May 2, 2011

Ms. Teresa Danforth
Subcontracts Manager
Thomas Jefferson National Accelerator Facility
12000 Jefferson Avenue
Newport News, VA 23606

Subject: Close out of CRADA JSA 2006S008

Dear Teresa:

Please find in three separate e-mails the final report of the JLab - Linde CRADA.

Based on the JLab study and calculations, Linde made the following changes to the LR1610 heat exchanger. The LR 1610 redesign changed two different aspects of the original LR1610 design. The heat exchanger and the boiler are wrapped differently than the original LR1610 per the following:

A. Heat Exchanger:

Section A :

Current LR 1610	---	2 wraps	---	1 path
Redesign	-	2 wraps	---	2 paths

Section B :

Current LR 1610	---	2 wraps	---	1 path
Redesign	-	2 wraps	---	2 paths

B. Boiler:

Current design	--	1 wrap	---	2 paths
Redesign	-	1 wrap	---	1 path

The contents of the attachments are:

1. Assembly

Pictures of the LR1610 Redesign Heat Exchanger after manufacturing

2. Drawings

3D and 2D drawings used to fabricate the Redesign LR1610 Heat Exchanger and the Precooler-Boiler.

3. Performance Curves

The expected performance curves and the TS diagram for a single proposed new compressor that is more capacity than the RSX .

4. Test Pictures

Set up bench test of the LR1610 Redesign Heat Exchanger.

5. Warm Test Data

- Warm N2 test data of the LR1610 Redesign Heat Exchanger.
- Warm test data of the LR1610 Redesign Heat Exchange vs. the warm test data of the two standard LR1610 heat exchangers.

Sincerely,

John B. Urbin
Business Unit Manager
Linde Cryogenics
A Division of Linde Process Plants, Inc.
Phone: (918) 477-1341
E-Mail: john.urbin@lppusa.com

/jr

5/18/2009

NO.	REVISION / ISSUE	BY	CHK.	REVIEW	APPR.	DATE

PROPRIETARY AND CONFIDENTIAL
EXCEPT AS OTHERWISE AGREED IN WRITING,
THE INFORMATION AND DESIGN DISCLOSED
HEREIN ARE THE PROPERTY OF LINDE CRYOGENICS
PLANTS AND SERVICES AND MUST NOT BE
COPIED OR DISTRIBUTED OUTSIDE OFS EXCEPT
TO AUTHORIZED PERSONNEL WITHIN A COMPANY
NEED TO KNOW WHO BY THE USE HEREOF
ACKNOWLEDGE OWNERSHIP AND AGREE
TO MAINTAIN THIS INFORMATION AND DESIGN
IN STRICT CONFIDENCE.

LINDE CRYOGENICS
A Division of Linde Process Plants, Inc.
Tulsa, Oklahoma U.S.A.

Linde

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL * 1/16
ANGULAR * 30° MIN

THREE PLACE DECIMAL
THREE PLACE DECIMAL
FINISHED SURFACE RMB
THIRD
ANGLE
PROJECTION

TITLE

TYPE HX REDESIGN

SIZE B PROJECT NO. 8054944 MODIFICATION REV. 0
CAD FILE NO. BOILER-PRECOOLER SCALE NONE SHEET 1 of 1

- Notes:
1. Use plate 805I089P2 in plug unused holes.
 2. Maintain the 1.0 diameter (the real hole is .756")

5/4/2009

Corrected per shop info

805I089-C-4-29-2

Flange III

8/18/2010

																																																																																																																																																																																																																																																																																																																																																																																										</
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	----

4/29/2009

NO.	REVISION / ISSUE	BY	CHK.	REVIEW	APPR.	DATE

PROPRIETARY AND CONFIDENTIAL
EXCEPT AS OTHERWISE AGREED IN WRITING,
THE INFORMATION AND DESIGN DISCLOSED
HEREIN ARE THE PROPERTY OF LINDE CRYOGENICS
PLANTS AND SERVICES AND MUST NOT BE
COPIED OR DISTRIBUTED OUTSIDE OF THE
TO AUTHORIZED PERSONS WITH A SIGNATURE
NEED TO KNOW WHO BY THE USER HEREOF
ACKNOWLEDGES THE OWNERSHIP AND AGREES
TO MAINTAIN THIS INFORMATION AND DESIGN
IN STRICT CONFIDENCE.

LINDE CRYOGENICS A Division of Linde Process Plants, Inc. Tulsa, Oklahoma U.S.A.				TITLE TYPE: TOP AND BOTTOM VIEW	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ± 1/16 DECIMAL: ± 0.005 ANGULAR: ± 0.5°		UNLESS OTHERWISE SPECIFIED: TWO PLACE DECIMAL: ± 0.01 THREE PLACE DECIMAL: ± 0.005 FINISHED SURFACE FINISH: 32 BREAK CORNERS: R. 0.015		DO NOT SCALE THIS DRAWING THIRD ANGLE PROJECTION	
SIZE: B		PROJECT NO.:		DWG. NO.:	
CAD FILE NO.:		SCALE: NONE		SHEET: 1 of 1

TOP VIEW

BOTTOM VIEW

4/28/2009

NO.	REVISION / ISSUE	BY	CHK.	REVIEW	APPR.	DATE

PROPRIETARY AND CONFIDENTIAL
EXCEPT AS OTHERWISE AGREED IN WRITING,
THE INFORMATION AND DESIGN DISCLOSED
HEREIN ARE THE PROPERTY OF LINDE CRYOGENICS
PLANTS AND SERVICES AND MUST NOT BE
COPIED OR DISTRIBUTED OUTSIDE OF THE
TO AUTHORIZED PERSONS WITH A SIGNATURE
NEED TO KNOW WHO BY THE USE HEREOF
ACKNOWLEDGE THE CONFIDENTIALITY AND OBLIGE
TO MAINTAIN THIS INFORMATION AND DESIGN
IN STRICT CONFIDENCE.

LINDE CRYOGENICS
A Division of Linde Process Plants, Inc.
Tulsa, Oklahoma U.S.A.

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES

TOLERANCES:

FRACTIONAL ± 1/16

ANGULAR ± 0.50 DEGREE

TWO PLACE DECIMAL ± .010

THREE PLACE DECIMAL ± .005

FINISHED SURFACE FINISH

BREAK CORNERS IN: .005

TITLE	TYPE	SIZE	PROJECT NO.	DWG. NO.	REV.
TOP AND BOTTOM VIEW	B				0
CAD FILE NO.	FLANGE ARRANGEMENTS	SCALE	NONE	SHEET	1 of 1

Notes:

Item 1. Stainless Steel 304L, tube 1.0" OD x .065" W.T x 6.875" LG, P/N 35421316P36

Item 2. Stainless Steel 304, Cap, P/N 0510480

Item 3. Stainless Steel 316, 1.25" x 1.0", cut to length. P/N 0511111

Name? Name?	Name? Name? Name? Name? Name?	PROPRIETARY AND CONFIDENTIAL EXCEPT AS OTHERWISE AGREED IN WRITING, THE INFORMATION AND DESIGN DISCLOSED HEREIN ARE THE PROPERTY OF CRYOGENIC PLANTS AND SERVICES AND MUST NOT BE COPIED OR DISTRIBUTED OUTSIDE CRYOGENIC PLANTS AND SERVICES WITHOUT THE WRITTEN PERMISSION OF CRYOGENIC PLANTS AND SERVICES. TO AUTHORIZED PERSONS WITH A GENUINE NEED TO KNOW WHO BY THE USER HEREOF ACKNOWLEDGE CRYOGENIC PLANTS AND SERVICES TO MAINTAIN THIS INFORMATION AND DESIGN IN STRICT CONFIDENCE.					CRYOGENIC PLANTS AND SERVICES A Division of Linde BOC Process Plants LLC Tulsa, Oklahoma U.S.A.				TITLE					
Name? Name?	Name? Name? Name? Name? Name?	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES. TOLERANCES: FRACTIONAL ± .005 DECIMAL ± .005 ANGULAR ± .5°					DO NOT SCALE THIS DRAWING THIRD ANGLE PROJECTION			TYPE Name?	SIZE B	PROJECT NO. 10-16-2009	DWG. NO. 10-16-2009	CAD FILE NO. MANIFOLD-TOP-10-16-2009	SCALE Name?	SHEET 2 of x
NO.	REVISION/ISSUE	BY	CHK.	REVIEW	APPR.	DATE

Notes:

1. Item 1, 1.0" O.D x .065" W.T , 304 SS
P/N 0505793

2. Cap, 1.0 " OD x .065 W.t, 304SS
P/N 0510480 , quantity 2

						DISCREETARY AND CONFIDENTIAL EXCEPT AS OTHERWISE AGREED IN WRITING, THE INFORMATION AND DESIGN DISCLOSED HEREIN ARE THE PROPERTY OF CRYOSGIC PLANTS AND SERVICES AND MUST NOT BE COPIED OR DISTRIBUTED OUTSIDE CRYO EXCEPT TO AUTHORIZED PERSONS WITH A SIGNED NEED TO KNOW WHO BY THE USE HEREOF ACKNOWLEDGE OWNERSHIP AND AGREE TO MAINTAIN THIS INFORMATION AND DESIGN IN STRICT CONFIDENCE.	LINDE CRYOGENICS A Division of Linde Process Plants, Inc. Tulsa, Oklahoma U.S.A.				TITLE TYPE: HX REDESIGN	
NO.	REVISION / ISSUE	BY	CHK.	REVIEW	APPR.	DATE	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16 ANGULAR ± 30° BEND ± 3° BREAK CORNERS IN OUT THREE PLACE DECIMAL ± .030 THREE PLACE DECIMAL FINISHED SURFACE RMS ± .005 THIRD ANGLE PROJECTION		REMOVE ALL BURRS DO NOT SCALE THIS DRAWING THIRD ANGLE PROJECTION		SIZE: B PROJECT NO.: DWG NO.: LAD FILE NO.: OIL TRAP MANIFOLD SCALE: NONE SHEET: 1 of 1	REV: 0

1G10 HX - REDESIGN
TOP ARRANGEMENT 4/30/2009

①

* CLOSER TO CENTER
SEE FLANGE V 8051090-MOD
SKETCH.

1610 HX - REDESIGN

(2)

BOTTOM ARRANGEMENT

4/30/2009

"COIL FOR THE HX-A".

5/1/2009.

(3)

END TUBES OF HX-A OUT.

FLANGE VI

8051088-MOD

END TUBES OF HX-B OUT
(TO BOILER)

END TUBES OF
HX-A OUT
(TO OIL TRAP)

END TUBE
OF HX-A OUT
(TO OIL TRAP)

END TUBE OF
HX-A OUT
(4 PLACES TOTAL)

END TUBES OF HX-B OUT
(TO BOILER)

FLANGE III
8051089-MOD.

END TUBE OF HX-A
OUT (TO OIL TRAP)

REFER TO THE "TOP AND BOTTOM VIEW"
SKETCH FOR ORIENTATION.

④

CROSS-OVER TUBES - TYPICAL
COIL FOR THE HX-A.

5/1/2009

M1610- REDESIGN- PROTOTYPE

⑤

5/5/2009.

TOP VIEW.

MIGIO REDESIGN - PROTOTYPE

⑥

5/5/2009.

BOTTOM VIEW

M1610 REDESIGN - PROTOTYPE

7

5/5/2009

MIG10 REDESIGN - PROTOTYPE

8

5/5/2009.

M1610 REDESIGN - PROTOTYPE

⑨

5/5/2009.

5/5/2009.

L 1610 REDESIGN HEAT EXCHANGER FLOW TEST 9/23/2010

L1610 REDESIGN PROTOTYPE HX LOW PRESSURE SIDE 9/23/2010 REVISED 10-20-2010

PLUG THE E39 EXHAUST
THROUGH ALL HXS

PLUG THE V 308 RETURN
(FLOW OUT AT E39 EXHAUST)

CALC
HX6 FLOW
ONLY

	PRESSURE	FLOW	FLOW	PRESSURE	FLOW		FLOW
INLET	OUTLET			OUTLET			
PSI	PSI	SCFM	G / S	PSI	SCFM		SCFM
3	0	7.5		0.6	12.35		4.85
3	1	7.5		0.8	12.5		5.00
3	1	7.5		1	12.5		5.00
AVG	0.67	7.5	4.19	0.8	12.45	6.96	4.95
PRESS DROP	2.33			2.20			
SCFH		450			747		297.00
6	0.5	12		1.6	18.75		6.75
6	1	11.75		1.7	19		7.25
6	1	11.75		1.6	19		7.25
AVG	0.83	11.83	6.61	1.63	18.92	10.57	7.08
PRESS DROP	5.17			4.37			
SCFH		710			1135		425
9	1	15		2.8	23.75		
9	1	15		2.8	23.75		
9	1	15		2.8	23.75		
AVG	1.00	15	8.38	2.8	23.75	13.27	
PRESS DROP	8.00			6.20			
SCFH		900			1425		
12	1.3	16.5		4	28.5		
12	1.2	16.5		4	28.5		
12	1.2	16.5		4	28.5		
AVG	1.23	16.5	9.22	4	28.5	15.92	
PRESS DROP	10.77			8.00			
SCFH		990			1710		

	PRESSURE	FLOW		PRESSURE	FLOW
INLET	DROP			DROP	
PSI	PSI	SCFH		PSI	SCFH
3	2.33	450		2.2	747
6	5.17	710		4.37	1135
9	8	900		6.2	1425
12	10.77	990		8	1720

L1610 REDESIGN PROTOTYPE INDIVIDUAL FLOW HIGH PRESSURE SIDE SECTION A
9/23/2010

	1A	1A	2A	2A		1A + 2A	1A + 2A
INLET	OUTLET	FLOW	OUTLET	FLOW		OUTLET	FLOW
PRESSURE	PRESSURE	SCFM	PRESSURE	SCFM		PRESSURE	SCFM
PSI	PSI		PSI			PSI	
20	0.4	17.5	0.8	15		2.2	30
20	0.3	16	0.6	16			
AVG	0.35	16.75	0.7	15.5			
PRESS DROP	19.65		19.3				
SCFH		1005		930			1800
40	1	27.5	1	27.5		5.2	52.5
40	1.5	27.5	1.4	27.5			
AVG	1.25	27.5	1.2	27.5			
PRESS DROP	38.75		38.8				
SCFH		1650		1650			3150
60	2	37.5	2	37.5			
60	2.8	37.5	2.6	37.5			
AVG	2.4	37.5	2.3	37.5			
PRESS DROP	57.6		57.7				
SCFH		2250		2250			

	1A	2A	3A	4A
INLET	FLOW	FLOW	FLOW	FLOW
PRESSURE	SCFH	SCFH	SCFH	SCFH
20	1005	930	960	960
40	1650	1650	1650	1650
60	2250	2250	2250	2250

L1610 REDESIGN PROTOTYPE INDIVIDUAL FLOW HIGH PRESSURE SIDE SECTION A

9/23/2010

	3A	3A	4A	4A		3A +4A	3A + 4A
INLET	OUTLET	FLOW	OUTLET	FLOW		OUTLET	FLOW
PRESSURE	PRESSURE	SCFM	PRESSURE	SCFM		PRESSURE	SCFM
PSI	PSI		PSI			PSI	
20	0.4	16	0.6	16		1.6	32
20	1.1	16	1.2	16			
AVG	0.75	16	0.9	16			
PRESS DROP	19.25		19.1				
SCFH		960		960			1920
40	1.3	27.5	1.3	27.5		5.3	52.5
40	1.4	27.5	1.4	27.5			
AVG	1.35	27.5	1.35	27.5			
PRESS DROP	38.65		38.65				
SCFH		1650		1650			3150
60	2.6	37.5	2.7	37.5			
60	2.6	37.5	2.7	37.5			
AVG	2.6	37.5	2.7	37.5			
PRESS DROP	57.4		57.3				
SCFH		2250		2250			
80	4.4	47.5	4.4	47.5			
80	4.4	47.5	4.2	47.5			
AVG	4.4	47.5	4.3	47.5			
PRESS DROP	75.6		75.7				
SCFH		2850		2850			

L1610 REDESIGN PROTOTYPE INDIVIDUAL FLOW HIGH PRESSURE SIDE SECTION B
9/23/2010

	1B	1B	2B	2B		1B + 2B	1B + 2B
INLET	OUTLET	FLOW	OUTLET	FLOW		OUTLET	FLOW
PRESSURE	PRESSURE	SCFM	PRESSURE	SCFM		PRESSURE	SCFM
PSI	PSI		PSI			PSI	
20	1	17.5	0.8	17.5		2	33
20							
AVG	0.5	17.5	0.4	17.5			
PRESS DROP	19.5		19.6				
SCFH		1050		1050			1980
40	1.8	27.5	1.5	27.5		6	55
40	1.8	30	2	30			
AVG	1.8	28.75	1.75	28.75			
PRESS DROP	38.2		38.25				
SCFH		1725		1725			3300
60	3.2	41	3.4	42			
60							
AVG	3.2	41	3.4	42			
PRESS DROP	56.8		56.6				
SCFH		2460		2520			

	1B	2B	3B	4B
INLET	FLOW	FLOW	FLOW	FLOW
PRESSURE	SCFH	SCFH	SCFH	SCFH
20	1050	1050	1020	1050
40	1725	1725	1800	1740
60	2460	2520	2400	2400

L1610 REDESIGN PROTOTYPE INDIVIDUAL FLOW HIGH PRESSURE SIDE SECTION B
9/23/2010

	3B	3B	4B	4B		3B +4B	3B + 4B
INLET	OUTLET	FLOW	OUTLET	FLOW		OUTLET	FLOW
PRESSURE	PRESSURE	SCFM	PRESSURE	SCFM		PRESSURE	SCFM
PSI	PSI		PSI			PSI	
20	0.6	17	0.6	17.5		1.8	32
20			1.1	17.5		1.8	34
AVG	0.6	17	0.85	17.5			33
PRESS DROP	19.4		19.15				
SCFH		1020		1050			1980
SCFH							
40	1.5	30	1.4	28		6	57.5
40			1.5	30			
AVG	1.5	30	1.45	29			
PRESS DROP	38.5		38.55				
SCFH		1800		1740			3450
60	3	40	2.8	40			
60			2.8	40			
AVG	3	40	2.8	40			
PRESS DROP	57		57.2				
SCFH		2400		2400			
80	4.8	50	4.8	50			
80			4.5	51			
AVG	4.8	50	4.65	50.5			
PRESS DROP	75.2		75.35				
SCFH		3000		3030			

L1610 REDESIGN PROTOTYPE HX HIGH PRESSURE SIDE SECTION C/ D 9/23/2010

CD1			CD2		
INLET	OUTLET	FLOW	OUTLET	FLOW	
PRESSURE	PRESSURE	SCFM	PRESSURE	SCFM	
PSI	PSI		PSI		
20	0	7	0	7	
20	1	7	1	7	
AVG	0.5	7	0.5	7	
PRESS DROP	19.5		19.5		
SCFH		420		420	
40	0.9	12	0.6	12.5	
40	1.1	12.5	1	12.5	
AVG	1	12.25	0.8	12.5	
PRESS DROP	39		39.2		
SCFH		735		750	
60	1.7	18	1.6	17.5	
60	1.5	18	1.6	17.5	
AVG	1.6	18	1.6	17.5	
PRESS DROP	58.4		58.4		
SCFH		1080		1050	
80	2.6	23	2.7	23	
80	2.6	23	2.7	23	
AVG	2.6	23	2.7	23	
PRESS DROP	77.4		77.3		
SCFH		1380		1380	
100	4.2	27.5	4.1	27.5	
100	4	27.5	4.2	28	
AVG	4.1	27.5	4.15	27.75	
PRESS DROP	95.9		95.85		
SCFH		1650		1665	

48.7
907.5

48.8
900

	PRESSURE	FLOW		PRESSURE	FLOW
INLET	DROP			DROP	
PSI	PSI	SCFH		PSI	SCFH
20	19.5	420		19.5	420
40	39	735		39.2	750
60	58.4	1080		58.4	1050
80	77.4	1380		77.3	1380
100	95.9	1650		95.85	1665

INLET	OUTLET		FLOW
PRESSURE			SCFM
PSI			
20	0		4.5
20	0		4.5
AVERAGE			4.5
SCFH			270
40	0		6.5
40	0		6.5
AVERAGE			6.5
SCFH			390
60	0		8.5
60	0		8.5
AVERAGE			8.5
SCFH			510
80	0		10.75
80	0		10.75
AVERAGE			10.75
SCFH			645
100	0		13
100	0		12.75
AVERAGE			12.875
SCFH			772.5
120	0		15
120	0		15
AVERAGE			15
SCFH			900
150	0		18
150	0		18
AVERAGE			18
SCFH			1080

	PRESSURE	FLOW
INLET	DROP	
PSI	PSI	SCFH
20	0	270
40	0	390
60	0	510
80	0	645
100	0	772.5
120	0	896
150	0	1080

		FLOW	CONVERT	CONVERT		OUTLET
PIN	P IN	METER	TO	TO		PRESSURE
		READ OUT	G / S OF	G / S OF		BEFORE
PSI	PSIA	SCFM OF	NITROGEN	HELIUM		FLOW
		AIR				METER
PLUG THE EXPANDER E 39 EXHAUST ---- FLOW THROUGH ALL SECTIONS						
3	17.7	7.5	4.19	1.58		0.67
6	20.7	11.83	6.61	2.50		0.83
9	23.7	15	8.38	3.17		1
12	26.7	16.5	9.22	3.49		1.23
PLUG THE V 308 VALVE ---- FLOW BY- PASS THE LAST SECTION HX-6						
3	17.7	12.45	6.96	2.63		0.8
6	18.92	11.83	6.61	2.50		1.63
9	23.75	15	8.38	3.17		2.8
12	28.5	16.5	9.22	3.49		4
HX - 1A						
20	34.7	16.75	9.36	3.54		0.35
40	54.7	27.5	15.36	5.81		1.25
60	74.7	37.5	20.95	7.92		2.4
80	94.7	47.5	26.54	10.03		4.4
HX - 4B						
20	34.7	17.5	9.78	3.70		0.85
40	54.7	29	16.20	6.13		1.45
60	74.7	40	22.35	8.45		2.8
80	94.7	50.5	28.21	10.67		4.65
HX - C & D						
20	34.7	7	3.91	1.48		0.5
40	54.7	12.25	6.84	2.59		1
60	74.7	18	10.06	3.80		1.6
80	94.7	23	12.85	4.86		2.6
HX - E						
20	34.7	4.5	2.51	0.95		0
40	54.7	6.5	3.63	1.37		0
60	74.7	8.5	4.75	1.80		0
80	94.7	10.75	6.01	2.27		0
SCFH		645				

L 1610 Redesign Low Pressure Pressure Drops and Flow Rates Tested 9 / 23 / 2010

L 1610 Redesign CD1 & CD2 Flows Tested 9 / 23 / 2010

L 1610 Redesign Flow Rate Section E Tested 9 / 23 / 2010

L 1610 Redesign Paths 1A, 2A, 3A & 4A Flow Tested 9 / 23 / 2010

L 1610 Redesign Paths 1B, 2B, 3B & 4B Flow Tested 9 / 23 / 2010

L 1610 MTS 0326, MTS 0328 & Redesign Flow Rate Comparison Sections A, B, C, D & E1
Low Pressure 1 / 10 / 2011

L 1610 MTS 0326 & Redesign Flow Rate Comparison Sections A, B, C, D & E Low Pressure
1/10/2011

L 1610 MTS 0326, MTS 0328 & Redesign Flow Rate Comparison MTS 0326 & MTS 0328

Section A1 , Redesign Section 3A 1 / 10 / 2011

**L1610 MTS 0326, MTS 0328 & Redesign Flow Comparison MTS 0326 & MTS 0328 Section B1,
Redesign Section 3B High Pressure 1 / 12 / 2010**

L1610 MTS 0326, MTS 0328 & Redesign Flow Comparision Section CD1 High Pressure
1 / 12 / 2011

L 1610 MTS 0326, MTS 0328 & Redesign Flow Comparison Section E High Pressure
1 / 12 / 2011

1610 LIQUEFIER RE-DESIGN -- WITH LN2 -- EFFICIENCY INCREASES
9/20/2007

1610 LIQUEFIER RE-DESIGN -- WITH LN2 -- FLOWS THROUGH HEAT EXCHANGERS 9/20/2007

1610 LIQUEFIER RE-DESIGN -- WITH LN2 -- LOAD INCREASES
9/20/2007

**1610 LIQUEFIER RE-DESIGN NEW COMPRESSOR --- NO LN2 ---
EFFICIENCY INCREASES 9/24/2007**

1610 LIQUEFIER RE-DESIGN NEW COMPRESSOR --- NO LN2 --- FLOW
THROUGH HEAT EXCHANGERS 9/24/2007

1610 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- PRESSURE DROPS AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/27/2007

1610 RE-DESIGN NEW COMPRESSOR -- NO LN2 --- INLET PRESSURES AT HIGH SIDE HEAT EXCHANGERS AND JT -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

1610 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- INLET TEMPERATURES AT HIGH SIDE HEAT EXCHANGERS AND JT -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/27/2007

1610 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- OUTLET TEMPERATURES AT LOW SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

**1610 LIQUEFIER RE-DESIGN NEW COMPRESSOR --- NO LN2 --- LOAD
INCREASES 9/24/2007**

**1610 LIQUEFIER RE-DESIGN NEW COMPRESSOR --- NO LN2 --- RATE
OF RISE 9/24/2007**

1610 LIQUEFIER RE-DESIGN -- WITH LN2 -- RATE OF RISE 9/20/2007

**1610 LIQUEFIER RE-DESIGN NEW COMPRESSOR --- WITH LN2 ---
EFFICIENCY INCREASES 9/24/2007**

1610 LIQUEFIER RE-DESIGN NEW COMPRESSOR --- WITH LN2 --- FLOW THROUGH HEAT EXCHANGERS 9/24/2007

1610 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- PRESSURE DROPS AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/27/2007

1610 RE-DESIGN NEW COMPRESSOR -- WITH LN2 --- INLET PRESSURES AT HIGH SIDE HEAT EXCHANGERS AND JT -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

1610 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- INLET TEMPERATURES AT HIGH SIDE HEAT EXCHANGERS AND JT -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/27/2007

**1610 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- OUTLET TEMPERATURES AT LOW SIDE
HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007**

1610 LIQUEFIER RE-DESIGN NEW COMPRESSOR --- WITH LN2 --- LOAD INCREASES 9/24/2007

**1610 LIQUEFIER RE-DESIGN NEW COMPRESSOR --- WITH LN2 --- RATE
OF RISE 9/24/2007**

1620 REFRIGERATOR RE-DESIGN -- WITH LN2 -- EFFICIENCY INCREASES 9/24/2007

1620 REFRIGERATOR -- WITH LN2 -- FLOWS THROUGH HEAT EXCHANGERS 9/24/2007

1620 REFRIGERATOR RE-DESIGN -- WITH LN2 -- LOAD INCREASES

9/24/2007

1620 REFRIGERATOR RE-DESIGN --- NO LN2 --- EFFICIENCY INCREASES 9/24/2007

**1620 REFRIGERATOR RE-DESIGN --- NO LN2 --- FLOW THROUGH
HEAT EXCHANGERS 9/24/2007**

1620 REFRIGERATOR RE-DESIGN --- NO LN2 --- LOAD INCREASES 9/24/2007

1620 REFRIGERATOR RE-DESIGN --- NO LN2 --- REFRIGERATIONS 9-/24/2007

**1620 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- NO LN2 ---
EFFICIENCY INCREASES 9/24/2007**

**1620 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- NO LN2 ---
FLOW THROUGH HEAT EXCHANGERS 9/24/2007**

1620 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- PRESSURE DROPS AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/27/2007

1620 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- INLET PRESSURES AT HIGH SIDE HEAT EXCHANGERS AND EXPANDERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

1620 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- INLET TEMPERATURES AT HIGH SIDE HEAT EXCHANGERS AND EXPANDERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

1620 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- OUTLET TEMPERATURES AT LOW SIDE HEAT EXCHANGERS AND EXPANDERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

**1620 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- NO LN2 ---
LOAD INCREASES 9/24/2007**

**1620 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- NO LN2 ---
REFRIGERATIONS 9-/24/2007**

1620 REFRIGERATOR RE-DESIGN -- WITH LN2 -- REFRIGERATION LOADS 9/24/2007

1620 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- PRESSURE DRO
EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE

**JRE DROPS AT HIGH SIDE HEAT
PRESSURE 9/27/2007**

1620 RE-DESIGN NEW COMPRESSURE -- WITH LN2 -- INLET PRESSURES AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

1620 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- INLET TEMPERATURES AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

**1620 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- OUTLET TEMPERATURES AT LOW SIDE
HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007**

1630 REFRIGERATOR RE-DESIGN -- WITH LN2 -- EFFICIENCY INCREASES 9/21/2007

1630 REFRIGERATOR RE-DESIGN -- WITH LN2 -- FLOWS THROUGH HEAT EXCHANGERS 9/21/2007

1630 REFRIGERATOR RE-DESIGN -- WITH LN2 -- LOAD INCREASES

9/21/2007

1630 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- NO LN2 ---
EFFICIENCY INCREASES 9/24/2007

**1630 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- NO LN2 --- FLOW
THROUGH HEAT EXCHANGERS 9/24/2007**

1630 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- PRESSURE DROPS AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/27/2007

1630 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- INLET PRESSURES AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

1630 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- INLET TEMPERATURES AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

1630 RE-DESIGN NEW COMPRESSOR -- NO LN2 -- OUTLET TEMPERATURES AT LOW SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

1630 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- NO LN2 --- LOAD
INCREASES 9/24/2007

1630 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- NO LN2 ---
REFRIGERATIONS 9/24/2007

**1630 REFRIGERATOR RE-DESIGN -- WITH LN2 -- REFRIGERATION
LOAD 9/21/2007**

**1630 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- WITH LN2 ---
EFFICIENCY INCREASES 9/24/2007**

1610 LIQUEFIER RE-DESIGN --- WITH LN2 --- FLOW THROUGH HEAT
EXCHANGERS 9/24/2007

1630 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- PRESURE DROPS AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/27/2007

1630 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- INLET PRESSURES AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

1630 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- INLET TEMPERATURES AT HIGH SIDE HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007

**1630 RE-DESIGN NEW COMPRESSOR -- WITH LN2 -- OUTLET TEMPERATURES AT LOW SIDE
HEAT EXCHANGERS -- 1.05 ATM COMPRESSOR INLET PRESSURE 9/26/2007**

1630 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- WITH LN2 --
- LOAD INCREASES 9/24/2007

CHARACTERISTIC OF NEW MACHINE

**1630 REFRIGERATOR RE-DESIGN NEW COMPRESSOR --- WITH LN2 ---
REFRIGERATIONS 9/24/2007**

8/31/2007

1630 REDESIGN WITH LN2 UNMOD - 1 COMP 8/31/2007

EXP 1

EXP 2

COMPRESSOR

1630 RE-DESIGN WITH LN2 UNMOD - 2 COMPRESSORS 8/31/2007

COMPRESSOR

SCFM

WARM HELIUM IN

SCFM

W

W

W

W

W

W

W

8/31/2007

1610 REDESIGN UNMOD - 1 NEW COMP 17 ATM 9/20/2007

1610 RE-DESIGN WITH LN2 UNMOD - 1 COMP 8/31/2007

1610 REDESIGN UNMOD - 1 NEW COMP 17 ATM 9/20/2007

1610 REDESIGN UNMOD - 2 RSX COMP 17 ATM 9/20/2007

1610 RE-DESIGN WITH LN2 UNMOD - 2COMPRESSORS 8/31/2007

RE-DESIGN 1620 WITH LN2 MOD -1, 2 COMPRESSORS 8/31/2007

RE-DESIGN 1620 WITH LN2 MOD -2,1 COMPRESSOR 8/31/2007

RE-DESIGN 1620 MOD -2 ,2 COMPRESSORS 9/20/2007

RE-DESIGN 1620 NO LN2 - MOD - 1 , 1 COMPRESSOR 9/24/2007

RE-DESIGN 1620 NO LN2 - MOD - 1 , 2 COMPRESSORS 9/24/2007

RE-DESIGN 1620 NO LN2 - MOD -2 , 1 COMPRESSOR 8/31/2007

RE-DESIGN 1620 NO LN2 - MOD - 2 , 1 NEW COMPRESSOR 9/24/2007

RE-DESIGN 1620 NO LN2 - MOD - 2 , 2 NEW COMPRESSORS 9/24/2007

8/31/2007

1630 RE-DESIGN WITH LN2 MOD 1 - 2 COMPRESSORS 8/31/2007

9/20/2007

9/20/2007

1630 RE-DESIGN WITH LN2 MOD 2 - 2 COMPRESSORS 8/31/2007

9/20/2007

8/31/2007

1630 RE-DESIGN WITH LN2 MOD 3 - 2 COMPRESSORS 8/31/2007

(Reroute flow to the SCN --- Add pressure drop and heat leak to the Bed because no SC-N subroutine)

(Reroute flow to the SCN --- Add pressure drop and heat leak to the Bed because no SC-N subroutine)

(Reroute flow to the SCN --- Add pressure drop and heat leak to the Bed because no SC-N subroutine)

1630 REDESIGN NO LN2- M2 - 2 COMPS 9/24/2007

(Reroute flow to the SCN --- Add pressure drop and heat leak to the Bed because no SC-N subroutine)

(Reroute flow to the SCN --- Add pressure drop and heat leak to the Bed because no SC-N subroutine)

1630 REDESIGN NO LN2- UNMOD - 2 COMPRESSORS 9/21/2007

(Reroute flow to the SCN --- Add pressure drop and heat leak to the Bed because no SC-N subroutine)

EXP 1

EXP 2

COMPRESSOR

FLOW
WORK
SPEED
EFF
CAM
NO CYL
BORE
STROKE

329.5
114
0.70
0.48
1
3.0
2.0

G / S
WATTS
RPM

FLOW
WORK
SPEED
EFF
CAM
NO CYL
BORE
STROKE

213.8
111
0.72
0.38
1
3.0
2.0

G / S
WATTS
RPM

FLOW
WORK
SPEED
EFF
CAM
NO CYL
BORE
STROKE

1.44
24.00
3.68
0.50

G / S
WATTS
RPM

1630 REDESIGN WITH LN2 UNMOD - 1 COMP 8/31/2007

1630 RE-DESIGN WITH LN2 UNMOD - 2 COMPRESSORS 8/31/2007

[illegible]

1610	1630	1620
1 new comp	1 new comp	1 new comp
2.48		
74.80		
2	162	880
8.57	4.26	4.80
2.03	0.00	0.00
131.34	131.17	141.27
14.39	10.53	17.07
9.69	7.52	12.08
0.00	0.00	0.00
0.00	0.00	0.00
26.26	26.29	26.33
0.00	0.07	1.91
26.26	26.22	24.42
334.58	334.96	335.47
205.00	114	241

2.64		
79.6		
2	181	980
9.91	5.84	6.20
2.14	0.00	0.00
15.17	11.77	19.09
10.60	8.21	13.26
6.42	11.42	11.36
9.39	9.18	9.77
26.21	26.31	26.31
0.00	0.00	0.00
26.21	26.31	26.31
334.7	335.3	335
26.27	26.31	26.31
190	102	244

Mod-2						
Liq. Acc. [g/s]	3.25	2.29	0.00	0.00	0.00	0.00
Rate of Rise [LPH]	99.71	68.60				
Ref. Load [W]	2	2	227	148	985	845
LN2 Usage [g/s]	12.26	8.55	8.40	4.88	6.64	5.32
Make-up [g/s]	2.60	1.89	0.00	0.00	0.00	0.00
Input Power [kW]	182.76	111.42	186.85	113.90	175.16	115.73
Carnot Load [kW]	18.36	13.43	14.38	9.74	19.40	16.53
Useful Exergy [%]	8.86	10.45	7.07	7.88	10.30	13.10
Load Increase [%]	31.05	4.09	12.94	-2.63	14.00	5.63
Efficiency Increase [%]	24.26	4.92	6.64	-6.86	12.20	2.02
Compressor flow (g/s)	36.52	22.27	37.30	21.87	34.96	23.11
By - Pass Flow (g/ s)	4.67	0.10	0.18	0.27	7.53	0.08
Heat Exchanger Flow (g/s)	31.85	22.17	35.47	21.60	27.43	23.03
Compressor Flow SCFM	465.30	283.74	475.24	278.65	445.43	294.44
Comp 1218 K SCFM		334.70		334.70		334.70
Comp 1218 K G / S		26.27		26.27		26.27
Expander Speed RPM						
Mod-3						
Liq. Acc. [g/s]	3.35	2.33	0.00	0.00	0.00	0.00
Rate of Rise [LPH]	102.91	69.81				
Ref. Load [W]	2	2	230	150	1000	860
LN2 Usage [g/s]	14.54	9.76	11.02	6.14	8.53	6.94

2.72		
82.10		
2	170	974
10.07	5.66	6.07
2.22	0.00	0.00
15.74	11.07	18.78
10.38	7.75	13.05
9.76	4.94	10.68
7.12	3.06	8.03
26.29	26.27	26.3
0.00	0.00	0.00
26.29	26.27	26.30
334.70	334.6	335
26.27	26.27	26.3
182.00	106	242

Make-up [g/s]	2.67	1.92	0.00	0.00	0.00	0.00
Input Power [kW]	186.15	113.06	190.44	115.63	178.05	117.51
Carnot Load [kW]	18.89	13.66	14.52	9.86	19.65	16.80
Useful Exergy [%]	8.78	10.31	6.84	7.71	10.08	12.81
Load Increase [%]	35.08	5.91	14.43	-1.32	15.74	7.50
Efficiency Increase [%]	23.14	3.51	3.17	-8.87	9.80	-0.23
Compressor flow (g/s)	37.16	22.58	37.97	23.07	35.50	23.44
By - Pass Flow (g/ s)	4.62	0.13	0.17	0.18	7.85	0.11
Heat Exchanger Flow (g/s)	32.54	22.45	37.80	22.89	27.65	23.33
Compressor Flow SCFM	473.46	287.69	483.78	293.93	452.31	298.65
Compressor 1218 K SCFM	334.70		334.70		334.70	
Comp 1218 K G / S	26.27		26.27		26.27	
Expander Speed RPM						

184

104

M1600 - No LN2 - Summary

	1610		1610 - POD		1630		1620	
	2-Comp	1-Comp	2-Comp	1-Comp	2-Comp	1-Comp	2-Comp	1-Comp
Unmodified								
Liq. Acc. [g/s]		0.74			0.00	0.00	0.00	0.00
Rate of Rise [LPH]		22.58						
Ref. Load [W]		2			100	77	429	431
Make-up [g/s]		0.60			0.00	0.00	0.00	0.00
Input Power [kW]		107.43			177.84	108.46	165.41	101.21
Carnot Load [kW]		4.31			6.39	4.99	8.24	8.28
Useful Exergy [%]		4.01			3.60	4.60	4.98	8.18
Load Increase [%]		0.00			0.00	0.00	0.00	0.00
Efficiency Increase [%]		0.00			0.00	0.00	0.00	0.00
Compressor flow (g/s)		21.48			35.56	21.69	33.08	20.24
By - Pass Flow (g/ s)		3.04			9.72	0.11	15.95	3.04
Heat Exchanger Flow (g/s)		18.44			25.84	21.57	17.13	17.20
Expander Speed RPM								
Mod-2								
Liq. Acc. [g/s]		0.84		1.05	0.00	0.00	0.00	0.00
Rate of Rise [LPH]		25.78						
Ref. Load [W]		2		2	113	82	490	490
Make-up [g/s]		0.67		0.87	0.00	0.00	0.00	0.00
Input Power [kW]		108.09		110.91	178.91	109.39	149.33	94.32
Carnot Load [kW]		4.84		6.27	6.98	5.24	9.41	9.27
Useful Exergy [%]		4.48		5.66	3.90	4.79	6.30	9.82
Load Increase [%]		13.51		41.89	13.00	6.49	14.22	13.69
Efficiency Increase [%]		11.72		41.15	8.33	4.13	26.51	20.05
Compressor flow (g/s)		21.61		22.17	35.77	21.87	29.86	18.86
By - Pass Flow (g/ s)		1.35		3.02	4.69	0.27	10.28	0.32
Heat Exchanger Flow (g/s)		20.26		19.15	31.08	21.60	19.58	18.54
Expander Speed RPM								

M2200 Summary

C. Lac 9/25/2007

E. Yuksek 9/25/2007

	2-Comp	2-Comp	2-Comp	2-Comp
Mod-2				
Liq. Acc. [g/s]	4.40	4.00	0.00	0.00
Ref. Load [W]	5	5	286	373
LN2 Usage [g/s]	12.27	11.47	2.04	2.17
Make-up [g/s]	3.64	3.31	0.00	0.00
Input Power [kW]	181.18	181.18	181.18	181.18
Carnot Load [kW]	25.94	23.59	18.60	24.59
Useful Exergy [%]	12.60	11.55	10.04	13.25
Expander Speed RPM				

Finned-Tube Heat Exchanger Modifications

	Unmodified	Mod-1	Mod-2	Mod-3
HX-1				
Wraps	2	2	2	2
Passes	1	2	2	3
HX-1N				
Wraps	1	1	1	1
Passes	2	1	1	1
SC-N				
Wraps	1	1	1	1
Passes	2	2	2	2
HX-2				
Wraps	2	2	2	2
Passes	1	1	2	2
HX-3				
Wraps	2	2	2	2
Passes	1	1	1	1
HX-4				
Wraps	2	2	2	2
Passes	1	1	1	1
HX-5				
Wraps	1	1	1	1
Passes	1	1	1	1
HX-6				
C. Lac 9/25/2007				Page 4 of 5

Wraps	1	1	1	1
Passes	1	1	1	1

NEW COMPRESSOR PERFORMANCES 9-25-2007

1610 WITH LN2

1610 NO LN2

UNMOD MOD1 MOD2

UNMOD MOD1 MOD2

Liq. Acc. [g/s]		2.48	2.64	2.72		0.70	0.86	0.96
Rate of Rise [LPH]		74.80	79.6	82.10		21.27	26.92	29.45
Ref. Load [W]		2	2	2		2	2	2
LN2 Usage [g/s]		8.57	9.91	10.07		0.00	0.00	0.00
Make-up [g/s]		2.03	2.14	2.22		0.57	0.67	0.76
Input Power [kW]		131.34	151.37	151.59		131.41	131.41	131.41
Carnot Load [kW]		14.39	15.17	15.74		4.11	4.81	5.44
Useful Exergy [%]		9.69	10.60	10.38		3.13	3.66	4.14
Load Increase [%]		0.00	6.42	9.76		0.00	26.56	38.46
Efficiency Increase [%]		0.00	9.39	7.12		0.00	16.93	32.27
Compressor flow (g/s)		26.26	26.21	26.29		26.28	26.28	26.28
By - Pass Flow (g/ s)		0.00	0.00	0.00		9.10	4.31	5.69
Heat Exchanger Flow (g/s)		26.26	26.28	26.29		17.18	21.97	20.59
Compressor Flow SCFM		335	335	335		335	335	335
Expander Speed RPM		205.00	190	182.00		214	229	234

1620 WITH LN2

1620 NO LN2

UNMOD MOD1 MOD2

UNMOD MOD1 MOD2

Ref. Load [W]		880	980	974		431	462	505
LN2 Usage [g/s]		4.80	6.20	6.07		0.00	0.00	0.00
Make-up [g/s]		0.00	0.00	0.00		0.00	0.00	0.00
Input Power [kW]		141.27	144.03	143.83		131.52	131.38	132.07
Carnot Load [kW]		17.07	19.09	18.78		8.82	8.86	9.69
Useful Exergy [%]		12.08	13.26	13.05		6.29	6.74	7.34
Load Increase [%]		0.00	11.36	10.68		0.00	7.19	17.17
Efficiency Increase [%]		0.00	9.77	8.03		0.00	7.15	16.69
Compressor flow (g/s)		26.33	26.31	26.3		26.30	26.27	26.30
By - Pass Flow (g/ s)		1.91	0.00	0.00		9.10	7.74	6.80
Heat Exchanger Flow (g/s)		24.42	26.31	26.30		17.20	18.53	19.50
Compressor Flow SCFM		335	335	335		335	335	335
Expander Speed RPM		241	244	242		250	248	250

1630 WITH LN2**1630 NO LN2****UNMOD MOD1 MOD2****UNMOD MOD1 MOD2**

Ref. Load [W]		162	181	170		80	80	86
LN2 Usage [g/s]		4.26	5.84	5.66		0.00	0.00	0.00
Make-up [g/s]		0.00	0.00	0.00		0.00	0.00	0.00
Input Power [kW]		131.17	143.38	142.80		131.47	131.49	131.60
Carnot Load [kW]		10.53	11.77	11.07		5.25	5.11	5.50
Useful Exergy [%]		7.52	8.21	7.75		3.99	3.88	4.18
Load Increase [%]		0.00	11.42	4.94		0.00	0.00	7.50
Efficiency Increase [%]		0.00	9.18	3.06		0.00	-2.76	4.76
Compressor flow (g/s)		26.29	26.31	26.27		26.29	26.29	26.31
By - Pass Flow (g/ s)		0.07	0.00	0.00		7.81	3.07	3.97
Heat Exchanger Flow (g/s)		26.22	26.31	26.27		18.48	23.22	22.34
Compressor Flow SCFM		335	335	335		335	335	335
Expander Speed RPM		114	102	106		121.00	191	167

Note: Compressor flow is defined as the flow after the compressor cooler.

ASTM A269 1030

337213161

1508
8051
1/6 8/16
1/4
1/2

35421316

500005

OSTR. 10.12.95

P01000

4

5

8

9

7

6