Title :

Membrane Gas-Water Separation:

MEMBRANE CONDENSING HEAT EXCHANGER (MCHX) TECHNOLOGY DEMONSTRATOR

Abstract Report

ESTEC Contract No. 12333/97/NL/GD
Work Order No. 02

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EUROPEAN SPACE AGENCY
CONTRACT REPORT

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1. OVERVIEW

Manned missions into space require systems for Environmental Control and Life Support (ECLS). The major tasks of these systems are the control of the habitable volume atmosphere in which the astronauts shall feel themselves comfortable. Essential functions are to control cabin temperature and humidity. For these functions a Membrane-based Condensing Heat Exchanger (MCHX) Technology Demonstrator was developed and performance tested.

The MCHX comprises a membrane unit which shall remove heat and simultaneously water vapour from the atmosphere. The membrane heat exchanger technique promises a potential alternative for the conventional heat exchanger technique with its noisy and power-consuming rotary water separator.

Funded by ESAs general support and technology programme the development started in 1994 with a study phase and laboratory scaled modules. After the breadboarding phase initiated from 1995 to 1996, the unit was now scaled-up and further developed to the level of a technology demonstrator. The performance requirements for the MCHX are linked to those of the Columbus laboratory, the European contribution to the International Space Station.

The follow-on development performed comprises the review of achievements during the breadboarding phase, development and analysis work towards the technology demonstrator status, the design of the unit taking into account the recommendations from the previous phase and its manufacturing. The MCHX was performance tested in laboratory and also tested in a closed ventilation loop using Columbus ventilation mock-up in the frame of the pilot project ‘Closed Chamber Testing’. The MCHX successfully demonstrated the capability to remove the heat loads as defined and will occur in manned spacecraft cabins, e.g. in Columbus laboratory. The humidity removal capability predicted could not completely be confirmed by the tests and needs to be improved. The results obtained represent a sound basis for future follow-on development.

2. MEMBRANE-BASED CONDENSING HEAT EXCHANGER (MCHX)

The development history of the Membrane Condensing Heat Exchanger is shown in Fig. 2.1.

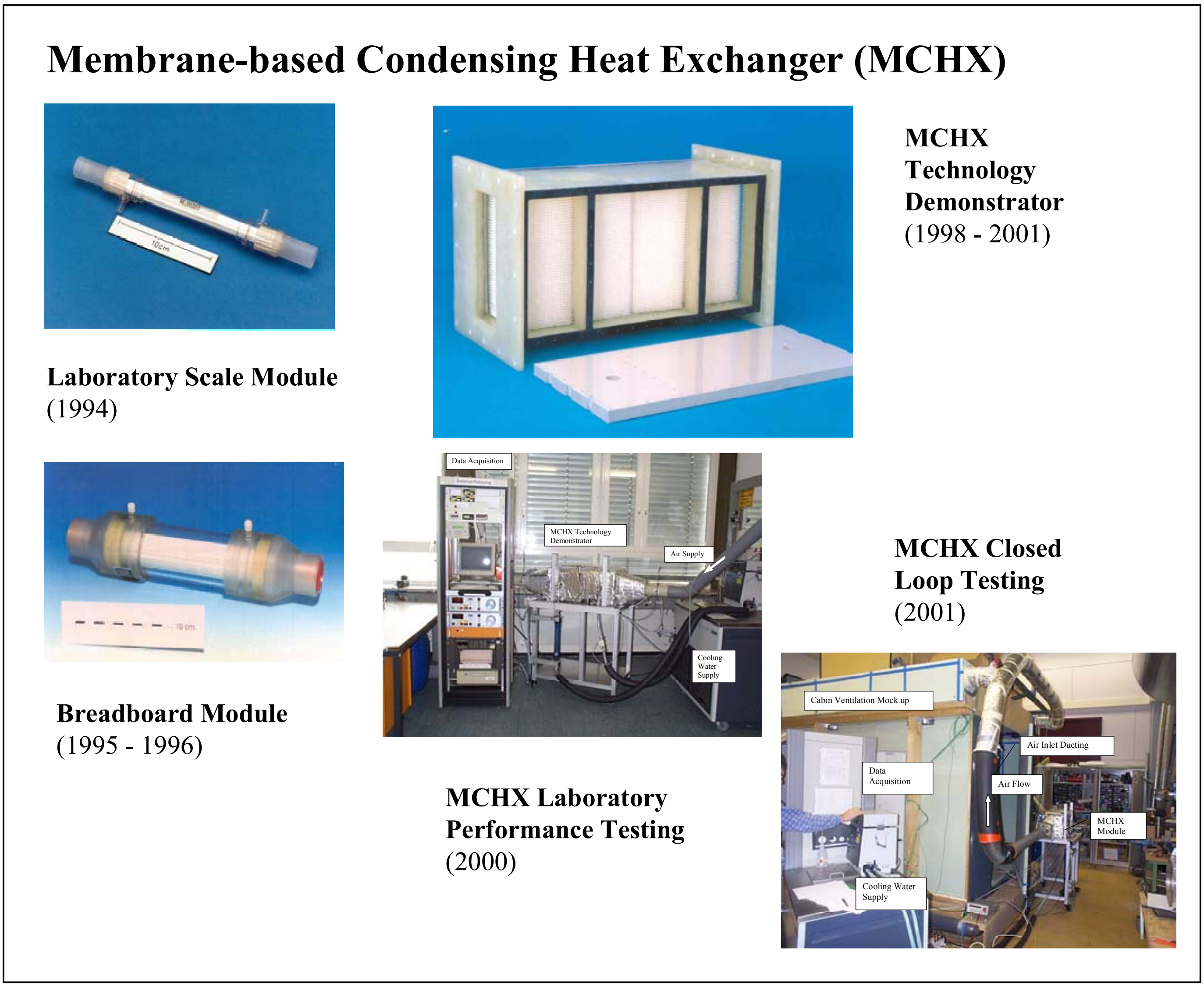

Figure 2.1: Development History of the MCHX

The MCHX Technology Demonstrator consists of a cross-counter flow type heat exchanger unit. The membranes used are microporous hydrophobic hollow fibres which are glued in an epoxy resin housing. The cooling water flow is inside the fibres. The air to be cooled and dehumidified flows around the fibres. The manufactured MCHX is shown in Figure 2.3.

The operational concept for cooling and dehumidification of the air stream in the MCHX is illustrated with Figure 2.2. The microporous membrane hollow fibres allow the diffusion of

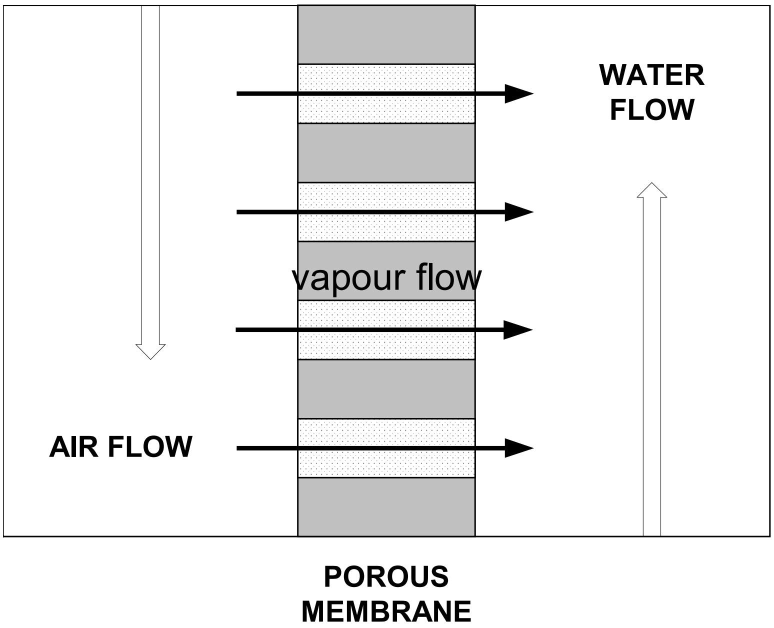

Figure 2.2: MCHX Operational Concept

water vapour from the air stream to the cooling water through the pores due to water vapour partial pressure difference. Because of the hydrophobic character of the membrane cooling water will not pass the pores. The two phases keep separated. A rotary power-consuming and noisy condensate separator will not be necessary.

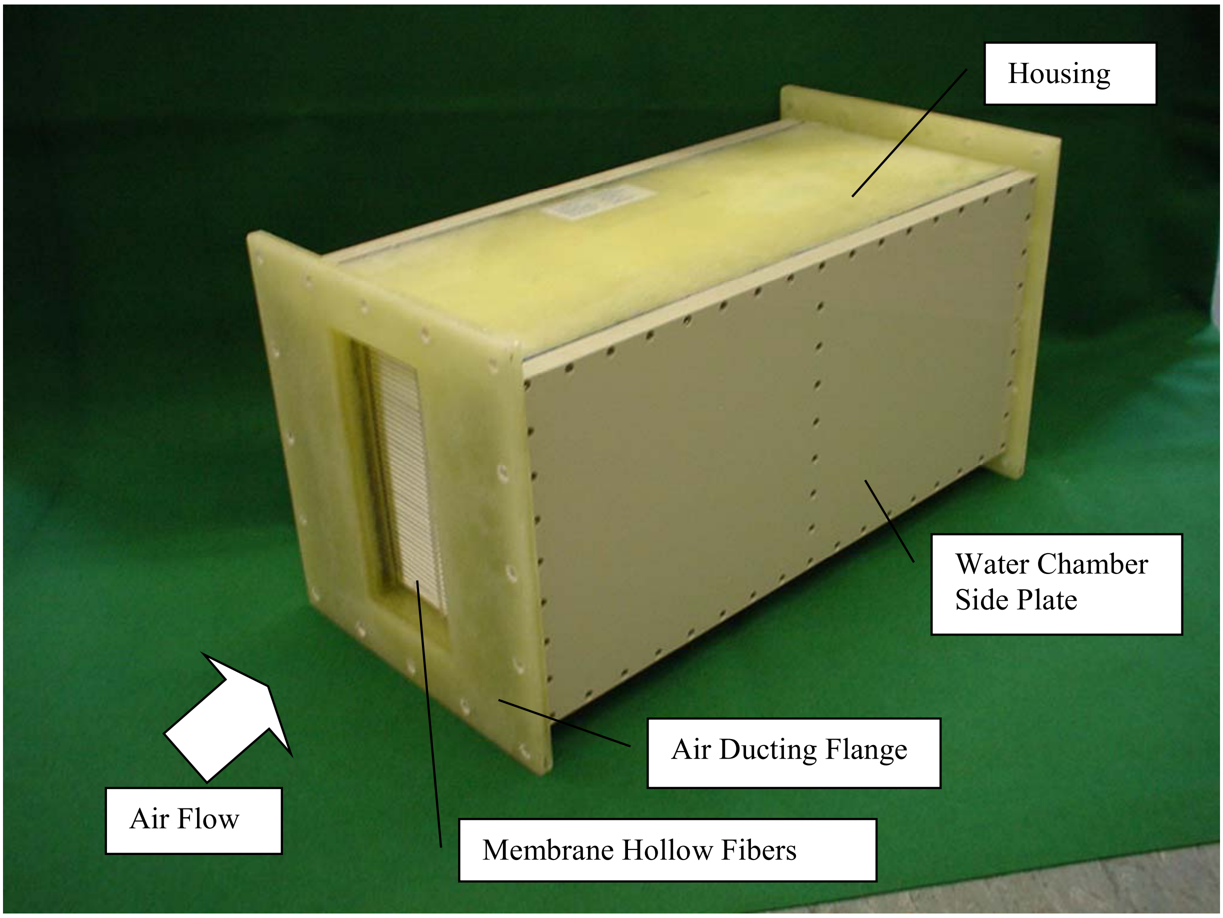

Figure 2.3: MCHX Technology Demonstrator Module

MCHX Design

The MCHX design was based on requirements linked to those applicable for the ECLSS of Columbus-laboratory. The MCHX module main data are summarised in Table 2.4.

Dimensions (l*w*h):	57*31*34 cm
Envelope Volume:	64.5 dm³
Mass:	19.6 kg
Membrane Fibre Type:	Accurel® Polypropylene Membrane S6/2, hydrophobic
Number of Fibres:	5000
Membrane Area:	5.1 m²
Air Flow Rate:	480 m³/h
Air Temperature:	18 – 33 °C
Air Humidity:	25 – 70 %.
Max. Dew Point Temperature:	15.5 °C
Cooling Water Flow Rate:	220 – 600 kg/h
Cooling Water Temperature	4 – 6 °C

Table 2.4: MCHX Design / Operational Features

For the MCHX design the recommendations from the previous phase have been taken into account. The MCHX design was supported by pre-development and analysis work including numerical performance prediction. A safety analysis in a simplified form was conducted for the MCHX in view of the design of a future flight unit. No show stoppers from safety point of view are present. Various recommendations for the flight assembly design as a result from safety assessment are given.

Test Campaign

The main objectives of the MCHX testing were to

- Explore the performance of the newly designed and built-up MCHX module.
- Examine the achieved performance of the MCHX in view of the application in a manned space compartment (linked to Columbus project).
- Identify performance limitations, highlight discrepancies and outline areas where future improvement work is necessary.

Performance and Results

The developed MCHX Technology Demonstrator was tested at different heat loads, ventilation air flow rates and conditions as well as different cooling water flow rates. The MCHX shows good performance regarding air cooling capability. The heat loads as may occur in a spacecraft habitable volume can be removed and transferred to the cooling water loop. Table 2.5 shows the measurement results for nominal operating modes as defined for Columbus-ECLSS. The water vapour removal capability of the unit is limited. For a crew of

air flow rate	kg/h	421.0	419.1	437.9	421.6	438.8
air temperature, inlet	°C	18.04	22.71	25.80	32.00	31.90
air inlet dew point temp.	°C	8.55	8.59	9.53	8.71	8.69
air relative humidity	%	54.2	41.0	36.1	24.0	24.1
air temperature, outlet	°C	7.12	7.50	9.09	8.60	8.90
water flow rate	l/min	8.04	8.04	8.04	8.12	8.91
water temperature, inlet	°C	5.88	6.00	7.33	6.50	6.63
water temperature outlet	°C	8.20	9.00	10.90	11.02	11.29
sensible heat transferred	W	1285.4	1852.4	2047.0	2752.2	2823.1
water vapour removed	g/h	128.9	84.8	28.0	*-27.6*	*-46.0*
latent heat transferred	W	88.0	57.6	20.3	*-18.6*	*-31.0*

Table 2.5: MCHX Performance

three persons a water vapour removal of approx. 220 g/h corresponding to 155 W as specified for Columbus-ECLSS will be required. This was not achieved with the developed unit. Improvement of the water vapour transfer is necessary for follow-on development. Negative figures in the table indicate, that the membrane unit will be able to operate as a humidifying unit when the cabin air will be dry (cabin conditions below comfort range of 25% relative humidity).

Testing of the MCHX in the closed ventilation loop of Columbus cabin mock-up also showed that the assembly completely meet the heat transfer capability required. Figure 2.6 depicts the temperatures measured inside the cabin. The cabin temperature can be controlled and maintained inside the comfort range for the astronauts between 18°C and 27°C. Even at high heat loads the chamber temperature did not exceed this range.

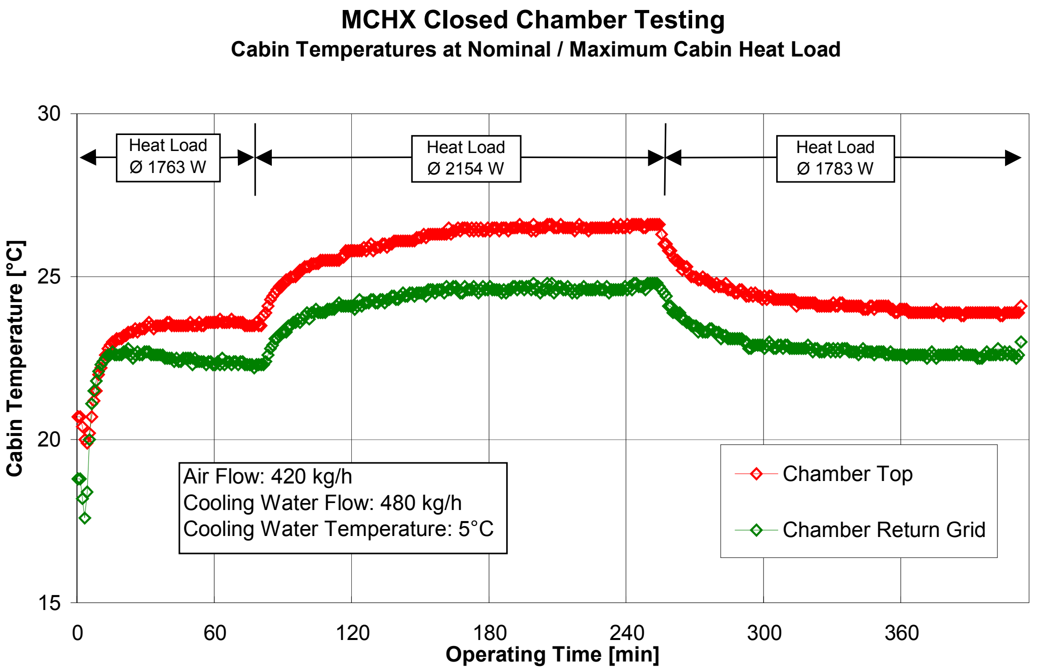

Figure 2.6: Cabin Temperatures during MCHX Closed-Loop Testing

The testing also showed, that further improvement of the design regarding low air pressure drop will be appropriate to save power required to operate the cabin ventilation fan of a habitable spacecraft. Compared to the conventional condensing heat exchanger unit of a spacecraft the measured pressure drop across the MCHX Technology Demonstrator is higher. This was also caused by some vibrations and audible noise production which can be avoided by a more rigid future design providing more stiffness to the system. However, with a MCHX system the power-consuming rotary water separation equipment of the conventional systems are not necessary.

3. PROGRAMMATIC

The work reported has been performed in the frame of Work Order No. 2 to ESTEC/Contract No. 12333/97/NL/GD – Membrane Gas Water Separation – from 11/1997 to 06/2002.

The work was performed by the department 'Environmental Control and Life Support' of Astrium, Space Infrastructure Division, Friedrichshafen (Germany).

Subcontractor in the project was institute with field of activity 'Apparatus Construction' of Technical University Hamburg-Harburg (Germany).

4. SUMMARY

A Membrane-Based Condensing Heat Exchanger (MCHX) Technology Demonstrator was designed, manufactured and tested. It removes heat load and humidity from a ventilation air flow of a habitable space compartment as required. Cabin temperatures can be maintained within nominal comfort ranges of 18°C to 27°C. The requirements have been linked to those for the Environmental Control and Life Support System of Columbus-laboratory, the European contribution to the International Space Station.

The testing of the newly developed unit was performed at different air flow rates, air temperatures, humidity conditions and cooling water flow rates. The testing confirmed the possible application of the MCHX in a ventilation system of a manned spacecraft volume. The heat removal requirements are successfully met. The dehumidifying capability of the developed unit was found to be limited and will have to be improved during future follow-on development phases.