AEROSTAK PEM FUEL CELL SYSTEM
A500-45

SPECIFICATIONS & OPERATIONS USER MANUAL

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DISCLAIMER

Please read this user guide thoroughly prior to product use. Follow all instructions stated within and follow all applicable local laws and regulations.

This user manual is not intended to cover all situations a user may encounter with the product. The user is responsible for the safe operation, care, and storage of the product.

While effort has been made to ensure the accuracy and completeness of the information contained in this document, HES Energy Systems Pte Ltd (hereinafter HES) reserves the right to change the information without notice at any time and assumes no liability for its accuracy or completeness.

Actions that will void the Product warranty are stated below:

- Attempt, under any circumstance, to disassemble or tamper with the product.
- Operate the fuel cell system with a controller not designed and built by HES for the specific product delivered to the user.
- Unauthorized modifications, adjustments, or other alterations of the product.
- Operating the system in a way that is not specified in this user manual.

For questions or technical support, please contact: sales@hes.sg

CONTENT

1. SAFETY INFORMATION

1.1 GENERAL INFORMATION

Do not attempt, under any circumstance, to disassemble or tamper with the Aerostak product. HES will not allow a return, offer a refund, or exchange should disassembly or tampering occur. Do not attempt to repair or replace any component in the system. **HES should be consulted for device's troubleshooting beyond the scope covered in this document.**

Keep away from direct sunlight and do not store at temperatures above 45 ºC or in freezing conditions. Do not submerge the product in water and ensure that it is not subjected to rain, snow, dust, dirt, mud, etc. Do not operate around combustion exhaust, sulfur, natural gas, or environments containing carbon monoxide or any other gases that may be harmful for proton exchange membrane (PEM) fuel cell systems (PEMFCs). The Aerostak fuel cell hardware may also be called "product" or "system" in this document.

Do not smoke around the fuel cell system. The highly flammable hydrogen fuel could ignite. Keep away from heat, catalytically active powders such as platinum or palladium, and open flames.

1.2 HYDROGEN AWARENESS

Hydrogen is a highly flammable gas. A mixture of hydrogen and air is potentially flammable and explosive. Hydrogen can be ignited by a spark, a catalyst, or hot surface with concentrations between 4% and 75% and becomes explosive when concentration reaches 15% - 59% by volume in the air.

- Use hydrogen only in a well-ventilated area.
- Follow the local safety and fire regulations when handling and storing hydrogen gas.
- Keep all sources of ignition away from the product and hydrogen (such as open flame, lighted cigarette, soldering equipment, etc.), catalytically active powders of platinum or palladium, etc.
- Use a hydrogen leak detector to periodically check for hydrogen leakage (at the tubing connections, at the pressure regulator, and any connections between the H2 supply source such as a composite cylinder and inlet of the H2 supply located on the side of the fuel cell system).

1.3 ELECTRICAL SAFETY

The system can deliver high voltage and current. Use caution when handling as high voltages can be present even when the system is off. Use proper personal protection to prevent exposure to electrical shock.

- Avoid contact with metal components inside of the enclosure.
- Minimize static discharge. Ground all equipment.
- Avoid contact with surfaces that are in contact with water or gases.
- Do not operate or store in wet or damp conditions.
- Never use damaged extension cords.

1.4 HIGH TEMPERATURE

The fuel cell stack can operate at a maximum temperature of around 65 °C (meaning the fuel cell stack temperature can reach to 65 °C during regular operation). This will result in the exhaust stream (fuel cell air output) temperature reaching around 45-60°C depending on the power output levels.

- Temperatures are sufficient to cause burns or discomfort.
- Keep body and materials away from the fan outlet of the fuel cell stack.
- Ensure the air inlet is unobstructed for at least 10 cm and the exhaust by 20 cm when the system is operating.

2. TECHNICAL SPECIFICATIONS

The A500-45 product specifications are provided in Table 1.

2.1 PRODUCT SPECIFICATIONS

Table 1. Details of the Aerostak A500-45 product specifications.

Type of Fuel Cell	PEM
No. of Cells in The Fuel Cell Stack	45
Rated Performance	14.1 A @ 35.4 V
Rated Power (Continuous Output Power)	500 W
Temporary Peak Power	600 W*
Recommended Hybrid LiPo Battery Module	8S**
Fuel Cell Stack Output Voltage Range	27.0 V to 42.8 V
Fuel Cell Stack Output Current Range	0.0 A to 25 A
Product Dimensions (with casing)	166.5 mm x 105 mm x 194 mm
Design Lifetime	500 hours***
Wet Weight (Stack Assembly, excluding interface cables)	1500 grams
Reactants	Hydrogen & Air
Hydrogen Gas Purity	99.999%
Hydrogen Consumption @ Rated Power	7.6 L/min
Hydrogen Input Pressure	0.6 to 0.8 bar
Air Input Temperature	0 °C to 35 °C
Stack High Temperature Warning	> 67 °C
Stack High Temperature Shutdown	> 70 °C
Stack Low Voltage Warning	< 0.6 V/cell
Stack Low Voltage Shutdown	< 0.5 V/cell
LiPo Battery Low Voltage Warning	< 3.4 V/cell
LiPo Battery Low Voltage Shutdown	< 3.0 V/cell
Humidification	Self-humidified****
Cooling	Air (Integrated Fan)
Start-up Time	< 30 s
Voltage Efficiency of Stack at Rated Power#	63.9% @ 35.4 V

** Operating the product at the "temporary peak power" continuously may damage the product. Repair costs will not be covered by terms of the warranty.*
*** Hybrid board supplied with the fuel cell system is designed and configured for an 8S LiPo battery module. User is strongly advised to use ONLY 8S LiPo battery module with this specific product. Use of other battery configurations will result in unsafe operation of the product. Resulting damage will not be covered by terms of the warranty.*
**** The design lifetime is either 500 hours of operational time or 1 year from the day of shipment to the user, whichever comes first.*
***** Self-humidification is carried out by the system automatically using a fuel cell stack conditioning process where the fuel cell stack is disconnected from the external load every 10 seconds and electromechanically shorted for a duration of ~100 milliseconds. More details are provided in Section 6 "Fuel Cell Stack Conditioning".*
 # Voltage efficiency of the stack at the "Rated Power" is calculated as follows: Experimentally obtained average cell voltage divided by the theoretical cell voltage and then normalized. Therefore, (Stack Voltage / # of cells in the stack) / Theoretical cell voltage. In this case, stack voltage at the rated power (which is 500 W) is 35.4 V, # of cells in the stack is 45, and the theoretical cell voltage is 1.23V: $\left(\frac{35.4\ Volts}{45}\right) \times \left(\frac{1}{1.23\ V}\right) \times 100 = 63.9\%$.

2.2 Product Dimension and Images

Overall product dimension is provided in Figure 1. Additional product images for Aerostak A500-45 fuel cell system are shown in Figure 2.

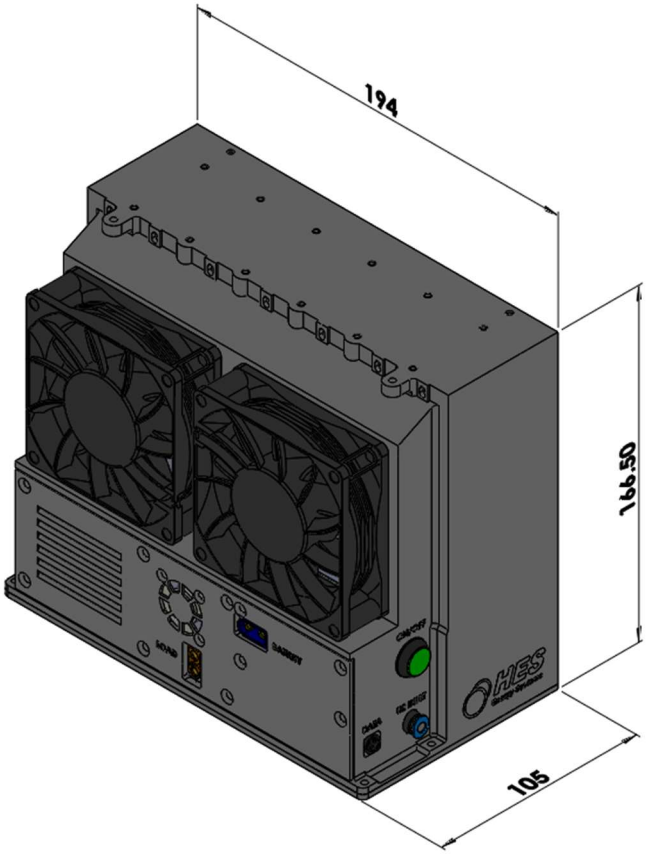

Figure 1. CAD model image showing the overall dimensions of the Aerostak A500-45 with a 45-cell design (with the casing). The overall dimensions are 166.5 mm x 105 mm x 194 mm (height x depth x width).

Figure 2. Fully assembled product images of Aerostak A500-45 fuel cell system.

3. AEROSTAK COMPONENTS

3.1 COMPONENTS AND CONNECTIONS

The lightweight Aerostak A500-45 fuel cell system consists of the following major components:

1) **500 W fuel cell stack (Figure 3 or Figure 5)**
   The PEM fuel cell acts as the primary power supply for the load. The fuel cell stack consists of 45-cells connected in series (electrically) in order to produce a nominal power of 500 W and peak power of 600 W.

2) **Fuel cell stack fan (Figure 3, Figure 4 or Figure 5):**
   Supplying air/O_2 to the cathode and air flow for cooling of the stack.

3) **H_2 supply tube (Figure 5):**
   Supplies H_2 gas to the stack from an external H_2 source.

4) **Anode water and H_2 purging tube (Figure 5):**
Removes water and unwanted gases during purging events.

5) **ON/OFF switch (Figure 3 or Figure 5):**
Momentary button to start and stop the fuel cell system operation.

6) **RS232 serial communication port (Figure 7):**
Provides operational performance data for monitoring and collection on a separate computer.

7) **Load connector (Figure 4 and Figure 7):**
Female XT60 connector to connect the system to a load.

8) **Battery connector (Figure 4 and Figure 7)**
Male XT60 connector to connect the 8S hybrid LiPo battery.

9) **Main control board (not shown here):**
Controls stack operation and overall system management.

10) **Hybrid board (not shown here):**
System power management of the fuel cell and hybrid LiPo battery. Provides recharging of hybrid LiPo battery during operation.

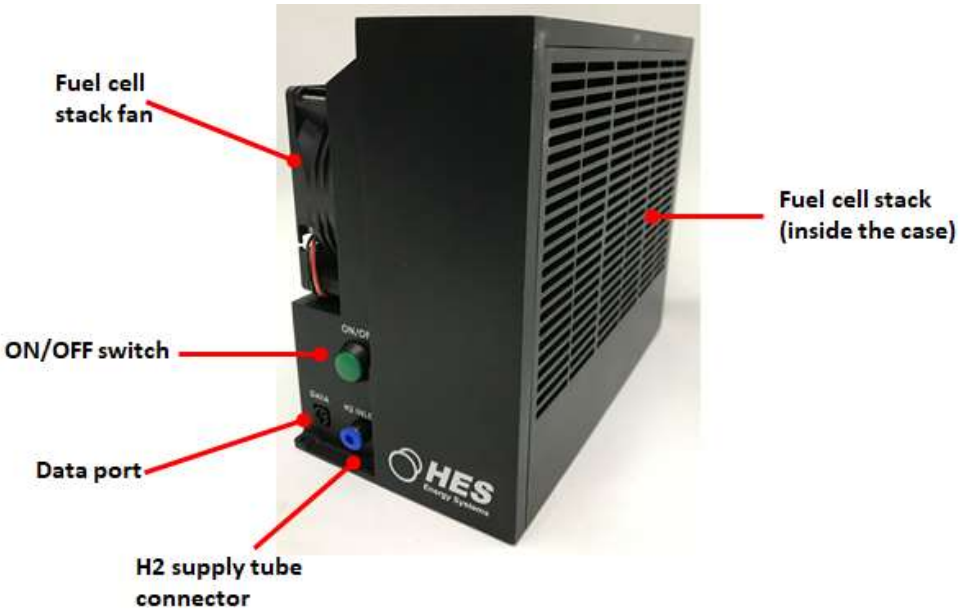

Figure 3. Side/diagonal view of the Aerostak A500-45 product showing the PEM fuel cell stack (inside the case), fuel cell stack fan, ON/OFF switch, data port, and H2 supply tube connector.

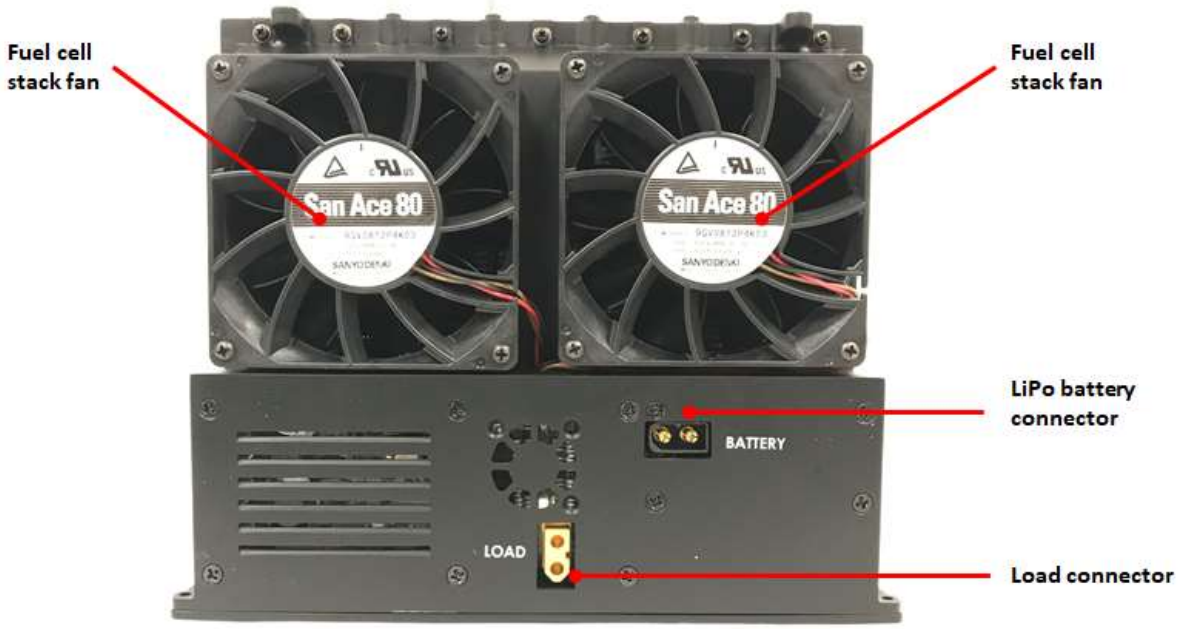

Figure 4. Back view of the Aerostak A500-45 system showing the fuel cell stack fans, load connector, and LiPo battery connector.

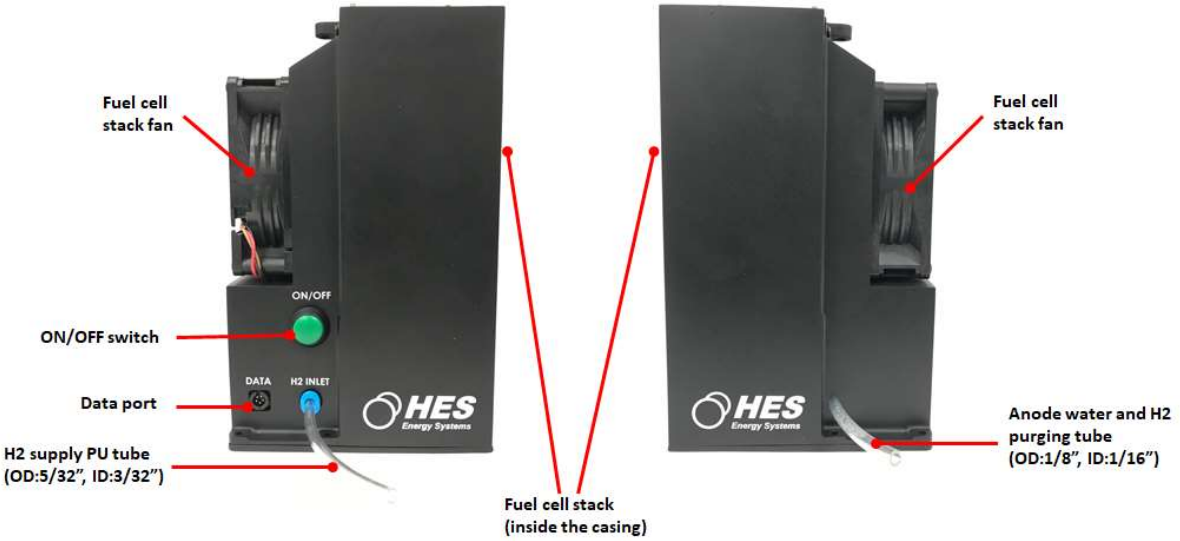

Figure 5. Side views of the Aerostak A500-45 system showing the fuel cell stack fans, ON/OFF switch, data port, H2 supply PU tube (O/D: 5/32", ID: 3/32"), fuel cell stack (inside the casing), and anode water and H2 purging tube (O/D: 1/8" OD, ID: 1/16") components.

3.2 Control Boards

There are two main control boards; main power management board and hybrid board. These two boards are used to control the operation and power management of the Aerostak A500-45 product.

The main control board controls the fuel cell stack, balance of plant components, and overall system management, and flow of fuel cell power to the load. The control board is limited to a maximum 25 A of electrical current from the fuel cell.

The hybrid board manages the flow of power from the Lithium-polymer (LiPo) battery pack during large transient power demands that exceed the capacity of the fuel cell, and the fuel cell stack electronics during conditioning cycles. This board is limited to a maximum peak of 25 A from the LiPo battery. The hybrid board will also supply up to 1.5A of current from fuel cell to recharge the LiPo battery during operation.

Electrical Current Limitations (Continuous Operation)	
PCB Trace*	35 A
Interface Connector (XT 60)*	35 A
Cables (14 AWG or 12 AWG)*	45 A
Maximum recommended load current and power from the fuel cell**	25 A 600 W
Maximum recommended load current and power from the LiPo battery**	25 A 600 W

** The given values are the maximum values at the component level and not to be implemented by the user. These values are provided to the user for clarification of electrical current limitations of the most important electrical/electronic components existing in the product.*

***Electronic boards supplied with the product are designed to safely operate the product within a certain range of electrical current, voltage, and power. The maximum amount of electrical current that can be pulled from the fuel cell system or LiPo battery must be limited to less than 25 Amps. If the user's load exceeds these values, irreversible damage will occur to the electronic boards and other components due to excessive heat generation and will not be covered by the terms of warranty.*

3.3 LiPo Battery Requirements

Through the internal electronics, the LiPo battery is connected in parallel with the fuel cell (not directly connected) and provides power for startup, load power during the stack conditioning, and transient power that exceeds the power capabilities of the fuel cell. The battery also acts as backup power source in case the application runs out of hydrogen fuel or the fuel cell stops functioning. The user is advised to ONLY use 8S LiPo battery for the Aerostak A500-45 product. Use of other battery configurations (such as 6S, 7S, 9S, etc.) or using other battery chemistries will irreversibly damage the control boards and/or the fuel cell. Such damages will not be covered by terms of the warranty. The capacity of the LiPo battery is dependent on the application and should be determined by the user to provide enough reserve power (typically 2 times of what is needed) to safely land from the operating altitude. The LiPo battery must have a discharge C-rate of at least 50C. This insures sufficiently high discharge current capacity with little voltage sag.

Ensure the electrical connections are made correctly to the system as shown in Figure 7. The LiPo battery is not included due to international shipping regulations. A LiPo battery charger is also required but not included with the system.

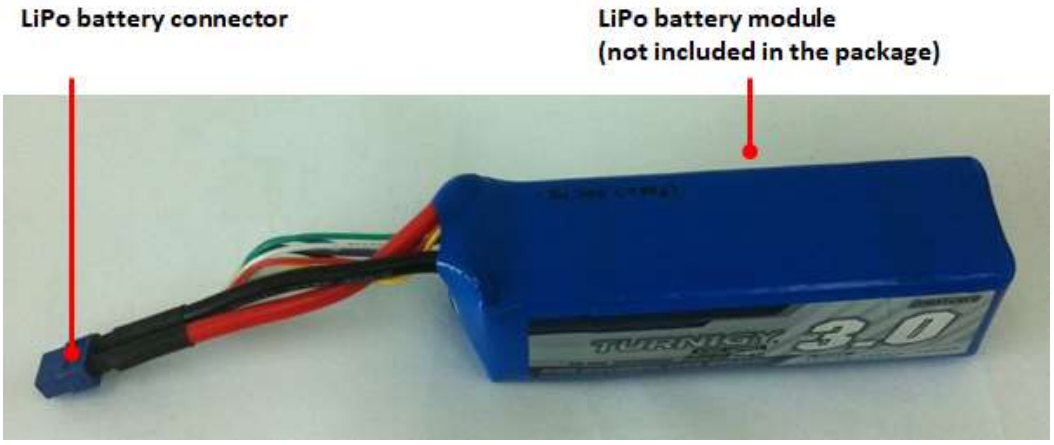

Figure 6. LiPo battery example. This is not an 8S LiPo module. The image is for illustration purposes only.

For assistance in selecting an appropriate LiPo battery, please contact HES Energy System at sales@hes.sg.

The LiPo battery must be charged prior to any use with an external LiPo battery charger. The fuel cell must not be used to charge the battery. It is the user's responsibility to find an external battery charger made for the LiPo batteries. The required battery configuration for Aerostak A500-45 product is 8S. The battery must be charged to at least 4.0V/cell equating to an overall minimum pack voltage of 32V. The battery system can be comprised of two 4S or one 5S and one 3S battery connected in series with a series adapter provided by the user. If combining multiple batteries to obtain an 8S configuration, each battery must have the same capacity (same mAh value), same C-rating values, and be manufactured by the same company. User is strongly advised not to mix/match LiPo batteries from different manufacturers due to use of different battery components by different manufacturers.

4. OPERATION INSTRUCTIONS

4.1 RECHARGING OF THE LIPO BATTERY MODULE

Prior to operation of the fuel cell system, the user must charge the LiPo battery (see information provided in Section 3.3 of this document) to a minimum of 4.0V/cell. The required LiPo battery voltage configuration for the A500-45 fuel cell system is an 8S configuration (28.0 V – 33.6 V). An external battery charger must be used to charge the battery before starting the system. The user must follow the instructions of the charger and battery manufacturers to safely charge the LiPo battery. If the battery becomes puffy during charging or use, the battery should be safely discarded according to local regulations and replaced with a new battery.

4.2 REFILLING THE COMPOSITE HYDROGEN TANK

Please refer to the separately provided refilling instructions in order to refill the composite hydrogen cylinder prior to system use. Refer to the cylinder label for refill pressure limit. The cylinder should not be filled above the stated working pressure.

4.3 Fuel Cell System Setup

1. Place or mount the Aerostak fuel cell system in an upright position. Ensure that there is no obstruction in front of and/or behind the system. Operate only in a well-ventilated area. The purging tube should point towards an empty space as water and hydrogen gas will be purged during operation.

2. Connect the hydrogen gas supply to the inlet tube located on the side of the system. Ensure that the pressure of the gas supply is between 0.6 to 0.8 bar. The supply tubing length between the hydrogen supply and the fuel cell system should be less than 30 cm to prevent excessive pressure drop through the tubing. Supply tubing is PU tubing and has the following physical dimensions: OD: 5/32" and ID: 3/32". To install the tubing, push tubing into the fitting until it stops. Check the connection with leak detector when pressurized with H_2. To remove the tubing, push the tubing inward and press on the blue ring. Then while pressing the ring pull the tubing out of the fitting.

3. Connect the power output to the external load with the provided load cable. Insert the load cable into the system connector labeled LOAD, located on the back panel. Refer to Figure 7 below for reference. Do not switch on the external load until the fuel cell is fully operational.

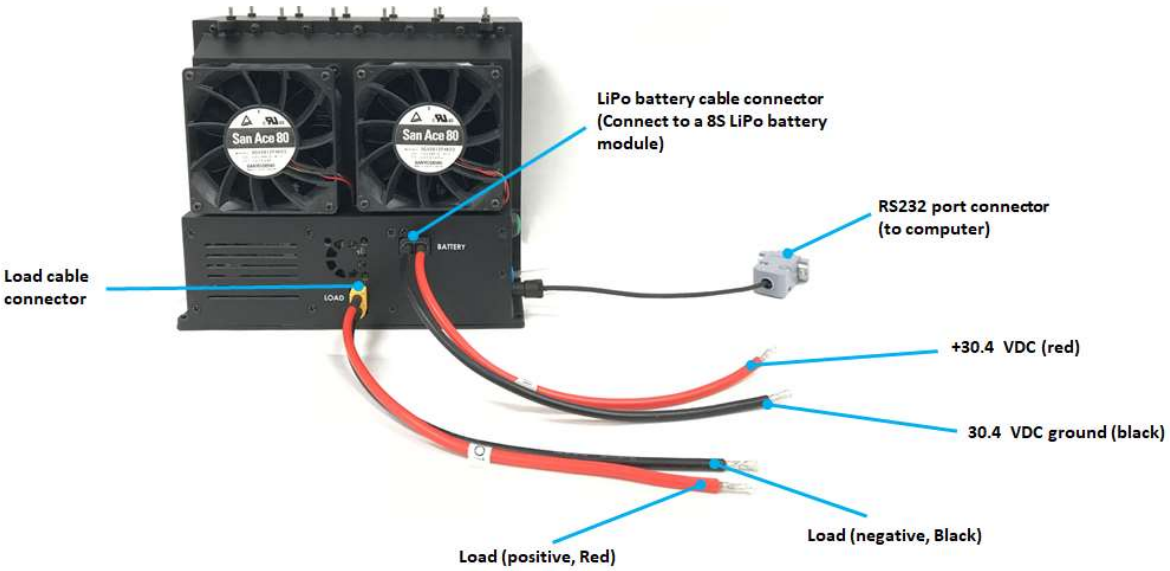

Figure 7. Load and wire connections for the Aerostak A500-45 fuel cell system.

4. Connect the 8S battery to the system at the "Battery" connector. (Ensure that the battery is charged up prior to use by using an external battery charger to a minimum of 4.0 V/cell. During system start up, the control software checks the LiPo battery voltage for a minimum of 30.4 V to successfully initialize the system.) The battery must be disconnected from the system when not in use to prevent damaging the battery and/or fuel cell system.

5. A complete system set up using an Aerostak product is shown in Figure 8 (below) as an example setup for benchtop testing of A500-45 product. [Note: This image shows a standard testing layout as an example to the user. Composite H2 cylinder with a pressure regulator and its connection to the product, placement of the stack module in the upright position, connection of the fuel cell to the battery and the external load, LiPo battery and its connection to the fuel cell and external load, electrical and data communications, an electronic load and a computer are all shown on the benchtop for the purpose of illustration and how the user can setup its own A500-45 product for benchtop testing.]

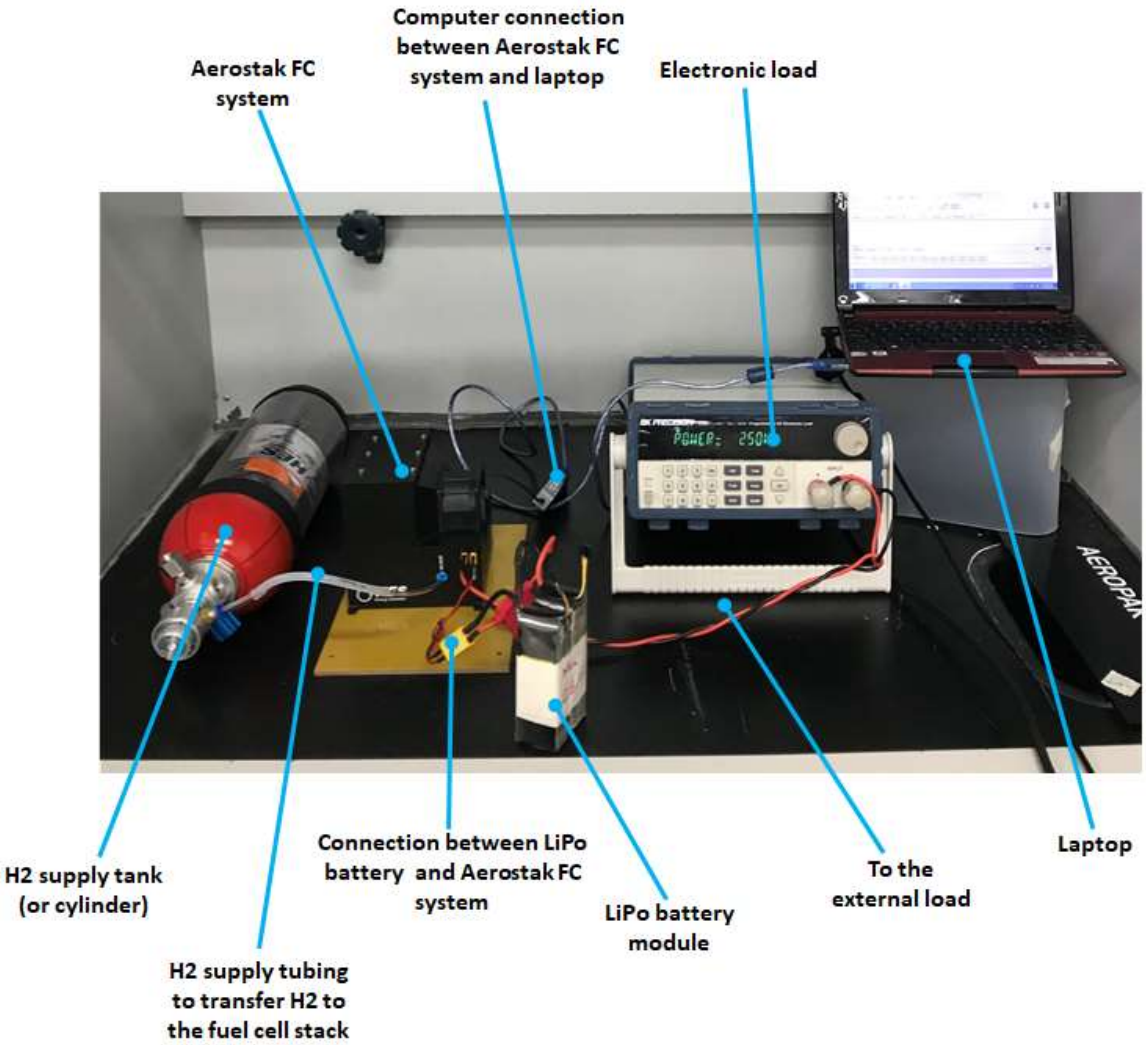

Figure 8. An example of a full system setup using an Aerostak FC system for benchtop testing.

NOTES:

i) Make sure the stack air inlet and fan outlets are not blocked.

ii) Do not physically short-circuit the fuel cell Load +ve (positive) and fuel cell Load –ve (negative) output terminals.

iii) Ensure that the maximum load does not exceed the system's electrical current capacity.

iv) Ensure that there are no loose connections.

v) Always unplug the LiPo battery after use. Failure to do so will result in permanent damage to the battery.

4.4 Fuel Cell Data Monitoring and Logging Setup

1. The system has a RS232 data port on the side (see Figure 9, labeled as "data port"). This allows the system to be connected to a computer for data logging, performance monitoring, and trouble shooting.

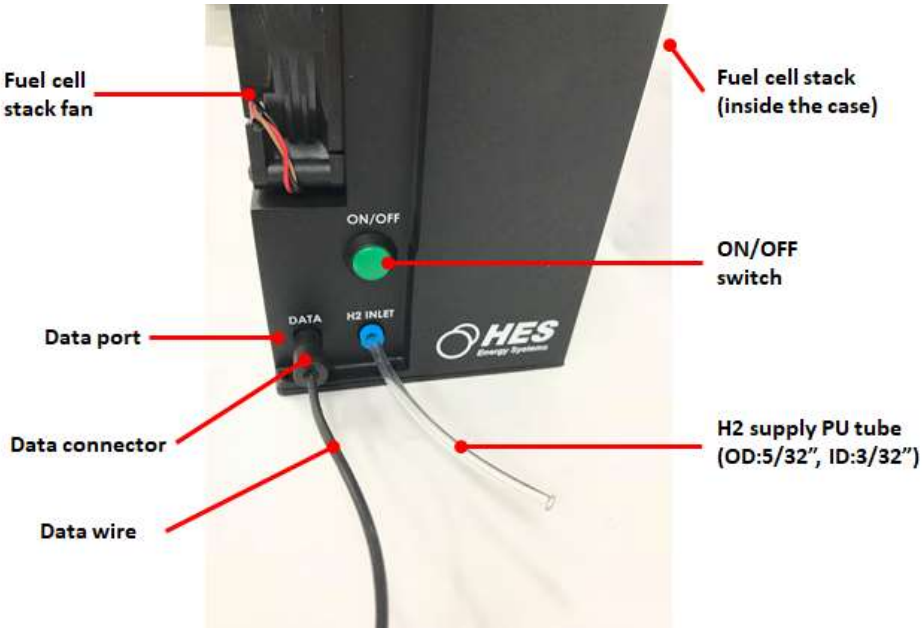

Figure 9. Location of RS232 data port for Aerostak A500-45.

2. Connect the provided data cable adapter to the round connector on the system. **Do not twist or rotate the data cable during plugging or unplugging process as this may cause damage. The data cable needs to be pushed in or pulled out to/from the data port (see Figure 10 for more detailed instructions and visuals).**

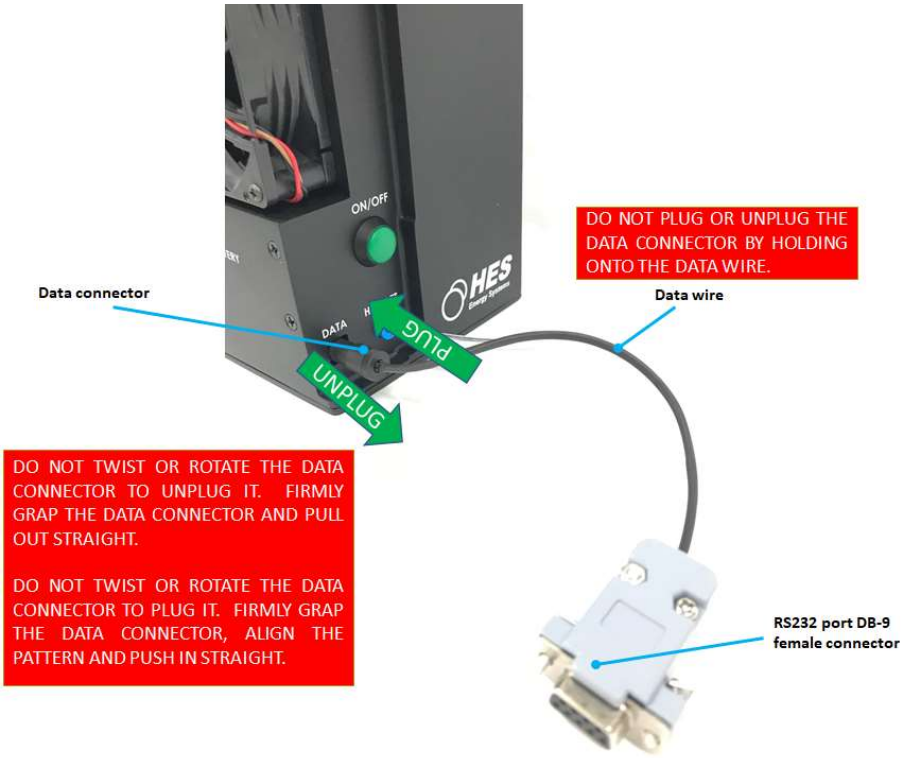

Figure 10. Instructions to plug and unplug the data connector to/from the Aerostak A500-45 product.

3. The pin layout of the RS232 port with a DB-9 female connector is shown in Figure 11.

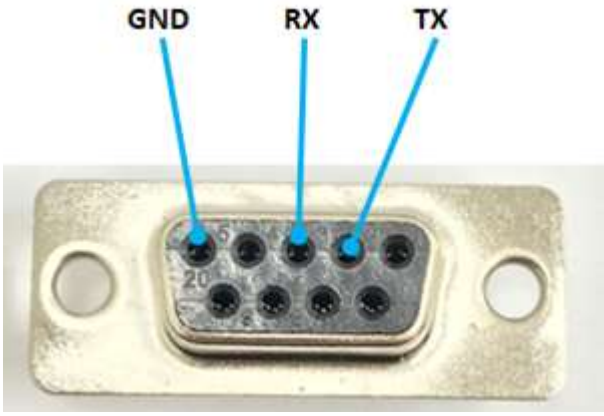

Figure 11. RS232 female DB-9 connector pin layout.

4. Connect the RS232 DB-9 female connector to a DB-9 Male connector at the computer (see Figure 12). A DB-9 male connector with a USB adapter is not included in the system but it is available commercially. If the user needs assistance with identification of the DB-9 male connector with a USB adapter, please contact HES at sales@hes.sg .

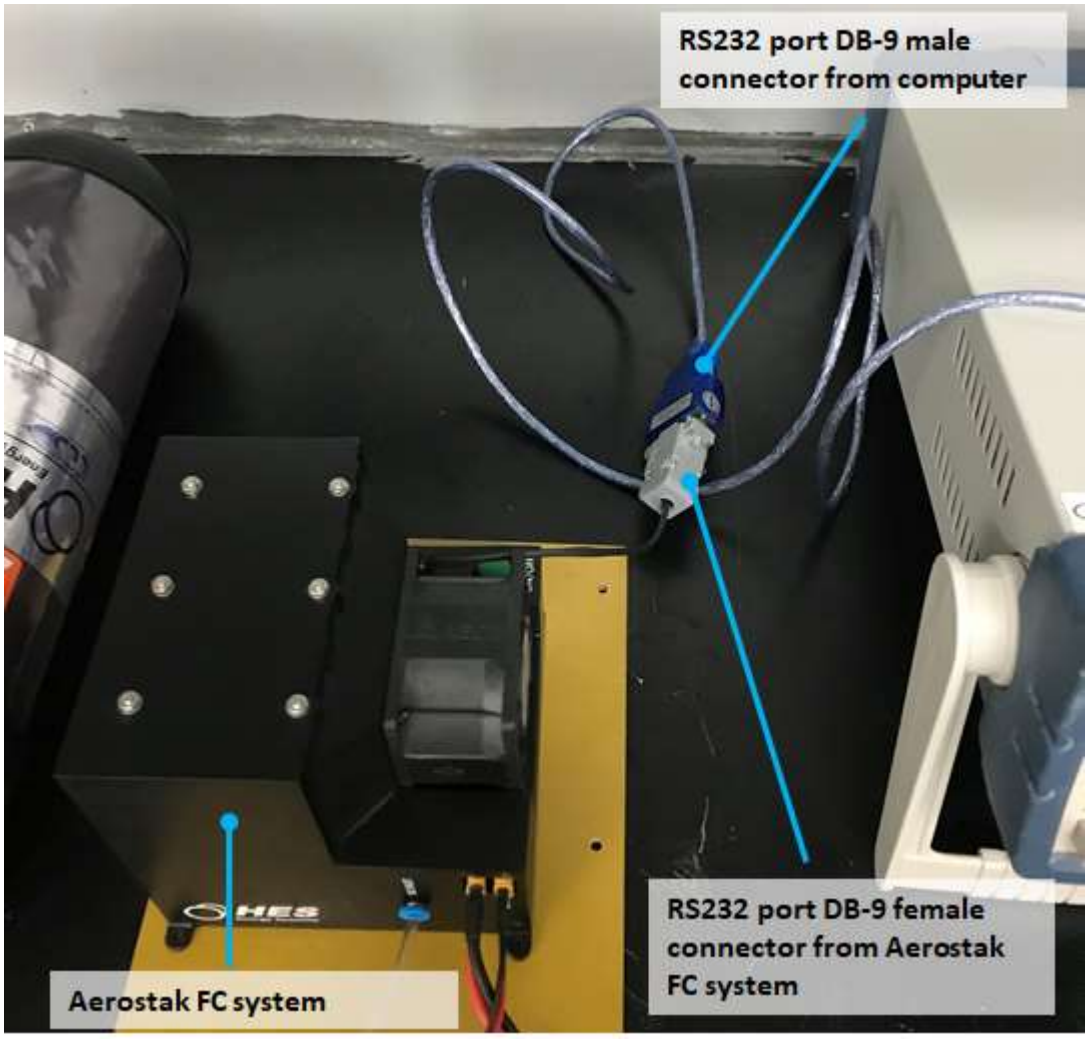

Figure 12. This setup is for illustration purposes. In this setup, an Aerostak FC product was used to show how to make connection to a standard computer.

5. Download the interface application software from the link: **https://sites.google.com/site/terminalbpp/**

6. Launch the Terminal application software.

7. Verify the settings as shown in Figure 13: (Baud Rate: 19200, Data Bits: 8, Stop Bits: 1, Parity: None, Handshaking: None)

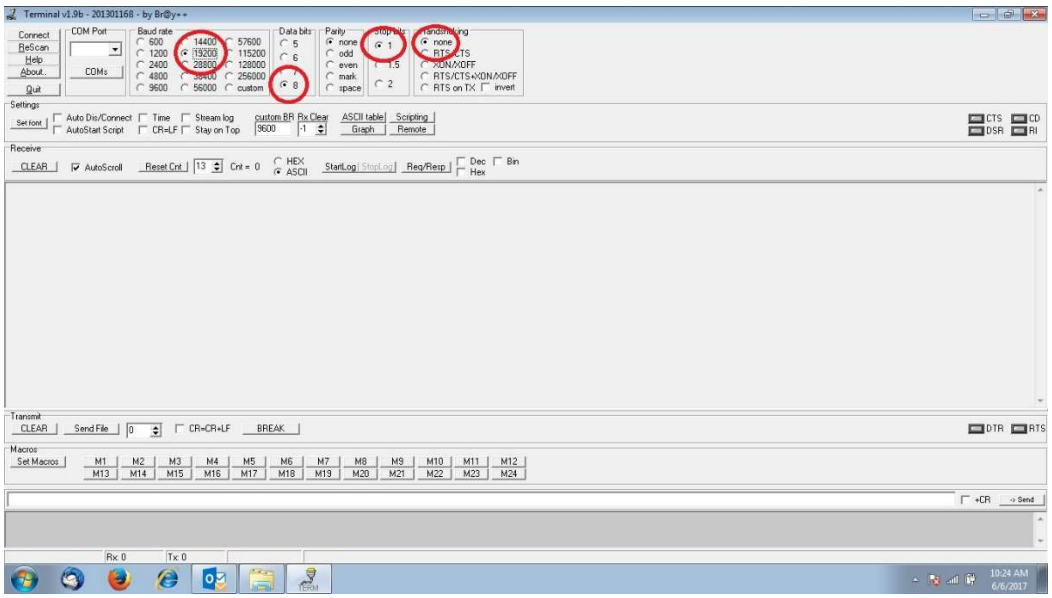

Figure 13. Terminal application settings.

8. Select the COM Port (also known as communication port) for the RS-232 connection (see Figure 14). If the correct port is not shown, click the rescan button as indicated below. Once scanning is completed, a communication port number will appear automatically on the COM PORT display. Click 'Connect' to connect to the system.

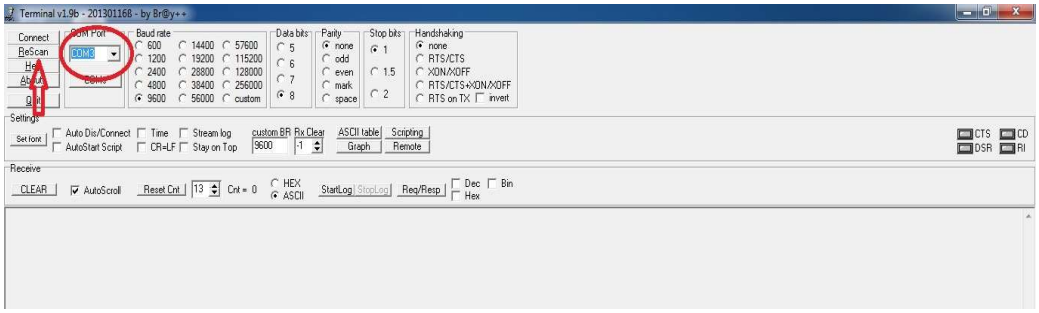

Figure 14. Computer communication port selection.

9. **Data should be recorded each time the system is operated** (see Figure 15). Click "Start Log" and select the generated file name or create a new one. Data will be logged once the system is started. Press the 'Stop Log' button at the end of data logging. The output data via RS-232 is ASCII Data ONLY.

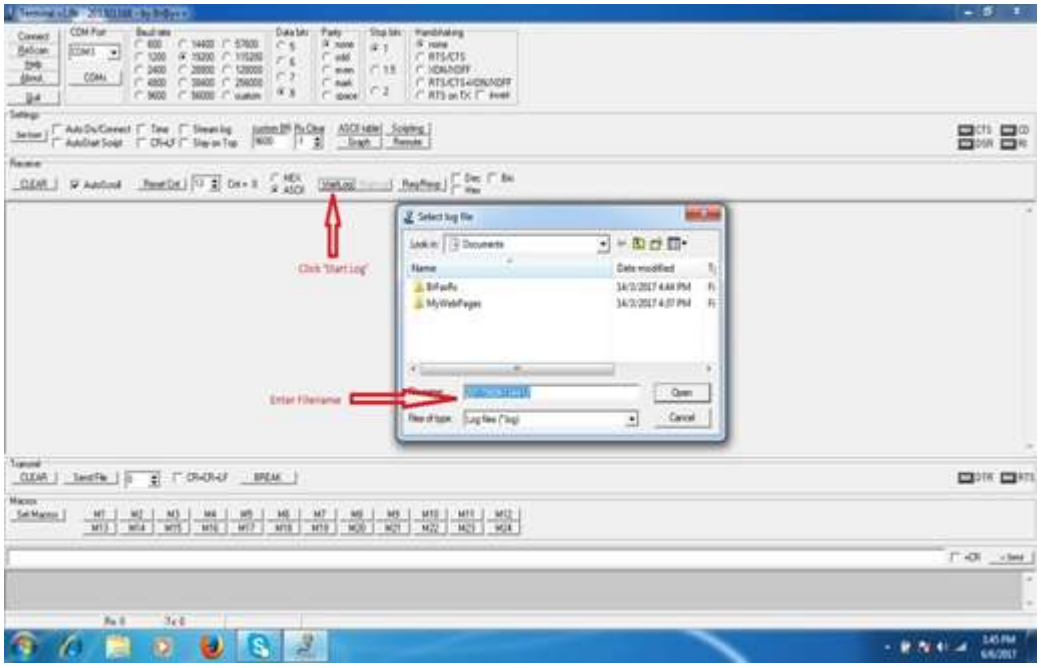

Figure 15. Data logging for Aerostak A500-45 fuel cell system.

10. When the system starts, the ASCII data can be seen on the computer screen as follows (this is an exemplary data set and may not represent the experimental data that can be obtained from A500-45 product):

****
Terminal log file
Date: 11/29/2018 - 10:39:26 AM

Welcome to HES Energy Systems
¬ System starts up...
>>11.0V 00.0A 0000W 0000Wh 22.9C 00.0V 0.91B S A05 00 012B
>>09.4V 00.0A 0000W 0000Wh 22.9C 27.8V 0.90B S A05 00 017B
>>39.1V 00.0A 0000W 0000Wh 23.1C 27.8V 0.79B S A05 00 034B
>>38.6V 00.0A 0000W 0000Wh 23.3C 27.8V 0.78B S A05 00 017B
>>38.2V 00.0A 0000W 0000Wh 23.1C 27.8V 0.88B S A05 00 012B
>>37.5V 00.0A 0000W 0000Wh 23.4C 27.8V 0.88B S A05 00 017B
>>36.9V 00.0A 0000W 0000Wh 23.6C 27.8V 0.78B S A05 00 022B
>>36.6V 00.0A 0000W 0000Wh 23.4C 27.8V 0.88B S A05 00 011B
>>36.2V 00.0A 0000W 0000Wh 23.6C 27.8V 0.88B S A05 00 022B
>>35.9V 00.0A 0000W 0000Wh 23.6C 27.8V 0.78B S A05 00 012B
>>35.6V 00.0A 0000W 0000Wh 23.6C 27.8V 0.88B S A05 00 012B
>>35.4V 00.0A 0000W 0000Wh 23.4C 27.8V 0.88B S A05 00 006B
>>35.1V 00.0A 0000W 0000Wh 23.4C 27.8V 0.78B S A05 00 003B
>>35.0V 00.2A 0007W 0000Wh 23.4C 27.8V 0.88B S A05 00 012B
>>35.6V 00.0A 0000W 0000Wh 23.6C 27.8V 0.87B S A05 00 006B
>>36.0V 00.0A 0000W 0000Wh 23.6C 27.8V 0.88B S A05 00 013B
****

1. The format of the RS232 data output is as follows:

Stack Voltage (V)	Load Current (A)	Power (W)	Energy (Wh)	Stack Temp Sensor (ºC)	Estimated Battery Voltage (V)	H_2 Supply Pressure (bar)	Operation status	SW version	Target Stack Temp Offset (ºC)	Ext. H_2 Supply Pressure (bar) (If connected)

*Note: Operation Status

S = Start Up Operation
O = Normal Operation
F = Shutdown

11. During shutting down, the following data will appear on the computer screen (this is an exemplary data set and may not represent the experimental data that can be obtained from A500-45 product).

****

>>34.5V 00.4A 0013W 0592Wh 46.1C 27.9V 0.84B O A05 20 029B
>>33.9V 00.8A 0027W 0592Wh 44.7C 27.9V 0.84B O A05 20 020B
>>33.7V 00.6A 0020W 0592Wh 43.1C 27.9V 0.84B O A05 20 026B
>>33.9V 00.0A 0000W 0592Wh 41.4C 27.9V 0.85B F A05 20 016B
>>>Manual Shutdown
>>>Entering Shutdown
>>36.4V 00.0A 0000W 0592Wh 39.5C 27.9V 0.87B F A05 20 024B
>>36.5V 00.0A 0000W 0592Wh 38.4C 27.9V 0.87B F A05 20 017B
>>36.7V 00.0A 0000W 0592Wh 36.6C 27.9V 0.88B F A05 20 008B
>>36.6V 00.0A 0000W 0592Wh 35.3C 27.9V 0.87B F A05 20 004B
>>36.7V 00.0A 0000W 0592Wh 33.7C 27.9V 0.87B F A05 20 002B

>>>Bye

Date: 11/29/2018 - 3:22:06 PM
End log file
****

4.5 FUEL CELL SYSTEM START UP

Once setup is complete, turn on the hydrogen supply and press the ON/OFF button once for approximately 3 seconds. The system will perform a startup sequence.

1. During startup, the cooling fans will first be turned on and run at high speed. Then the main hydrogen supply valve will open and followed by the purge valve cycling 7 times.
2. The startup sequence will take about 15 seconds to complete. Once this sequence complete, the system is ready to operate.
3. Apply the load and gradually increase until the desired the value is achieved. The rated power output for this system is 500 W (continuous). A temporary peak power output of 600 W is only available for short durations. Do not exceed the peak power of the system. Doing it so may cause a permanent damage.

4.6 FUEL CELL SYSTEM SHUT DOWN

Shut down the system by first turning off the external load. Then, press the ON/OFF button for 3 seconds to start the shutdown sequence.

1. The system will perform a purging sequence to remove water present in the anode side.
2. The LED light in the ON/OFF button will turn off indicating the shutdown is completed.
3. Manually disconnect the battery from the system. Failure to do so will cause permanent damage to the battery.
4. Turn off the hydrogen supply.

5. STORAGE AND CONDITIONING

5.1 PRODUCT STORAGE AND CONDITIONING

The Aerostak should be sealed in its original packaging and in an air-tight bag without moisture absorber (no silica gel desiccant) and stored in a cool (preferably at room temperature) and clean place. If the stack is stored for more than a month without any operation, the proton conducting membrane will lose moisture. This drying will lead to an overall lower fuel cell system performance due to an increase in the ionic resistance of the membrane. HES recommends periodically conditioning of the fuel cell system at least once a month in order to maintain its optimum electrochemical performance. Conditioning consists of operating the fuel cell system at 350 W to 450 W for about 0.5 hour to 1 hour each month. This will re-humidify the membrane components and maintain the performance.

5.2 SYSTEM OVERHAUL

The customer should return the power system to HES for maintenance/overhaul (at an additional cost) once the fuel cell stack's life time exceed 500 hours of operation or 1 year whichever comes first.

6. FUEL CELL STACK CONDITIONING

Closed-anode / closed-cathode based fuel cell stacks would usually require heavy external humidification devices to maintain the ionic conductivity of the proton exchange membrane and heavy fuel cell systems are not suitable for aerospace applications, particularly for drone (such as fixed-wing, multi-rotor, VTOL, etc.) applications. HES fuel cell stacks are based on the open-cathode technology and a self-humification approach (also known as fuel cell stack conditioning) is being used to yield lightweight fuel cell systems for aerospace applications. Stack conditioning eliminates the need for a heavy external humidification device. To maintain the ionic conductivity of the membrane, the fuel cell stack conditioning process is implemented electronically every 10 seconds. During the conditioning event, fuel cell stack is disconnected from the external load for ~100 milliseconds and short circuited for the same time duration. This short-circuiting phenomenon produces water at the cathode and hydrates the membrane, hence maintaining the ionic conductivity of the membrane. During fuel cell stack conditioning event, the external load is powered by the LiPo battery.

Fuel cell stack conditioning is carried out automatically and does not need any intervention by the user.

7. TROUBLESHOOTING

The electronic control board has several safety features to protect the system from faulty operation and prevent further damage to the A500-45 product. If the following ***warning*** messages are shown on the PC monitor during the regular operation of the product, perform the corrective actions accordingly.

No.	Warning code	Warning Description	Suggestion/Action
(i)	StackTemperature>MAX1	High stack temp warning; > 67 °C	Reduce the load and allow the stack to cool down.
(ii)	StackVoltage<MIN1	Low stack voltage warning; < 0.6 V/cell	Reduce the load.
(iii)	BatteryVoltage<MIN1	LiPo Low warning; < 3.4 V/cell	Turn the system off and charge the battery with an external charging unit.
(iv)	Pressure>MAX2	High pressure warning for H_2 fuel supply; > 1.3 Bars	Reduce the H_2 supply to the fuel cell system. Adjust the pressure regulator if a lab gas cylinder is the used.
(v)	Pressure<MIN1	Low pressure warning for H_2 fuel supply; < 0.45 Bars	Check and make sure the supply tubing is not blocked or pinched. Check gas supply pressure in the H_2 cylinder.

If one of the following ***errors*** occurred during the regular operation of the product, the error messages will be shown on the PC display and the system will shut down.

No.	Error code	Error Description	Suggestion/Action
(i)	StackTemperature>MAX2	High stack temperature error! Too high; > 70 °C	Disconnect the load and allow the stack to cool down.
(ii)	StackVoltage<MIN2	Low stack voltage error! Too low; < 0.5 V/cell	Disconnect the load.
(iii)	Pressure<MIN2	Low pressure error! Too low H_2 gas pressure in the cylinder; < 0.4 Bars	Reduce or Turn Off the load.
(iv)	BatteryVoltage<MIN2	LiPo battery voltage too low; < 3.0 V/cell	Turn Off the system, check the health status of the LiPo battery and then and charge the battery if it is not over-discharged. If the battery is over-discharged, use a new LiPo battery module. It is unsafe to charge an over-discharged LiPo battery. User is strongly advised to follow the instructions of the LiPo battery manufacturer for over-discharge conditions.

The System will not start if one of the following conditions occurs during the start-up sequence.

No.	If	Description	Suggestion/ Action
(i)	Starting Stack Temperature >60C	Stack temperature warning during the startup sequence	Cool down the stack.
(ii)	Stack Voltage <36V	Low stack open circuit voltage during the startup sequence	During the system start up, the fuel cell stack is not providing the desired open circuit voltage value for the entire stack. Check if the hydrogen supply is on. Observe if there is purging during start up or any hydrogen leakage.
(iii)	Pressure < 0.50B	Low pressure error during the startup sequence	Check and make sure the H2 supply tubing is not blocked or pinched. Check that the H2 gas supply is on.