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Performance of the 350 HP Sullair Oil Screw Compressor

K. C. Wu

July 1993

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

AD/RHIC/RD-59

RHIC PROJECT

Brookhaven National Laboratory

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PERFORMANCE OF THE 350 HP SULLAIR OIL SCREW COMPRESSOR

A 350 HP SULLAIR model C20LA704 oil screw compressor was purchased for servicing the vertical dewars in Building 902A. The compressor was purchased for dual purposes. It can be used to pump the vertical dewars to sub-atmospheric conditions or to provide half the needed capacity for a 1000 watt helium refrigerator for the vertical dewars. The specifications for this compressor are given in Table 1 in which performance conditions No. 1 and No. 2 refer to the applications for the refrigerator and the pump down respectively. The performance proposed by SULLAIR is given in Table 2 and more detailed information is given in Appendix 1.

Table 1. Performance requirement for the oil screw compressor per BNL specification

Rated Performance Condition:	No.1	No.2
Minimum Helium Mass Flow (g/s)	51.5	17.3
Suction Pressure (atm)	1.05	0.35
Suction Temperature (F)	80	80
Discharge Pressure (atm)	18	4 to 18
Discharge Temperature (F)	90	90

Table 2. Performance of the compressor as proposed by SULLAIR

	No. 1	No. 2a	No. 2b
Helium Flow Rate (g/s)	51.5 to 53.0	17.5 to 18.0	13.2
Suction Pressure (atm)	1.05	0.35	0.35
Suction Temperature (F)	Not specified		
Discharge Pressure (atm)	18	4	18
Discharge Temperature (F)	Not specified		
Volumetric Efficiency (%)	$75.1^{-0}_{+3\%}$	$82^{-0}_{+3\%}$	62±5%
Adiabatic Efficiency (%)	75±3%	74.2±3%	48±5%
Isothermal Efficiency (%)	40	42.5±3%	19±5%
Brake Horse Power (HP)	333	93±3%	258±3%

In Table 2, conditions No. 2a and No. 2b refer to performance conditions in Table 1 under No. 2 specifically at 4 and 18 atmospheres.

The compressor was purchased in April, 1991 and was delivered to BNL in September, 1991. It was installed in the compressor room in Building 902 in December, 1992. Between January and March, 1993, several tests were performed to verify the compressor throughput. These initial results indicated the flow was about 15 % lower than specified. On May 26, 1993, in a test to verify the capacity of the compressor, the low flow capacity observed in earlier tests was found to be due to leakage in the oil blow down valves installed on the four stage oil removing coalescers. The leaks were fixed, compressor re-tested and results are given in this technical note. The compressor now appears to have the rated capacity and the flow delivered is adequate.

SYSTEM DESCRIPTION

The test loop flow schematic for the SULLAIR compressor is given in Figure 1. The compressor driven by a 350 HP motor. Helium from compressor discharge goes through the oil separator, after cooler, four stages coalescers, pressure control valve and back to the suction of the compressor. The standard instrumentation on the SULLAIR compressor includes pressure and temperature gages in the gas circuit and in the oil circuit. A MERIAM two inch orifice plate with a bore of 0.755 inches and a BARCO 3/4 inch Venturi with a beta ratio of 0.55 are used for flow measurement. A Wallace-Tiernan pressure gage is installed between the last stage of the coalescer and the pressure control valve. The flow curves for the orifice plate and the Venturi flow meter are given in Appendices 2 and 3. For calculating the mass flow rate in gm/sec, the performance curves can be represented as eqn. 1 for the orifice plate and eqn. 2 for the Venturi.

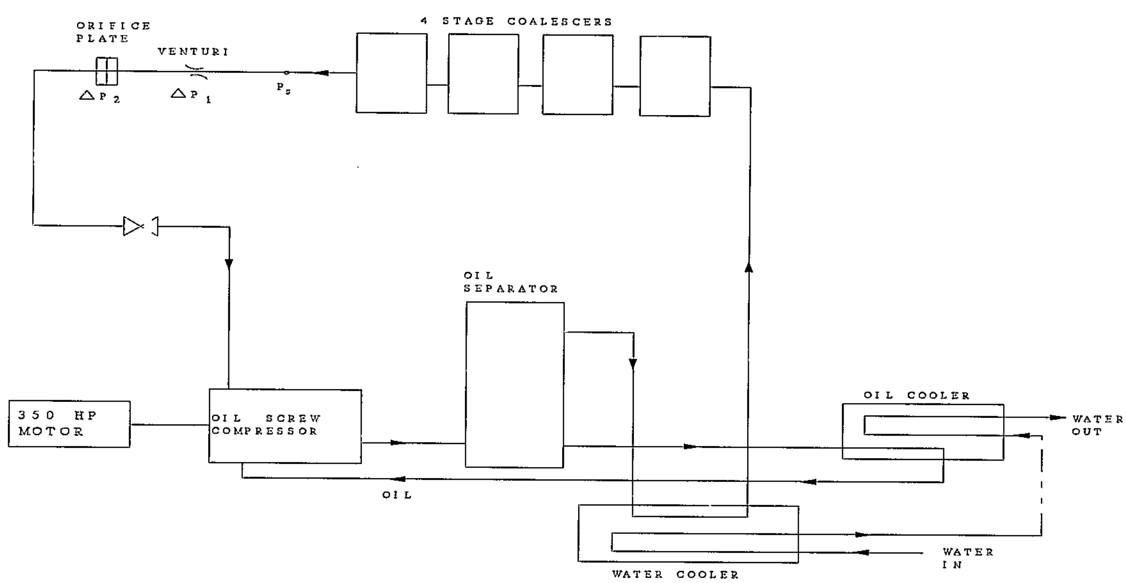


Figure 1. Flow schematic for testing SULLAIR compressor

$$\dot{m} = 124 \times \sqrt{\Delta P \times \rho} \tag{1}$$

$$\dot{m} = 78 \times \sqrt{\Delta P \times \rho} \tag{2}$$

Where $\dot{m}$ is the mass flow rate in gm/sec

ΔP is the differential pressure in inches of water

and ρ is the density in gm/cm^3 and is calculated from pressure and temperature.

A Fluke multimeter is used to measure the voltages provided and a clamp-on-ampere meter is used to measure the current for each phase. The power factor is measured by a EPIC power factor meter. The isothermal and adiabatic work are calculated using eqns. 3 and 4 respectively. The electric power to the motor is calculated from the voltage, the current and the power factor as given in eqn. 5. The brake horse power defined as the useful power delivered to the compressor equals the electric power multiplied by the motor efficiency as shown in eqn. 6. This report uses 0.95 as the motor efficiency. The isothermal and the adiabatic efficiencies of the compressor are defined as the ratio of isothermal and adiabatic compression work to the brake horse power as given in eqns. 7 and 8 respectively.

$$Work_{isothermal} = \dot{m} \times R \times T \times \ln\left(\frac{P_{dis}}{P_{suc}}\right) \tag{3}$$

$$Work_{adiabatic} = \dot{m} \times \frac{k}{k-1} \times R \times T \times \left[\left(\frac{P_{dis}}{P_{suc}}\right)^{\frac{k-1}{k}} - 1\right] \tag{4}$$

$$Power_{electric} = V \times I \times P.f. \times \sqrt{3} \tag{5}$$

$$B.H.P. = Power_{electric} \times \eta_{motor} \tag{6}$$

$$\eta_{isothermal} = \frac{Work_{isothermal}}{B.H.P.} \tag{7}$$

$$\eta_{adiabatic} = \frac{Work_{adiabatic}}{B.H.P.} \tag{8}$$

where *Work* is the input work,

R is the gas constant, 20 cm^3-atm/g-K,

T is the gas temperature,

P is the pressure,

k is ratio of the specific heats,

Power is the electric input power,

V is the voltage,

I is the current,

P.f. is the power factor,

B.H.P. is the brake horse power,

η is the efficiency,

subscripts *dis* and *suc* refer to the discharge and suction of the compressor, and *isothermal* and *adiabatic* refer to the isothermal and adiabatic processes respectively.

RESULTS

Tests have been performed at the suction and discharge pressures given in Table 2. After the tests, the two differential pressure gages were calibrated and the results are given in Appendix 4. As seen from Appendix 4, the differential pressure gage connected to the venturi is accurate but the one connected to the orifice plate is low by approximately 4 inches of water in the range of measurement. Flow rates and compressor efficiencies have been calculated based on the flow measurements from both the Venturi and orifice plate with corrected differential pressures. The test data and calculations are given in Appendix 5. The results corresponding to conditions No.1, 2b and 2a are summarized in Tables 3, 4 and 5. As seen, the flow rates measured from the orifice plate agree well with that of the venturi. For performance conditions No. 1 and No. 2b, the flow rates are higher than the manufacturer predicts and the compressor efficiencies are as predicted. For performance condition No. 2a, the flow rate equals the manufacturer's prediction, but the compressor efficiencies are lower. The manufacturer suspects the 50 % motor load for condition No. 2a and the cold oil temperature of 96 F as the cause for low efficiency. See Appendix 6 for reference.

Table 3. Performance for Condition No. 1 of the SULLAIR compressor

	Predicted	Measurement	
		Orifice Plate	Venturi
Helium Flow Rate (g/s)	51.5	56.9	57.3
Suction Pressure (atm)	1.05	1.05	1.05
Discharge Pressure (atm)	18	18	18
Suction Temperature (F)	N. A.	76	76
Discharge Temperature (F)	N. A.	162	162
Isothermal Efficiency (%)	40	39.0	39.3
Adiabatic Efficiency (%)	75±3	72.5	73.1

Table 4. Performance for Condition No. 2b of the SULLAIR compressor

	Predicted	Measurement Orifice Plate	Measurement Venturi
Helium Flow Rate (g/s)	13.2	17.6	18.8
Suction Pressure (atm)	0.35	0.346	0.346
Discharge Pressure (atm)	18	18	18
Suction Temperature (F)	N. A.	79	79
Discharge Temperature (F)	N. A.	154	154
Isothermal Efficiency (%)	19±5	20.0	21.4
Adiabatic Efficiency (%)	48±5	48.9	52.1

Table 5. Performance for Condition No. 2a of the SULLAIR compressor

	Predicted	Measurement Orifice Plate	Measurement Venturi
Helium Flow Rate (g/s)	17.5	17.7	18.2
Suction Pressure (atm)	0.35	0.362	0.362
Discharge Pressure (atm)	4	4.08	4.08
Suction Temperature (F)	N. A.	78	78
Discharge Temperature (F)	N. A.	130	130
Isothermal Efficiency (%)	42.5±3	32.5	33.3
Adiabatic Efficiency (%)	74.2±3	54.9	56.2

CONCLUSION

For performance conditions No. 1 and 2b, the compressor appears to have the proper throughput and efficiencies as the manufacturer predicted. For performance condition No. 2a, the low compressor efficiencies are believed to result from the small loads on the motor.

APPENDIX 1. Technical Information Summary Sheet for the SULLAIR Compressor

PERFORMANCE CONDITION 1
- Technical Information Summary Sheet -

Screw Compressor Manufacturer Sullair Refrigeration

Helium Flow Rate (g/s)	51.5 $\mp{}^{0}_{3}$%
Male Rotor Diameter & RPM	204mm @ 3560 RPM
Female Rotor Diameter & RPM	204mm @ 2377 RPM
Rotating Seal Type	John Crane Type 9
Pressure Difference Across Seal	252 PSI
Brake H.P. for Performance Spec. 2.1	333
Compressor Volumetric Efficiency Spec. 2.1	75.1 $\mp{}^{0}_{3}$%
Compressor Adiabatic Efficiency Spec. 2.1	75 ± 3%
Compressor Isothermal Efficiency Spec. 2.1	40
Screw Compressor Volume Ratio	4.8
Electric Motor	
Manufacturer	Reliance
Rated HP @ RPM	350HP @ 3560 RPM
NEMA Frame	445TS
Rated Amps	381
Bearing Type	Ball
Power Factor @ 100%, 75%, 50%, 25%	90.3/90.5/88.3/72.9
Efficiency @ 100%, 75%, 50%, 25%	95.3/95.7/95.7/93.8
Current per Phase Spec. 2.1	381 @ FL
Total electrical power consumption Spec. 2.1	

Range of Unloading; from 100 % to 20 %

Oil Pump: HP, Type and Manufacturer: Gear; Tuthill

Oil Charge: Type and Quantity: 45 Gallons, UCON LB170

Oil Separation Equipment: No. of Stages, Types and Sizes 3; Centrifugal, Demistor Pad and Coalescing Element

Oil Pressure: 297 psig Flow: 38.5 gpm

Cooling Water Pressure: ______ psig Flow: 75 gpm

Total Weight of Assembly: 7500 lbs.

Approximate OA Dimensions: 156" L x 58" W x 97" H

Sound Level @ 100% Operation: 95 dBA @ 3'

PERFORMANCE CONDITION 2
- Technical Information Summary Sheet -

Screw Compressor Manufacturer Sullair Refrigeration

	P_1 = 0.35 ATM, P_2 = 4.0 ATM	P_1 = 0.35 ATM, P_2 = 18 ATM
Helium Flow Rate (g/s)	17.5 $\mp\,^{0}_{3}$%	13.2
Male Rotor Diameter & RPM	204mm @ 3560 RPM	
Female Rotor Diameter & RPM	204mm @ 2377 RPM	
Rotating Seal Type	John Crane Type 9	
Pressure Difference Across Seal	44 PSI	252 PSI
Brake H.P. for Performance Spec. 2.1	93 $\pm$ 3%	258 $\pm$ 3%
Compressor Volumetric Efficiency Spec. 2.1	82% $\mp\,^{0}_{3}$%	62% $\pm$ 5%
Compressor Adiabatic Efficiency Spec. 2.1	74.2 $\pm$ 3%	48% $\pm$ 5%
Compressor Isothermal Efficiency Spec. 2.1	42.5 $\pm$ 3%	19% $\pm$ 5%
Screw Compressor Volume Ratio	4.8	4.8
Electric Motor		
Manufacturer	Reliance	See Data
Rated HP @ RPM		Sheet for
NEMA Frame		Performance
Rated Amps		Condition 1
Bearing Type		
Power Factor @ 100%, 75%, 50%, 25%		
Efficiency @ 100%, 75%, 50%, 25%		
Current per Phase Spec. 2.1		
Total electrical power consumption Spec. 2.1		

Range of Unloading; from ______% to ______%

Oil Pump: Type and Manufacturer: ____________________

Oil Charge: Type and Quantity: ____________________

Oil Separation Equipment: No. of Stages, Types and Sizes ____________________

____

____

Oil Pressure: __________ psig Flow: __________ gpm

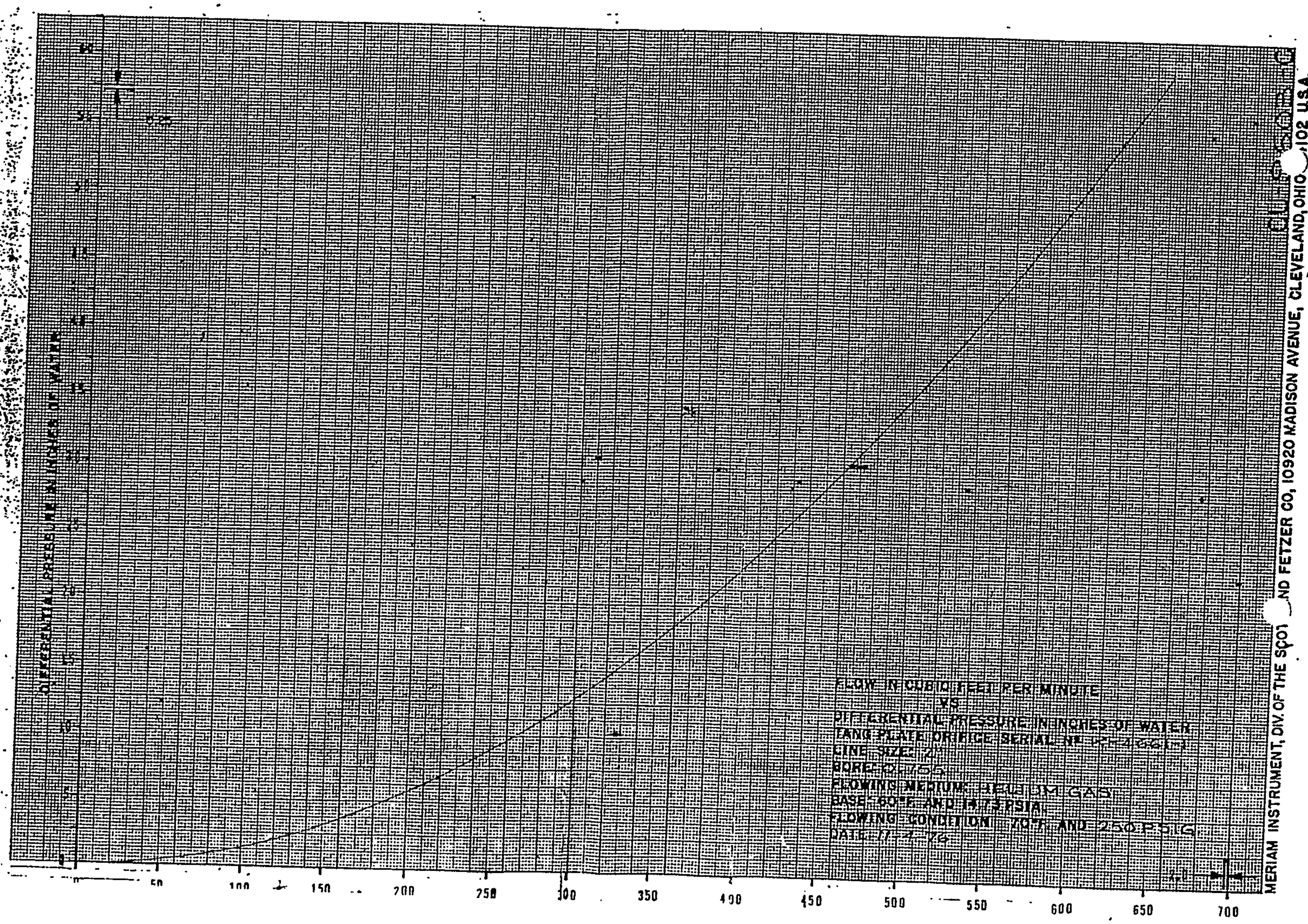
Cooling Water Pressure: __________ psig Flow: __________ gpm

Total Weight of Assembly: ____________________ lbs.

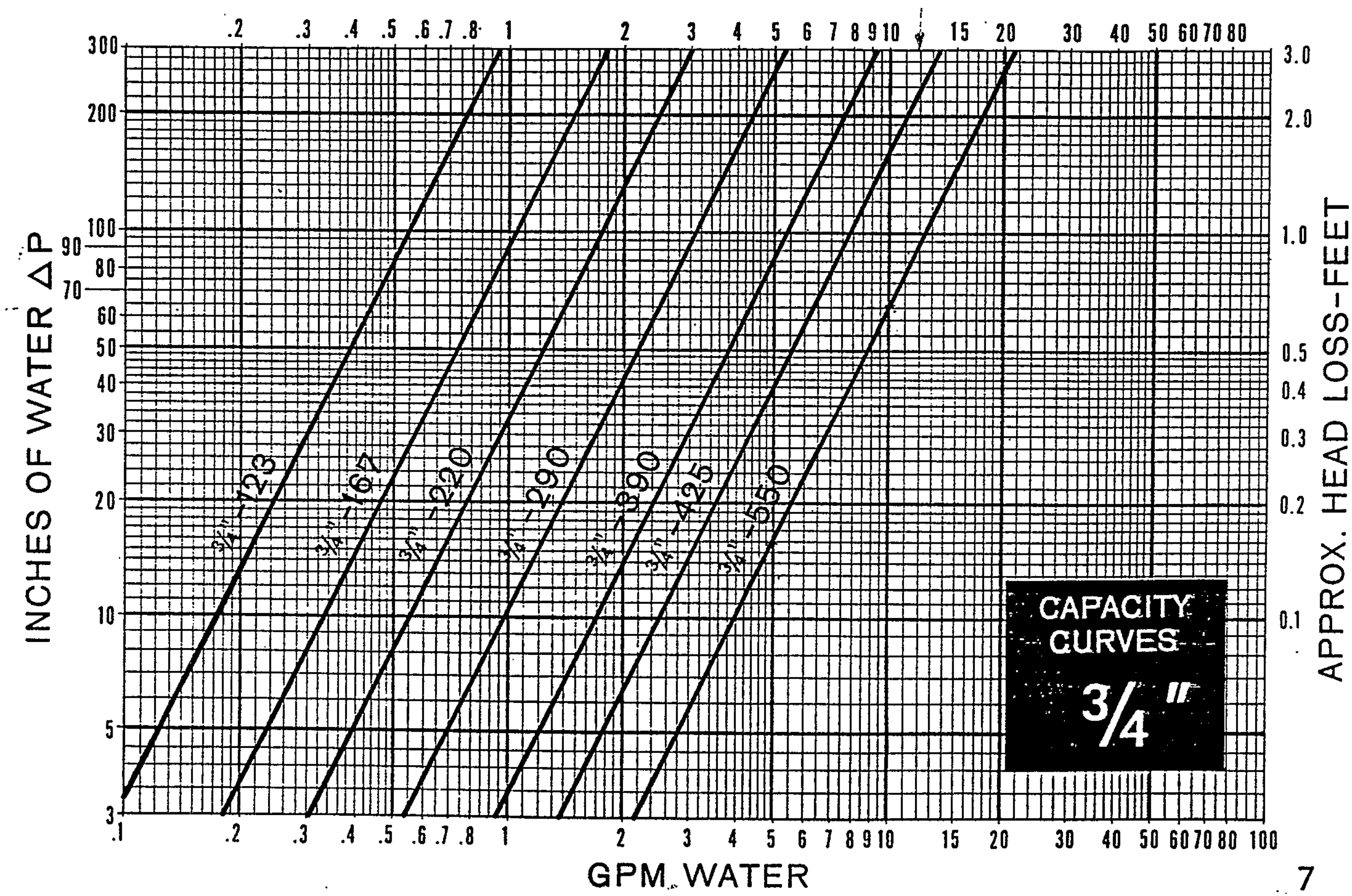
Approximate OA Dimensions: ____________________

Sound Level @ 100% Operation: ____________________

APPENDIX 2. Performance Curve for the MERIAM Orifice Plate



APPENDIX 3. Performance Curve for the BARCO Venturi Flow Meter



APPENDIX 4. Calibration Results for the Differential Pressure Gages

The following two gages are calibrated using a NIST Traceable MENSOR PCS 400 Pressure Calibration System by W. DeVito on June 21, 1993. The accuracy is 0.025% for a 30 psi scale.

Gage 1). BARTON differential gage SN#200-34397, used for the venturi

Inches of water at 20 C

MENSOR	BARTON
0	1
50	51
100	100.5
150	150
200	200
250	249
300	301

Gage 2). BARTON differential gage E1316-74, used for the orifice plate

Inches of water at 20 C

MENSOR	BARTON
4	0
20	17
40	37
60	56
80	76
100	94
150	140
200	183
250	226
300	271
4	0
6.7	3
8.9	5
13.5	10
18.5	15
23.5	20
33.5	30
43.5	40
53.5	50
63.7	60
75.6	70

APPENDIX 5. Test Results for the SULLAIR Compressor

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Evaluate the performance of the 350 HP SULLAIR													6/4/9
compressor in 902A													K. C.
	W & T gage			From compressor panel					From gages installed on th				
												Orifice D P1	P. ml
Time	Psuc psia	Psuc atm	Psuc psig	Pdis psig	Poil psig	Tsuc F	Toil F	Tdis F	Pres psia	Pres atm	Dens. g/cc	D P1 "H2O	ml g/s
10:35	16.4	1.12	2	250	300	75	108	162	265	18.0	.0029	78	58.8
10:40	16.2	1.10	1.8	250	300	75	108	162	264	18.0	.0029	75	57.6
10:45	16.2	1.10	1.8	250	300	76	108	162	264	18.0	.0029	74	57.3
												AVG =	57.9
11:00	15.4	1.05	1	250	300	76	108	162	265.	18.0	.0029	68	54.9
11:05	15.5	1.05	1	250	300	76	108	162	264	18.0	.0029	69	55.3
11:10	15.5	1.05	1	250	300	77	108	162	264	18.0	.0029	70	55.7
												AVG =	55.3
Reduce suction to 5 psia and maintain discharge at 265 psia													
			"H2O										
11:30	5.05	.344	-23.	247	295	79	106	154	265	18.0	.0029	3	11.5
11:35	5.1	.347	-23	248	295	79	106	154	265	18.0	.0029	3	11.5
11:45	5.1	.347	-23	249	295	79	105	154	265	18.0	.0029	3	11.5
												AVG =	11.5
Reduce suction to 5 psia and discharge to 60 psia													
12:00	5.25	.357	-22	46	133	78	96	132	60	4.08	.0007	29	17.0
12:05	5.3	.361	-22	46	133	78	96	132	60	4.08	.0007	28	16.7
12:10	5.4	.367	-22	46	133	78	96	130	60	4.08	.0007	26	16.1
												AVG =	16.6

O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
3												
Wu										K =	1.667	
										R =	20.5	
										T =	300	
e line				Electric input								Est.
Corrected				to motor							Energy	Brake
Orifice		Venturi										H.P.
D P1'	m1'	D P2	m2	Va-c	Vb-c	Vc-a	I1	I2	I3	P.F.	Input	
H2O	g/s	H2O	g/s	Volt	Volt	Volt	Amp	Amp	Amp		K.W.	K.W.
												Comp.E
												.95
82	60.27	210	60.9	474	476	473	370	370	370	.89	270.5	257.0
79	59.16	200	59.4	474	474	472	370	370	365	.9	271.8	258.2
78	58.78	202	59.7	474	475	472	370	370	365	.9	272.0	258.4
	59.41		60.0			474.			369	.897	271.4	257.9
72	56.48	184	57.0	474	477	473	370	370	365	.9	272.5	258.9
73	56.87	185	57.1	474	473	472	370	370	362	.9	270.8	257.3
74	57.26	190	57.9	473	475	473	370	370	362	.9	271.2	257.7
	56.87		57.3			474.			368	.9	271.5	258.0
7	17.61	20	18.8	476	476	472	313	316	305	.89	227.8	216.4
7	17.61	20	18.8	476	476	472	313	316	305	.89	227.8	216.4
7	17.61	20	18.8	473	475	475	314	317	306	.89	228.4	217.0
	17.61		18.8			475.			312	.89	228.0	216.6
33	18.10	85	18.3	475	476	472	144	145	135	.75	87.09	82.73
32	17.83	84	18.2	474	475	475	142	144	135	.75	86.53	82.20
30	17.26	82	18.0	474	475	475	142	144	135	.75	86.53	82.20
	17.73		18.2			475.			141	.75	86.72	82.38

	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM
1												
2	K/(K-1) =				2.5							
5	Compressor											
6	Isothermal						Adiabatic					
7	based on m1		based on m1'		based on m2		based on m1		based on m1'		based on m2	
8	work	Eff.	work	Eff.	work	Eff.	work	Eff.	work	Eff.	work	Eff
9	K.W.	%	K.W.	%	K.W.	%	K.W.	%	K.W.	%	K.W.	
10	ff											
12	101.9	39.65	104.5	40.65	105.5	41.05	187.1	72.79	191.8	74.64	193.7	75.3
13	100.2	38.82	102.9	39.84	103.3	40.00	184.4	71.41	189.2	73.29	190.0	73.6
14	99.56	38.53	102.2	39.56	103.8	40.18	183.2	70.89	188.0	72.78	191.0	73.9
16	100.6	39.00	103.2	40.02	104.2	40.41	184.9	71.70	189.7	73.57	191.6	74.2
19	97.23	37.55	100.1	38.64	100.9	38.98	181.1	69.95	186.4	71.98	188.0	72.6
20	97.66	37.95	100.4	39.04	100.9	39.22	181.5	70.56	186.7	72.57	187.6	72.9
21	98.36	38.17	101.1	39.25	102.3	39.69	182.9	70.96	188.0	72.96	190.1	73.7
23	97.75	37.89	100.5	38.98	101.4	39.30	181.8	70.49	187.0	72.50	188.6	73.1
28	28.44	13.14	43.45	20.08	46.35	21.42	69.58	32.15	106.3	49.11	113.4	52.3
29	28.37	13.11	43.34	20.03	46.23	21.36	69.24	31.99	105.8	48.87	112.8	52.1
30	28.37	13.08	43.34	19.98	46.23	21.31	69.24	31.91	105.8	48.75	112.8	52.0
32	28.40	13.11	43.38	20.03	46.27	21.36	69.35	32.02	105.9	48.91	113.0	52.1
36	25.75	31.13	27.47	33.21	27.83	33.63	43.60	52.70	46.51	56.22	47.11	56.9
37	25.21	30.67	26.95	32.78	27.55	33.52	42.58	51.80	45.52	55.38	46.54	56.6
38	24.10	29.32	25.89	31.50	27.01	32.86	40.54	49.32	43.55	52.98	45.44	55.2
40	25.02	30.37	26.77	32.50	27.46	33.34	42.24	51.28	45.19	54.86	46.36	56.2

APPENDIX 6. Response from SULLAIR Corporation

SULLAIR

Sullair Corporation
Subsidiary of Sundstrand Corporation
3700 East Michigan Blvd.
Michigan City, IN 46360

Phone 219-879-5451
Telex 258318

June 28, 1993

K. C. Wu
Brookhaven National Laboratory
Building 830
Upton, NY 11973-5000

Refer: C20LA704 Compressor/Magcool

Dear Sir:

I have reviewed your draft letter on the "performance of the 350 HP Sullair Oil Screw Compressor" which you sent me on June 14, 1993.

The basic difference between the quoted efficiencies and your efficiencies are the fact that you are using electric power into the motor while we are using mechanical power into the compressor. The difference is the motor efficiency. This results in an approximate 5% difference in both efficiencies. This would bring our values and your values in line on both applications with 18 atm. discharges.

The discrepancies in the 4 atm discharge application may be due to several factors. As the motor is only loaded 50%, the change in motor power factor would account for part of this. The test data also was run with cold oil (96°F) while the rest of the data was run closer to design oil temperatures of 110°F.

If you have any questions feel free to contact me.

Yours Truly,

Kenneth Puetzer
Engineering Manager

cc. D. Mantei