Humidicore™ Application Manual

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The Humidicore™ is covered by the following U.S. patents: 6,013,385
6,436,562
6,780,227

Other foreign patents are pending.

1.0 Principle of Operation

The Humidicore™ belongs to a class of heat exchangers known as enthalpy wheels. As the name implies, it's a wheel, it turns and it exchanges both sensible and latent heat (enthalpy). Enthalpy wheels are most commonly used in HVAC applications where the heat exchange devices recover energy from ventilating exhaust streams. In those applications the temperatures and pressures are near ambient. The Humidicore™ works exactly the same way but is uniquely designed to operate at higher temperatures and pressures with little cross leakage. The main application for the Humidicore™ enthalpy wheel is to humidify incoming gas streams to fuel cells using moisture and thermal energy in the exhaust streams that would otherwise be wasted.

Figure 1-1 shows a cutaway view of the Humidicore™. Hot, moist fuel cell exhaust flows through one half of the rotating core. Cold, dry fresh air flows in the opposite direction through the other half of the core. The core is a honeycomb material that allows the air streams to flow through freely. End seals divide the core and minimize cross contamination between the two streams.

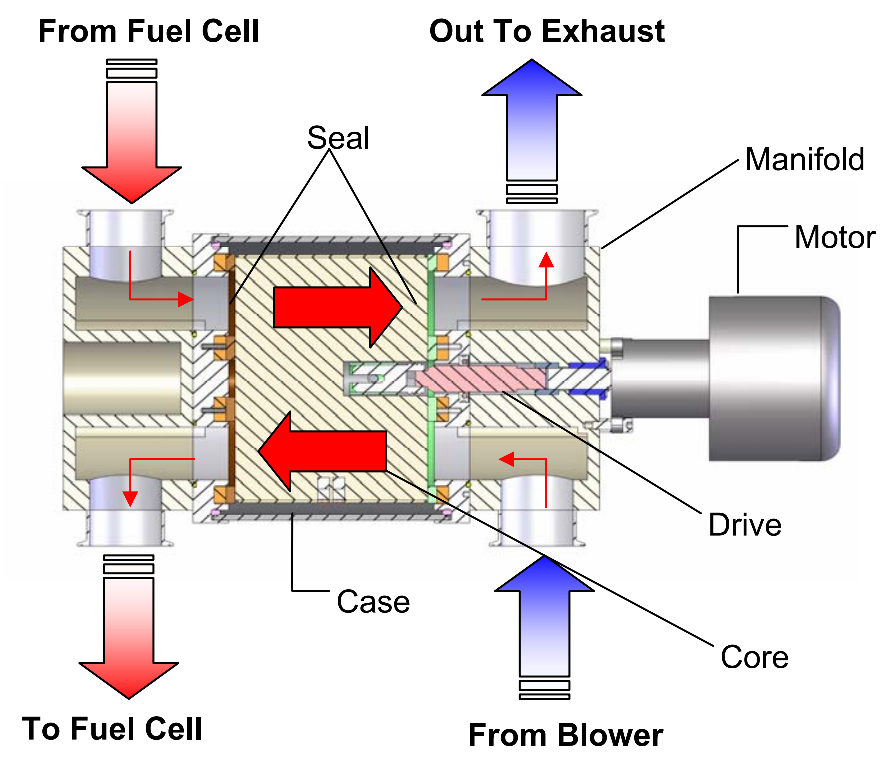

Figure 1-1

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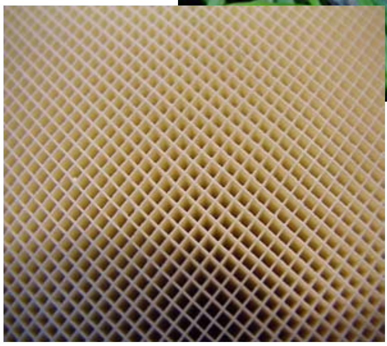
More about Cordierite

The Emprise Fuel Cell Humidifier uses a ceramic honeycomb material. Its dominant chemical composition is Cordierite ($2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$). Properties include:

- Low pressure drop
- High structural strength
- Chemically inert
- Lightweight
- High surface area
- Low cost
- Dimensionally stable
- Long life



In addition, Cordierite is currently in mass production. It is commonly used in automotive catalytic converters and costs as little as 30 cents per cubic inch.

The unique properties of Cordierite allow the construction of a simple, inexpensive and almost indestructible enthalpy wheel. The rotor is a unitary cylinder of the honeycomb material shown above. The contact type end seals act directly against the honeycomb to form very efficient labyrinth seals. The very low thermal expansion rate of Cordierite greatly simplifies the sealing system by minimizing axial growth during operation.

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Figure 1-2

The core material is a ceramic called cordierite. Cordierite is a strong, inert material that is typically used in automotive catalytic converters (see Figure 1-2). In the Humidicore™ application the core is coated with a desiccant instead of a catalyst. As the hot, moist air travels through the core, the desiccant adsorbs the moisture and the mass of the cordierite absorbs the sensible heat. As the wheel turns, this energy (sensible and latent heat) transfers to the cooler, drier fresh air stream. The speed of rotation of the core controls the amount of energy transferred. Typically, 65 to 85% of the energy in the exhaust transfers to the inlet stream while only 1 to 2% of the flowing gas leaks from the fresh to the exhaust.

The two forms of energy transfer (sensible and latent heat) occur independently. Energy always moves from the stream with the higher potential to the one with the lower potential. In some applications sensible and latent heat move together but in others, they move in opposite directions. In high pressure fuel cell applications, sensible heat from the compression cycle moves from the inlet stream to the exhaust while latent heat from the fuel cell moves from the exhaust stream to the inlet.

All Humidicore™ materials are compatible with deionized water. The seal system withstands about 5 psid (0.34 bar) and the design pressure for the case and end caps is about 30 psig (3 bar abs). Seal and case materials vary to suit each application.

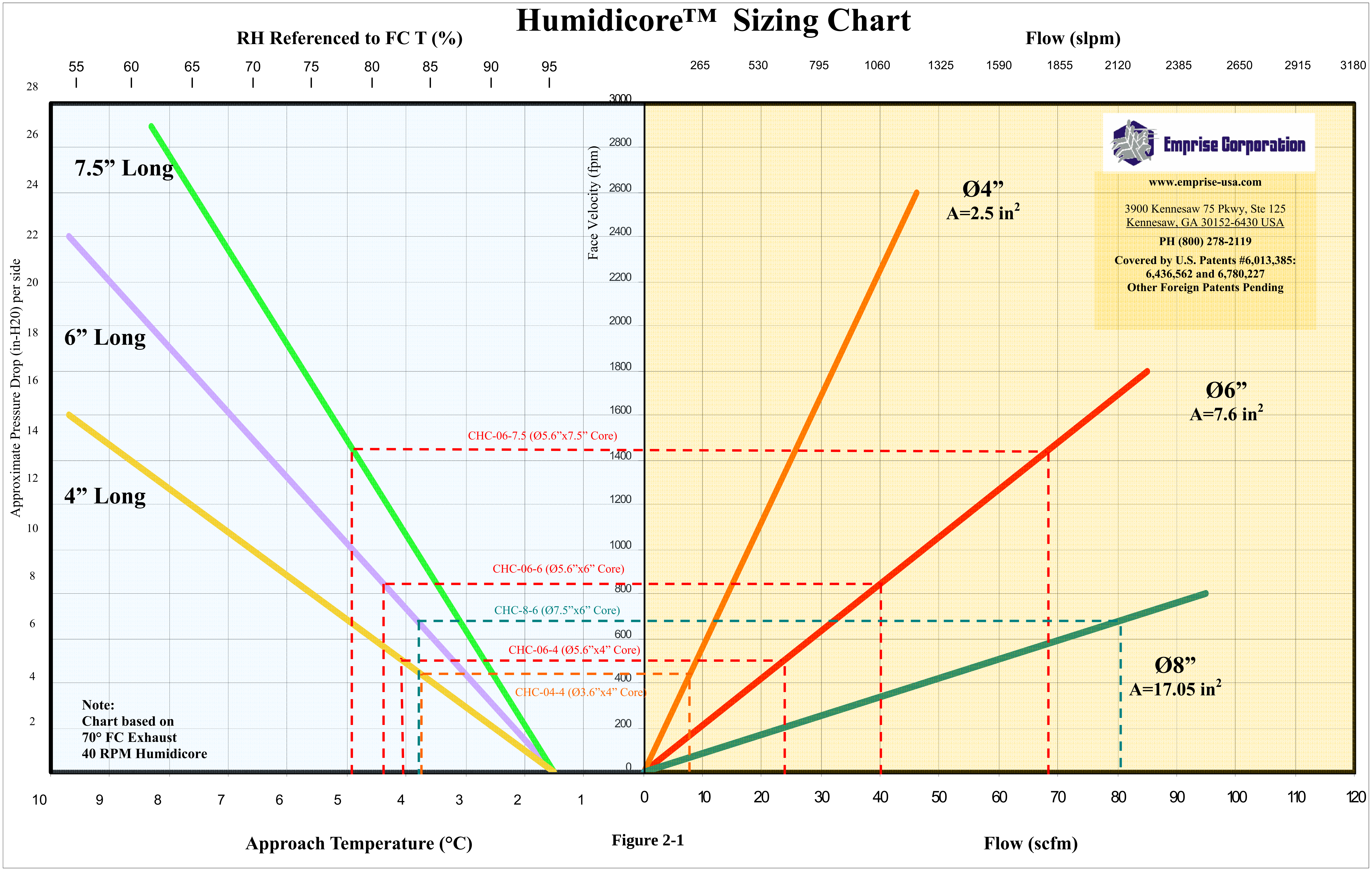
The brushless direct current drive motor with integral speed controller rotates the core up to 60rpm. Voltage, speed command and feedback signals vary to suit the application.

2.0 Picking the Right Size

The performance of the Humidicore™ depends on several factors but the most important are wheel speed and face velocity. Increasing wheel speed increases enthalpy transfer but this effect begins to fade at about 50 rpm. Decreasing face velocity increases enthalpy transfer. The face velocity is a direct function of the volumetric flow rate and the diameter of the core. The core length is also very important. Enthalpy transfer increases with core length.

Figure 2-1 is a handy chart for use with low pressure applications most often associated with atmospheric pressure fuel cells. To use this chart, determine the maximum flow rate (scfm or slpm) and approach temperature and pressure drop you need. The approach temperature is the difference between the fuel cell exhaust dew point temperature and the desired fuel cell inlet dew point temperature.

Figure 2-1 shows conditions for a 70°C fuel cell exhaust dew point and a 40 rpm wheel speed but it gives a good estimate for most fuel cell applications. It shows approach temperature achieved by various combinations of core diameter and length. The ordinates show approximate face velocity and pressure drops per side. This is approximate because it is very dependant on the size of pipe connections and the aerodynamic design of the manifolds. The abscissas show inlet air flow rate and approach temperature.



Humidicore™ Sizing Chart
RH Referenced to FC T (%)
55 60 65 70 75 80 85 90 95
Flow (slpm)
265 530 795 1060 1325 1590 1855 2120 2385 2650 2915 3180
Approximate Pressure Drop (in-H20) per side
28 26 24 22 20 18 16 14 12 10 8 6 4 2
Face Velocity (fpm)
3000 2800 2600 2400 2200 2000 1800 1600 1400 1200 1000 800 600 400 200 0
7.5" Long
6" Long
4" Long
CHC-06-7.5 (Ø5.6"x7.5" Core)
CHC-06-6 (Ø5.6"x6" Core)
CHC-8-6 (Ø7.5"x6" Core)
CHC-06-4 (Ø5.6"x4" Core)
CHC-04-4 (Ø3.6"x4" Core)
Ø4"
A=2.5 in2
Ø6"
A=7.6 in2
Ø8"
A=17.05 in2
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Covered by U.S. Patents #6,013,385:
6,436,562 and 6,780,227
Other Foreign Patents Pending
Note:
Chart based on
70° FC Exhaust
40 RPM Humidicore
10 9 8 7 6 5 4 3 2 1 0 10 20 30 40 50 60 70 80 90 100 110 120
Approach Temperature (°C)
Flow (scfm)

Figure 2-1

Enter the chart by marking your desired flow rate and drawing a vertical line there. This line will cross one or more of the core diameter lines. At each crossing point, trace a horizontal line over to the left side of the chart. There it will cross the three standard core length lines. At these crossings, trace another vertical line to the approach temperature scale.

You should have one or more solutions of core diameter and length to consider. Pick the one that gives you the desired approach temperature and pressure drop. You may also consider packaging dimensions for your specific application. Typically, practical solutions have a face velocity in the 500 to 1,000 fpm (2.5-5.0 m/s) range but any face velocity that yields the results you need is fine.

For high pressure applications the process is a little different. Figure 2-2 compares face velocity with delivery relative humidity (RH) referenced to the cathode operation temperature. Calculate your maximum actual cubic feet per minute (acfm) and your desired RH at the stack inlet. The horizontal "RH" line should intersect the family of lines representing the various core lengths. At each intersection, note the "face velocity" on the abscissa. Determine your face velocity for each cartridge size as follows:

Table 2-1

Nominal Core Diameter	Face area (ft^2)	Face velocity (fpm) acfm ÷ face area
4	0.0271	
6	0.0528	
8	0.1184	

Draw these face velocity lines on Figure 2-2. Solutions exist where these vertical lines intersect one of the families of core length lines above the desired RH line. Thus you may have several diameter/length choices for your engine.

In both low and high pressure applications, it is possible to operate cartridges in parallel or series to achieve conditions outside those on the chart.

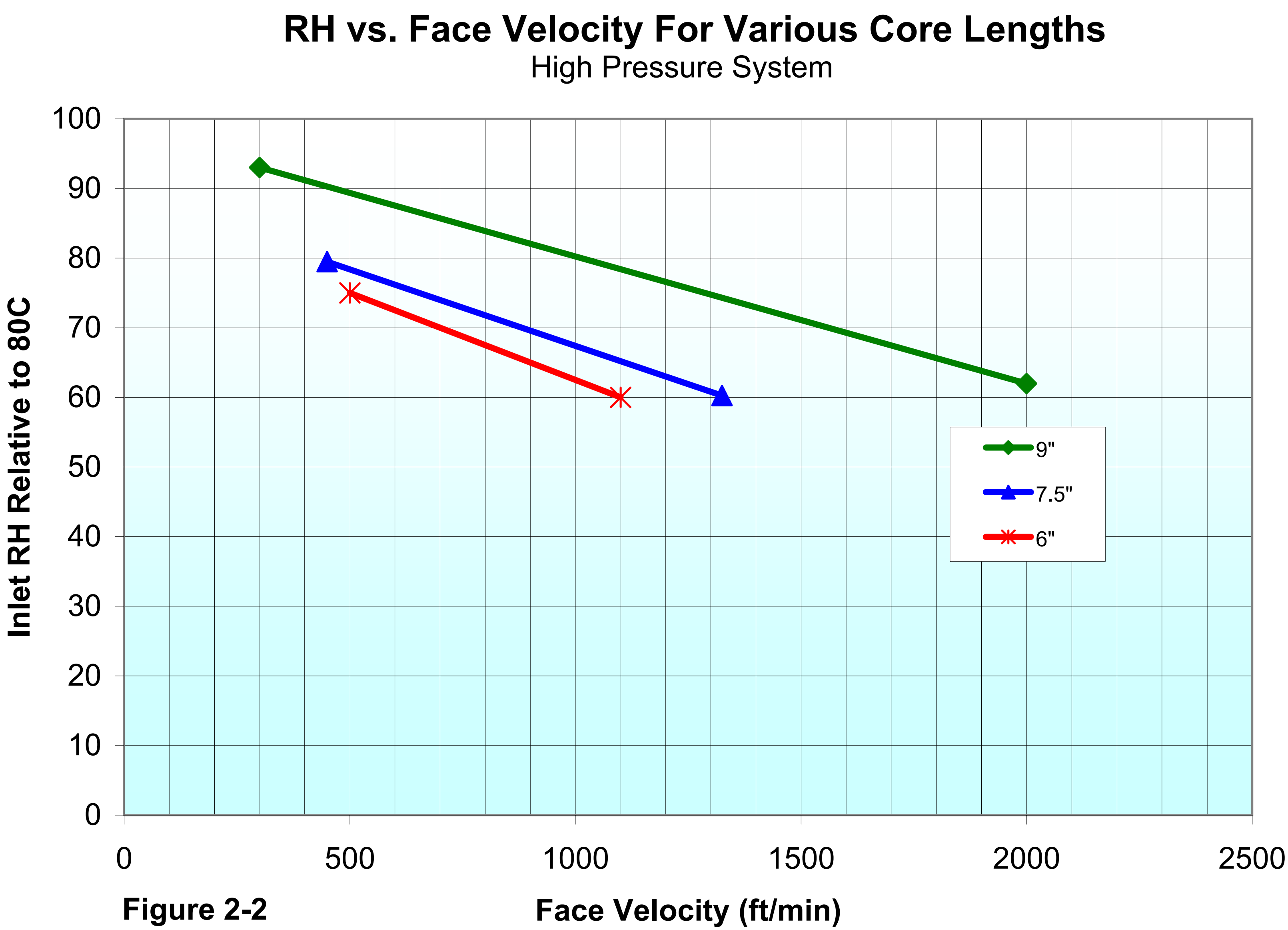

RH vs. Face Velocity For Various Core Lengths
High Pressure System
Inlet RH Relative to 80C
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
2500
Face Velocity (ft/min)
9"
7.5"
6"

Figure 2-2

3.0 Cartridge Details

The cartridge concept is widely used in everyday products. Oil and air filters, for example, are mass produced in a range of sizes and shapes. Designers pick the element they need and design their engine to use it. This way, a few element designs can be mass produced and everybody benefits from the cost savings. The fuel cell industry must achieve similar cost reductions if it is to succeed.

It seems that every fuel cell engine package is different. With respect to the humidifier, our clients want different nozzle sizes and orientations. Some want long skinny units and some want short fat ones. Everybody wants a different motor.

The Humidicore™ cartridge is simply the enthalpy wheel and container without the end manifolds and motor. The cartridge includes the essential "element" but leaves the integration to the engine designer. Figure 3-1 describes the current production cartridge models.

By eliminating "custom" humidifiers, Emprise hopes to provide a line of standardized mass produced humidifier cartridges to the fuel cell industry. Another advantage is that all wearing components (bearings, seals and rotors) are included in the cartridge. When it wears out, simply replace it!

Humidicore™ cartridges include our patented cordierite rotor in a hard anodized aluminum case. It operates from vacuum to 3 atmospheres absolute and up to 200º Celsius.

4.0 Manifold Design

The cartridge concept allows fuel cell plant designers the maximum flexibility for piping arrangements. By designing a custom manifold, you can connect to the Humidicore™ cartridge as you please.

However, Emprise offers a line of standard manifolds that also offers some flexibility. Figure 4-1 illustrates the basic manifold blank. Starting from this blank, we can cut nozzle openings in several ways as shown in Figure 4-2. Basically, the nozzles can penetrate the manifold blank from the top or sides or some combination of orientations. The nozzle port is usually a standard NPT size but other fittings are possible within the geometry of the blank.

The manifold blanks may be made from hard anodized aluminum, type 316 stainless steel or various plastics such as Celcon.

As you consider manifold designs, remember that most of the Humidicore™ pressure loss comes from the nozzle dump loss. It is a good idea to keep manifold flow velocities low. Smooth, well distributed flow at the core face minimizes pressure drop and improves Humidicore™ performance.

Cartridge Humidicore

NOTES:

1. Up to 30 psig all models
2. Hard anodized aluminum construction (Housing and End Plates)

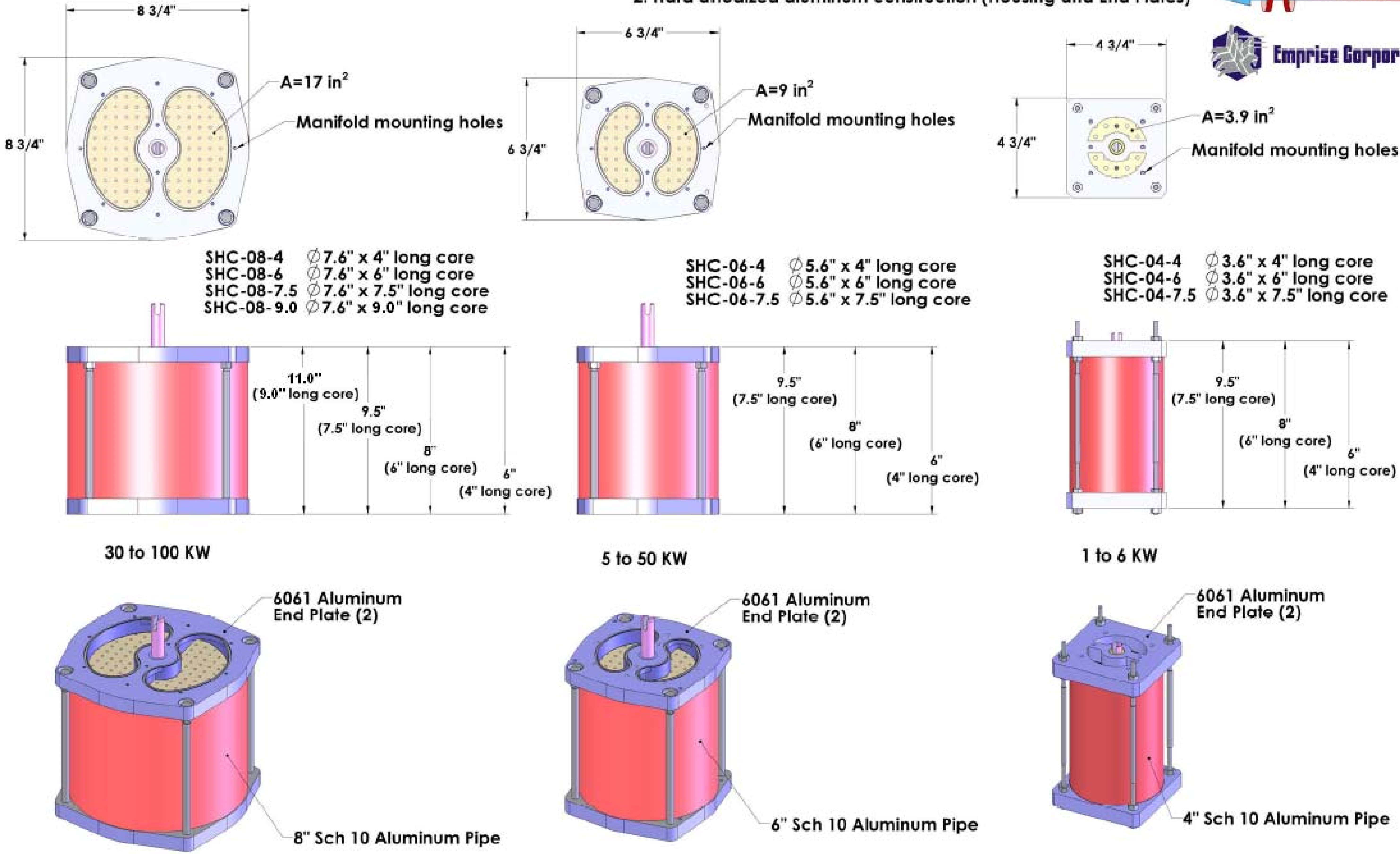
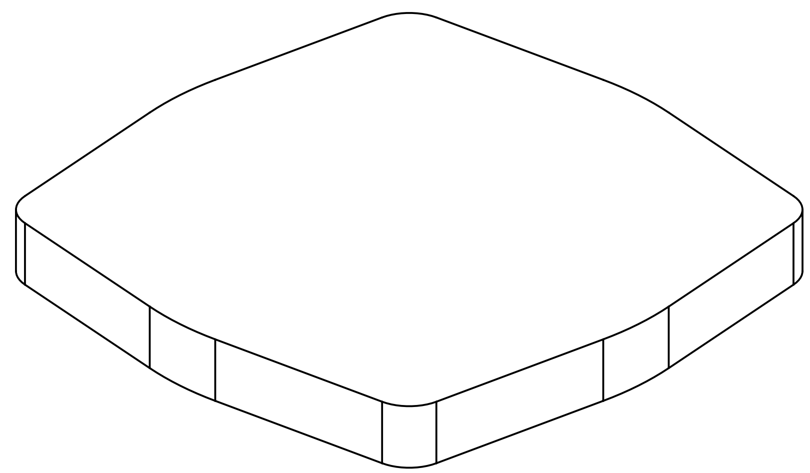
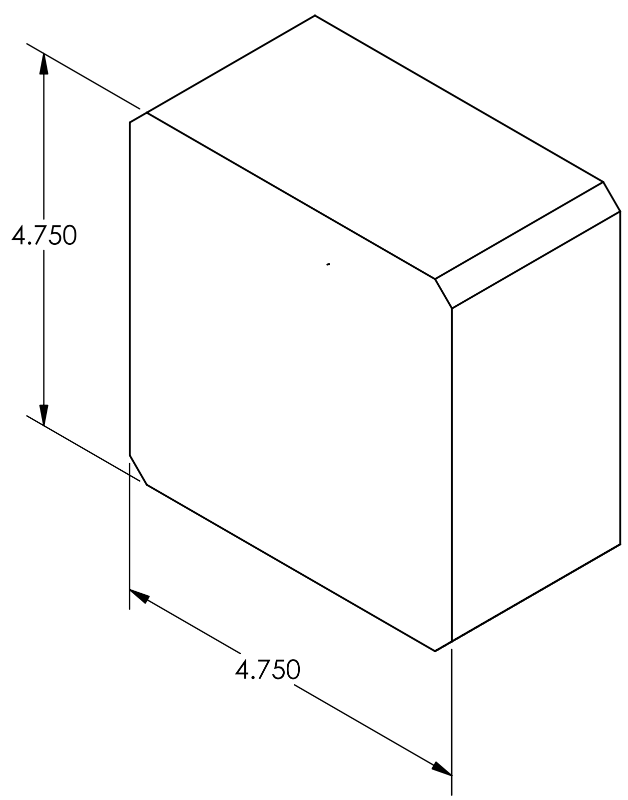


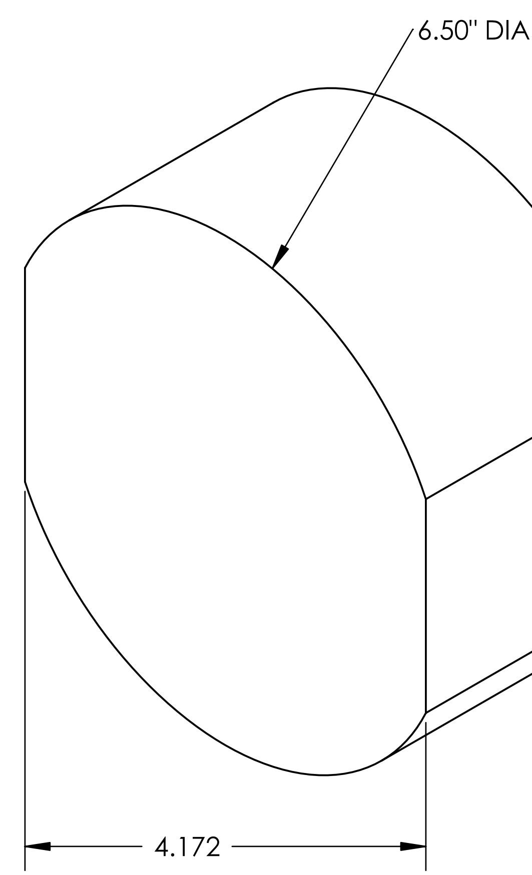
Figure 3-1



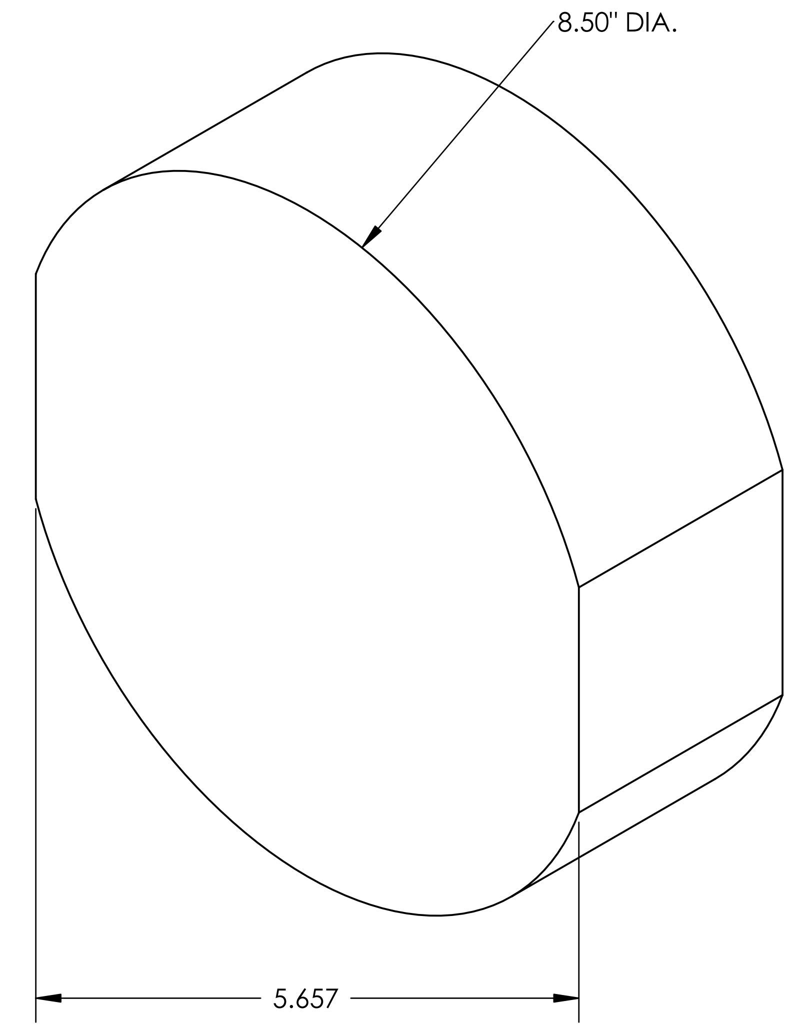
4", 6" , 8" BLANK END PLATE
(NEED NO MANIFOLD)



4" BLANK

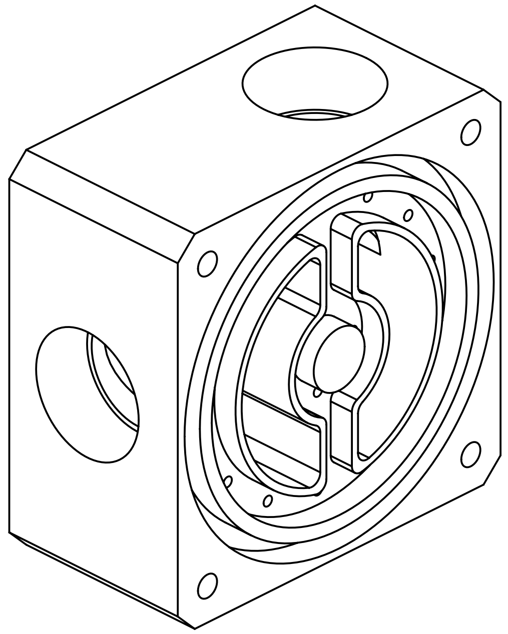


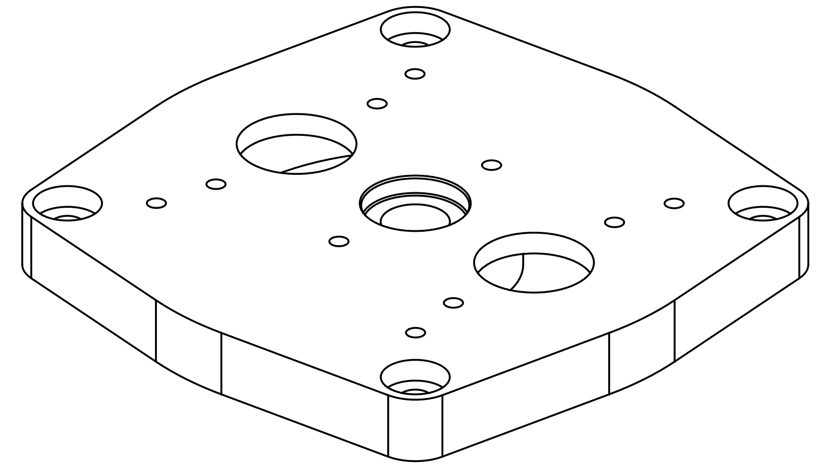
6" BLANK



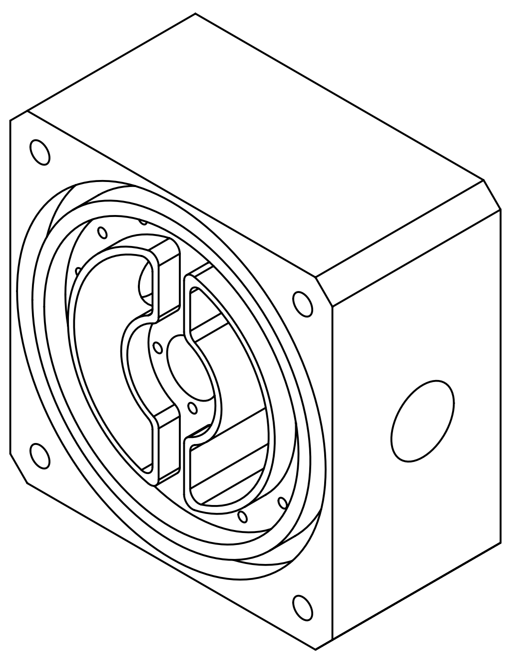
8" BLANK

FIGURE 4-1
BASIC MANIFOLD

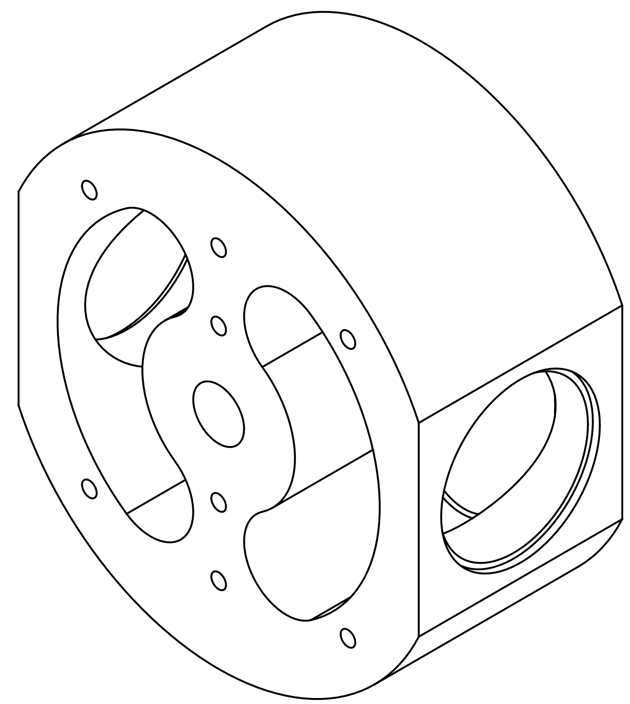




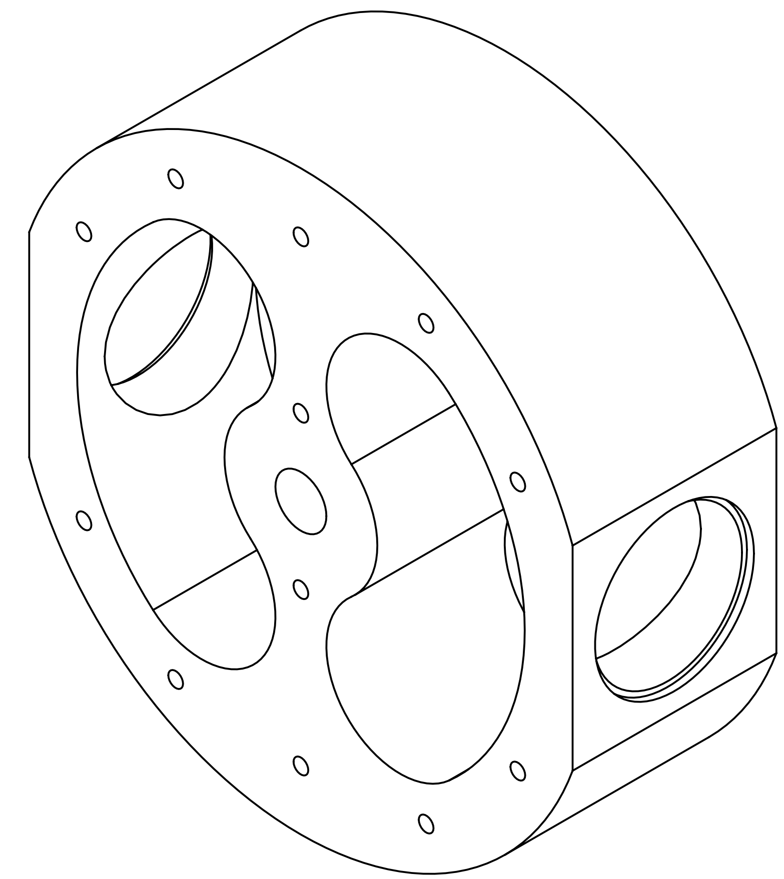
4", 6", 8" NOZZLE OPTION
3/4" NPT TO 2-1/2" NPT



4" NOZZLE OPTION
3/4" NPT TO 2" NPT



6" NOZZLE OPTION
3/4" NPT TO 2-1/2" NPT



8" NOZZLE OPTION
3/4" NPT TO 2-1/2" NPT

FIGURE 4-2
TYPICAL NOZZLE OPTIONS

5.0 Motor Options

The Humidicore™ depends upon a reliable motor to turn the core. Core rotation speed controls the outlet dew point. A variable speed motor is usually desired, although some fuel cell plants work fine at a fixed speed.

Brushless DC motors work best because of their long lives and non-sparking characteristics.

Emprise offers three motor models:

Manufacturer	Speed (rpm)	Torque (in-lbf)	Voltage (volts)	Maximum Power (watts)
Merkle-Korff (M-K)	0-55	15	12 to 36	24
Brushless Motor Corp (BMC)	0-40	30	12, 24, 48	50
Brushless Motor Corp (BMC)	40	30	12,24,48	50
Brushless Motor Corp (BMC	0-60	60	12,24, 48	111

Figure 5-1 illustrates the outline dimensions of these motors. The torque requirements of the various cartridge sizes are as follows:

Nominal Core Diameter	Torque (in-lbf)	Power Consumption (watts)
4	10	16
6	15	25
8	20	35

Any motor that meets these requirements may be used.

Figures 5-3 through 5-5 show wiring details for these motors.

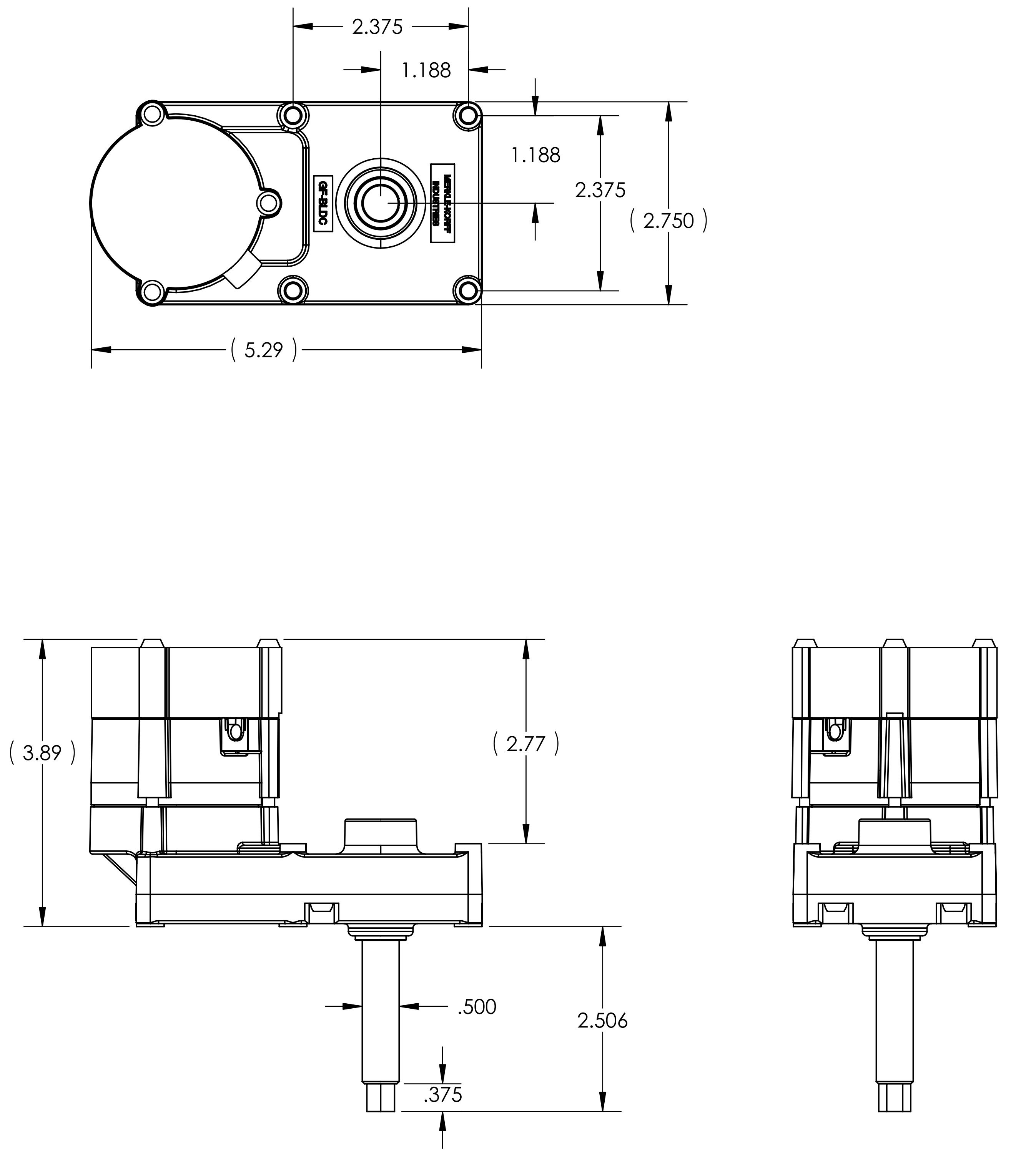
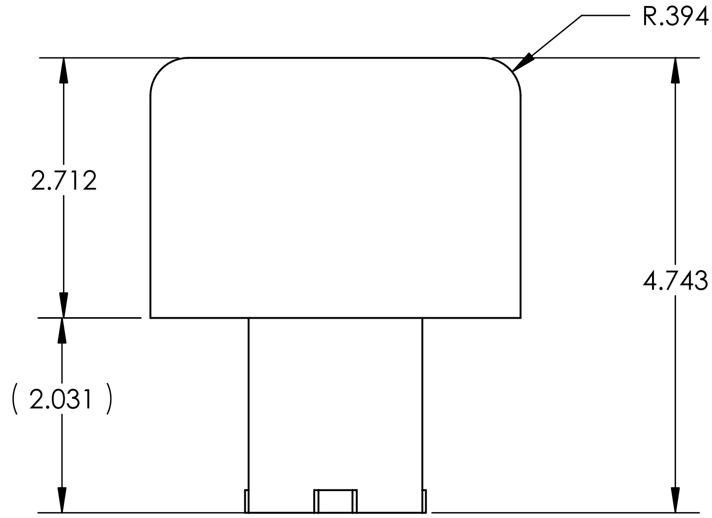


FIGURE 5-1-A
MERKLE KORFF MOTOR



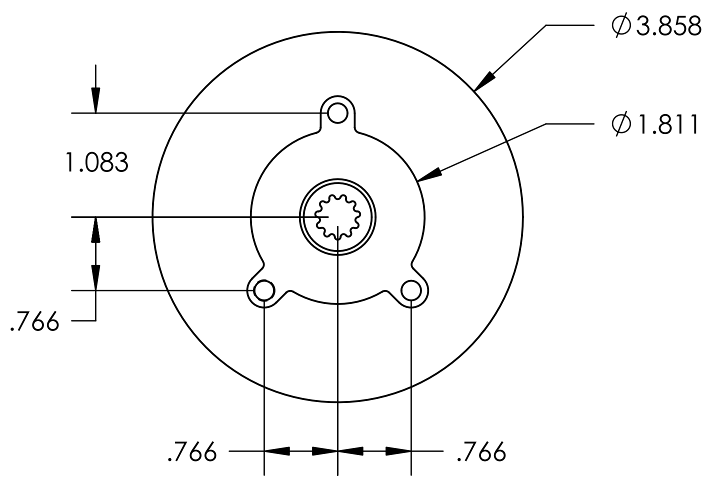
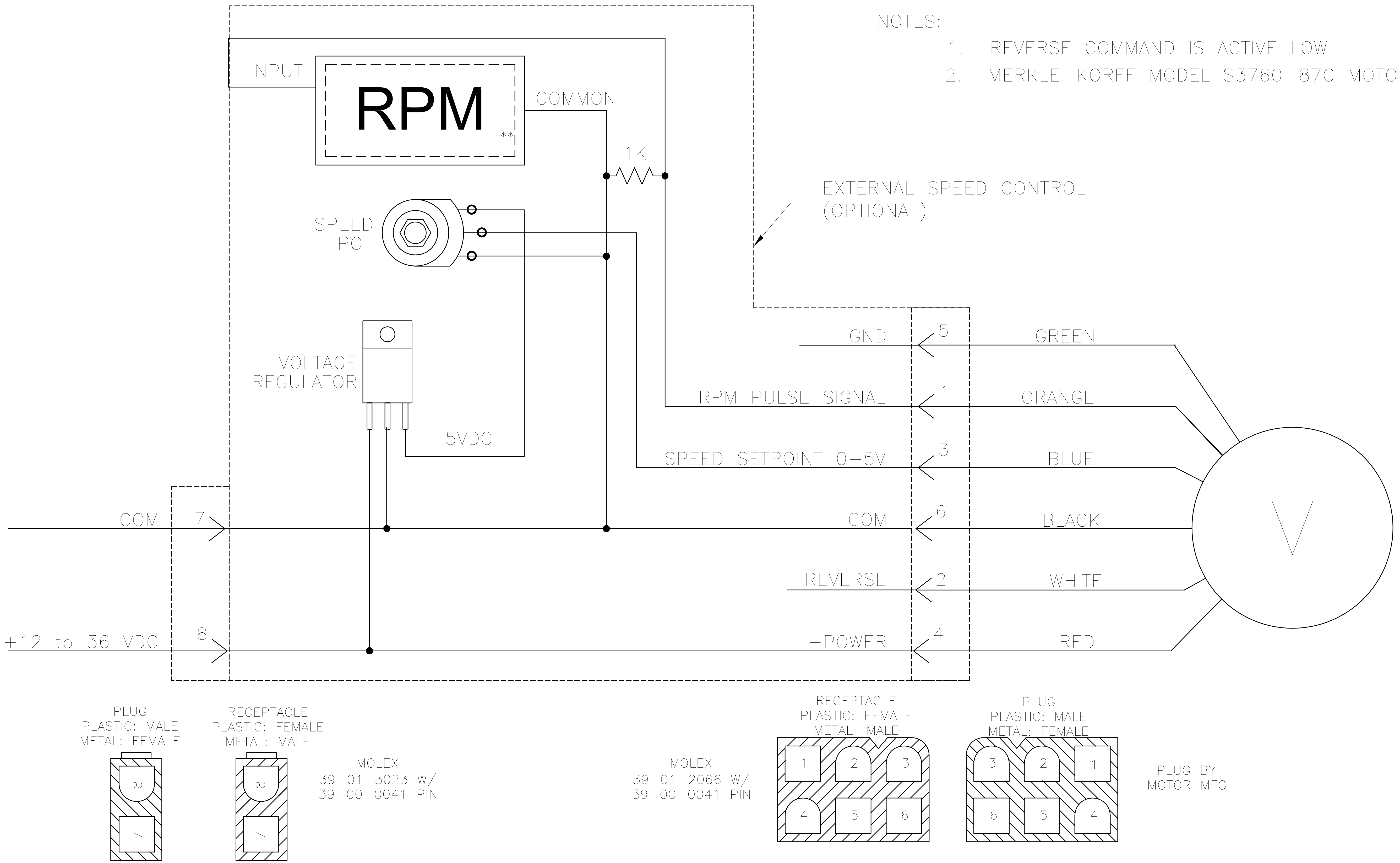


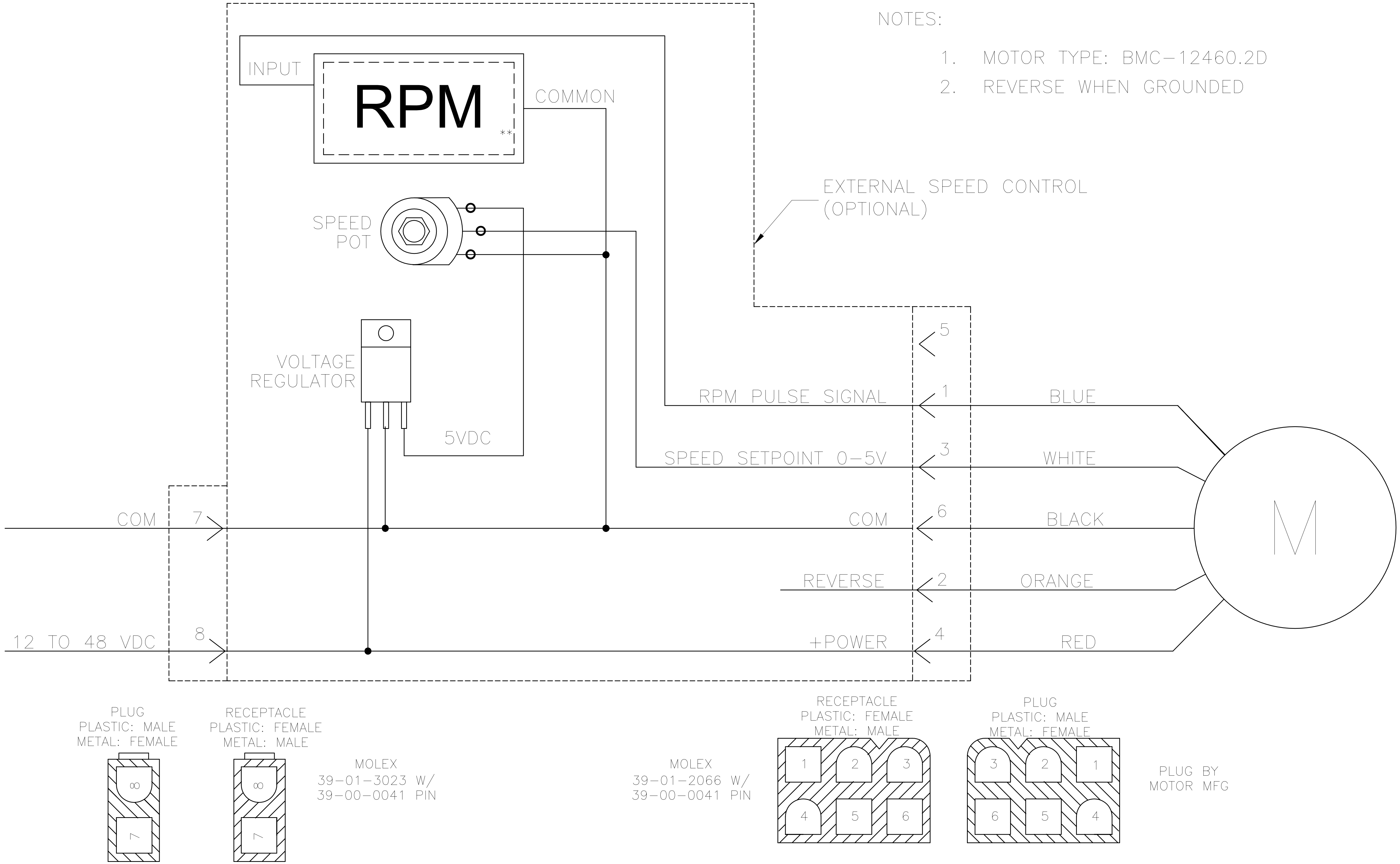
FIGURE 5-1-B
BMC MOTOR



M-K MOTOR
FIGURE 5-3

NOTES:

1. MOTOR TYPE: BMC–12460.2D
2. REVERSE WHEN GROUNDED



BMC MOTOR
FIGURE 5–4

6.0 Leakage Considerations

The Humidicore™ should not exhibit external leaks from the case. Should such leaks occur, the cause may be cut or worn "O" rings or loose fasteners. A small amount of shaft seal leakage may occur and is normal. However, excessive venting indicates a worn seal and will require a replacement seal and shaft re-surfacing.

The Humidicore™ internal face seals are designed to reduce the leakage from the fresh side to the exhaust side. Cross-over leakage in this mode consists of two components:

1) Crack flow – air leaking between the seal/core dynamic interface

2) Pump over – air carried over from the fresh side to the exhaust side in the volume of the rotating core

The crack flow component predominates, especially in the smaller wheels, but the pump-over component is noticeable in the 8 inch diameter units. It is a direct function of the core size, speed and pressure differential and can account for a third of total leakage.

The total cross-over leakage specifications for the various cartridge sizes are as follows, at 40 rpm and 3 psid (0.2 bar):

1) 4 inch diameter < 1.0 scfm (28 l/m)
2) 6 inch diameter < 1.5 scfm (42 l/m)
3) 8 inch diameter < 2.5 scfm (70 l/m)

The seal system is designed for a 5 psi (0.3 bar) differential.

7.0 Installation Considerations

The Humidicore™ is a counter flow heat exchanger. Therefore, it is mandatory that the direction of incoming fresh air flow is opposite to the exhaust flow (see Figure 1-1). It doesn't matter which side is assigned to which flow, only that the two sides be in a counterflow arrangement.

The Humidicore™ may be installed in any orientation but it must be arranged so that condensate cannot collect in the unit. Thus, the saturated flows (fuel cell side) should slope down away from the Humidicore™.

Liquid water will not permanently harm the Humidicore™ but will reduce effectiveness. Therefore, it is necessary to install a water separator between the Humidicore and the fuel cell exhaust. Other water traps may also be needed if lines carrying moist flows leave the Humidicore™ on an incline. Condensation in these lines can run back into the core and reduce performance.

The motor shaft is sealed but all seals leak a little so it is best to mount the unit with the motor on top or horizontal. Mounting the motor on the dry end is usually better than mounting it on the fuel cell or wet end. The motor end should not be arranged on the bottom, wet end as any leak will ultimately drip into the motor.

8.0 Field Service

The Humidicore™ may be removed for cleaning with warm water. This is best done by removing the manifolds, to avoid damage to the motor and to allow for a better inspection. The only field adjustment that can be made is to adjust the tension in the four tie-rods. These rods control the tension on the end face seals. As the seals wear, internal springs maintain the seal pressure. However, as the unit gets older, it may be necessary to tighten the tie-rods to maintain a low seal leakage rate.

While you have the manifold off, use a torque wrench to turn the core slowly. The 4" diameter units should require about 10 in-lbs (1.1 n-m); the 6" units about 15 in-lbs (1.6 n-m) and the 8" units about 15-20 in-lbs (1.6-2.2 n-m). If wear is excessive, the torques will be lower than specified and the tie-rods may require adjustment if cross leakage is above specifications. It is common to find an "experienced" unit that has a low torque but excellent leakage characteristics. If leakage is a problem, loosening the lock nuts and tightening the tension nuts evenly will re-establish the correct torque. Be sure that the top and bottom end plates remain parallel within ±0.005 inches (±0.13mm). When the turning torque is correct, tighten the lock nuts to prevent further movement.

9.0 Humidicore™ Advantages

The Humidicore™ offers several advantages over membrane humidifiers:

1) Higher efficiency in a smaller package
2) Core rotation speed allows fine control of humidification level
3) Lower pressure loss saves blower energy
4) Long life because there are no membranes to dry out and crack
5) Higher allowable inlet temperature eliminates the need for an after cooler in high pressure applications
6) The heat of compression is recovered for use in the turbocharger in high pressure applications
7) The drive motor typically draws less than 30 watts
8) The cartridge concept simplifies initial production and future maintenance.

Please feel free to contact Emprise with any application needs you have. We will be happy to help you select the right Humidicore™ for your fuel cell project!