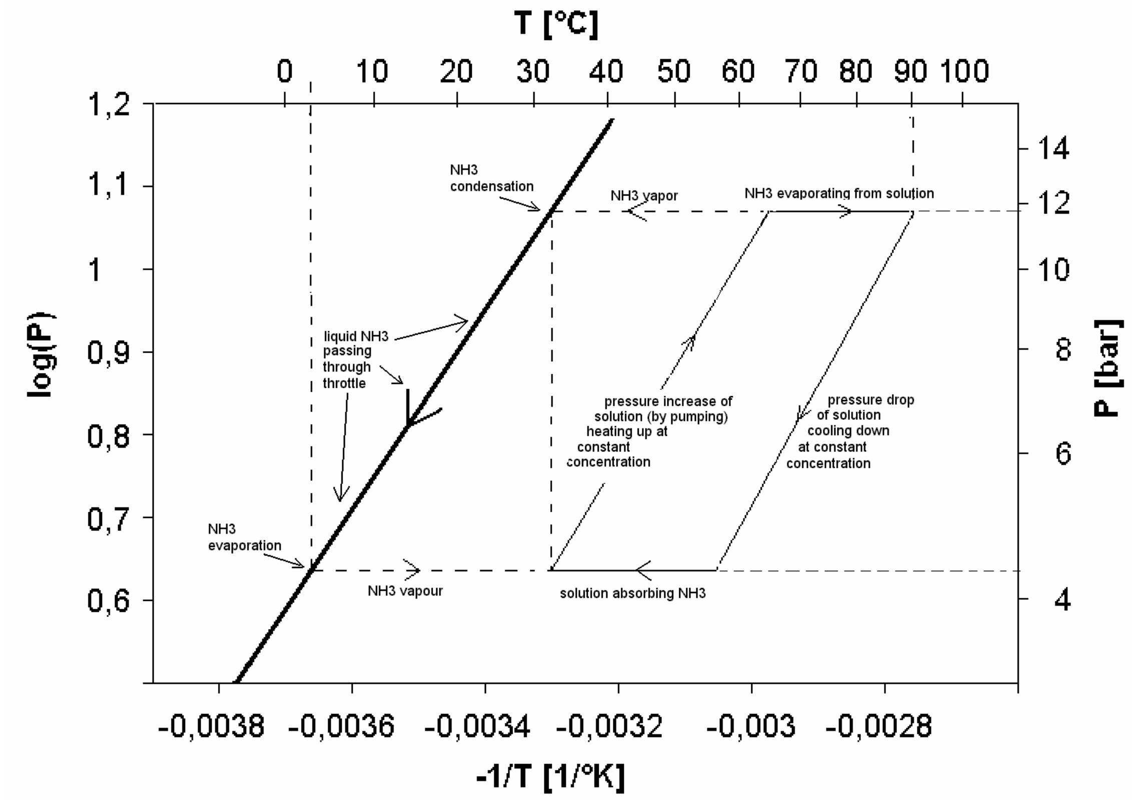


Fig. 2

Thermodynamic cycle of a conventional ammonia-water absorption engine. It works with 2 pressure levels (approx. 4,5 bar and 12bar), the high pressure for condensation the low pressure for absorption of ammonia in water. Note that generator as well as absorption processes do not happen only at one specific temperature but in a whole temperature range.

In order to obtain the desired temperatures of all parts of the cycle you have to use heat exchangers. You have 3 cycles: a heating, a cooling and a back-cooling cycle. In the heating cycle water from a solar system is heating the generator process through a heat exchanger. In the cooling cycle water from a ceiling or wall heat collector or a fan-coil (which is cooling the house) is cooled by the evaporator through a heat exchanger and in the back-cooling cycle the condenser and the absorber are cooled by water at ambient temperature through a heat exchanger too. Each water system has different inlet and outlet temperatures – see Fig. 3, each cycle represented by an arrow.

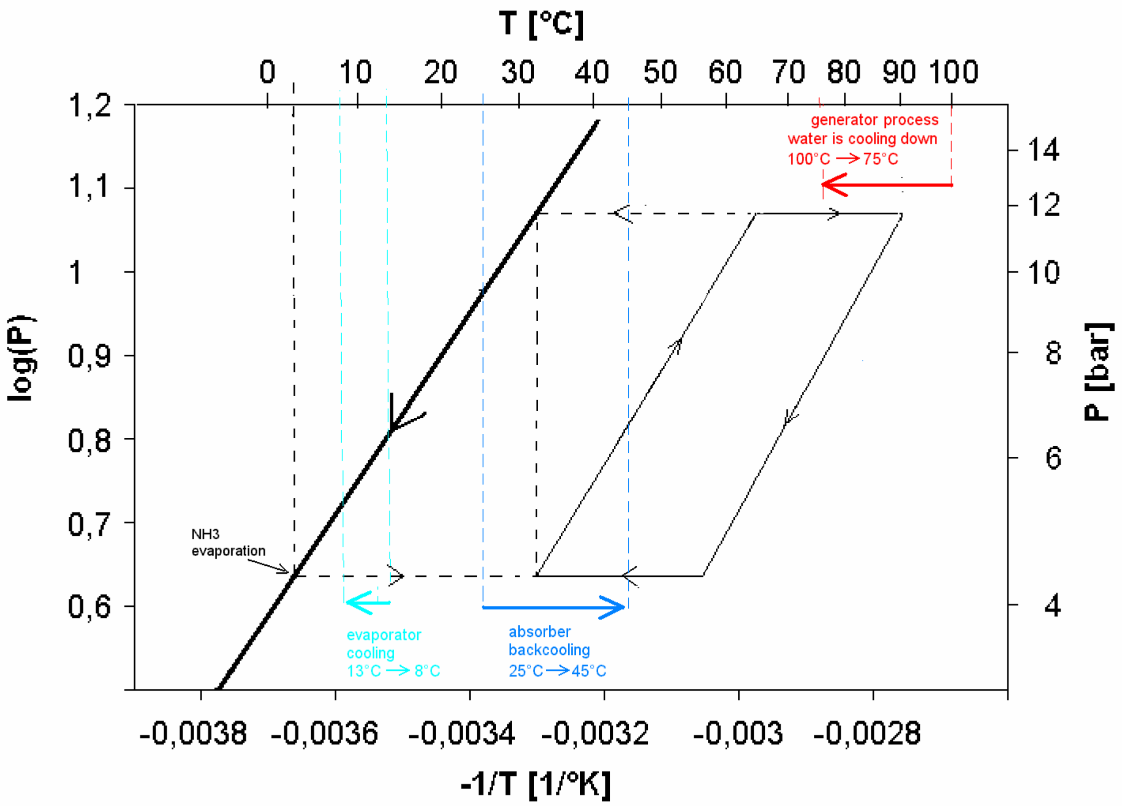


Fig.3

The ammonia-absorption is connected to 3 outside water systems: Heating, cooling and back-cooling. Each water system has different inlet and outlet temperatures (represented by an arrow). These temperatures are far away from the corresponding points of the ammonia cycle because of the usually bad designed heat exchangers.

These temperatures are far away from the corresponding points of the ammonia cycle (typically temperature difference is about 10°C or greater) because of the heat exchangers. Commercial heat exchangers usually are designed for considerably larger water flows as are necessary for ammonia water absorption engines. The problem with ammonia-water solutions is that its enthalpy change (including evaporation or absorption) per degree of temperature is more than 5 times greater than with normal water. Thus compared to the surface of heat exchanger as necessary for the total heat transfer, flow rate is much lower than it would be with water alone. Detailed calculation shows that heat exchanger length should be typically 10-30m, while real length of normal heat exchangers does not exceed 1m.

Of course it is possible to design small heat exchangers with great hydraulic length which are still small in total size. You only have to choose a very small flow diameter and to curl the flow path up. This is achieved in the SolarFrost Icebook. Typically temperature differences of only 1-2°C may be obtained.

This implies a significant change of the ammonia absorption cycle (see Fig. 4 and Fig. 5) if we use better heat exchangers: With heating water temperature of 100°C in the conventional way, generator cycle extended only to 90°C, with back-cooling-water temperature of 25°C condensation and absorption started at 35°C in the conventional way while with better heat exchangers 27°C for the real back-cooling process is possible. In order to obtain a cooling water temperature in the range between 8°C-13°C in the conventional way ammonia evaporation temperature had to be close to 0°C. With better heat exchangers an evaporation temperature of 7°C is possible.

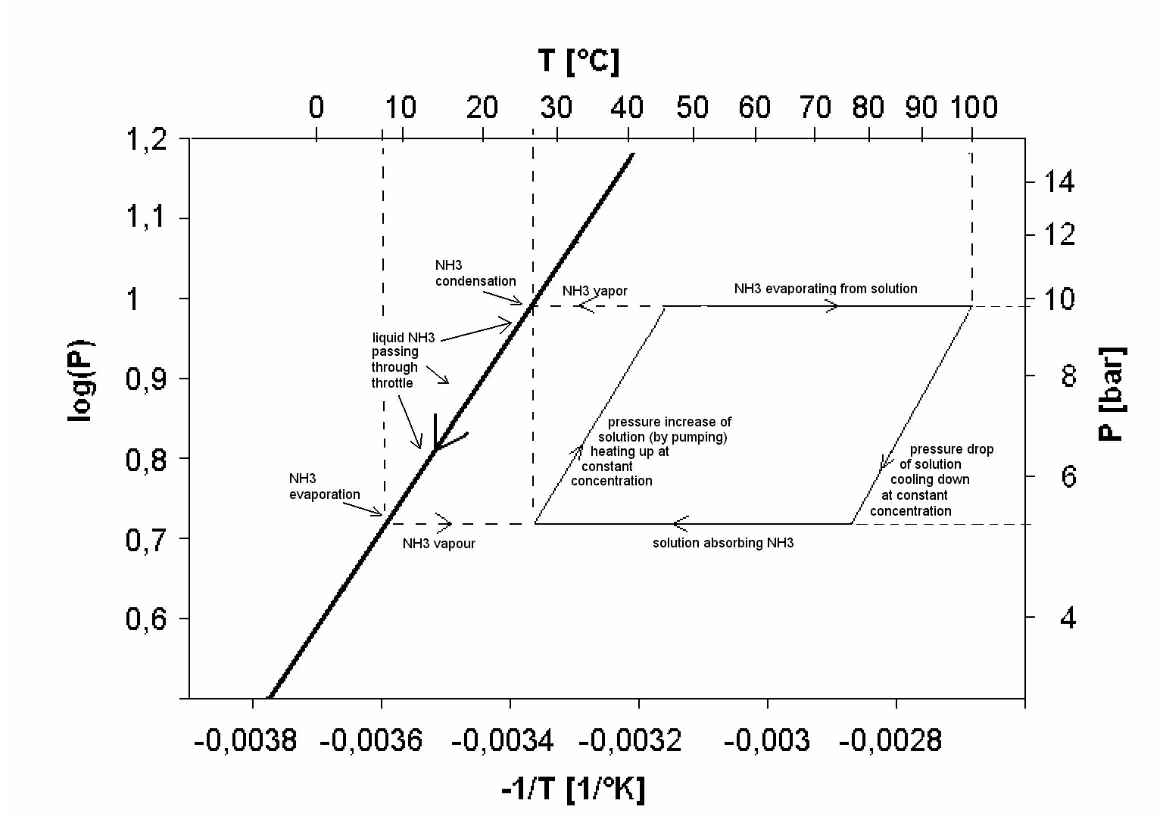


Fig.4

If we had perfect heat exchangers, maintaining the same inlet temperatures of the 3 water systems, the ammonia-absorption cycle would look like this. Note that the two pressure levels have changed to 5,5 bar and 10 bar and that the temperature intervals of generator process and absorption process now overlap significantly.

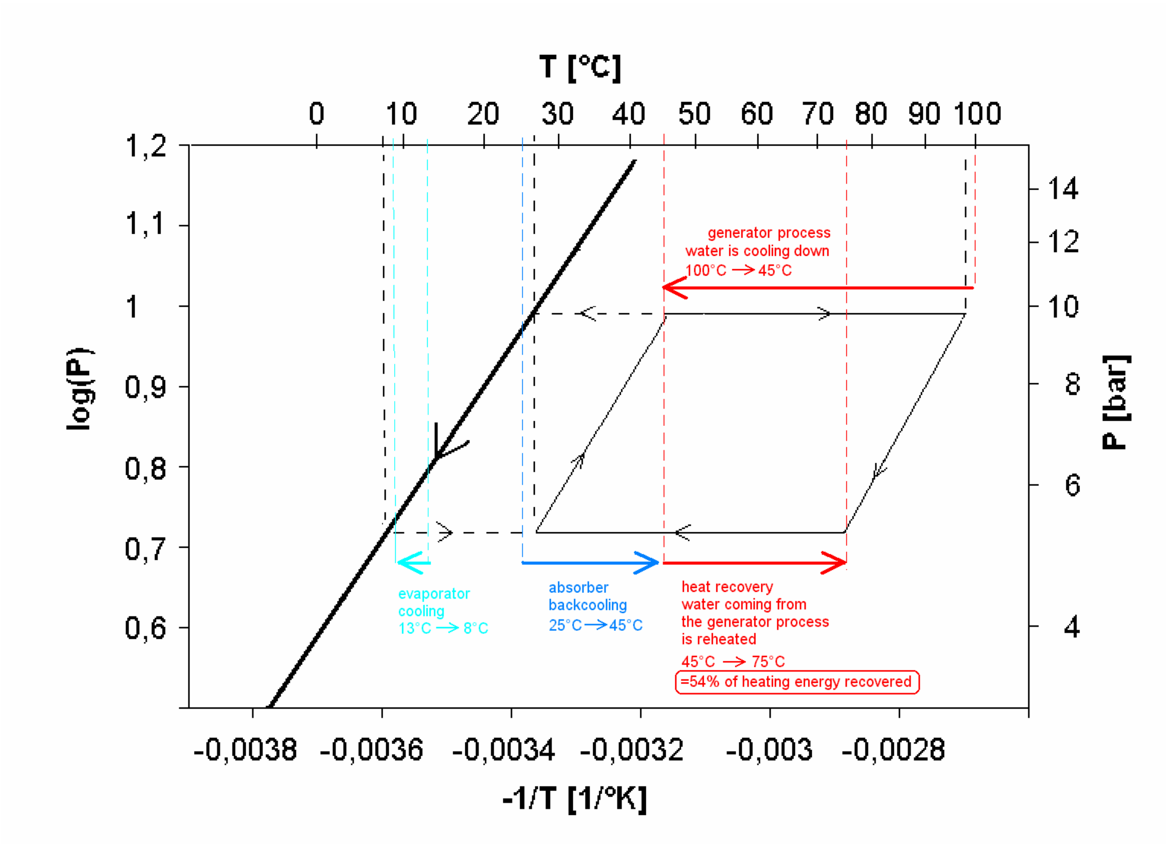


Fig. 5

The generator process consumes energy, while the absorption process produces energy. Thus the overlap of both temperature intervals allows a partial energy recovery. The water to heat the generator process in counter flow cools down, later this cool water can take heat from the absorption process to heat itself up again. While normal ammonia water cooling machines have an efficiency of approx. 0,5 energy recovery allows a much better efficiency even more than 1.

The lower condensation temperature of only 27°C causes lower condensation pressure (10 bar instead of 12 bar) higher evaporation temperature of 7°C allows higher absorption pressure (5,5 bar instead of 4,5 bar). Fig. 4 shows that the cycle parallelogram flattens and generator process temperature interval overlaps now the absorption process temperature interval. The generator process consumes energy, while the absorption process produces energy. Thus the overlap of both temperature intervals allows a partial energy recovery. The water to heat the generator process in counter flow cools down, later this cool water can take heat from the absorption process to heat itself up again. While normal ammonia water cooling machines have an efficiency of approx. 0,5 energy-recovery allows a much better system efficiency (COP, defined as cooling power divided by heating power) even more than 1.

2) The Bypass Principle

The conventional absorption cycle is limited by all three temperatures: heating, back-cooling and cooling. Fig. 6 shows that heating and back-cooling temperatures shift the inclined sides of the cycle-parallelogram to the side. Simultaneously the horizontal bars corresponding to the generator process and to the absorption process change size. If the heating temperature is lowered and/or the back-cooling temperature is raised the bars of generator and absorption processes shrink. In practice this means, that the amount of ammonia generated or absorbed per cycle is becoming smaller while the energy balance of the rest of the process remains constant. In other words, in order to obtain the same cooling power with lower heating or higher back-cooling temperatures one needs a bigger machine with higher energy in- and outputs.

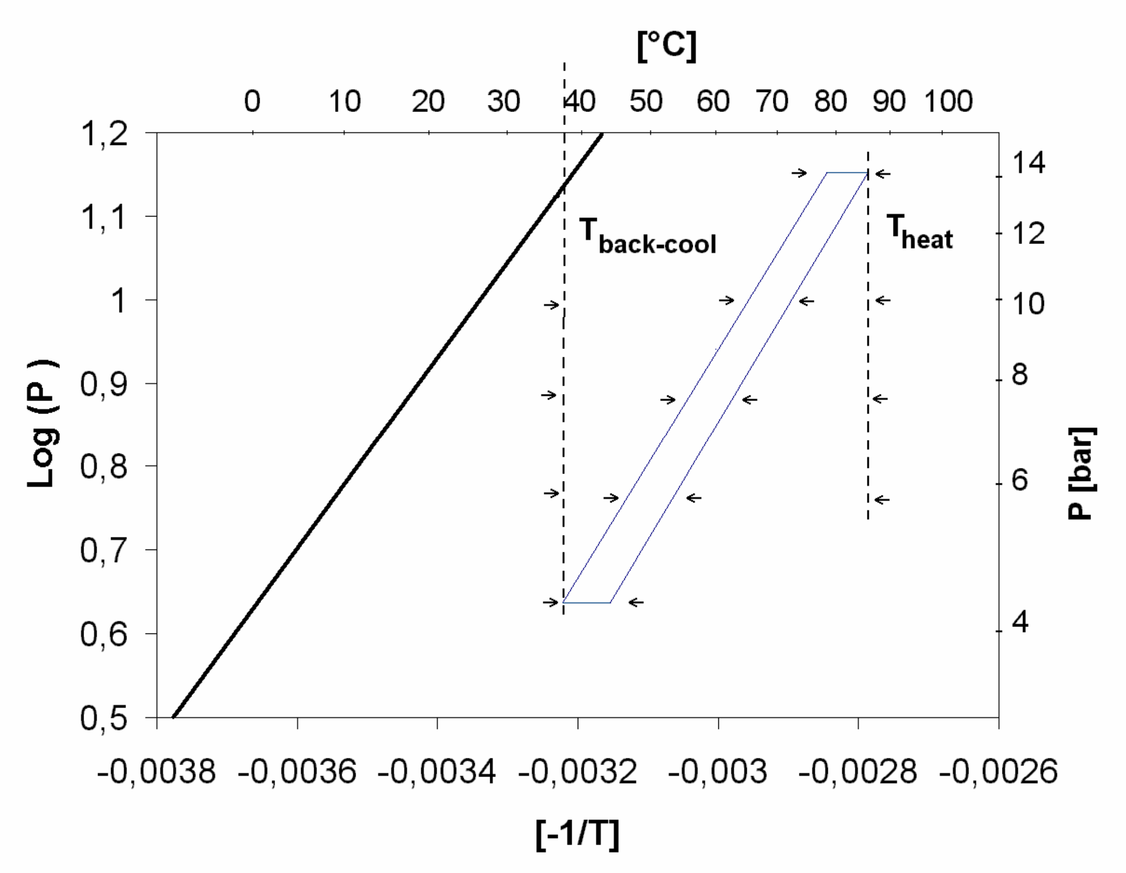


Fig. 6
The effects of the heating temperature and the back-cooling temperature on the absorption cycle. Both temperatures shift the inclined sides of the parallelogram to the side. Simultaneously the horizontal bars corresponding to the generator process and to the absorption process change size.

A lower cooling temperature leads to a similar effect as can be seen in Fig. 7. When the cooling temperature is lowered from T cool 1 to T cool 2 the intersection on the ammonia evaporation line moves from point 1 to point 2. Simultaneously the intersection points with the back-cooling temperature move from 1' to 2': The original blue cycle parallelogram changes into the new red one. Again the horizontal bars corresponding to the generator process and to the absorption process change size. If the cooling temperature is lowered the bars of generator and absorption process shrink and the amount of ammonia generated or absorbed per cycle is becoming smaller.

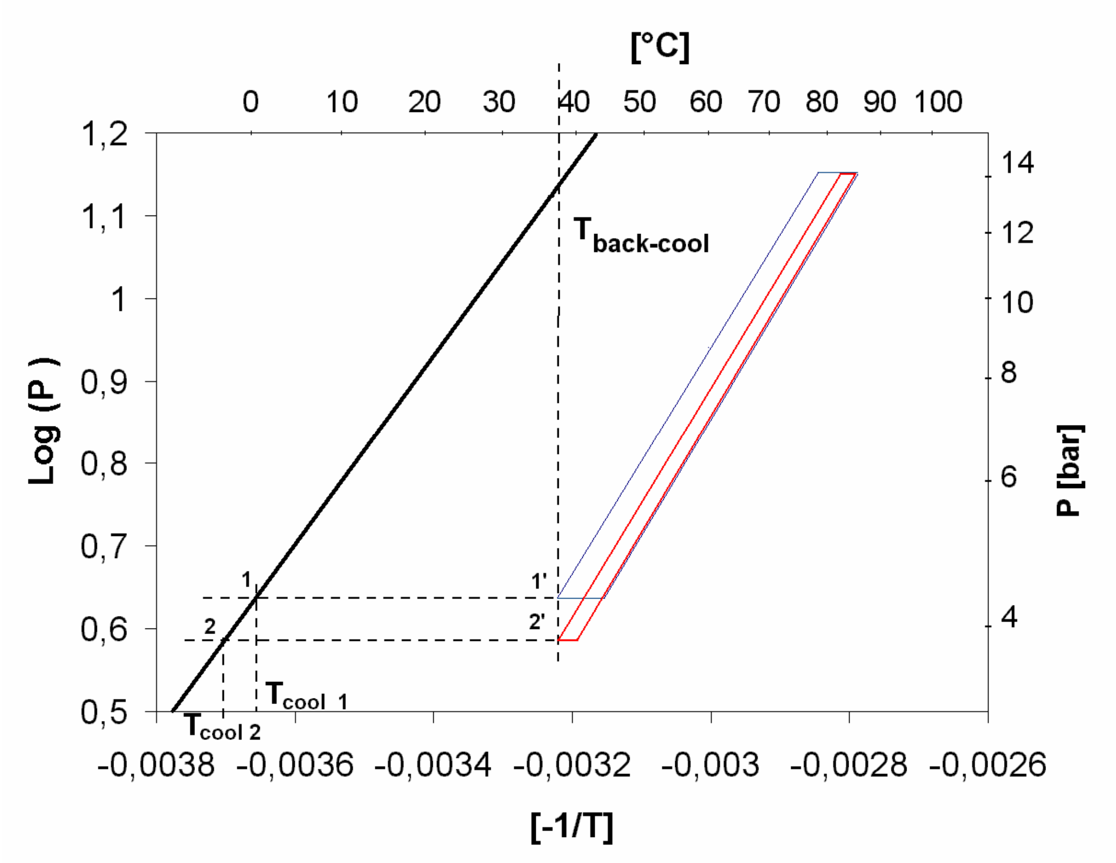


Fig.7
When the cooling temperature is lowered from T cool 1 to T cool 2 the intersection on the Ammonia evaporation line moves from point 1 to point 2. simultaneously the intersection points with the back-cooling temperature move from 1' to 2': The original blue cycle parallelogram changes into the new red one.

Obviously there must exist limiting temperatures for certain combinations of heating, back-cooling and cooling temperatures, where the lengths of bars for generator and absorption processes become zero or even negative. In such situations absorption cooling will not work at all. Unfortunately such situations arise typically when cooling shall be combined with solar energy under extreme conditions like low temperature of the solar system (because of insufficient quality of the collectors), high back-cooling temperature (e.g. with a fan coil at hot ambient temperature or with a wet cooling tower and very humid air) or very low cooling temperature (e.g. for freezing of if drying humid air is necessary).

In order to overcome this problem SolarFrost has developed and patented a new type of cooling cycle, the so-called “Bypass Process”, shown in Fig. 8.

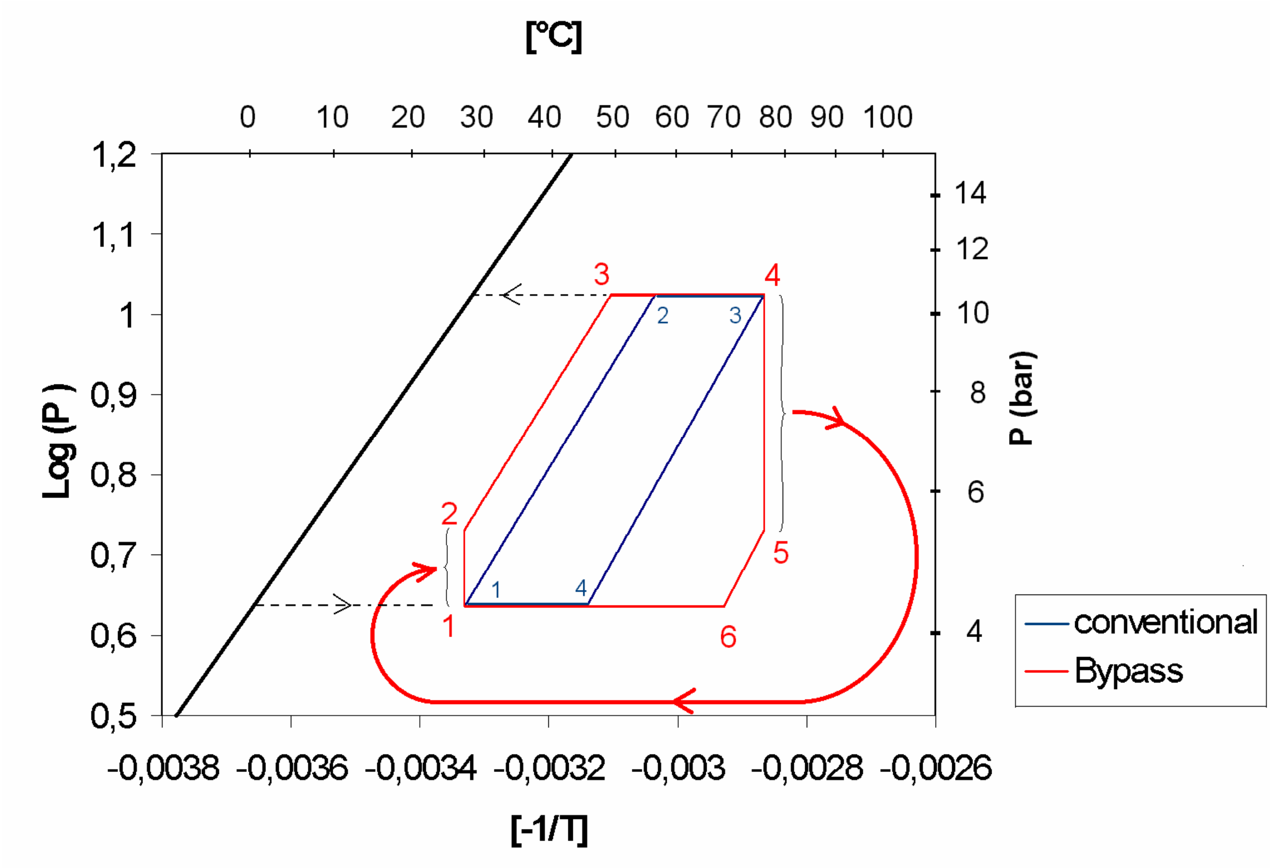


Fig.8

By means of the Bypass Process the conventional blue cycle parallelogram 1, 2, 3, 4 is changed into the red cycle hexagon 1, 2, 3, 4, 5, 6. Between the red points 4 and 5 ammonia is extracted from the solution and re-added to the solution between the red points 1 and 2. The generator and absorption process bars grow considerably. Both temperature intervals show a good overlap which allows a great part of the heating energy to be recycled.

By means of this Bypass Process the conventional blue cycle parallelogram 1, 2, 3, 4 is changed into the red cycle hexagon 1, 2, 3, 4, 5, 6. Between the red points 4 and 5 ammonia is extracted from the solution and re-added to the solution between the red points 1 and 2. This portion of ammonia does not pass through the processes of condensation, evaporation and absorption. It "bypasses" them all, going directly to the preheating of the generator process. Of course such a process consumes a certain amount of energy. Nevertheless at the same time the generator and absorption process bars grow considerably. Both temperature intervals show a good overlap which allows a great part of the heating energy to be recycled. The amount of recycled heat in most cases is bigger then the amount consumed by the bypass process. Thus overall balance is positive, combined with the fact that the bypass cycle is possible under all meaningful temperature conditions.

3) The Steam Driven Solution Pump

As mentioned in the introduction every Ammonia Absorption System needs a pump to transport the solution from the low pressure section of the absorber to the high pressure section of the generator process. This pump usually is an electric one. In the case of a heat driven cooling machine this electric pump is a serious drawback. SolarFrost therefore has developed a steam driven solution pump without moving parts (except 2 ball-check valves).

It is based on the principle that hot ammonia solution has a high steam pressure while cold ammonia solution absorbs ammonia gas.

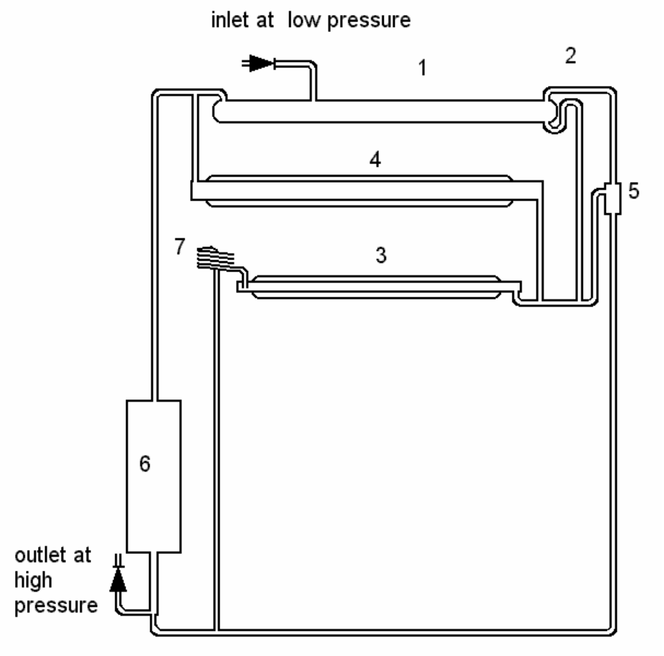


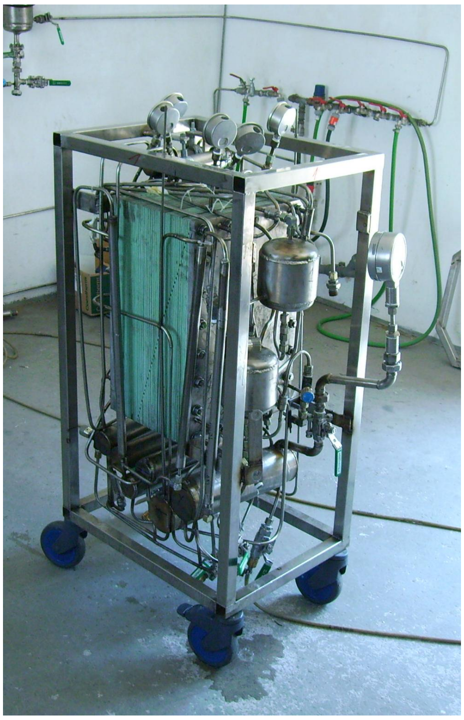
Fig.9

Suppose that at the beginning there is low pressure inside the pump (see Fig. 9). Through the inlet valve flows cold solution into the first tank (1) the solution reaches the upper level of the S-shaped pipe of its right side. This pipe draws the solution down into the pressure lowering unit (3) at back-cooling temperature and fills it completely, then it fills the boiler (4) at heating temperature until it is half full. The rest of the solution passes through the connector (5) down into the expulsion vessel (6). The boiler (4) generates steam at high pressure. This pressure expulses the solution from (6) into the pump outlet. In the moment when the expulsion vessel (6) is empty the hydrostatic pressure which before had stopped the solution in the unit (3) from flowing through the spiral (7) downwards has vanished and the solution from the pressure lowering unit (3) flows into the expulsion vessel (6). Now the weak solution (with low ammonia content) from the boiler (4) flows into the pressure lowering unit (3) where it is cooled down. At the same time it absorbs a great part of the ammonia vapour which is still in the pump, thus lowering the pump pressure to a level where it can suck in new solution.

Fig.10
The Icebook version of the steam pump

4) The State of the Art

An Icebook consists of a series of heat exchangers, steam pumps, check valves, valves regulated by floaters and a complex network of connections between them.



So far only the heat exchangers, steam pumps and the corresponding connecting network are in a state of prototype which could be produced industrially within very short time.
For bigger machines it could be advantageous to substitute the steam pump by an electric pump for economic reasons.

Check valves and valves regulated by floaters are still handmade in our workshop. Possibly similar flow regulating elements already exist in the market and a company with experience in this field could start mass production in a short time span, too. We did not investigate this so far.

Experiments to connect our Icebook with different regulating elements as are commercially available or which might be built and provided specifically for this purpose according to the systems requirements of the Icebook by an interested partner company should not take longer than 6 – 12 months. Then industrial production could start immediately because the production of the Icebook can be outsourced to workshops for laser-cutting or water-jet-cutting. In a second step towards mass-production the sheets of the book may be punched out as a very cheap production method. The material for the Icebook is relatively cheap; it is steel and/or aluminium and synthetic rubber sheets, each book for some hundred Euros.

5) Components of a turn-key solar cooling solution

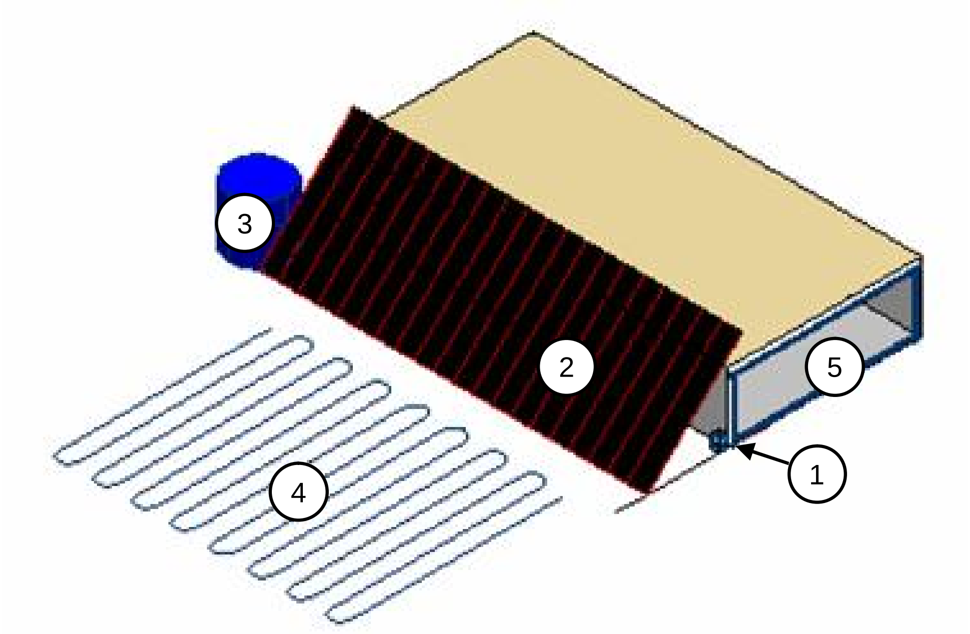


Fig.11

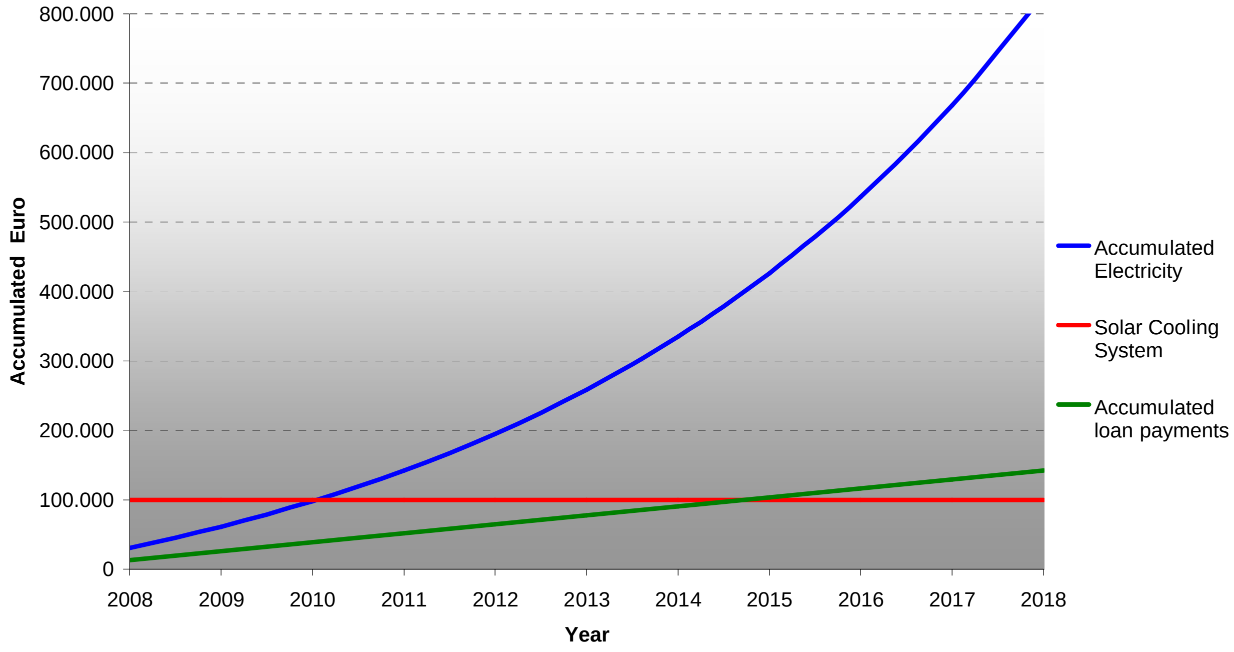
The components of a solar cooling system (Fig. 11) are:

1. SolarFrost cooling machine
2. Solar thermal system
3. Buffer storage
4. Back cooling system (e.g. an earth heat exchanger)
5. Thermally insulated cold store

Some of the components (solar collectors, back cooling system) have to be calculated according to the climate conditions of a region.

Further components:
- A system to distribute the cold in the building
- Controls including a system for remote monitoring
- Backup System for times with no solar radiation

A calculation for a cold store with a size of about 800 m^3, thermal insulation of 18 cm and a required cooling temperature of -5°C / 24 hours/day, based on a presumed total purchase price of Euro 100.000[*)] for the whole cooling solution and interests of 5% for the loan, an electricity tariff of Euro 0,14 / kWh plus a price increase of 20% for electricity results in the following payback analysis:



Purkersdorf, June 2008

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[*] The estimated production costs for the solar collectors will be about Euro 150 / m^2 = in total Euro 15.000. The production costs for the Icebook should not exceed Euro 3.000 (industrially manufactured). The installation costs will be about Euro 10.000.