THE DEVELOPMENT OF A 1 KW DIRECT METHANOL FUEL CELL SYSTEM

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ELECTROCHEMICAL TECHNOLOGIES GROUP
DESIGN OBJECTIVE

A DIRECT METHANOL FUEL CELL SYSTEM WITH THE FOLLOWING PROPERTIES:

• AIR FED

• CONVENTIONAL NAFION BASED MEAs

• NET OUTPUT OF >=1KW

• OPERATING AMBIENT TEMPERATURE RANGE 25°C - 40°C

• THERMAL BALANCE MAINTAINED WITHOUT EXTERNAL POWER

• LITTLE OR NO NET WATER CONSUMPTION

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SYSTEM CHARACTERISTICS

STACK OUTPUT 1.45 KILOWATTS
NET SYSTEM OUTPUT 1.15 KILOWATTS
STACK OPERATING TEMPERATURE 60°C
STACK PRESSURE 1 ATM AIR
FUEL CONCENTRATION .5M METHANOL
SYSTEM EFFICIENCY 21.0%
1.15 KW SYSTEM DESIGN

**CO₂, METHANOL, AND WATER VAPOR**

- **methanol out**
- **stack**
- **air out**
- **Blower**
- **condenser**
- **EXHAUST AIR**

**Level sensor**
- **CO₂, METHANOL, AND WATER VAPOR**
- **methanol out**
- **stack**
- **air out**
- **Blower**
- **condenser**
- **EXHAUST AIR**

**Level sensor**
- **sump pump**
- **gas-liquid separator**
- **Fan**
- **methanol sensor**
- **air/water return**
- **pure methanol**

**Level sensor**
- **circulation pump**
- **feed pump**
- **Electric valve**
- **Drain**

**Sump tank**

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SYSTEM FEATURES

STACK
- INTERNALLY MANIFOLDED TO MINIMIZE VOLUME AND SIMPLIFY PLUMBING
- LOW PRESSURE DROP
  - BLOWER AIR SUPPLY
  - GRAVITY/PRESSURE HYBRID WATER DRAINING SYSTEM

CONDENSER
- POLYCAPILLARY MATRIX HEAT EXCHANGE ELEMENTS
- FIRST-OF-A-KIND
- LIGHT WEIGHT
- COMPACT

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FUEL SYSTEM FEATURES

- AUTOMATIC FUEL DILUTION
  - STORAGE OF CONCENTRATED FUEL POSSIBLE

- METHANOL SENSOR
  - METHANOL CONCENTRATION FEEDBACK CONTROLLED
SYSTEM FEATURES
DATA ACQUISITION AND CONTROL

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SYSTEM DESIGN

- THERMAL ANALYSIS
  - MAINTAIN STACK TEMPERATURE CONSTANT

- WATER BALANCE
  - MINIMIZE OR ELIMINATE EVAPORATIVE WATER LOSS
THERMAL ANALYSIS

HEAT GENERATION
• STACK

HEAT DISSIPATION
MAJOR
• RADIATOR
• EVAPORATIVE COOLING AT EACH CATHODE

MINOR
• SURFACES OF STACK AND GAS LIQUID SEPARATOR
• PLUMBING
CONDITION 1 40°C @ 100% RELATIVE HUMIDITY
DETERMINES POTENTIAL FOR SYSTEM OVERHEAT

• MAXIMUM HEAT LOAD ON RADIATOR - NO EVAPORATIVE COOLING
• DETERMINES MINIMUM RADIATOR SIZE

CONDITION 2 25°C @ 0% RELATIVE HUMIDITY
DETERMINES POTENTIAL FOR SYSTEM UNDERHEAT
• MAX EVAPORATIVE COOLING
THERMAL ANALYSIS

STACK HEAT GENERATION

4126 WATTS HEAT FOR 1450 WATTS ELECTRICAL OUTPUT @ 26% STACK EFFICIENCY

CONDITION 1 40°C @ 100% RELATIVE HUMIDITY

RADIATOR HEAT DISSIPATION

4000 WATTS-NOMINAL
LIQUID FLOW RATE AND FAN SPEED CAN BE ADJUSTED TO INCREASE CAPACITY MODESTLY

STACK, GAS/LIQUID SEPARATOR, AND PLUMBING-NATURAL CONVECTION
416 WATTS – 1664 WATTS (NO INSULATION)

TOTAL DISSIPATION 4416 WATTS-5664 WATTS @ NOMINAL RADIATOR CAPACITY

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THERMAL ANALYSIS

STACK HEAT GENERATION

4126 WATTS HEAT FOR 1450 WATTS ELECTRICAL OUTPUT @ 26% EFFICIENCY

- CONDITION 2 25°C @ 0% R.H.
- EVAPORATIVE WATER LOSS 56.7 gr/min AT 60°C
- HEAT LOSS 2227 WATT
- STACK, GAS/LIQUID SEPARATOR, AND PLUMBING-NATURAL CONVECTION 728 WATTs - 2912 WATT (NO INSULATION)
- TOTAL HEAT LOSS 2743 WATT - 4927 WATT
THERMAL ANALYSIS

HEAT LOSS BY EVAPORATION @ 0% RELATIVE HUMIDITY 315 LIT/MIN AIR (3.2 STOKE)

STACK HEAT OUTPUT 4126 WATTS

CONSTANT WATTS AND STOKE

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WATER BALANCE

- WATER GENERATION RATE FROM ELECTROCHEMICAL OXIDATION OF METHANOL PLUS CHEMICAL OXIDATION ARISING FROM CROSSTOVER

18.16 GR/MIN

- WATER LOSS BY EVAPORATION @ 40°C AMBIENT 0% R.H. -WORST CASE
  ASSUMING TEMPERATURE AT CONDENSER EXIT = 45°C  LOSS = 23.1 gm/min

- WATER DEFICIT 4.9 gm/min @ 40°C AMBIENT

- METHANOL FUEL MUST CONTAIN 25% WATER BY WEIGHT AT 40°C AMBIENT
  AT ≤34°C AMBIENT FUEL REQUIRES NO WATER ADDITION

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WATER BALANCE

WATER GAINS AT DIFFERENT AMBIENT TEMPERATURES
0% RELATIVE HUMIDITY 315 LITER/MIN AIR INPUT TO STACK (3.2 STOKE)

ASSUME CONDENSER EXHAUST IS 5°C ABOVE AMBIENT

WATER BALANCE ACHIEVED AT 34°C

34°C = 93.2°F
40°C = 104°F

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COMPONENT DEVELOPMENT

STACK

CONDENSER

METHANOL SENSOR

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PRESSURE DROP < 1 TORR FAN FED

GRAVITY DRAINED

PRESSURE DRAINED < 100 TORR PUMP FED

GRAVITY/PRESSURE DRAINED < 10 TORR BLOWER FED

EXTERNAL AIR MANIFOLD
INTERNAL FUEL MANIFOLD

AIR INLET
AIR EXIT

FUEL INLET

FUEL INLET
FUEL OUTLET

AIR INLET
AIR OUTLET

INTERNAL MANIFOLD

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STACK

- OPERATING TEMPERATURE 60°C
- 68 CELLS
- 1450 WATTS
- AIR FLOW RATE 315 liter/min (11.1 cfm)
  - AIR FLOW RATE IS APPROX. 3.25 STOKE (CROSSOVER INCLUDED)
- PRESSURE DROP < 10 torr
- FUEL FLOW RATE 14-17.5 liter/min (3.7-4.6 gpm)
- ACTIVE CELL AREA 400 cm² (62 in²)
- STACK DIMENSIONS 9.7” X 10.2” X 13.75” (24.6 cm x 25.9 cm x 34.9 cm)
  INCLUDING ENDPLATE
- BIPLATE 22.86 cm x 24.1 (9” X 9.5”)
- VOLUME 19.3 liter (.68 ft³)
- WEIGHT 26 kg (57.3 lb)
- CURRENT DENSITY 140 ma/cm² @ .4 V (CROSSOVER ~ 32ma/cm²)
  56 watt/kg
  75 watt/liter

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68 CELL STACK

GINER LLC
1.45 kW DMFC STACK

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CONDENSER

CONDENSER REQUIREMENT

PROCESS STREAM 360 lit/min @ 60°C AND 100% R.H.

- 1335 WATTS COOLING CAPACITY
- 40°C AMBIENT AIR TEMP
- 45°C CONDENSER EXIT TEMP
- <10 torr PRESSURE DROP
CONDENSER

- CONVENTIONAL TUBE AND FIN HEAT EXCHANGER
- STAINLESS STEEL TUBES ALUMINUM FIN AND CASE
- 800 watt CAPACITY
- 57.2 cm x 47.6 cm x 15.2 cm (41.4 LITER, 19.3 WATTS/LITER)
- 13.6 kg (30 LBS) 59 WATTS/KG
- ~100 watt COOLING FAN

- ADVANCED POLYCAPILLARY MATRIX (PCM) HEAT EXCHANGER
- CHROME PLATED ALUMINUM HEAT EXCHANGE ELEMENTS
- 2000 watt CAPACITY APPROX
- 36.8 cm x 29.2 cm x 10.2cm (11 LITER, 182 WATTS/LITER)
- 7.5 kg (16.52 LBS) 266 WATTS/KG
- 38 watt COOLING FAN

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TUBE AND FIN CONDENSER
PCM CONDENSER
PCM ELEMENTS
FUEL SYSTEM
CONCENTRATION CONTROL

METHANOL INJECTION
PUMP

DILUTE METHANOL
CIRCULATION
PUMP

METHANOL SENSOR

STACK

COMPUTER

METHANOL

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A constant voltage $V_s$ is applied, then the current is proportional to the methanol concentration. The sensor is operated in a diffusion controlled mode. Methanol is oxidized at the anode, and hydrogen is reduced at the cathode.
METHANOL CONCENTRATION SENSOR
CALIBRATION CURVES

0.5M Methanol, Sensor Calibration

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ANCILLARY COMPONENT POWER CONSUMPTION

TOTAL ~ 295 WATTS

STACK AIR SUPPLY BLOWER 105 WATTS

- RADIATOR COOLING FAN < 50 WATTS
- CONDENSER COOLING FAN 38 WATTS
- DILUTE METHANOL PUMP 66 WATTS
- PURE METHANOL METERING PUMP 6 WATTS
- RELAY BOX 5-10 WATTS

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COMPONENT WEIGHTS

FUEL NOT INCLUDED TOTAL 68KG (150 lb)
STACK 26 KG (57.3 LB)
RADIATOR 6.45 KG (14.2 LB)
CONDENSER 7.5 KG (16.5 LB)
STACK BLOWER AND DRIVE UNIT 2.27 KG (5 LB)
RADIATOR FAN 1.54 KG (3.4 LB)
CONDENSER FAN .82 KG (1.8 LB)
COMPUTER 3.0 KG (6.6 LB)
DATA ACQUISITION AND CONTROL ELECTRONICS 2.18 KG (4.8 LB)
DILUTE METHANOL PUMP 1.18 KG (2.6 LB)
PURE METHANOL METERING PUMP AND DRIVE UNIT .56 KG (1.2 LB)
STARTUP BATTERIES 1.27 KG (2.8 LB)
LEVEL SENSORS .04 KG (.09 LB)
PURE METHANOL TANK .43 KG (.95 KG)
SUMP TANK .24 KG (.53 LB)
GAS LIQUID SEPARATOR (TANK) 1KG (2.2 LB)
PURE METHANOL 4 HOURS OPERATION 5.2 KG (11.5 LB)
DILUTE FUEL IN GAS LIQUID SEPARATOR 8 KG (17.5 LB)
FITTINGS, TUBING AND ODDS AND ENDS 5 KG (11 LB)
METHANOL SENSOR AND ELECTRONICS 500 GM (1.1 LB)

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1 KW DIRECT METHANOL FUEL CELL SYSTEM

Front View
JPL Fuel Cell System

Rear View
JPL Fuel Cell System

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REDUCED STACK PERFORMANCE FOLLOWING LEAK

POWER VS. CURRENT FOR THE FUEL CELL SYSTEM, CONSTANT AIR AND FUEL FLOW

Unstable beyond this point

VOLTAGE CURRENT PLOT OF THE FUEL CELL SYSTEM, CONSTANT FUEL AND AIR FLOW

400 cm² electrode surface area

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