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(54) Title: IMPROVED FUEL-CELL HEAT MANAGEMENT

(57) Abstract: A fuel cell heat management system with a fuel cell and a compressor is presented. The heat management system comprises a bi-directional heat exchanger configured to either transfer heat from the incoming air to the exhaust air or transfer heat from the exhaust air to the incoming air.

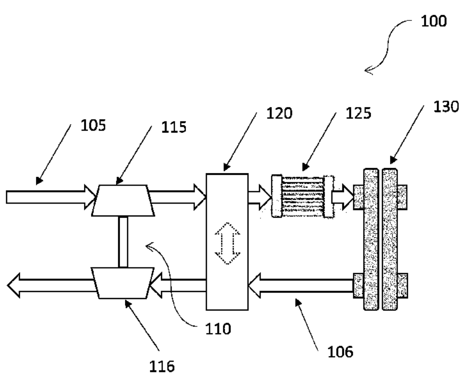

Fig. 1

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[Continued on next page]

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Description

Improved Fuel-Cell Heat Management

The instant disclosure relates to Heat Management systems, especially for fuel cells. It may be advantageous to transfer heat between incoming and outgoing air to and from the fuel cell in order to increase efficiency of the fuel cell system.

Background

Automotive vehicle manufacturers (OEM's) and Tier-1 suppliers to the automotive industry are increasingly looking to fuel cells as it power supply featuring clean and energy-efficient power. Fuel cells may also find application in a variety of use cases such as motor vehicles, both private and commercial, forklifts, airplanes, and other mobile use cases.

One consideration with mobile use cases, is that there are often variations in load. Due to this, a power supply such as a fuel-cell must maintain efficiency despite varying load. In addition, the operating conditions for and operating temperature of a fuel-cell may vary between startup conditions, where a fuel-cell does not have or has not yet reached its normal operating temperature, and continuous operation conditions, where the fuel-cell temperature typically is maintained at an optimal value.

Another consideration with a mobile use case is the penalty associated with a heavy and complex system, which system must be moved around as part of the mobile use. A fuel cell system may be subject to shock and vibration, and energy is needed to move the mass of the system. Therefore, it may be of interest to have a system which is as light as possible, and also which simple as possible.

At the start of use of a fuel-cell, the fuel-cell is often cool, and does not achieve optimal effectiveness in generation of electricity because of a cooler temperature. Therefore, it is desirable to warm up the fuel-cell as quickly as possible to an optimal temperature while still maintaining a reasonable use of energy, especially if electrical heating must be used.

In one aspect of the inventive concept, heat which is available in the exhaust air leaving the fuel-cell is reused or recycled to provide heat to the incoming air, and in this way to provide warmth to the fuel-cell with moderate energy consumption.

In another aspect of the inventive concept, the incoming air is compressed in order to increase the power generation capability, and heat which accumulates in the incoming air after compression is transferred to the exhaust air. The higher temperature of the exhaust air may make possible an increase in the efficiency of the power generation capability of the turbine, which in turn increases the efficiency of the compressor system.

Brief description of the Figures

The invention is best understood with reference to the figures, as described below.

Figure 1 shows an overview of the inventive system.

Figure 2 shows a comparison of the incoming air temperature before and after the heat exchanger.

Figure 3 shows a comparison of the exhaust air temperature before and after the heat exchanger.

Detailed Description

The detailed description set forth herein is meant to give the person of skill an understanding of certain implementations of the instant invention.

Figure 1 shows an overview of the different elements of a fuel-cell system 100 including an embodiment of the inventive concept. Fresh incoming air 105 enters to the compressor 115 which is part of a turbocharger 110. In other embodiments the compressor might be electrically driven or driven by a combination of a turbocharger and an electric compressor. In this embodiment the turbocharger is driven by an exhaust turbine 116. The compressed air from the compressor passes to the heat exchanger 120. This heat exchanger is a bidirectional heat exchanger.

The compressed air passes from the heat exchanger through an optional further heat exchanger 125 to the fuel-cell 130. In the fuel-cell incoming air may provide oxygen, for example, to react with a fuel such as hydrogen to generate electrical energy.

Exhaust air from the fuel-cell passes to the bidirectional heat exchanger 120, and then in this embodiment continues to drive the turbine 116 of the turbocharger before exiting the system.

The bidirectional heat exchanger 120 can be operated in one of two directions: it can transfer heat from incoming air 105 to exhaust air 106, or it can transfer heat from exhaust air to incoming air. The direction in which the heat is transferred depends on the requirements of the system in a particular operating mode. For example, if the system is used in a vehicle, and the vehicle has just been started, then the fuel-cell may be at room temperature, for example, or an outside temperature. However, the fuel-cell may operate best at a temperature of around 80°C or 350° Kelvin. Therefore, it may be desirable to take heat from exhaust air and transfer it to incoming air in order to warm the air to the optimal operating temperature of the fuel-cell.

Likewise, the action of the compressor may raise the temperature of incoming air, in which case it may be desirable to take heat out of the incoming air. This kind of operation in conjunction with a turbocharger is often referred to as an intercooler. The heat which is taken out of the incoming air can be transferred to the exhaust air, in order to thus remove it from the system.

Thus the fuel cell heat management system benefits from a bi-directional heat exchanger configured to transfer heat from the exhaust air to the incoming air when the fuel cell is operating well below maximum power generation. Likewise the heat exchanger may be configured to transfer heat from the incoming air to the exhaust air when the fuel cell is operating at or close to maximum power generation. To do this, the heat exchanger may transfer heat from incoming air at a cooler temperature to exhaust air at a higher temperature. Likewise, the heat exchanger may transfer heat from exhaust air at a cooler temperature to incoming air at a higher temperature.

Other systems may use water-based cooling systems or other transfer agents such as a gas in order to remove or transfer heat. Heat exchanger 125 represents such an optional heat exchanger which may or may not be part of an inventive system.

The disadvantage of water-based cooling systems and other systems which use a liquid or a gas to transfer heat, is that they add additional complexity and/or weight.

Heat added to the incoming air by the action of the compressor 115 may be most problematic when the fuel-cell is operating at maximum capacity or at a substantial part of maximal capacity, for example at more than 90% or more than 80% or more than 70% of maximum capacity. In this case the efficiency of the fuel-cell can be increased by decreasing the temperature of the incoming air before it reaches the fuel-cell. It may be desirable that the incoming air be at the same temperature as the optimal operating temperature of the fuel-cell. In this case, the bidirectional heat exchanger 120 can be used to transfer heat from the incoming air after the compressor to the exhaust air. This transfer to the exhaust air may occur before the exhaust air gets to the turbine of the turbocharger.

The transfer of heat from the incoming air to the exhaust air may occur from a higher-temperature incoming air to a lower-temperature exhaust air. In other embodiments, the system may be arranged such that heat is transferred to incoming air at a lower temperature from exhaust air at a higher temperature.

When the fuel-cell is operating at low or no-load conditions, well below maximum power generation capacity, for example at 10% or at 20% or at 30% of maximum capacity, then the efficiency of the fuel-cell may be improved by increasing the temperature of the incoming air. This can be accomplished, by transferring heat from the exhaust air to the incoming air using the bidirectional heat exchanger 120. It may also be advantageous to heat the incoming air when the fuel cell is below its optimum operating temperature. This may be the case, for example, when starting a vehicle after the fuel cell has cooled off to a lower temperature.

As with the transfer of heat from incoming to exhaust air, the transfer of heat from exhaust air to incoming air may occur from a higher temperature exhaust air to a lower temperature incoming air, or the system may be arranged such that the heat is transferred from higher temperature incoming air to lower temperature exhaust air.

Figure 2 shows the temperature of incoming air before and after the compressor as 200. On the vertical axis 210 is shown the temperature in Kelvin of the air and on the horizontal axis 220 is shown the power generation of a particular embodiment of a fuel-cell in the inventive system. In this particular embodiment the power generation varies from zero to 90 kW, which represents the variation between a no-load condition and a maximum capacity condition. At no and those load conditions the air before the heat exchanger 221 is at a higher temperature than the air after the heat exchanger 222, while at higher load conditions the air from the compressor to the heat exchanger is at a higher temperature than the air exiting the heat exchanger. In this way, at high load conditions the air from the compressor to the fuel-cell will be at a temperature closer to the optimum operating temperature.

In Figure 3 is shown the temperature of the exhaust air before and after the heat exchanger as 300. On the vertical axis 310 is shown the temperature in Kelvin of the air and on the horizontal axis 320 is shown the power generation of a particular embodiment of a fuel-cell in the inventive system. In this particular embodiment the power generation varies from zero to 90 kW, which represents the variation between a no-load condition and a maximum capacity condition. The air before the heat exchanger 321 is at a constant temperature corresponding to the optimum operating temperature of the fuel-cell, which temperature is maintained in order to have optimal operating efficiency of the fuel-cell. The exhaust air after the heat exchanger 322 has a varying temperature, which results from heat being exchanged with the incoming air. At no or low-load conditions, the air exiting the heat exchanger is cooler, because heat has been transferred to incoming air. At higher load conditions, the air exiting the heat exchanger is at a higher temperature, because heat has been transferred from incoming air to exhaust air.

Claims

1. A fuel cell heat management system comprising
   a fuel cell, and
   a compressor,
   characterized in that
   the system comprises a bi-directional heat exchanger configured to either transfer heat from the incoming air to the exhaust air or transfer heat from the exhaust air to the incoming air, wherein the heat exchanger is configured to transfer heat from the exhaust air to the incoming air when the fuel cell is operating well below maximum power generation.

2. The system of claim 1 or 2 wherein the heat exchanger is configured to transfer heat from the incoming air to the exhaust air when the fuel cell is operating at or close to maximum power generation.

3. The system of any previous claim in which the heat exchanger transfers heat from incoming air at a cooler temperature to exhaust air at a higher temperature.

4. The system of any previous claim in which the heat exchanger transfers heat to incoming air at a higher temperature from exhaust air at a lower temperature.

5. The system of any previous claim wherein the heat exchanger receives incoming air via a compressor.

6. The system of any previous claim wherein the compressor is driven by a turbine which receives exhaust air from the heat exchanger.

7. The system of any previous claim wherein the incoming air passes through an additional heat exchanger.

8. The system of any previous claim configured for use in a motor vehicle.

9. A method of operating a fuel-cell system wherein heat is transferred from the incoming air to the exhaust air when the fuel cell is operating in a first operating mode, and heat is transferred from the exhaust air to the incoming

air when the fuel cell is operating in a second operating mode, wherein the second operating mode comprises transferring heat from the exhaust air to the incoming air when the fuel cell is operating well below maximum power generation.

10. The method of claim 9 wherein the first operating mode comprises transferring heat from the incoming air to the exhaust air when the fuel cell is operating at or close to maximum power generation.

11. The method of claims 9 or 10 wherein the transfer of heat to the incoming air occurs only when the fuel cell has a temperature below an optimal operating temperature.

12. The method of any of claims 9 to 11 wherein heat is transferred away from incoming air after incoming air has been compressed by a compressor.

13. The method of any of claims 9 to 12 wherein heat is additionally transferred away from incoming air by an additional heat exchanger.

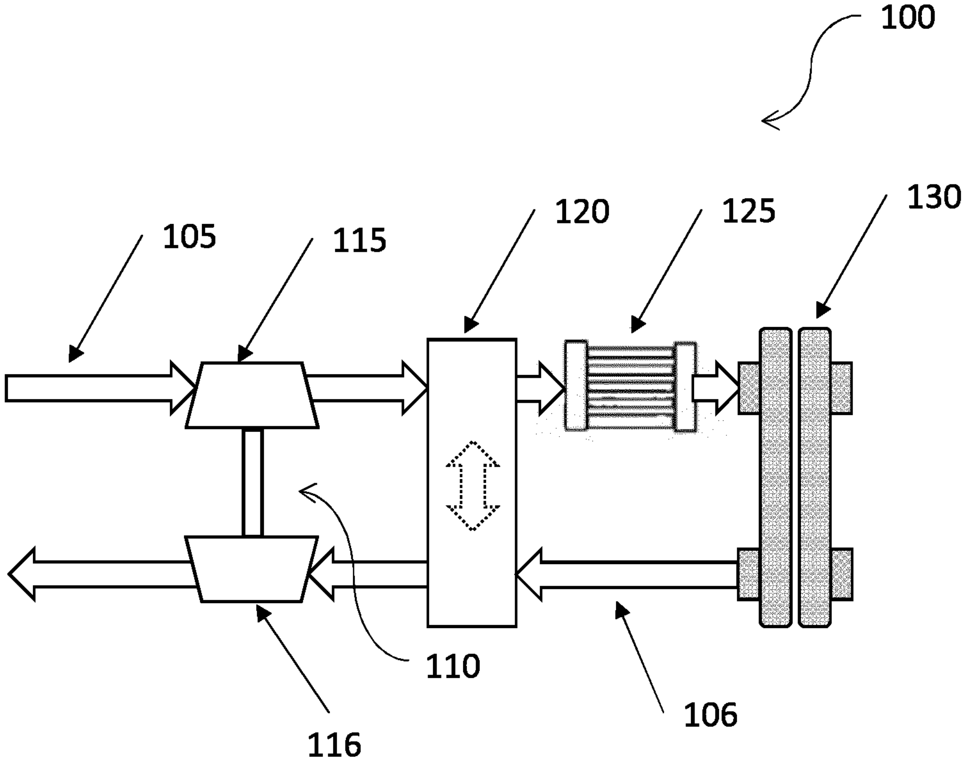

Fig. 1

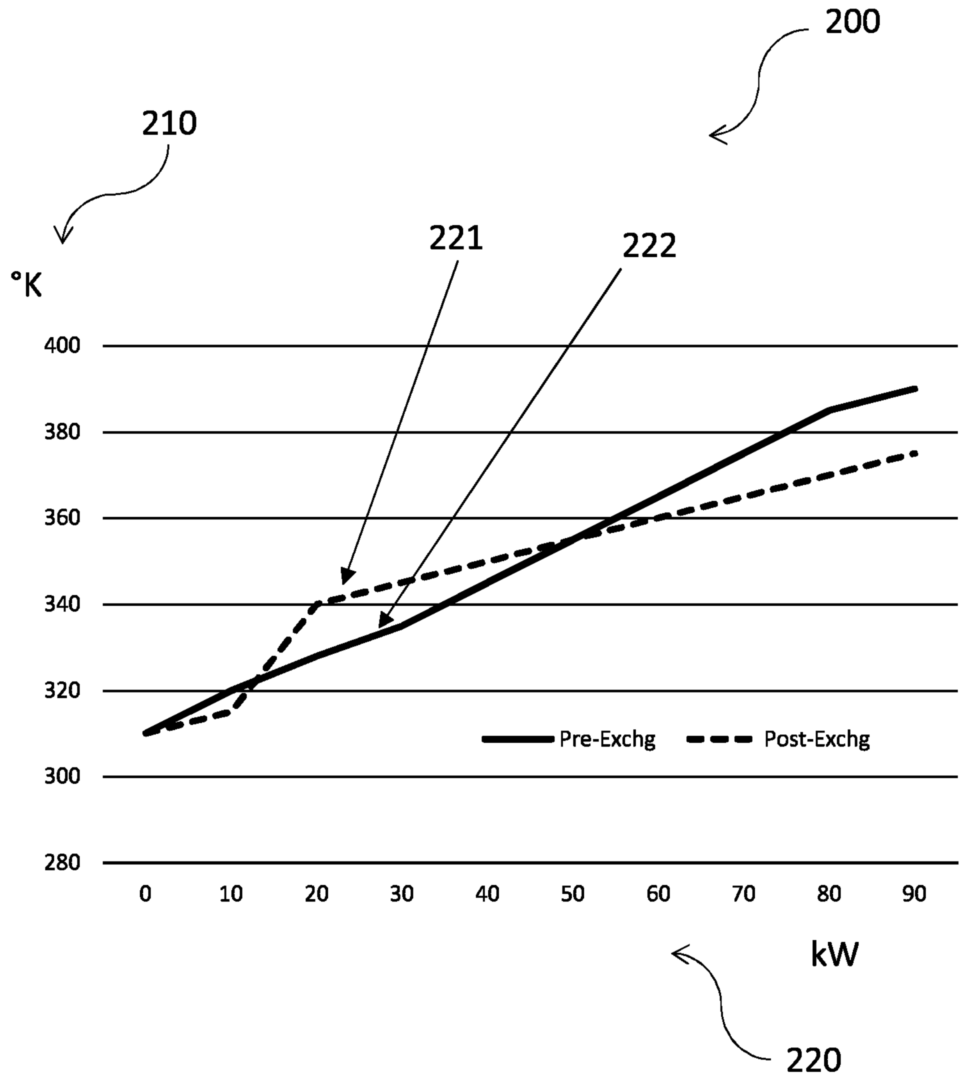
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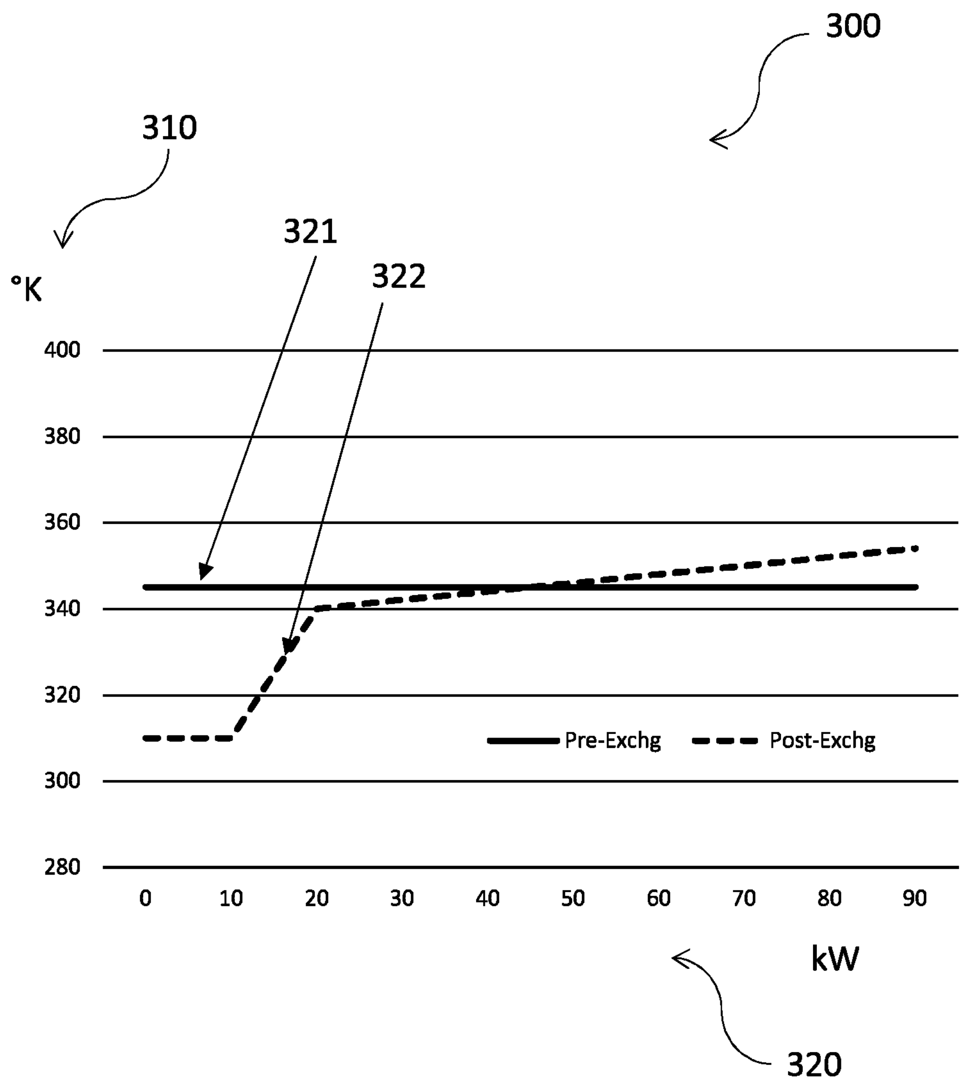
Fig. 2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Pre-Exchg
Post-Exchg
kW
320

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/056566

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01M8/04014 H01M8/04111 H01M8/04225 H01M8/043 H01M8/04302
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/077459 A1 (WALTON JAMES F II [US] ET AL) 5 April 2007 (2007-04-05) figure 1 -----	1-13
X	US 2018/114995 A1 (STOIA TINA [US] ET AL) 26 April 2018 (2018-04-26) figure 1 -----	1-13
X	DE 10 2014 000571 A1 (DAIMLER AG [DE]) 23 July 2015 (2015-07-23) paragraph [0023] - paragraph [0024]; figure 1 -----	1-13
X	DE 10 2009 014743 A1 (DAIMLER AG [DE]; FORD GLOBAL TECH LLC [US]) 30 September 2010 (2010-09-30) claims 1, 4; figure 1 -----	1-13

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
11 May 2020	20/05/2020

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2020/056566

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007077459 A1	05-04-2007	NONE	
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