Waterless Heat Exchanger

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BIOMEDICAL ENGINEERING DESIGN — DEPARTMENT OF BIOMEDICAL ENGINEERING — CHEMICAL ENGINEERING — MECHANICAL ENGINEERING — DESIGN — CARNEGIE MELLON UNIVERSITY, PITTSBURGH, PA

Problem

- A **Cardiopulmonary Bypass (CPB) machine** is a device that temporarily takes over the functions of the heart and lungs during surgery to enable the surgeon to work on the heart or lungs more effectively
  - Used for 378 thousand cardiothoracic surgeries in US in 2014
- **Heater-Cooler Device (HCD)** is used in conjunction with the CPB machine to control blood temperature during surgery
  - Cool patient down (induce hypothermia) at start to slow down metabolism
  - Heat patient back up to body temperature at end
- ***M. chimaera*** is a strain of nontuberculous bacteria that is transmitted to surgery patients via the HCD
  - Symptoms (fatigue, fever and weight-loss) are non-specific yet devastating
  - *M. chimaera* is water-borne and resistant to sterilization efforts

50%
M. chimaera fatality rate

50k–210k
patients at risk of contracting this infection annually

Problems associated with HCD use

- Infection risk from *M. chimaera* is high
- Usability issues cited by perfusionists: non-intuitive buttons and generic alarm bells

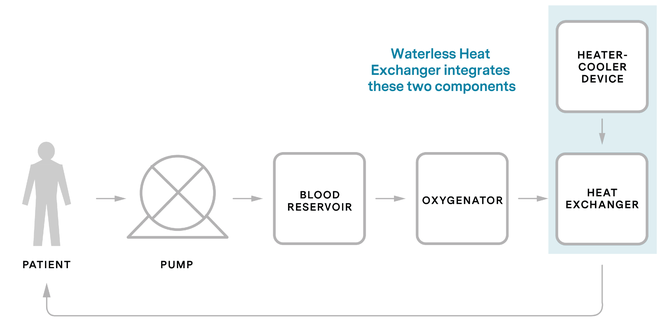

FIG 1. Overall Schematic of how an HCD works in conjunction with a CPB and how our device integrates with a CPB.

Reimbursement, Patents, Market Analysis, and Cost

Reimbursement

- Likely to be covered by medicaid/medicare as the major parts of the device is durable, according to the durable medical equipment coverage[10]

Market Analysis

- Global Cardiopulmonary Bypass Equipment Market by product type valued at US$11.3 million in 2017[11]
- Projected compound annual growth rate = 1.2%[11]

Manufacturing Costs:

- Cost = $55 USD for warming and cooling hardware and essential functionality
- Cost likely to increase with further development (user panel electronics, software, etc.)
- Expected to be cheaper compared with new commercial HCDs at ~$10,000 USD[7]
- Costs born by hospitals, is a long-term investment as our device can be reused multiple times

Proposed Solution

A **waterless heat exchanger** to reduce infection risk by **eliminating** mode of **transmission.**

- **Temperature control achieved by:** A) Metal bead bath cooling B) Thermoelectric Heating
- Size of HEX comparable to commercial HCDs at ~8500 in^3

HEATING CIRCUIT

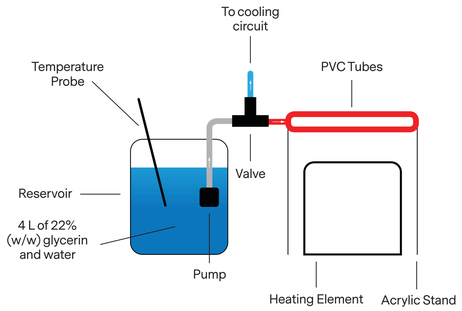

FIG 2. Heating Circuit Diagram.

COOLING UNIT

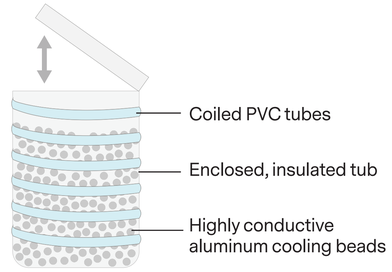

FIG 3. Cooling Unit Diagram.

SYSTEM DIAGRAM

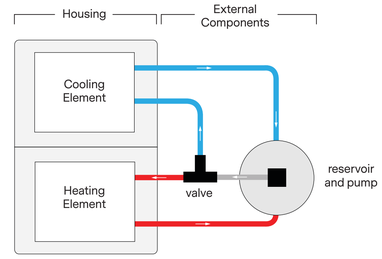

FIG 4. Overall Circuit Diagram.

HOUSING ILLUSTRATION

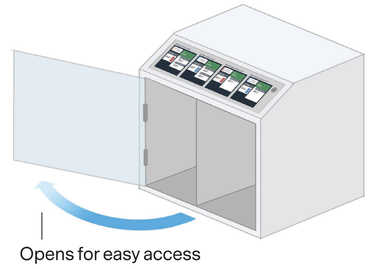

FIG 5. Housing.

An **augmented user interface** with an LCD touchscreen

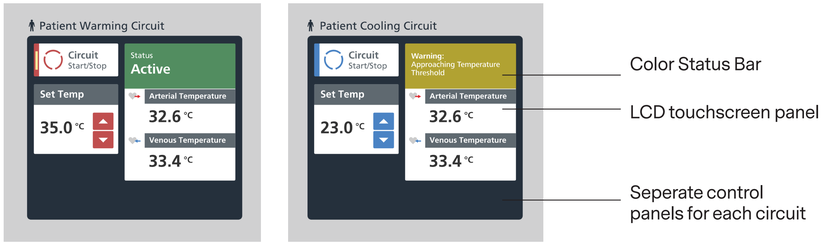

FIG 6. Control panel with normal status.

FIG 7. Control panel with warning status.

Proof of Feasibility

Temperature control for 5L blood-substitute (22% glycerin and water solution)

- Cooling: 37°C to 18°C[9]
- Heating: 18°C to 37°C
- Flow rate: 2.2L/min
- To reduce damage to blood:
  - **Gradual temperature changes** desired
  - Medical grade PVC tubes used

Cooling

- 0.75L aluminum beads as ice-substitute
- Length of tube: 78.5 in
- Surface area for heat exchange: 92.5 in^2
- Average cooling rate in first 30 min = **-0.14°C/min**
  - **same rate as ice cooling**
- Estimated frequency of replacement = every 30 minutes

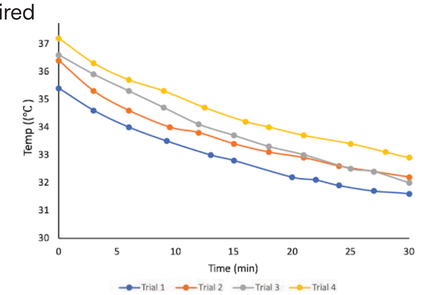

FIG 9. Experimental data from cooling trials.

Heating

- Heat source: commercial heating element
- Length of tube: 99 in
- Surface area for heat exchange: 117 in^2
- Average heating rate = **0.37°C/min**
- ~50 minutes to heat from 18°C to 37°C

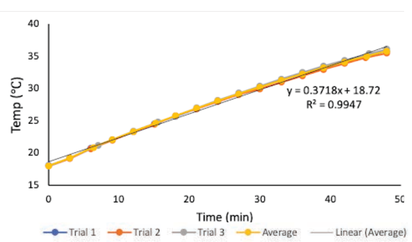

FIG 10. Experimental data from heating trials.

Future Work

- Computer programming to fully integrate the user interface with the heating/cooling circuits
- Implement feedback loop for temperature control
- Develop a draining system to return residual blood within the tubes back to the patient

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