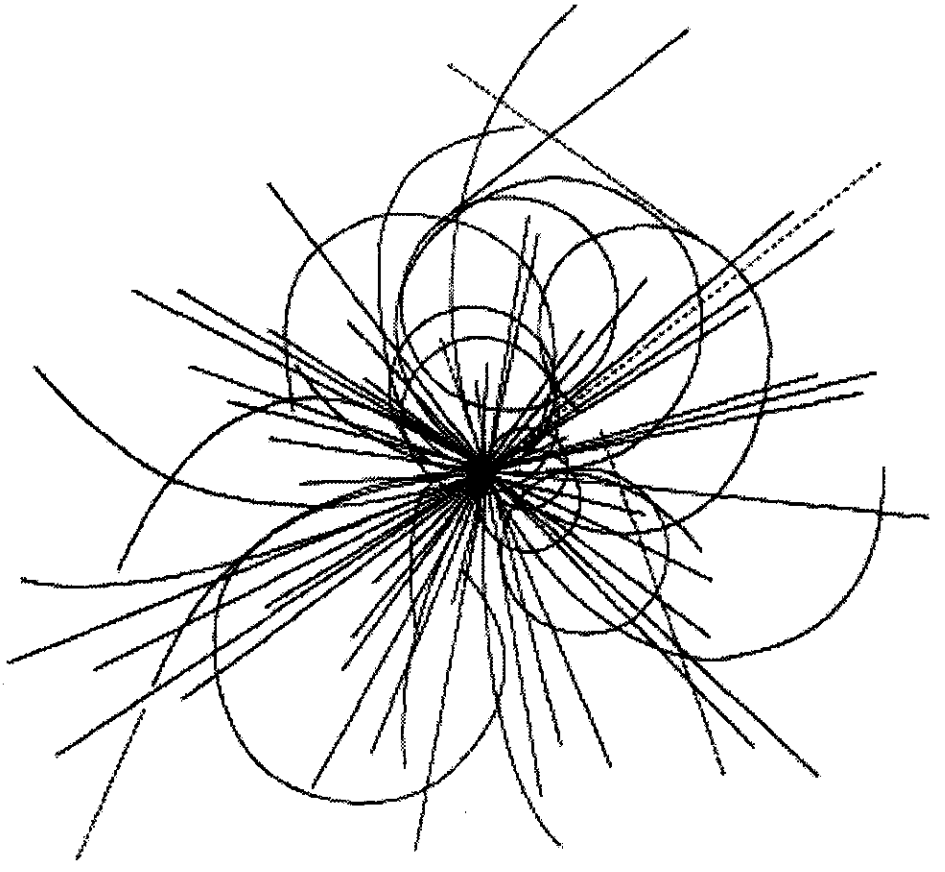
SSCL-N-879

SSCL-N-879
October 1994
Distribution Category: 400

T.V.V.R. Apparao
V. Ganni

Comparison of ASST-Helium Refrigeration System Performance: Design vs. Actual Test at 50% of Compressor Flow Conditions



Superconducting Super Collider Laboratory

SSCL-N-879

Comparison of ASST-Helium Refrigeration System Performance: Design vs. Actual Test at 50% of Compressor Flow Conditions

T.V.V.R. Apparao and V. Ganni

Superconducting Super Collider Laboratory*
2550 Beckleymeade Ave.
Dallas, TX 75237

October 1994

*Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

COMPARISON OF ASST-A HELIUM REFRIGERATION SYSTEM PERFORMANCE: DESIGN VS. ACTUAL TEST AT 50% OF COMPRESSOR FLOW CONDITIONS

T.V.V.R. Apparao and V. Ganni
Cryogenics Department, Accelerator Systems Division
SSC Laboratory, Dallas, TX 75237

The ASST-A refrigeration system has two first stage and two second stage compressors. Parametric tests on the compressors and the total refrigeration system were conducted to verify the performance and compare these results with the manufacturer's design for this refrigeration system. A summary of the initial performance test data is given in reference [1]. The refrigeration system is designed to operate in several modes. However, the main modes of operation are: Mode 1 (50% refrigeration - 50% Liquefaction), Mode 2 (100% Refrigeration) and Mode 3 (100% Liquefaction). Under normal conditions of operation all the four compressors are running. The results of the process analyses and exergy analyses for the manufacturer's design and actual test data for Case 1 conditions when all the four compressors are operating are discussed in reference [2]. The process flow diagram, the mapping of the compressors, the description of the cold box system and the theory behind the process and exergy analyses are also given in reference [2]. This report presents the process and exergy analyses for the three modes of operation for Case 2 conditions (when only one first stage and one second stage compressors are operated).

Figure 1 compares the manufacturer's design vs. actual reduced test data of the process on a T-S diagram for Mode 1 operation . In this mode according to the manufacturer's design the 4 K refrigeration capacity is 765 Watts in addition to the plant liquefaction load of 7.65 g/s also at 4 K. The system is designed to operate with all the four expanders operating. However, in the actual test as shown on the T-S diagram (figure 1) for the test data, the system operated with the expander 3 shut off. The plant produced 7.4 g/s of liquid at 4 K and the 4 K refrigeration load was 795 watts. Table 1 compares the total exergy distribution for the manufacturer's design and test conditions.

The comparison for Mode 2 (100% refrigferation) operation of the manufacturer's design and reduced test data for the process is shown on a T-S diagram in figure 2. The plant was designed to operate in this mode with a capacity of 1370 watts of refrigeration at 4 K. During the test, the applied load on the plant was as high as 1450 watts. The probable reasons for the higher capacity of the plant are due to the selection of larger capacity compressors and a lower suction temperature of the first stage compressor. The distribution of exergy in the compressor system, the cold box and the dewar for the manufacturer's design and the actual test are given in Table 2.

The results for Mode 3 operation (100% liquefaction) for the manufacturer's design and the reduced test data for the process are shown in figure 3. The plant was designed to liquefy 15.6 g/s with one first and one second stage compressors operating. During the tests conducted to verify the plant capacity in this mode of operation, the liquefaction rate was as high as 18.0 g/s. The results of the exergy analysis for this mode of operation are shown in Table 3. Figure 4 summarizes the exergy distribution of all the three modes of operations for Case 2 conditions.

Discussion of results

The ASST-A refrigeration system under normal conditions of operation requires two first stage and two second stage compressors. The plant is designed to operate at maximum efficiency when operated in mode 1 under Case 1 conditions. The efficiency of this refrigeration system for all other modes and cases of operation is lower. As shown in reference [2] the system efficiency for Mode 1 Case 1 design operation is 18.6%. For Mode 1 and Case 2 operation the system efficiency as given in Table 1 is 14.3% for the manufacturer's design and 14.8% for the test data. Comparison of the exergy losses for Case 1 with the exergy losses for Case 2 for all the three modes of operation shows that a larger percentage of the losses are in the cold box for Case 2 operation. The larger percentage of the exergy losses for Case 2 operation are mainly due to the higher inefficiencies in the heat exchangers. The exergy losses in the heat exchangers in Mode 1 and Case 2 operation for the manufacturer's design and test conditions as given in Table 1 are 13.3%. Where as for Mode 1 and Case 1 operation the exergy losses in the heat exchangers as given in Table 1 of reference [2] for the manufacturer's design and test data are 9.0%. The heat exchangers are designed for mass flow rates, heat loads and pinches as required for Case 1 conditions. However, the mass flow rates and heat loads in Case 2 are much lower. Hence the values of LMTD especially in the lower end of the cold box are higher resulting in higher exergy losses. The percentage of exergy losses in the expanders in Case 1 and Case 2 operation are about the same.

1. T. Kobel and R. Than, Initial operation and performance test results of the ASST cryogenic system, *to be published in* "Supercollider 5: Proceedings of the 5th International Symposium on the Super Collider, San Francisco, CA, May 1993." New York: Plenum Press.

2. V. Ganni and T.V.V.R. Apparao, Design Verification and Acceptance Tests of the ASST-A Helium Refrigeration System. Presented at the CEC-ICEC Conference, Albequerque, New Mexico, July 12- 16,1993.

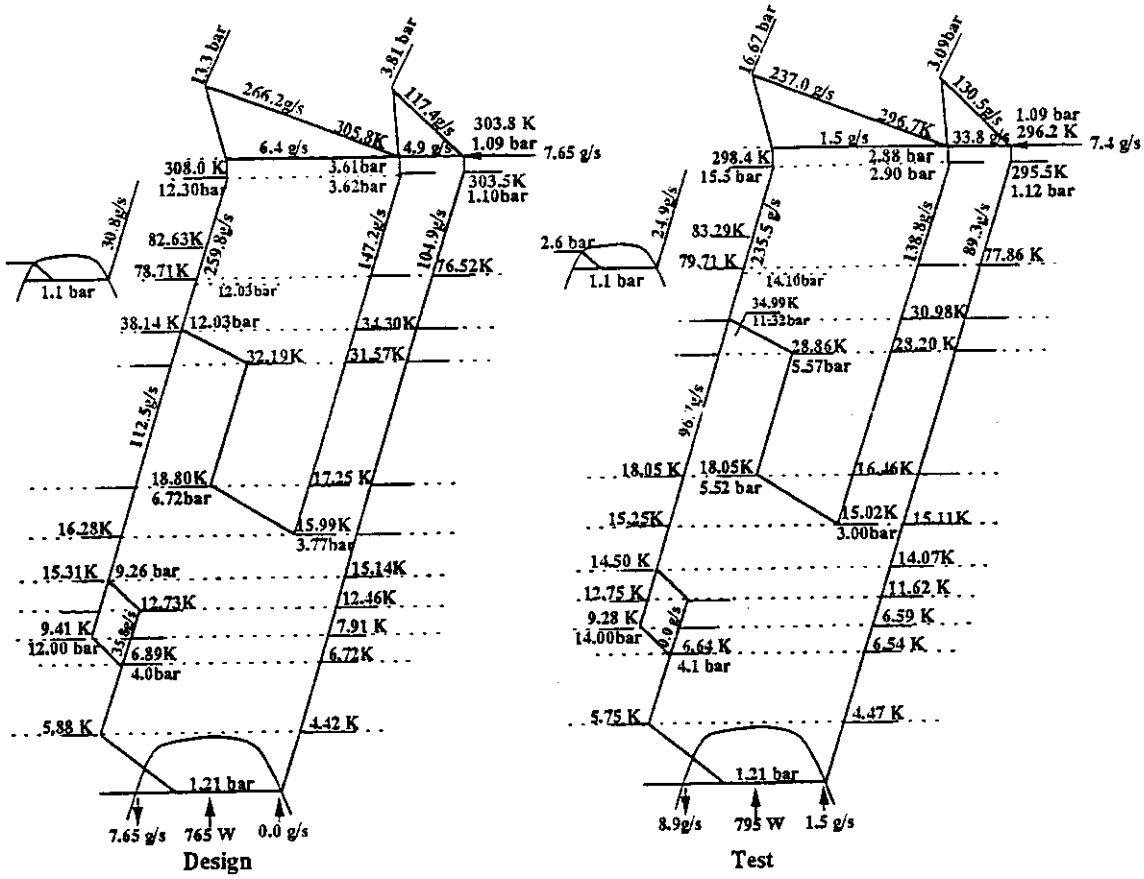


Figure 1: Mode 1 (50L-50R) Process analysis

(1 first stage and 1 second stage compressors operating)

Table 1: Mode 1 (50L-50R) Exergy analysis for **50% compressor flow conditions.**

	DESIGN		TEST	
4.5 K Refrigeration load (W)	765.0		795.0	
Liquefaction load (g/s)	7.65		7.4	
Reliquefaction load (g/s)	0.0		1.5	
Coolant reference temperature (K)	305.8		296.95	
INPUT	*kW*	%	*kW*	%
First-Stage Compressor	192.4	26.3	146.3	20.9
Second-Stage Compressor	475.5	65.0	502.8	71.9
LN_2 System (Eff. Carnot = 0.35)	63.8	8.7	50.1	7.2
INPUT EXERGY TOTAL	**731.7**	**100.0**	**699.2**	**100.0**
OUTPUT	*kW*	%	*kW*	%
First-stage: compressor & motor	99.5	13.6	62.4	8.9
First-stage bypass	3.8	0.5	21.2	3.0
First-stage suction mixing	2.1	0.3	2.2	0.3
First-stage aftercooler DP	3.0	0.4	4.6	0.7
First-stage subtotal	*108.6*	*14.8*	*90.4*	*12.9*
Second-stage compressor & motor	255.8	35.0	245.1	35.1
Second-stage bypass	5.3	0.7	1.6	0.2
Second-stage suction mixing	2.5	0.3	1.4	0.2
Second-stage AC & oil rem. DP	10.9	1.5	10.6	1.5
Second-stage subtotal	*274.5*	*37.5*	*258.8*	*37.0*
COMPRESSORS - SUBTOTAL	383.1	52.4	349.1	49.9
Heat exchanger 1A	28.9	4.0	19.0	2.7
Heat exchanger 1B	3.4	0.5	1.0	0.1
Heat exchanger 2	20.1	2.8	21.3	3.1
Heat exchanger 3	2.9	0.4	3.4	0.5
Heat exchanger 4	11.8	1.6	12.0	1.7
Heat exchanger 5	1.9	0.3	3.1	0.4
Heat exchanger 6	0.8	0.1	0.8	0.1
Heat exchanger 7	1.9	0.3	2.4	0.3
Heat exchanger 8	7.2	1.0	17.5	2.5
Heat exchanger 9	3.4	0.5	0.0	0.0
Heat exchanger 10	14.9	2.0	12.3	1.8
Heat exchangers - subtotal	**97.3**	**13.3**	**92.8**	**13.3**
Expander 1	15.2	2.1	20.1	2.9
Expander 2	17.9	2.4	14.2	2.0
Expander 3	10.1	1.4	0.0	0.0
Expander 4	17.6	2.4	20.9	3.0
Expanders - subtotal	**60.8**	**8.3**	**55.2**	**7.9**
LN_2 system	41.7	5.7	32.6	4.7
80 K bed	0.5	0.1	13.0	1.9
DP I/O expanders	5.7	0.8	19.3	2.8
JT	31.8	4.3	22.3	3.2
Transfer line	3.5	0.5	3.4	0.5
Dewar heat leak	0.0	0.0	0.7	0.1
Calculation error	2.6	0.4	7.2	1.0
Miscellaneous - subtotal	**85.8**	**11.7**	**98.6**	**14.1**
COLDBOX - SUBTOTAL	244.0	33.3	246.6	35.3
EXERGY LOSS - TOTAL	*627.0*	*85.7*	*595.7*	*85.2*
Refrigeration load	52.0	7.1	52.5	7.5
Liquefaction load	52.6	7.2	49.1	7.0
Reliquefaction load	0.0	0.0	1.9	0.3
EXERGY USEFUL -TOTAL	104.6	14.3	103.5	14.8
OUTPUT EXERGY TOTAL	731.7	100.0	699.2	100.0

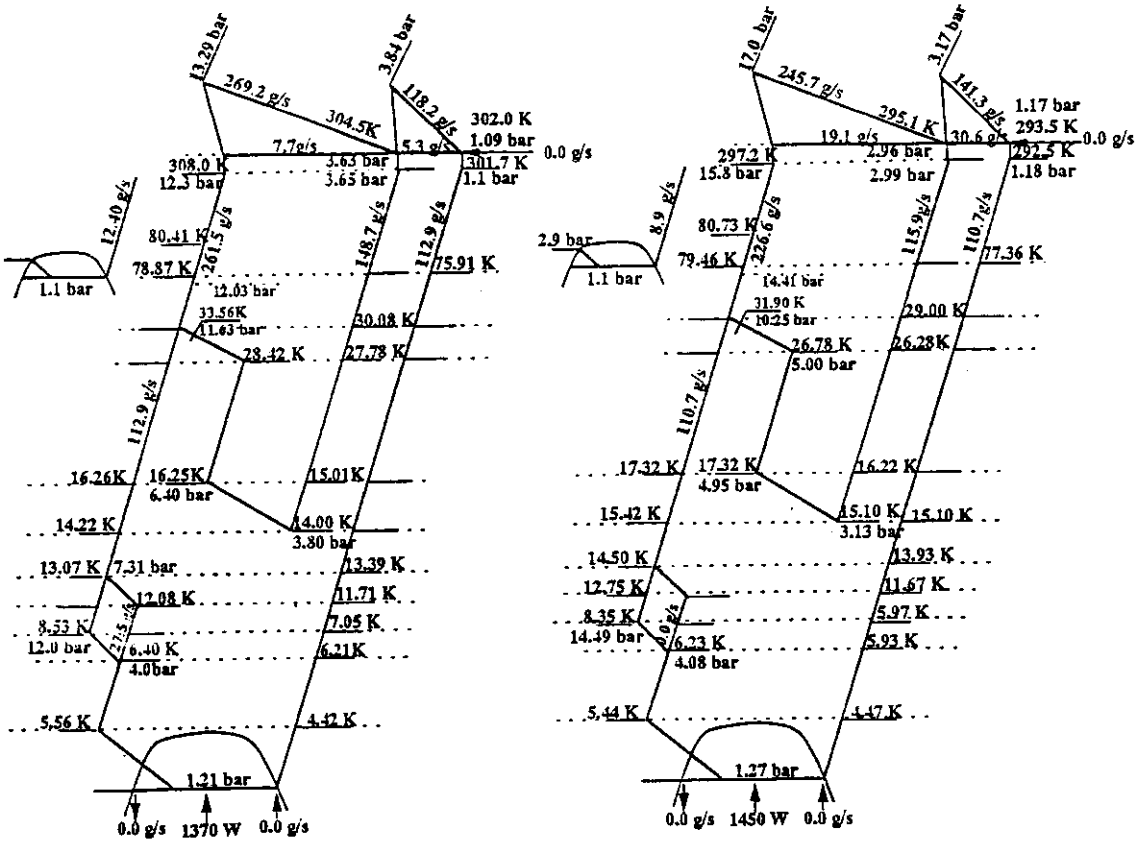


Figure 2 :Mode 2 Process analysis
(1 first stage and 1 second stage compressors operating)

Table 2: Mode 2 (100R) Exergy analysis for 50% compressor flow conditions.

	DESIGN		TEST	
4.5 K Refrigeration load (W)	1370.0		1450.0	
Liquefaction load (g/s)	0.0		0.0	
Reliquefaction load (g/s)	0.0		0.0	
Coolant reference temperature (K)	304.9		294.9	
INPUT	*kW*	%	*kW*	%
First-Stage Compressor	193.6	27.8	151.1	22.1
Second-Stage Compressor	476.4	68.5	513.5	75.3
LN_2 System (Eff. Carnot = 0.35)	25.6	3.7	17.6	2.6
INPUT EXERGY TOTAL	**695.6**	**100.0**	**682.2**	**100.0**
OUTPUT	*kW*	%	*kW*	%
First-stage: compressor & motor	100.2	14.4	64.6	9.5
First-stage bypass	4.1	0.6	18.6	2.7
First-stage suction mixing	1.7	0.2	0.7	0.1
First-stage aftercooler DP	3.0	0.4	4.8	0.7
First-stage subtotal	*109.0*	*15.7*	*38.8*	*13.0*
Second-stage compressor & motor	256.8	36.9	249.7	36.6
Second-stage bypass	6.3	0.9	20.4	3.0
Second-stage suction mixing	2.5	0.4	1.6	0.2
Second-stage AC & oil rem. DP	11.0	1.6	10.7	1.6
Second-stage subtotal	*276.7*	*39.8*	*282.4*	*41.4*
COMPRESSORS - SUBTOTAL	**385.7**	**55.4**	**371.2**	**54.4**
Heat exchanger 1A	28.1	4.0	14.9	2.2
Heat exchanger 1B	2.7	0.4	0.4	0.1
Heat exchanger 2	25.8	3.7	20.7	3.0
Heat exchanger 3	2.5	0.4	2.9	0.4
Heat exchanger 4	11.9	1.7	8.2	1.2
Heat exchanger 5	1.7	0.3	2.0	0.3
Heat exchanger 6	0.8	0.1	0.9	0.1
Heat exchanger 7	1.9	0.3	2.5	0.4
Heat exchanger 8	10.1	1.5	25.0	3.7
Heat exchanger 9	3.2	0.5	0.0	0.0
Heat exchanger 10	14.1	2.0	10.3	1.5
Heat exchangers - subtotal	**103.0**	**14.8**	**87.9**	**12.9**
Expander 1	17.7	2.5	20.6	3.0
Expander 2	16.0	2.3	9.0	1.3
Expander 3	8.5	1.2	0.0	0.0
Expander 4	15.8	2.3	20.9	3.1
Expanders - subtotal	**58.0**	**8.3**	**50.6**	**7.4**
LN_2 system	16.7	2.4	11.4	1.7
80 K bed	0.5	0.1	12.6	1.8
DP I/O expanders	11.3	1.6	24.9	3.7
JT	23.8	3.4	19.7	2.9
Transfer line	3.5	0.5	3.3	0.5
Dewar heat leak	0.0	0.0	0.6	0.1
Calculation error	0.2	0.0	6.0	0.9
Miscellaneous - subtotal	**56.0**	**8.0**	**78.6**	**11.5**
COLDBOX - SUBTOTAL	**217.0**	**31.2**	**217.1**	**31.8**
EXERGY LOSS - TOTAL	*602.7*	*86.6*	*588.3*	*86.2*
Refrigeration load	92.9	13.4	93.9	13.8
Liquefaction load	0.0	0.0	0.0	0.0
Reliquefaction load	0.0	0.0	0.0	0.0
EXERGY USEFUL -TOTAL	92.9	13.4	93.9	13.8
OUTPUT EXERGY TOTAL	695.6	100.0	682.2	100.0

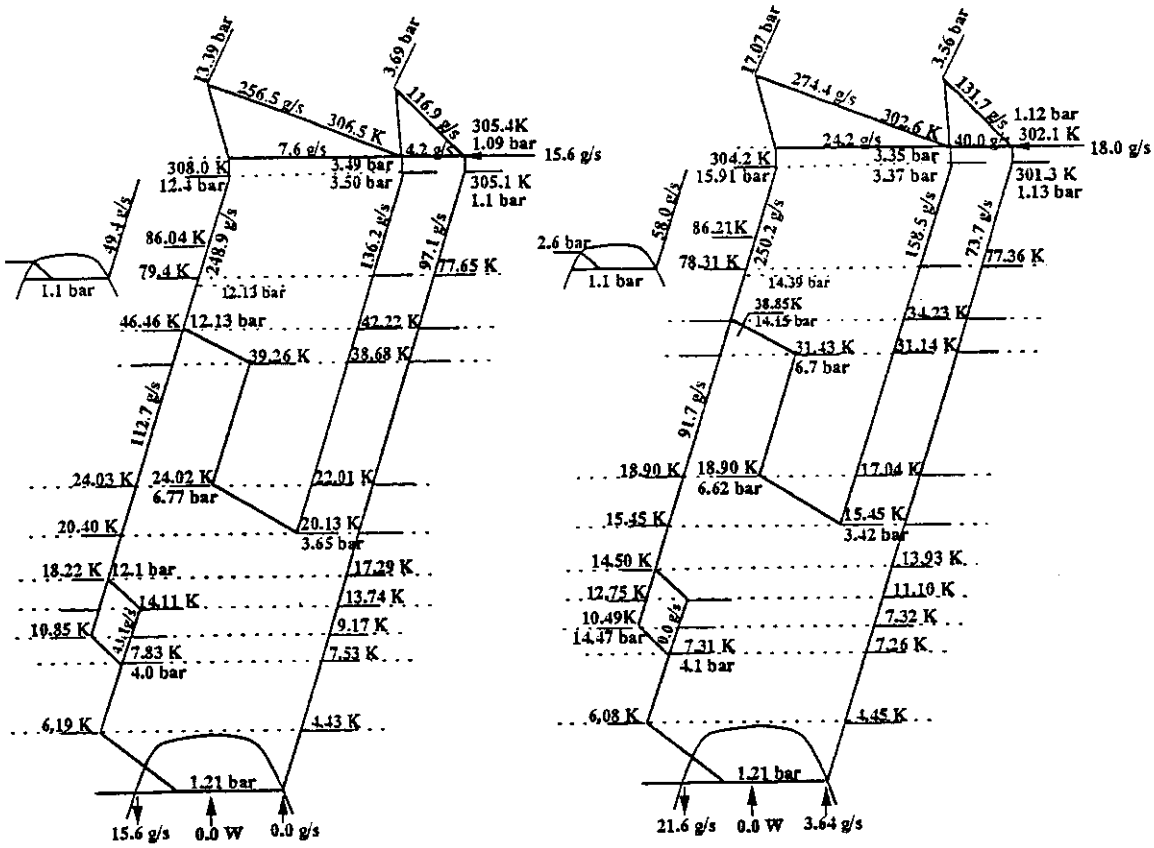


Figure 3 : Mode 3 Process analysis
(1 first stage and 1 second stage compressors operating)

Table 3: Mode 3 (100L) Exergy analysis for 50% compressor flow conditions.

	DESIGN		TEST	
4.5 K Refrigeration load (W)	0.0		0.0	
Liquefaction load (g/s)	15.6		18.0	
Reliquefaction load (g/s)	0.0		3.6	
Coolant reference temperature (K)	306.6		302.8	
INPUT	*kW*	%	*kW*	%
First-Stage Compressor	187.5	24.5	166.9	20.5
Second-Stage Compressor	474.2	62.0	526.6	64.7
LN_2 System (Eff. Carnot = 0.35)	102.9	13.5	120.2	14.8
INPUT EXERGY TOTAL	**764.6**	**100.0**	**813.7**	**100.0**
OUTPUT	*kW*	%	*kW*	%
First-stage: compressor & motor	97.0	12.7	71.1	8.7
First-stage bypass	3.2	0.4	28.9	3.5
First-stage suction mixing	2.6	0.3	0.7	0.1
First-stage aftercooler DP	3.2	0.4	3.9	0.5
First-stage subtotal	106.0	13.9	104.7	12.9
Second-stage compressor & motor	254.7	33.3	244.6	30.1
Second-stage bypass	6.5	0.8	24.8	3.0
Second-stage suction mixing	2.4	0.3	1.6	0.2
Second-stage AC & oil rem. DP	10.5	1.4	12.2	1.5
Second-stage subtotal	**274.1**	**35.8**	**283.2**	**34.8**
COMPRESSORS - SUBTOTAL	**380.0**	**49.7**	**387.9**	**47.7**
Heat exchanger 1A	30.6	4.0	26.5	3.3
Heat exchanger 1B	4.3	0.6	2.7	0.3
Heat exchanger 2	13.6	1.8	18.5	2.3
Heat exchanger 3	2.6	0.3	3.2	0.4
Heat exchanger 4	10.0	1.3	13.2	1.6
Heat exchanger 5	2.0	0.3	2.9	0.4
Heat exchanger 6	1.2	0.2	0.7	0.1
Heat exchanger 7	2.3	0.3	2.9	0.4
Heat exchanger 8	5.9	0.8	12.5	1.5
Heat exchanger 9	3.9	0.5	0.0	0.0
Heat exchanger 10	17.9	2.3	12.1	1.5
Heat exchangers - subtotal	**94.3**	**12.3**	**95.3**	**11.7**
Expander 1	14.2	1.9	22.2	2.7
Expander 2	16.1	2.1	17.3	2.1
Expander 3	14.7	1.9	0.0	0.0
Expander 4	17.3	2.3	25.0	3.1
Expanders - subtotal	**62.3**	**8.2**	**64.5**	**7.9**
LN_2 system	67.2	8.8	78.1	9.6
80 K bed	0.4	0.1	15.2	1.9
DP I/O expanders	0.0	0.0	1.8	0.2
JT	43.9	5.7	30.1	3.7
Transfer line	3.5	0.5	3.5	0.4
Dewar heat leak	0.0	0.0	0.7	0.1
Calculation error	5.1	0.7	9.8	1.2
Miscellaneous - subtotal	**120.2**	**15.7**	**139.2**	**17.1**
COLDBOX - SUBTOTAL	**276.9**	**36.2**	**299.0**	**36.7**
EXERGY LOSS - TOTAL	**656.9**	**85.9**	**686.9**	**84.4**
Refrigeration Load	0.0	0.0	0.0	0.0
Liquefaction Load	107.7	14.1	122.1	15.0
Reliquefaction Load	0.0	0.0	4.8	0.6
EXERGY USEFUL -TOTAL	**107.7**	**14.1**	**126.9**	**15.6**
OUTPUT EXERGY TOTAL	**764.6**	**100.0**	**813.7**	**100.0**

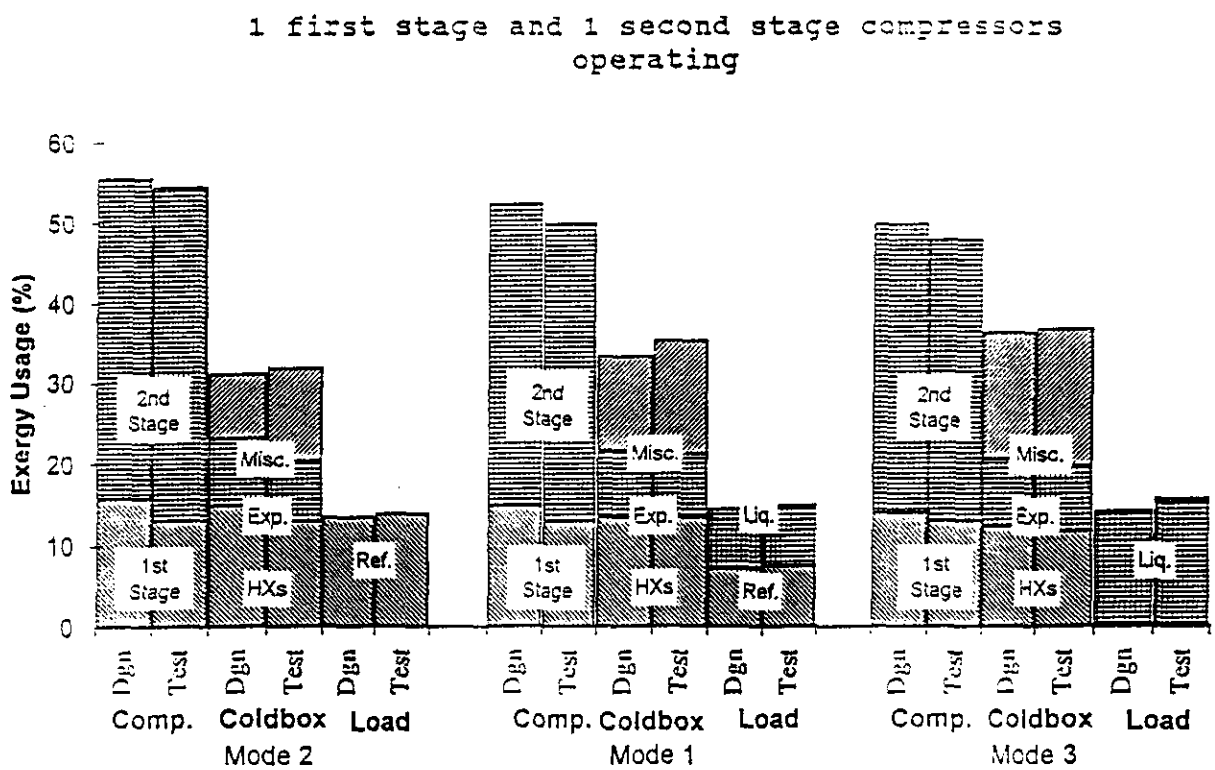


Figure 4: Summary of Exergy Analysis