Case – 7 Reciprocating Compressor

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Case Background:

1.0 An inquiry is received from a customer asking for reciprocating compressor; the operating conditions for the compressor are as the following:

Capacity:	398,400 Btu/Hr.
Refrigerant:	R-22
Evaporative Temperature:	35°F
Condensing Temperature:	105°F
Suction piping loss:	3.2 Psi
Suction line superheat:	5°F
Discharge Piping Loss:	5.2 Psi
Power input:	380-3-50

Figure 7-1 is a copy of the performance table of the "Z" series standard compressors; the compressor selection shall base on the information shown in the performance table. The following information is required for the compressor selected:

A. Compressor Model Number.
B. Power Consumption.
C. Heat Rejection to the Condenser.

2.0 Use the Compressor Data available from Figure 7-2 to Figure 7-6 for the FX series open reciprocating compressors to calculate and to make the compressor selection to meet the duty shown below:

Capacity:	76 TR
Refrigerant:	R-22
Evaporative Temperature:	20°F
Condensing Temperature:	105°F
Suction piping loss:	2.2 Psi

Suction line superheat:	15°F
Discharge Piping Loss:	3.2 Psi
Power input:	380-3-50
Standby cold room temperature:	55°F

The following information is required for the selection:

(a) Compressor Model Number selected.
(b) Direct drive or Belt drive, Speed Designation selected.
(c) Power Consumption at the design point.
(d) Heat Rejection to the Condenser at the design point.
(e) What size of motor recommended by considering the pull down.

Related Technical Data and Engineering Information for the Case:

R-22 CAPACITY RATINGS – 50 Hz

MODEL		Z4H1-A		Z4J1-B		Z4K1-B		Z4M1-C		Z6N2-C		Z6R2-D		Z6S2-D		Z6W2-E	
Cond. Temp. °F	Evap. Temp. °F	47 CFM		54 CFM		58 CFM		67 CFM		70 CFM		81 CFM		88 CFM		101 CFM	
		TONS	KW	TONS	KW	TONS	KW	TONS	KW	TONS	KW	TONS	KW	TONS	KW	TONS	KW
80	25	17.9	11.6	20.8	13.9	22.9	15.5	26.0	17.6	27.3	17.5	31.8	20.6	34.8	23.2	40.6	26.9
	30	20.2	11.7	23.3	13.9	25.7	15.4	29.2	17.7	30.8	17.5	35.7	20.6	38.8	23.2	45.4	27.0
	35	22.6	11.8	25.9	13.9	28.7	15.3	32.6	17.6	34.4	17.4	39.8	20.5	43.1	23.2	50.4	27.1
	40	25.2	11.6	28.8	13.7	31.8	15.0	36.2	17.4	38.4	17.2	44.3	20.1	47.8	23.1	55.9	27.0
	45	28.0	11.1	31.9	13.4	35.3	14.5	40.2	16.9	42.8	16.7	49.1	19.6	52.9	22.8	61.7	26.6
	50	31.1	10.5	35.2	13.1	39.0	13.9	44.4	16.4	47.5	16.1	54.3	18.9	58.4	22.5	68.0	26.2
90	25	16.5	12.5	19.4	15.3	21.3	16.9	24.2	19.4	25.2	19.0	29.6	22.7	32.2	25.4	38.1	29.6
	30	18.7	12.9	21.7	15.5	24.1	17.2	27.2	19.8	28.5	19.5	33.3	23.1	36.3	25.9	42.6	30.2
	35	21.0	13.1	24.4	15.7	26.9	17.3	30.5	20.0	32.0	19.8	37.3	23.3	40.6	26.2	47.6	30.7
	40	23.5	13.2	27.1	15.6	29.9	17.2	34.0	20.0	35.9	19.8	41.6	23.2	45.2	26.3	52.8	30.8
	45	26.3	13.3	30.0	15.6	33.3	17.1	37.8	20.0	40.1	19.7	46.2	23.1	50.0	26.3	58.5	31.0
	50	29.2	12.9	33.3	15.4	36.9	16.6	41.9	19.6	44.5	19.3	51.2	22.6	55.2	26.1	64.5	30.7
100	25	15.2	13.3	18.0	16.6	19.7	18.3	22.4	20.9	23.1	20.4	27.4	24.7	29.9	27.4	35.6	32.3
	30	17.2	13.8	20.3	17.0	22.3	18.8	25.2	21.6	26.3	21.2	30.9	25.4	33.7	28.3	39.9	33.2
	35	19.4	14.2	22.8	17.3	25.1	19.2	28.4	22.1	29.6	21.7	34.8	25.9	37.9	28.9	44.6	34.0
	40	21.8	14.6	25.4	17.5	28.0	19.5	31.7	22.5	33.3	22.2	38.9	26.3	42.4	29.5	49.7	34.7
	45	24.5	14.8	28.3	17.6	31.2	19.5	35.4	22.6	37.3	22.3	43.3	26.3	47.2	29.7	55.1	35.0
	50	27.3	14.9	31.3	17.6	34.7	19.3	39.3	22.5	41.6	22.3	48.1	26.2	52.1	29.7	61.0	35.1
105	25	14.5	13.6	17.2	17.1	18.9	19.0	21.4	21.6	22.1	21.0	26.3	25.6	28.8	28.4	34.3	33.5
	30	16.5	14.2	19.5	17.7	21.4	19.6	24.3	22.3	25.1	21.8	29.7	26.4	32.5	29.4	38.5	34.6
	35	18.7	14.8	22.0	18.1	24.2	20.1	27.3	23.0	28.5	22.6	33.4	27.1	36.4	30.2	43.2	35.6
	40	21.0	15.2	24.6	18.4	27.0	20.4	30.7	23.4	32.0	23.1	37.5	27.6	40.9	30.9	48.1	36.3
	45	23.5	15.5	27.3	18.6	30.1	20.7	34.2	23.8	35.9	23.5	41.8	28.0	45.7	31.4	53.5	37.0
	50	26.3	15.7	30.4	18.7	33.5	20.6	38.0	23.9	40.1	23.6	46.5	27.9	50.5	31.6	59.2	37.2
110	25	13.9	13.9	16.6	17.6	18.2	19.6	20.6	22.1	21.0	21.5	25.2	26.3	27.6	29.2	33.1	34.5
	30	15.8	14.6	18.7	18.3	20.6	20.3	23.3	23.1	23.9	22.4	28.6	27.4	31.2	30.4	37.2	35.9
	35	17.9	15.2	21.1	18.8	23.2	20.9	26.3	23.8	27.2	23.3	32.1	28.2	35.1	31.4	41.7	37.0
	40	20.2	15.7	23.6	19.3	26.0	21.4	29.5	24.4	30.8	24.0	36.1	28.9	39.4	32.3	46.5	38.0
	45	22.7	16.2	26.4	19.6	29.1	21.7	33.0	24.9	34.6	24.5	40.3	29.4	44.0	32.9	51.8	38.8
	50	25.3	16.5	29.4	19.8	32.3	22.0	36.8	25.2	38.6	24.9	44.9	29.7	49.0	33.4	57.3	39.4
120	25	12.5	14.4	15.1	18.5	16.5	20.7	18.8	23.1	18.9	22.3	23.0	27.5	25.2	30.7	30.5	36.5
	30	14.3	15.2	17.2	19.4	18.8	21.6	21.4	24.2	21.6	23.5	26.2	29.0	28.7	32.2	34.4	38.2
	35	16.3	15.9	19.4	20.2	21.3	22.4	24.2	25.3	24.8	24.5	29.6	30.3	32.3	33.6	38.8	39.8
	40	18.5	16.7	21.8	20.8	24.1	23.1	27.2	26.2	28.1	25.5	33.3	31.3	36.4	34.8	43.4	41.1
	45	20.8	17.4	24.5	21.4	27.0	23.7	30.6	27.0	31.7	26.4	37.4	32.2	40.7	35.9	48.3	42.4
	50	23.4	17.9	27.3	21.8	30.1	24.2	34.1	27.6	35.6	27.1	41.8	32.9	45.6	36.7	53.7	43.3
130	25	11.1	14.6	13.7	19.1	14.9	21.5	17.1	23.8	16.8	22.9	20.8	28.6	22.8	31.8	27.8	38.2
	30	12.9	15.7	15.7	20.2	17.1	22.7	19.5	25.1	19.4	24.3	23.8	30.3	26.2	33.7	31.6	40.2
	35	14.8	16.6	17.8	21.3	19.4	23.7	22.2	26.5	22.4	25.6	27.1	31.9	29.6	35.5	35.7	42.1
	40	16.8	17.5	20.1	22.2	22.1	24.7	25.0	27.7	25.5	26.8	30.6	33.3	33.5	37.0	40.1	44.0
	45	19.0	18.3	22.6	23.0	24.8	25.5	28.1	28.9	28.9	28.0	34.4	34.7	37.7	38.4	44.9	45.7
	50	21.4	19.1	25.3	23.7	27.8	26.3	31.5	29.8	32.7	29.0	38.5	35.8	42.1	39.7	50.0	47.1
140	25	9.9	15.0	12.3	19.5	13.3	22.2	15.4	24.4	14.8	23.3	18.7	29.4	20.5	32.7	25.3	39.6
	30	11.6	15.9	14.2	20.9	15.3	23.6	17.6	25.9	17.2	24.9	21.5	31.3	23.5	34.8	28.9	42.0
	35	13.2	17.0	16.2	22.1	17.6	24.8	20.2	27.4	20.0	26.4	24.6	33.2	26.9	37.0	32.8	44.2
	40	15.2	18.1	18.4	23.3	20.1	26.0	22.8	28.9	22.9	27.9	27.8	35.0	30.6	38.8	36.9	46.4
	45	17.2	19.1	20.7	24.4	22.7	27.1	25.7	30.4	26.2	29.3	31.5	36.7	34.4	40.8	41.4	48.5
	50	19.5	20.0	23.2	25.4	25.5	28.1	28.9	31.8	29.6	30.7	35.4	38.2	38.8	42.5	46.3	50.5

METHOD OF CONVERSION: °C = 5/9 (°F - 32°C) 1KCAL/HR = 3.968 BTU/HR

HEAT REJECTION (MBH) = TONS x 12 + KW x 3.415

Figure 7-1 Performance Table for Type "Z" Reciprocating Compressor

Compressor Data, FX Series

Compressor Unit	Max. Speed	CFM Displacement
4-Cylinder Units		
FX-3049	1750	134
6-Cylinder Units		
FX-3069	1750	201
8-Cylinder Units		
FX-3089	1750	268
12-Cylinder Units		
FX-3129	1750	402
16-Cylinder Units		
FX-3169	1750	536

Figure 7-2 Compressor Data for FX Reciprocating Compressors

BELT DRIVEN CAPACITY FACTORS

60 Cycle - 1750 RPM Input

Compressor Speed-RPM	Speed Designation	Tons Factor	BHP Factor	Max. HP 4 Belts	Max. HP 8 Belts 4, 6, 8 & 12 Cyl.	Max. HP 8 Belts 16 Cyl.
1750	B69	1.000	1.030	73	115	99
1650	B68	.943	.960	71	115	94
1480	B67	.845	.846	65	112	85
1290	B66	.737	.720	57	97	73
1160	B65	.663	.633	51	87	66
1000	B64	.572	.525	42	75	56
890	B63	.509	.452	36	67	50

50 Cycle - 1450 RPM Input

Compressor Speed-RPM	Speed Designation	Tons Factor	BHP Factor	Max. HP 4 Belts	Max. HP 8 Belts 4, 6, 8 & 12 Cyl.	Max. HP 8 Belts 16 Cyl.
1760	B59	1.005	1.035	75	115	99
1550	B58	.887	.896	70	115	88
1450	B57	.828	825	67	110	83
1370	B56	.783	.774	64	104	78
1220	B55	.698	.672	57	91	69
960	B54	.549	.500	45	72	54
830	B53	.475	.412	37	61	46

Figure 7-3 Capacity and HP Correction Factors
Belt Drive – FX Compressors

DIRECT DRIVEN CAPACITY FACTORS

Speed RPM	Speed Designation	Tons Factor	BHP Factor
1750	D69	1.000	1.000
1450	D57	.828	.803
1170	D65	.668	.620
975	D54	.557	.495

Figure 7-4 Capacity and HP Correction Factors
Direct Drive – FX Compressors

REDUCED CAPACITY FACTORS

% Full Load Capacity	Tons Factor	BHP Factor
83.3	.833	.867
75.0	.750	.784
66.7	.667	.700
50.0	.500	.545
33.3	.333	.384
25.0	.250	.305

Figure 7-5 BHP Correction Factors Vs Percent of FL Capacity
FX Compressors

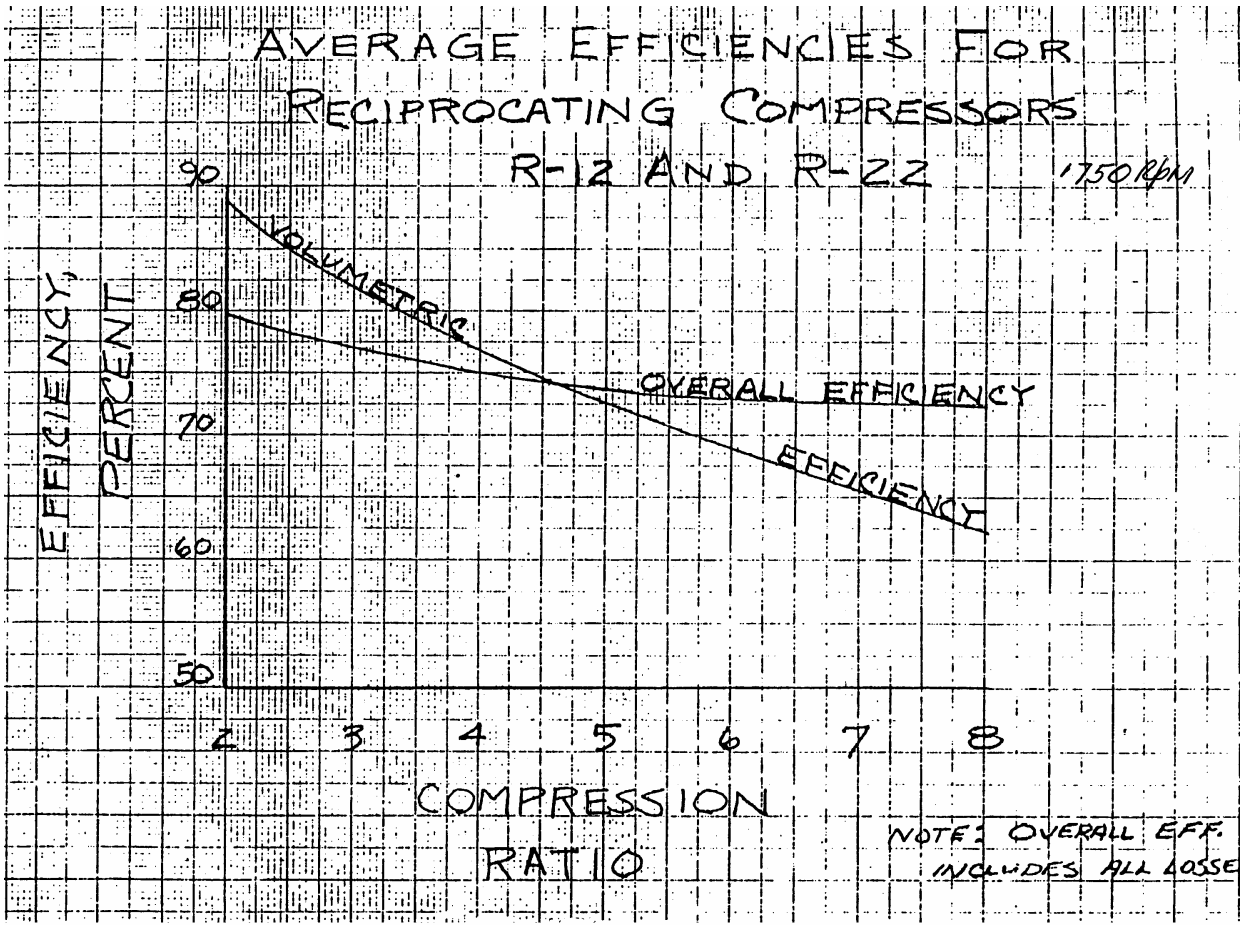

Figure 7-6 Typical Average Efficiencies for FX Reciprocating Compressors

Cogitation

Reciprocating compressor selection can be obtained either by:

(a) Performance table provided by the compressor maker.
(b) Computer software provided by the manufacturer.
(c) Efficiency Curves provided by the compressor maker.

If compressor is selected by using the performance table or efficiency curves, be sure to apply the capacity and BHP correction factors as required; also it is important to adjust the compressor speed in accordance with the motor speed, such as if the power supply is 60 Hz or 50 Hz or if the compressor is belt drive. If belt drive is used for the compressor, it is important to keep the driving horsepower not to exceed the maximum horsepower limitation.

1.0 "Z" Standard Compressor selection:

Operating conditions given by the specification:

Capacity:	398,400 Btu/Hr.
Refrigerant:	R-22
Evaporative Temperature:	35°F
Condensing Temperature:	105°F
Suction piping loss:	3.2 Psi
Suction line superheat:	5°F
Discharge Piping Loss:	5.2 Psi
Power input:	380-3-50

398,400 Btu/Hr = 33.2 TR

From Figure 7-1, the Capacity Rating table of "Z" compressors, at ET 35°F and CT 105°F, Model Z6R2-D has 33.4 TR. Check capacity with suction and discharge loses as specified.

The equivalent ET and CT calculation with loses:

Equivalent ET = 32.61°F

Suction Pressure = 76.13 Psia (Pt at ET 35°F) – 3.2 Psi
= 72.94 Psia

At Pt = 72.94Psia, Tp = 32.61°F

Equivalent CT = 106.7°F

Discharge Pressure = 225.39 Psia (Pt at CT 105°F) + 5.2 Psi

= 230.59 Psia

AT Pt = 230.59 Psia; Tp = 106.7°F

Interpolate the rating with the corrected ET and CT:

CT	ET	TR	KW
	30°F	29.7	26.4
105°F	*32.61°F*	31.62	26.76
	35°F	33.4	27.1
106.7°F	*32.61°F*	*31.11 TR*	
	30°F	28.6	27.4
110°F	*32.61°F*	30.43	27.82
	35°F	32.1	28.2

At the equivalent ET 32.61°F and CT 106.7°F
Z6R2-D is only having a capacity of 31.22 TR,
6% short of the capacity 33.2 TR specified.

Go to the next larger size compressor model Z6S2-D:

CT	ET	TR	KW
	30°F	32.5	29.4
105°F	*32.61°F*	34.54	29.82
	35°F	36.4	30.2
106.7°F	*32.61°F*	*34.10*	*30.19*
	30°F	31.2	30.4
110°F	*32.61°F*	34.24	30.92
	35°F	35.1	31.4

At the equivalent ET 32.61°F and CT 106.7°F
Z6S2-D is having a capacity of 34.1 TR (or 409,200 Btu/Hr.)
Therefore, Z6S2-D is Ok.

$$\text{Power consumption at rated capacity} = \frac{33.2}{34.1} \times 30.19 = 29.4 \text{ KW}$$

Heat rejection, MBH = 33.2 x 12 + 29.4 x 3.415
= 498.8 MBH

Conclusion:

A. Model Z6S2-D is selected.
B. Power consumption is 30.9 KW.
C. Heat rejection to condenser is 498,800 Btu/Hr.

2.0 FX Series compressor selection using efficiency curves:

Operating conditions given:

Capacity:	76 TR
Refrigerant:	R-22
Evaporative Temperature:	20°F
Condensing Temperature:	105°F
Suction piping loss:	2.2 Psi
Suction line superheat:	15°F
Discharge Piping Loss:	3.2 Psi
Power input:	380-3-50

Solution:

Compressor suction temp. = 20 + 15 =	35°F
Evaporative Pressure:	57.71 Psia
Compressor suction pres. = 57.71 – 2.2 =	55.51 Psia
Condensing Pressure:	225.39 Psia
Compressor Discharge = 225.39 + 3.2 =	228.59 Psia

Compression Ratio: CR = 228.59/55.51 = 4.12

From the curve, at 4.12 CR Volumetric V_{ff} = 76.2
Overall E_{ff} = 74.9

P-H Diagram:

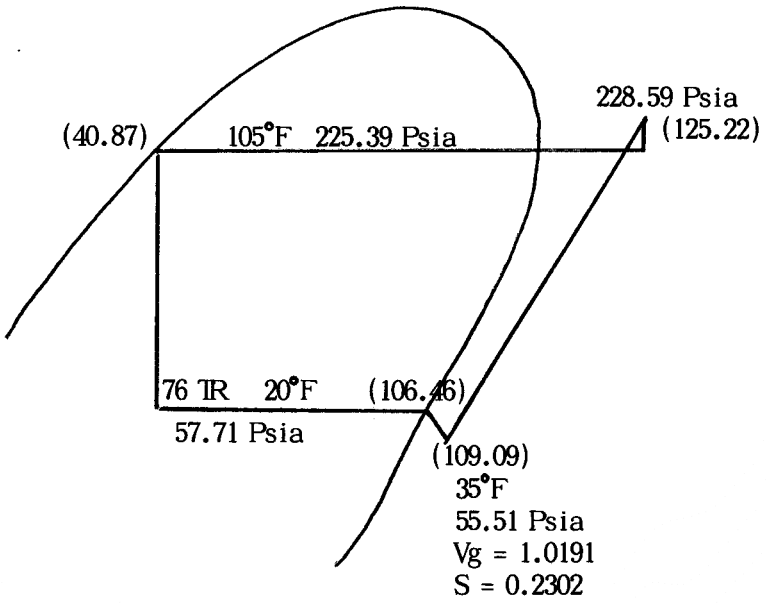

Figure 7-7 P-H Diagram at Design Conditions

$$\text{Refrigerant Flow} = \frac{200}{H_2 - H_1} \times TR = \frac{200}{106.46 - 40.87} \times 76$$

$$= 231.74 \text{ Lbs/Min.}$$

Suction Flow = (Lbs/Min) x Vg
= 231.74 x 1.0191 = 236.17 ACFM

$$\text{Compressor Cylinder Displacement} = \frac{ACFM}{V_{ff}} = \frac{236.17}{0.762}$$

$$= 309.9 \text{ CFM}$$

Try Model FX-3129, which is having swept volume of 402 CFM at 1750 RPM maximum speed..

For 50 Hz , use a 4-pole motor of 1450 RPM speed.

Tentative selections: Two possibilities of either belt drive or direct drive.

Option-1: Belt Drive, use B56, 1,370 Rpm, CFM Displacement = 314.7 CFM

Option-2: Direct Drive, use D57, 1,450 Rpm, CFM Displacement =333.1 CFM

Power Consumption required for the compressor at design load:

$$SHP = \frac{\text{Flow x Head}}{33000 \times E_{ff}} = \frac{231.74 \times (125.22 - 109.09) \times 778}{33000 \times 0.749}$$

$$= 117.7 \text{ HP}$$

Maximum HP for 8-Belt B56 is limited at 104 BHP, therefore belt drive option cannot be used.

FX-3129 Direct Drive with D57 is therefore selected.

Heat rejection = 76 x 12000 + 117.7 x 2545

= 1,211,547 Btu/Hr.

Calculate the pull down HP:

Pressure drop for suction and discharge are negligible.

Stand by temperature is 55°F. ET = 55°F

P-H Diagram:

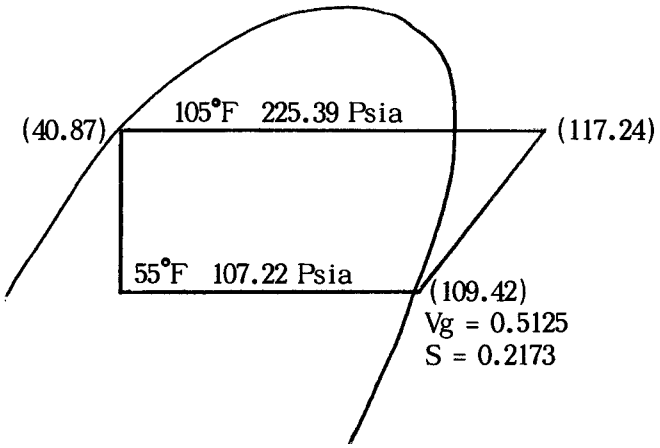

Figure 7-8 P-H Diagram at Stand-by Conditions

$$CR = \frac{P_2}{P_1} = \frac{225.39}{107.22} = 2.1$$

From Figure 7-6, at CR = 2.1

Volumetric V_{ff} = 87.7%
Overall E_{ff} = 79.4%

Displacement of FX-3129 at 1,450 RPM is 333.1 CFM

ACFM at CR = 2.1 is 333.1 x 0.877

ACFM = 333.1 x 0.877 = 292 ACFM

Mass Flow for FX-3129 Compressor at 1,450 RPM at stand by condition:

$$\text{Lbs./Min.} = \frac{\text{ACFM}}{\text{Vg}} = \frac{292}{0.5125} = 570 \text{ Lbs/Min.}$$

Driving BHP:

$$\text{BHP} = \frac{\text{Flow x Head}}{33000 \times E_{ff}} = \frac{570 \times (117.24 - 109.42) \times 778}{33000 \times 0.794}$$

$$= 132.4 \text{ HP}$$

$$\text{PULL DOWN HP} = \frac{132.35 + 117.7}{2} = 124.9$$

Therefore, Size of motor to be used is 125 HP motor.

Conclusion:

(a) Compressor Model Number selected:FX-3129
(b) Direct Drive, Speed Designation is D57.
(c) Power Consumption at design point is 117.7 BHP.
(d) Heat rejection to condenser is 1,211,547 Btu/hr.
(e) Size of driving motor is 125 HP.