

Air Ventilated Heating and Cooling Based on Zeolite Technology

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Summary

A promising technology identified and ready to be used for a man mounted micro-climatization system (MiCS) is the zeolite vacuum-adsorption technology. This technology uses the non-hazardous, non-explosive, non-toxic and environmental friendly working pair zeolite and water. Zeolites are crystalline, porous aluminum-silicates with well-defined pore structures. The most important property of the zeolite is its ability for adsorption of water in a reversible process. The adsorption / desorption technology inherently provides for storage of energy, to be used either for heating and cooling. Besides moving the air flow heat is the only energy input. The core module of the MiCS is a conditioning unit consisting of the zeolite-sorber and the water reservoir interconnected by a control valve. Sorber and reservoir are designed as heat exchangers to provide either cooling or heating to the climate air flow. The technology has been successfully used by US Navy within the HAILSS Program with its APACS (Advanced Portable Air Conditioning System). The recent flight model configuration provides a cooling power of about 50 Watts for more than 2.5 hours to the conditioned air flow. The heating performance of such a system is in the same power range. The zeolite/water adsorption technology offers manifold applications in various domains of cooling, heating, and dehumidification.

1. Introduction

Advanced protective ensembles integrating life support functions such as GKSS (see paper of Just, J. et al.) rely on air supply, to be distributed to the system's interior climatization zones and to the respirator by means of an air blower. Depending on the prevailing environmental conditions, the air flow has to be conditioned for cooling and heating - which transforms the blower into a Climatization System. The major challenge is, to have such a system independent of external power supply and simultaneously man mounted at smallest weight and size. The realization of an autonomous Micro-Climatization System integrated with a GKSS will grant a close to the body climatization. A promising technology identified and ready to be used for a man mounted micro-climatization system (MiCS) is the zeolite vacuum-adsorption technology.

2. Zeolite/Water Adsorption Technology

The name Zeolite is a general term for minerals which consist of crystalline metal-alumo-silicates with a large internal surface area of up to 1,000 m²/g, strong electrostatic fields in the crystal lattice and with a volumetric density of about 0.8 kg/dm³. The word zeolite is of Greek origin and means »boiling stone« which describes the effect which is to be seen if water is poured over dry zeolite. In 1925 the process of water and methanol separation using zeolites was observed for the first time. And due to this separation action (sieve action) the name »molecular sieve« was later attributed to zeolites. Zeolites are non-poisonous, inflammable, are naturally available in abundance and therefore compatible with the environment. More than 40 natural and over 100 synthetic zeolites are known. The most important property of a number of zeolites is their ability for reversible adsorption of water.

Even after several thousand adsorption/desorption cycles the structural changes of the crystal lattice are insignificant if the process parameters pressure and temperature do not exceed certain limits. – The application diversity of zeolites is tremendous: They are applied as molecular sieves, as adsorbents, as catalyst in cracking of hydrocarbons in the petro-chemical industry, as filler component in paper production and as ion exchange material in detergents. Currently the chemical industry produces more than 1.4 million tons of synthetic zeolite annually, and it can be expected that the world wide demand and consequently the production will further increase. The price, e.g. for laundry detergent zeolite is between 0.5 and 2.00 DM/kg, depending on the type and consistency of material delivered. The price for specialized zeolites is higher.

The primary modules of zeolites are tetrahedrons consisting of four oxygen anions and one centrally positioned silicon or aluminum cation. Zeolites are classified according to the various tetrahedral frameworks formed by these basic modules. The structure of the synthetic zeolites of types A, X and Y which have gained importance in industrial processes, are shown in the Figure 1.

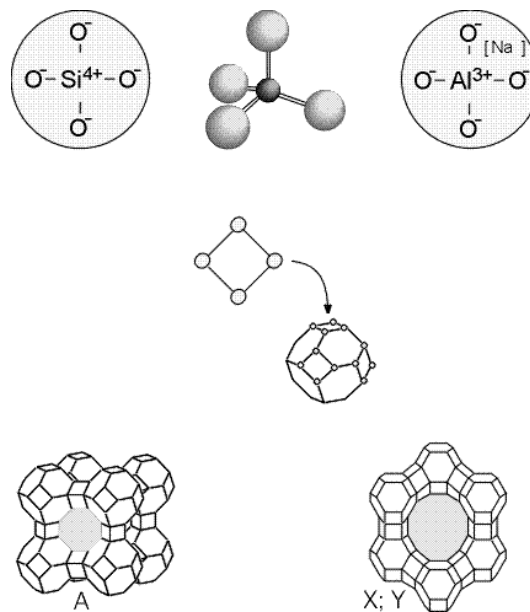


Figure 1: Structure of Zeolite

The aluminum and silicon atoms are positioned at the junctions while the oxygen atoms form the bridges between the tetrahedrons. The difference in electro-chemical charges between the aluminum and silicon atoms per one aluminum atom results in a non-compensated negative charge. The balance is restored by metal cations which occupy preferred positions. Because of the strong local electrical dipole moment in the lattice framework, zeolites adsorb all polar and non-polar molecules that fit into their specific framework. This adsorption process is accompanied by release of heat, the »heat of adsorption«. Theoretical and experimental studies have determined quantitative heat of adsorption values for zeolite based thermal processes.

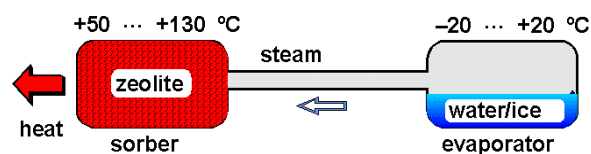


Figure 2: Adsorption Phase

In contrast to absorbing techniques we have in the case of zeolite a non-chemical but reversible physical process (adsorption) taking place: This crystalline mineral has the very special property of attracting and adsorbing water vapour in its crystal structure while at the same time releasing heat. If the adsorption process takes place in air-free and vacuum-tight vessels, then the adsorption of water

vapour proceeds very rapidly. Due to the heat of evaporation, the water in the evaporator cools down and freezes (s. Fig. 2). The ice produced in the evaporator can then be utilized for cooling and air conditioning purposes, while simultaneously heat is produced in the other compartment of the equipment, in the zeolite adsorber zone. If a valve is placed in between the two vessels (evaporator and adsorber) then the adsorption process can be interrupted for an arbitrary period of time without loss of energy. The process of adsorption continues until the zeolite is fully saturated with water.

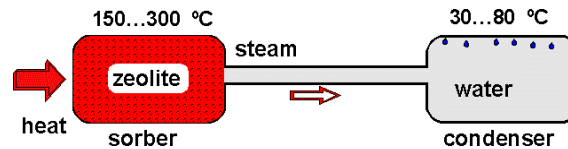


Figure 3: Desorption Phase

In a consecutive phase the zeolite can be regenerated (s. Fig. 3) by applying heat to the zeolite: the water is now desorbed in gaseous form from the zeolite. By removing heat in the evaporator vessel, the water is condensed and collected. If the valve between the two vessels is closed, the expended energy for charging is stored and can be retrieved after an arbitrary period of time. An almost continuous production of cooling power can be accomplished if two or more sorption devices are operated in a phase shifted manner. The desorption of water can be powered by electrical heaters or, in a more energy-efficient system, with heat produced in combustion systems or even solar collectors. If this system is applied in dual use mode for heating as well as cooling in parallel, the overall net effect as shown in Fig. 4 amounts to 160 % of the expended input heat (100 %), provided as heat (130 %) and cooling power (30 %).

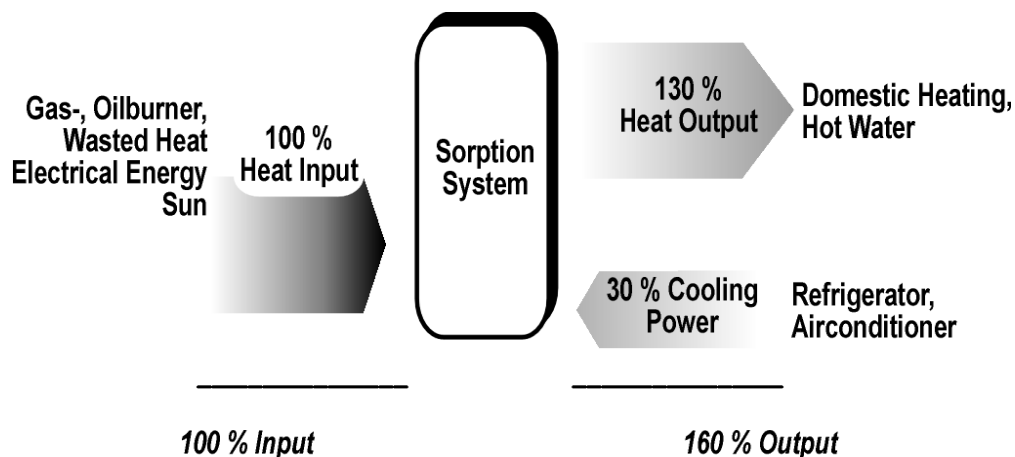


Figure 4: Energy Flow Diagram

Even with electrical heating, a sorption system provides considerable energy savings and a corresponding reduction of carbon dioxide production. With other input heat sources the energy saving potential is much higher with corresponding environmental benefits. Even the single use mode, utilizing only heating or only cooling power, is comparable or better (with respect to energy utilization) than any conventional technology. It is important to note that zeolite is very environmental friendly, it is non-toxic, non-hazardous, non-explosive and has no global warming and no ozone depletion potential. Further advantages of a zeolite system is the little need for maintenance (virtually no moving parts) and the unlimited lifetime of zeolite.

3. The Micro Climatization System (MiCS)

The challenge of the development of MiCS was the provision of conditioned air flow for the generation of a micro climate inside NBC protection suit e.g. the full HAILSS ensemble (helmet, respirator, suit). Due to external requirements, e.g. in an aircraft where no access to aircraft systems or modifications are allowed and different operational environments are existent, the need for a man mounted portable air conditioning system evolved. The anticipation is, that aircrews using the new system will benefit from its performance to lower the heat stress during their missions in hot environments. The performance of MiCS is independent of the attitude in which it operates and the inherent zeolite adsorption technology needs no moving parts compared to compressor technology.

System description

The MiCS performance requirements for the APACS Flight Model (FM) have been set up to:

- provide approx. 250 l/min of air at least 2 hours:
- cool ambient air of 35 °C (95°F) at relative humidity below 50 % by approx. 8 ± 1 °C for a minimum time period of 2 hours.
- total weight of the system < 6 kg

The main task of APACS FM is to provide heat stress protection. This will be realised with an aviator cooling in the HAILSS by blowing cooled air over all body surfaces including contact surfaces, thereby improving operational effectiveness and enhancing flight safety. A further very important point is that the APACS FM will not compromise on any of the protection functions of the HAILSS: This will be achieved by proper integration with HAILSS and by establishing its own APACS protection measures against environmental threats.

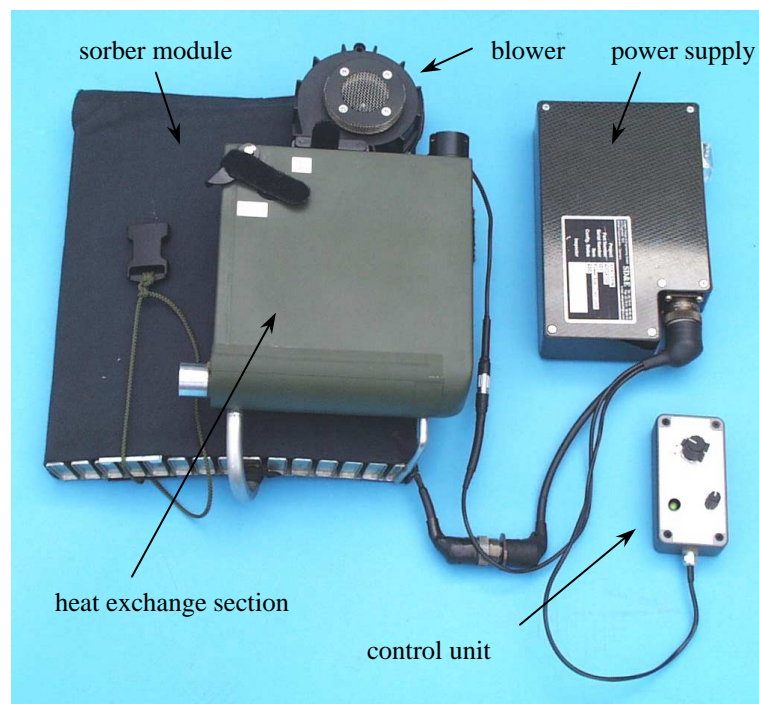


Figure 5: The APACS FM with Integrated Modules

The operation of APACS will be independent of the aircraft systems. This will be achieved by its own power supply and regenerative heat capacity technologies. The benefits are reducing the number of helicopter interfaces, eliminating the requirement for additional air on board and reducing the cockpit air conditioning requirement as well as eliminating additional purging air for CB-protection and saving electrical energy. Further important is that the maintenance and acquisition costs are reduced

and the use of the APACS outside the aircraft as well as in pre- / postflights, ground and in emergency conditions is possible without restrictions. Due to the requirements arising for flight testing, the design of the APACS FM had to consider a high degree of integration issues which has led to the configuration with modules as shown in Figure 5:

Conditioning Module

The design of this module as the core of the APACS FM unit (s. Fig. 5 and 6) consists of the heat exchange section with control valve and a solid housing which also provides the functions of air inlet for the heat exchange section and air distribution for suit, helmet and respirator. The sorber section together with a flexible case acts as sorber module for cooling (ventilation) and protection purposes.

The principle of the conditioning module is based on Zeolite technology as described above which allows the conditioning of air, i.e. for the APACS FM to provide cooling for a minimum of 250 l/min with a temperature drop of $\Delta T = 8 \pm 1$ K for approx. 2 hours.

The interconnected and evacuated heat exchange and sorber sections are made of stainless steel with a completely new exterior design and interior configuration. The exterior design as well as the interior configuration have been chosen in order to meet the customer's dimensional requirements and to optimise the access to the zeolite energy.

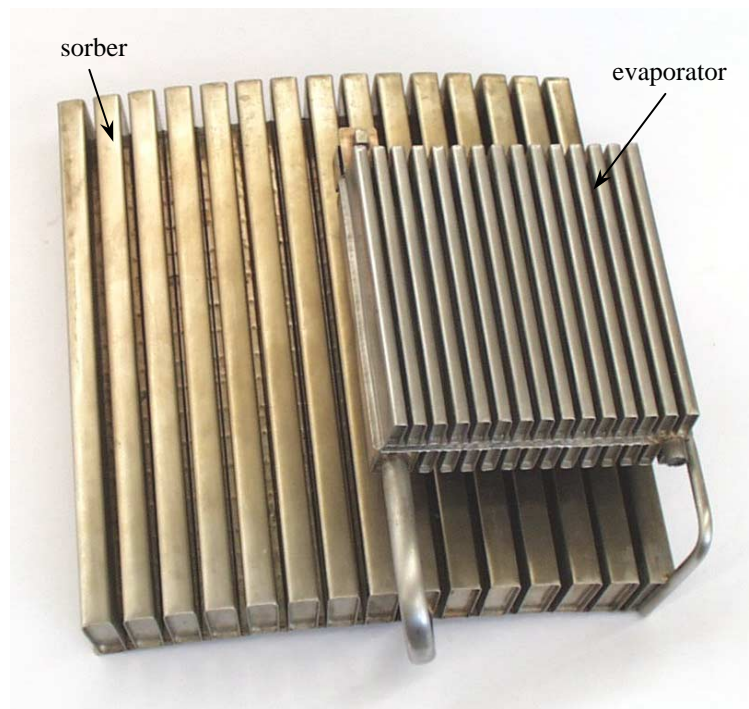


Figure 6. Conditioning Module with Heat Exchange and Sorber Section

Heat Exchange Section

The heat exchange section is the cold section of the conditioning module for cooling the external air flow while inside the section the water evaporation process occurs. It is designed with a structure in the longitudinal direction with integrated ribs which are filled with a water absorbing filling. The lower section incorporates a manual control valve. After joining both sections, the junction forms the vapour channel. After the control valve has been opened the channel allows the water vapor to be either transferred via the connecting tube to the sorber section (when adsorbing) or vice versa (when desorbing). A spring shuts off the conical control valve when the control lever is in the "CLOSED" position. The solid housing (s. Fig. 7) around the heat exchange section is made of a sandwich structure made of Carbon - Glass Fiber. It functions as a protection cover (housing) for the heat exchange section and reception provision for the manual control lever as well as air inlet with

attachment provision for the ventilation module. It further provides the air distribution with outlets for the suit and receptacles for the connectors to the helmet and the respirator.

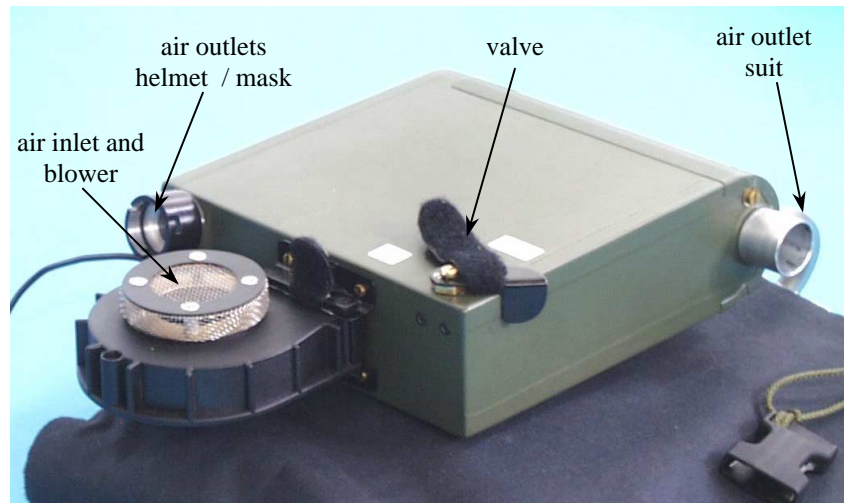


Figure:7: Heat Exchange Section with Housing

Heat Exchange Section with Housing

The air flow enters over the integrated air inlet module on top of the housing. The heat capacity of the inlet air will be exchanged along the distance via the ribs around the rectangular water tank. After the air has been cooled down, it leaves via the integrated air distribution to the outlets for the suit and respirator / helmet. When opening the two position control valve (off / on) the heat exchange section and the sorber section will be connected. This will activate the physical reaction of the zeolite (water vapour) and will cause the heat exchanger to cool down the surrounding air flow inside the housing. After passing the whole heat exchange section the cooled air will be ducted on the air distribution outlets.

Sorber Module

For the ventilation of the Sorber module a flexible case made of Nomex Delta T/A is used, and a provision for forming an air channel and reception of two ventilation blowers and a connector to the power supply module. The Power supply module is consisting of a case with e.g. a high power Lithium-Ion battery, a master power switch, an interface board with the ASIC for controlling the blower of the ventilation module.

Attachment to AIRSAVE Vest

The attachment of APACS FM to the AIRSAVE vest is conducted by means of attachment straps with snap fasteners which will be slid into the vest structure. The APACS FM itself will be positioned with the sorber section underneath the AIRSAVE vest while the heat exchange section will remain on the outside. The final arrangement is shown in Fig. 8.



Figure 8: APACS FM Arrangement on AIRSAVE Vest

Regeneration Unit

A very important requirement for the APACS FM is that the system is reusable with a lifetime of at least 10 years. As pointed out above, zeolite can be periodically regenerated with a virtually unlimited lifetime as long as the applied temperature and pressure do not exceed certain limits. For the APACS FM a regeneration unit has been specially designed. The regeneration unit is not an integral part of the APACS but an independent device for desorption (regeneration) of the conditioning module. The unit consists of the ventilation tunnel which is designed to house the sorber section of the conditioning module and also to distribute the hot air provided by the heat gun and to desorb (regenerate) the zeolite. The heat gun is operated electrically (AC 110V/220V). The regeneration process will take about 2.5 hours at a temperature of 350° C (662° F) for complete regeneration (drying) of the zeolite.

4. Performance of the APACS FM

A typical experiment with the APACS FM is shown in Fig. 9. After starting the ventilation and cooling at $t = 0$ of the system integrated in a GKSS at $t = 10$ min a constant temperature drop of approx. 10 K between the ambient air and the air ventilated to the helmet (head) and body (suit) is established for about 160 min. The mean cooling power of the system during this time period can be calculated from the data shown in the viewgraph:

$$P_{\text{cooling}} = Q (t= 170 \text{ min})/\Delta t = 500 \text{ kJ}/160 \text{ min} = 52 \text{ W}$$

For safety considerations it is important to note that even after 200 minutes running time of the system a temperature difference between the ambient and inside the suit/helmet of 8 K is perpetuated. This significant additional cooling energy can be used, e. g. in a case of emergency, where the running time of the APACS FM has to be significantly extended.

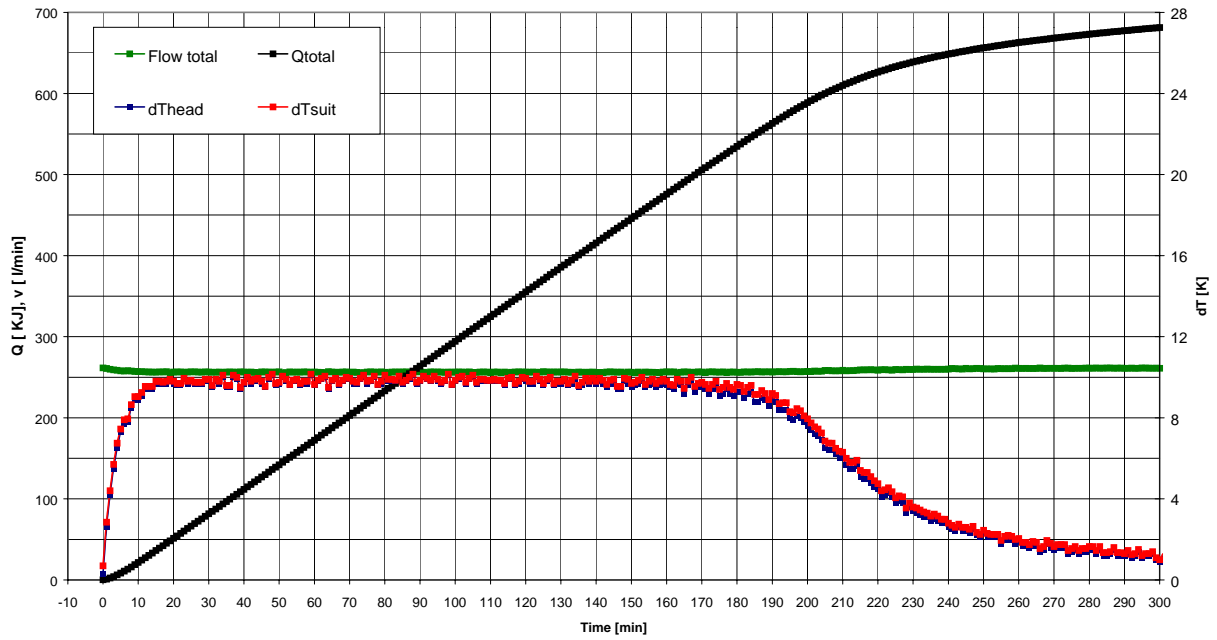


Figure 9: Typical measurement with the APACS FM. Ventilation and cooling of a GKSS at a total flow rate of ca. 250 l/min and an ambient temperature of 35 °C (95 °F) and 40% r. h.

Personnel located in hot climates often suffer severe cognitive and/or physical performance degradation or injury while performing military tasks due to extended exposure to very high environmental temperatures. The application of man-mounted cooling units as the APACS FM, will extend individual tolerance to environmental conditions without affecting task performance. To test the full cooling capacity installed in the APACS FM the internal vapour valve had been set to a full open position. Figure 10 shows the simulation of a so-called “helicopter start” in a clime chamber at high ambient temperature of 55 °C (131 °F) and relative humidity well below 30 %, e. g. typical for special desert missions. The air flow rate through the APACS FM was adjusted to (280 – 290) l/min.

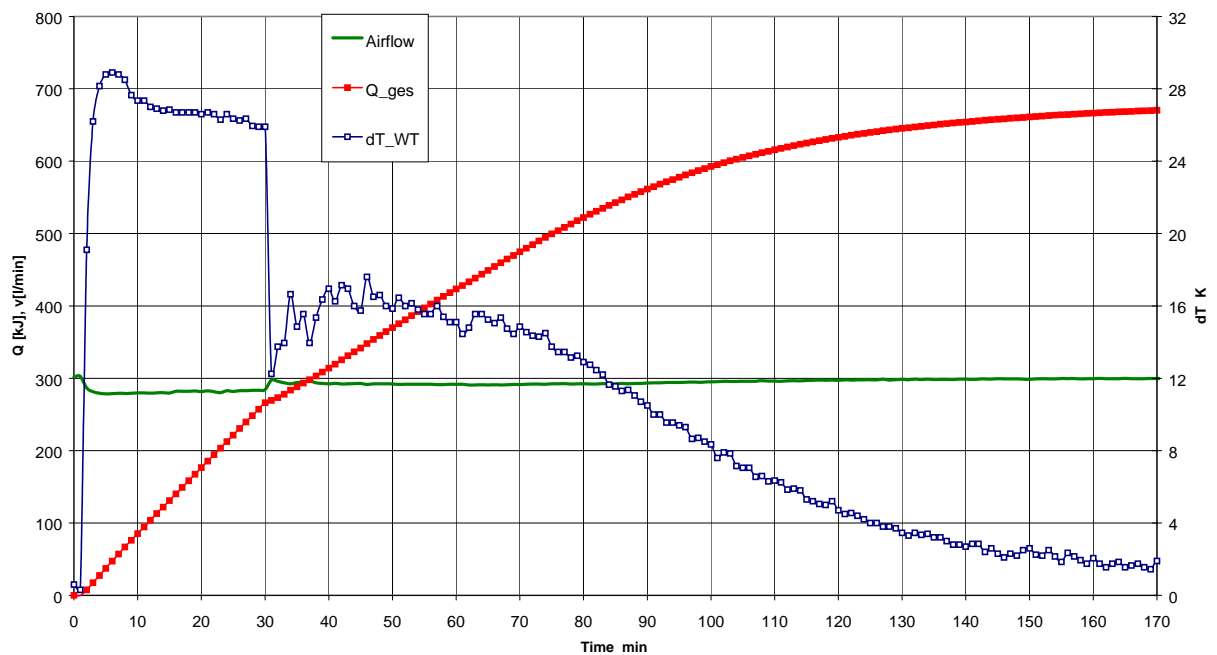


Figure 10: Clime chamber simulation of a “helicopter take-off”-procedure and pilots using the APACS FM in connection with a GKSS..

The procedure was: From $t = 0$ to 30 min there were high ambient temperature conditions of 55 °C (helicopter waiting for take-off). Afterwards the helicopter takes off and the ambient temperature drops to 35 °C.

It is important to note that during the stand-by period at high ambient temperature of 55°C the APACS FM generated a temperature difference between suit/helmet and ambient of $\Delta T = (26 - 28)$ K with a corresponding cooling power of about 160 W! The explanation for this behaviour of the APACS FM is the higher pressure inside the evaporator at a higher ambient temperature. The water vapour flow to the adsorber unit is enhanced compared to the lower temperature situation. Therefore the cooling power of the system is higher at higher ambient temperatures.

Operating an APACS FM, the user benefits from a temperature of approx. 28 °C (82 °F) inside the suit and helmet even at these high ambient temperature. After take off the cooling power of the APACS FM falls down to about 87 W without further manual adjustment. The resulting temperature inside the helmet and suit is approx. 21 °C (70 °F).

In cases where the ambient temperature is well below 35 °C (95 °F), the resulting temperature difference between inside the suit/helmet and the ambient diminish and the resulting overall mission time increases respectively.

5. Outlook

In future advanced versions of the APACS FM, a manually adjustable cooling power of the system will be realised in order to enhance the complacency of the operators especially under variable ambient conditions and in situations of changing physical/psychological and/or thermal stress. A further main task will be the development of well-suited set-ups of the MiCS for special applications, where besides ventilation and cooling also heating of the ventilated air and/or dehumidification are system options. The advanced MiCS will have special inlet and outlet connecting elements which can readily be attached to, detached from and exchanged for one another on the gas flow channels for supplying and discharging gas streams that are to be heated or cooled. The MiCS of the future will also have a significant lower total mass with the usage of thinner metal sheets for both the evaporator and the adsorber unit.

Future application fields for the innovative MiCS are in the civil domain, e. g.:

- gas-tight chemical protection suits for chemical spillage fighters
- racing suits
- dry diving suits
- closed-circuit breathing devices
- heat protection suits for fire fighters
- special emergency equipment (casualty litter bags)

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