An Energy Efficient and Lightweight On-Board Cooling System using CO2

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### Abstract

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Oral session 4 Fuel Cells for More Electric Aircraft (Xavier Roboam, Frank Thielecke)

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An Energy Efficient and Lightweight On-Board Cooling System using CO2 Johannes Chodura (1), Frank Thielecke (2) 1 : Hamburg University of Technology – Institute of Aircraft Systems Engineering, Nesspriel 5, 21129 Hamburg, johannes.chodura@tuhh.de 2 : Hamburg University of Technology – Institute of Aircraft Systems Engineering, frank.thielecke@tuhh.de Abstract On-Board galley cooling systems have been continuously modified and improved to meet the increasing requirements of modern aircraft. Initially only dry ice or air chilling systems have been used, whereas fluid based cooling systems are in focus nowadays. By now they are highly integrated systems covering further cooling tasks and using compact pipings and centralized vapor cycle machines. Investigations have shown potentials of improving those systems by use of the two-phase coolant carbon dioxide (CO2 / R744). By evaporating the CO2 within the consumers, fluid mass, mass flow rate and thereby power consumption can be clearly reduced. Main topic of this publication will be the description of an optimized, indirect R134a/CO2 cooling system and a representative test-rig, which has been built, respecting dimensions, geometry and performance of a commercial long range aircraft on-board cooling system. Main benefits and experimental results concerning energy consumption will be presented. Introduction Modern commercial aircraft are using different cooling systems, dedicated to several tasks. The cabin air conditioning system (reversed Brayton cycle [1]) is the main system, ensuring sufficient cabin pressure even at cruise level and comfortable temperatures in all situations during operation. Besides the cabin air temperature, especially in long-range commercial airplanes, there is the demand for another, lower temperature-level. It is needed for cooling of food and beverages on long-distance flights. On board of the aircraft, food is mostly stored within trolleys, which are stored inside trolley compartments in the galleys. In modern aircraft galley cooling mostly is realized by use of vapor-compression refrigeration, whereas time tested dry-ice is of secondary interest because of its limited cooling capacity during long lasting flights. Vapor-cycle machines are integrated within so called Air Chiller Systems, Remote Chiller Systems or the state-of-the-art Supplemental Cooling System [1]. Their main task is to provide cold air with respect to applicable standards. Increasing needs for cooling capacity and flexibility to place the galley monuments within the fuselage led to fluid based cooling systems like Remote Chiller and Supplemental Cooling System. Those systems use (centralized) refrigeration units and transport the cold via fluid pipings to the consumers within the galleys using Galden or Propylene-Glycol-Water. Air Chiller Systems directly produce cold air but they have disadvantages because of their bulky piping to lead the chilled air. To avoid those disadvantages fluid based systems have been introduced [2]. Investigations have shown further potentials to reduce system weight and increase energy efficiency. Therefore the liquid coolant could be replaced by the natural refrigerant CO2. Carbon dioxide is an eco-friendly, cheap and easily accessible fluid. By evaporating the CO2 within the consumers and up the enthalpy of evaporation one can significantly reduce fluid weight, the needed mass flow rates and thereby power consumption of the needed fluid pumps. In addition high volumetric refrigeration capacity allow minimizing component dimensions, excellent heat transfer and pressure loss characteristics allow further improvements in terms of system mass and energy consumption. High system pressure especially during stand is one major disadvantage that attends the use of CO2 [2]. Extensive experiences during operation of CO2-Systems are made in stationary, commercial plants for example in supermarkets [3]. Concept of a Cooling System Design and Operation of refrigeration machines or indirect, two phase cooling systems require consideration of several parameters and criteria which are not important during operation of pure liquid cooling systems. The following section contains the description and discussion of key attributes as well as the description of the designed cooling system. While the central refrigeration machine (primary cycle) is set up in the style of a conventional R134a vapor-compression refrigeration machine within a commercial airplane, the liquid coolant inside the cold distribution cycle (secondary cycle) will be replaced by the natural refrigerant CO2. This leads to a significant reduction in fluid weight [2]. The primary cycle with its electronic expansion valve also uses an inner heat exchanger to enhance performance by subcooling and superheating respectively without lowering compressor suction pressure. Because of the ambient conditions during typical aircraft operation and to ensure comparability R134a is still used as refrigerant. Phase changing CO2 is used to operate the secondary cycle. Main elements needed for such a system are described in what follows (see Fig. 1 and Fig. 2). Liquid CO2 is pumped by a centralized pump through a piping network. It is completely or partially vaporized in the evaporators by accommodating a heat flow from the air, circulated inside the trolley compartments. Distribution of liquid is done by controllable valves which are placed upstream the evaporators. The two-phase or gaseous CO2 is led via pipings to the central part of the system. Condensation of vaporized CO2 is done in the condenser, which is supplied by the primary cycle. The collector is placed downstream the condenser. Its function is to separate liquid and gaseous phase, which is essential for correct system operation due to operation nearby state of boiling. The subcooler is needed to prevent cavitation inside the pump and its
associated risk of damage. Proper subcooling is one of the main difficulties within the presented system because limited installation space forbids geodetic feed of the pump. In addition a subsystem for limiting high pressure during stand to the central part of the secondary cycle instead of the entire piping network has been implemented. Fig. 1: ph-Diagram of CO2-secondary cycle Fig. 2: system chart of CO2-secondary cycle Testrig An R134a/CO2-Testrig has been built to account for proof of concept. It has been built respecting dimensions, geometry and performance of a commercial long range aircraft on-board cooling system. Therefore compact, industrial standard components have been used. Pumping of liquid CO2 is carried out by an electrically driven gear- pump. To consider possible system geometry within a long- range commercial aircraft, the testrig has been built over the height of two floors respective four meters. The refrigeration unit and the central part of the secondary cycle are placed at the bottom whereas the piping network and the consumers are located on top. The total testrig is controllable via a dSpace Real-Time measurement system, which is also designated for data acquisition. Experimental Analyses Proof of concept could be adduced by use of the testrig. Normal operation was focused, while operation during extreme or failure conditions was performed within the possibilities inside the testing site. Measurements have shown a distinct reduction in energy consumption, which is possible by the use of CO2 and an appropriate pump. Reduction of pressure losses via the piping network and improving thermodynamic behavior contribute to the positive overall balance of the coolant replacement. Detailed results will be presented and comparisons will be drawn with a conventional liquid-based cooling system. Summary In this publication the conception of an indirect cooling system, using CO2 as secondary working fluid, was presented. Main benefits compared with a state of the art liquid cooling system, in terms of fluid- and system-mass as well as energy efficiency are highlighted. The most important thing for system mass reduction is the use of enthalpy of evaporation and thereby a reduction of fluid mass. Needed mass flow rates are lowered as well which leads to a significant reduction of power consumption. Experimental results marking energy consumption and efficiency are presented and potentials for further improvement are worked out. References 1 MÜHLTHALER, G.; COLBERG, C.: Cooling on board of aircraft: from dry ice to thermal management. In: Proceedings of the 2nd International Workshop on Aircraft System Technologies, Hamburg, 2009 2 ADEYEFA, S. u.a.: COP-optimised pressure control for a centralised CO2 cooling system in aircraft applications. In: Proceedings of the 7 th IIR Gustav Lorentzen Conference on Natural Working Fluids, Trondheim, Norway, 2006 3 SAWALHA, S.: Carbon Dioxide in Supermarket Refrigeration, Stockholm, Schweden, Royal Institute of Technology, Diss., 2008