Particle Physics Division

Mechanical Department Engineering Note

Number: MD-ENG-349 Date: June 20, 2011

Project: MicroBooNE

Project Internal Reference: MicroBooNE Document #1421.

Title: MicroBooNE Plate-fin Heat Exchanger Specification Version 2

Author(s): Andy Stefanik

Reviewer(s):

Key Words: E-1 plate-fin heat exchanger cooldown

Abstract/Summary: Version 1 updated to obtain final quotations.

Applicable Codes: Noted in the Specification.

Fermilab

MicroBooNE Plate-fin Heat Exchanger Specification

Version 1: Glenn Morgan December 1, 2009
Version 2: Andy Stefanik June 20, 2011

1. General Description

The heat exchanger, tag number E-1, is part of a cool down system that is used to cool a large argon cryostat in the MicroBooNE experiment at Fermilab from 300 K (80.6 °F) to 115 K (-252.4°F). A diagram in the Design Requirements section shows reference points that are used throughout this document for each flow stream. Argon gas load stream is labeled CD. Argon gas heat recovery stream is labeled AB. Nitrogen stream is labeled EF. A recirculation pump with water-cooled aftercooler is between B and C and the cryostat is between D and A.

Operating procedure: Initially, the entire system is at 300 K. Gas recirculation pump P-4 is started and initially circulates warm gas through the system with no nitrogen flow in the heat exchanger. Temperature of argon gas load stream, CD, at exit of the heat exchanger - point D, is gradually decreased at a rate of 2 K (3.6F°) per hour from 300 K (80.6 °F) to 100 K (-279.4°F) during the cryostat cool down operation. Argon gas load stream AB is cooled against liquid nitrogen stream EF and argon gas heat recovery stream CD. Liquid nitrogen enters the heat exchanger at point E as liquid with very low quality and exits at point F at a minimum temperature of 277.4 K (+40 °F) for all operating conditions. The mass flow rate of liquid nitrogen flowing through the heat exchanger is throttled with a control valve. Throttling (or varying) liquid nitrogen mass flow rate with the control valve is the only way to vary nitrogen cooling power.

In addition to cooling argon gas load stream CD, streams EF and AB will cool the heat exchanger during the cool down of the cryostat.

The heat exchanger shall have three, straight-through passes. “Straight-through” means the stream enters its pass on one end of the heat exchanger and exits on the other end of the heat exchanger without splitting inside the core. Inlet and outlet nozzles for a stream can be placed on the bottom or side of the core so each stream can enter or exit at the appropriate temperature

level. Manufacturer shall advise if three straight-through passes are not recommended for this heat exchanger and explain why.

We are concerned with the possibility of locally condensing and freezing the argon streams against the liquid nitrogen stream. Manufacturer shall check for argon freezing in the proposed plate-fin and shall address this possibility in the quotation.

The heat exchanger shall be a vertical design (all streams run in the vertical direction) with two structural support angles welded to two opposite sides of the core. The support angles on the heat exchanger will be bolted down to our support structure. Support placement on the core and bolt through-hole pattern will be finalized after order. Orientations of the inlet and outlet nozzles are to be determined by the manufacturer.

Any deviations from this specification due to conflicts between codes or design feasibility shall be brought to the attention of Fermilab for resolution. Any design requirements with a "~" symbol can be used as an approximation but must be within a suitable range determined by engineering judgment.

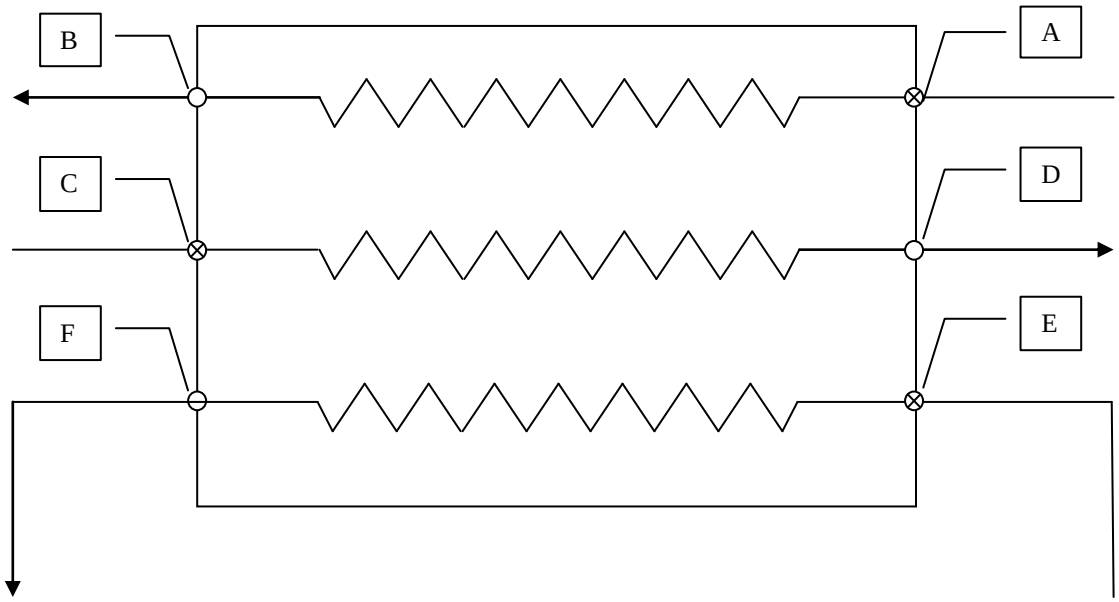
2. General Requirements—Three Stream Plate-Fin Heat Exchanger

- **a.** The heat exchanger shall comply with the current edition of the Standards of the Brazed Aluminum Plate-fin Heat Exchanger Manufacturers' Association, also known as ALPEMA. Manufacturer shall note exceptions to this Standard in the quotation.
- **b.** Design and fabrication shall be in accordance with ASME Code, Section VIII, Division 1. Unit shall be code stamped.
- **c.** Effectiveness of heat exchanger should exceed 95%.
- **d.** Pressure drop of each argon stream shall be no more than 2 psi.
- **e.** All connections shall terminate in stainless steel nozzles suitable for welding.
- **f.** Vertical, hanging orientation of heat exchanger.
- **g.** Heat exchanger design shall be checked to verify that core thermal stresses are below the allowable limit over the range of operating conditions. Manufacturer shall state any operating limits or restrictions to protect against core damage by thermal stresses.
- **h.** All streams shall be absolutely oil-free. Oil will contaminate purity of the argon streams.
- **i.** Lift points shall be provided to safely lift the heat exchanger from horizontal to vertical orientation.
- **j.** Wind load: None.

k. Seismic load: ANSI/ASCE 7-88, Minimum Design Loads for Buildings and other structures, Zone 1.

3. Design Requirements

Figure 1 - Reference points for each flow stream used throughout this document are shown in the diagram below. Argon gas load stream is labeled CD. Argon gas heat recovery stream is labeled AB. Nitrogen stream is labeled EF.



The heat exchanger shall be designed for the maximum heat transfer case defined in Table 1 and then heat exchanger performance shall be calculated at the selected operating conditions shown in Table 2. Additionally, manufacturer shall calculate performance at other operating conditions to illustrate critical operating points, such as maximum core thermal stress, etc.

Table 1 - Maximum heat transfer case

Stream/Fluid name →		Argon gas heat recovery stream	Argon gas load stream	Nitrogen cooling stream
Stream Designation - Inlet/Outlet→		AB	CD	EF
NOTE: Nitrogen flow rate based on ~5 F°/2.8 K temperature difference at the pinch point between the combined load curve and the combined cooling curve.				
Flow rate:				
Vapor In	Lbm/hr	2,212	2,212	3.9
Liquid In	Lbm/hr	-	-	92.1
Vapor out	Lbm/hr	2,212	2,212	96
Liquid out	Lbm/hr	-	-	0
Temperature:				
In	°F/K	-252.4/115	80.6/300	-318.5/78.3
Out	°F/K	~51.6/283.9	-279.4/100	~51.6/283.9
Inlet pressure	psia	16.5	24	17.3
Allowable pressure drop	psi	2	2	2
Heat Transfer	Btu/hr	84,399.20	100,744.36	16,345.16
Fouling resistance	hr-ft-°F/Btu	0.001	0.001	0.001
Design pressure	psig	50 and full vacuum	50 and full vacuum	50 and full vacuum
Design temperature max/min	°F	150/-325	150/-325	150/-325
Minimum nozzle size:				
Inlet	IPS - inches	3	3	1
Outlet	IPS -inches	3	3	1¼

Figure 2 – Heat transfer vs Temperature for maximum heat transfer case in Table 1

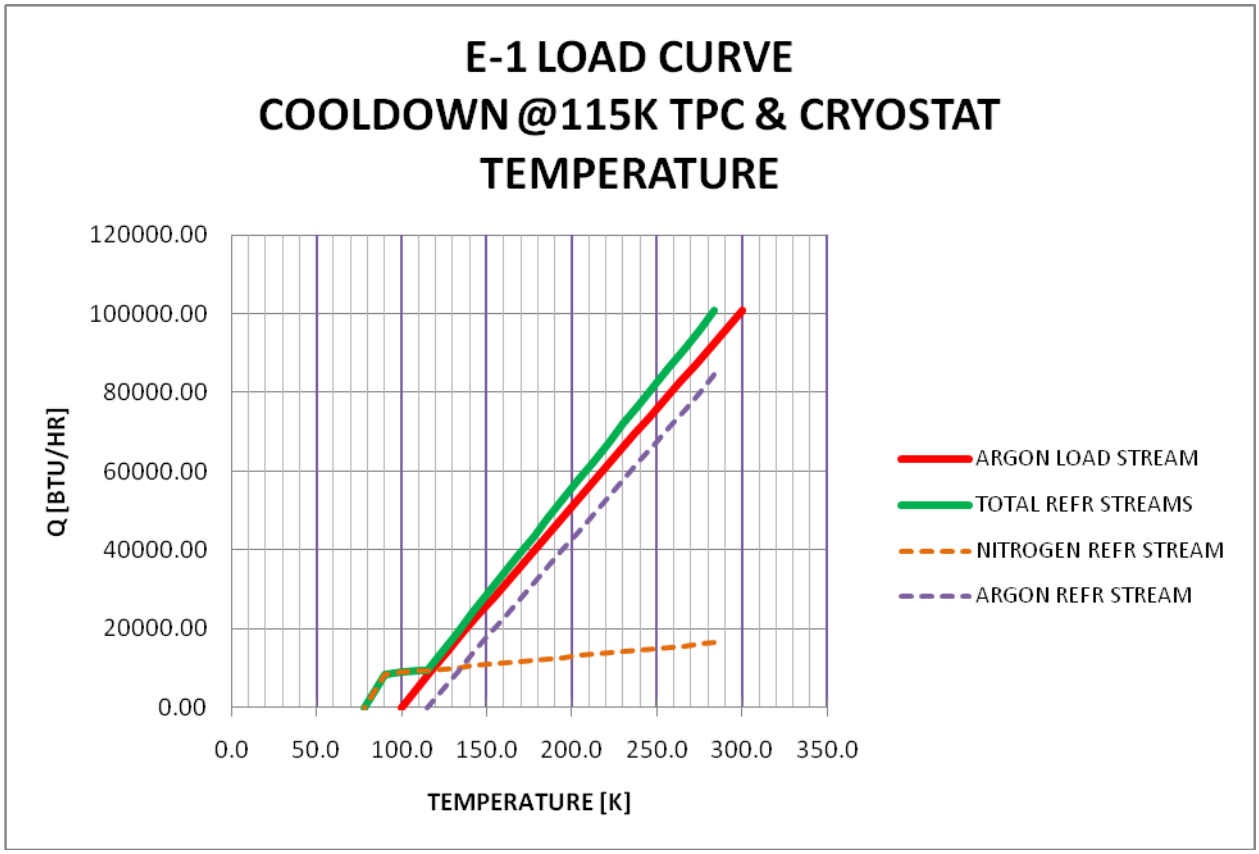

E-1 LOAD CURVE
COOLDOWN @115K TPC & CRYOSTAT TEMPERATURE
Q [BTU/HR]
120000.00
100000.00
80000.00
60000.00
40000.00
20000.00
0.00
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
TEMPERATURE [K]
ARGON LOAD STREAM
TOTAL REFR STREAMS
NITROGEN REFR STREAM
ARGON REFR STREAM

Table 2 – Calculate heat exchanger performance at these selected operating conditions as a minimum. Calculate performance at other operating conditions to illustrate critical operating points.

		Argon gas heat recovery stream	Argon gas load stream	Nitrogen cooling stream
Stream/Fluid name →		Argon gas heat recovery stream	Argon gas load stream	Nitrogen cooling stream
Stream Designation - Inlet/Outlet→		AB	CD	EF
Flow rate:				5% vapor by mass
Vapor In	Lbm/hr	2,212	2,212	Calculate
Liquid In	Lbm/hr	-	-	Calculate
Vapor out	Lbm/hr	2,212	2,212	Calculate
Liquid out	Lbm/hr	-	-	0
Temperature:				
In	°F/K	27 F°/15 K warmer than stream CD exit temperature	80.6/300	-318.5/78.3
Exit #1	°F/K	Calculate, 40 F/277.4 K min.	-9.4/250	Calculate, 40 F/277.4 K min.
Exit #2	°F/K	Calculate, 40 F/277.4 K min.	-99.4/200	Calculate, 40 F/277.4 K min.
Exit #3	°F/K	Calculate, 40 F/277.4 K min.	-189.4/150	Calculate, 40 F/277.4 K min.
Exit #4	°F/K	Calculate, 40 F/277.4 K min.	-234.4/125	Calculate, 40 F/277.4 K min.
Inlet pressure	psia	16.5	24	17.3
Allowable pressure drop	psi	2	2	2
Heat Transfer	Btu/hr	Calculate	Calculate	Calculate
Fouling resistance	hr-ft-°F/Btu	0.001	0.001	0.001

4. Leak Testing

Each passage in the heat exchanger shall be leak tested with dry, absolutely oil-free helium gas. All leak tests shall be conducted in accordance with manufacturer's standard written procedures. No detectable leaks shall be found with a sensitivity of 1×10^{-9} std. cc/sec of helium both pass-to-pass and from each pass to atmosphere. Manufacturer shall furnish a copy of the leak test report to Fermilab.

5. Pressure Testing

Each passage in the heat exchanger shall be designed for 50 psig MAWP as well as full vacuum. Fluid used for pressure testing shall be dry, absolutely oil-free nitrogen gas. The pressure and vacuum proof-tests shall be conducted in accordance with ASME Section VIII, Division 1 requirements. Manufacturer shall furnish a copy of the pressure test report and vacuum test report to Fermilab.

6. Documentation and Drawings

Outline drawings, showing overall external dimensions, size, and location of all nozzles shall be provided for approval prior to construction.

7. Shipping

The unit shall be shipped with all streams pressurized with dry, absolutely oil-free nitrogen gas to ~10 psi. Adequate packing and padding shall be provided to prevent damage while in transit.