RECIPROCATING COMPRESSOR CALCULATION SHEET

WITH INTERCOOLER

Gas properties, flowrate and conditions

1	Gas name	Nitrogen (N2)				
	Item or symbol	Quantity	Unit	Item or symbol	Quantity	Unit
2	Suction pressure, ps	1	bar A	Discharge pressure, pd	40	bar A
3	Suction temperature, ts	40	^{O}C			
4	Ts	313	^{O}K	p_{CR}	33.70	bar A
5	MW	28.0	kg/kgmol	T_{CR}	126.70	^{O}K
6	k_S	1.400		$p_R = p / p_{CR}$	0.03	
7	R_S	0.297	kJ/kg.^{O}K	$T_R = T / T_{CR}$	2.47	
8	DSs	1.076	kg/m3	Z_S	1	
9	MCp	29.19	kJ/kgmol.^{O}K	Cp_S	1.04	kJ/kg
10	G	70000	kg/hr	G_{mol}	2500	kgmol/hr
11	Q_S	65073	m^3/hr	Q_N	56028	Nm^3/hr
12						

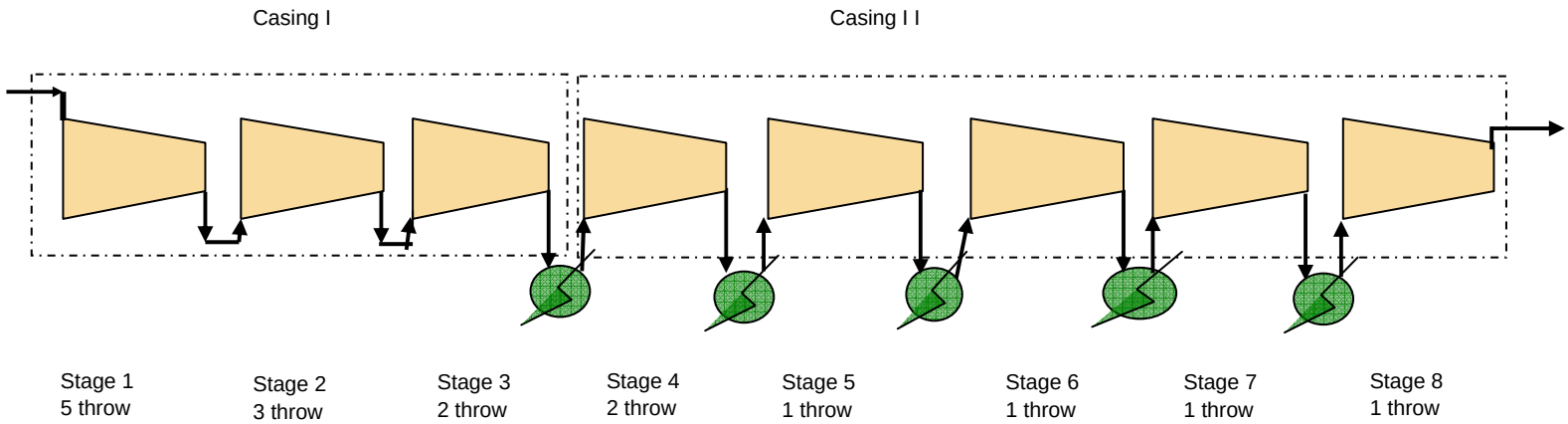
Compressor Calculation Sheet

	Item	Symbol	Unit	Quantity	Note
13	***Preliminary Calculation***				
14	**Check whether need intercooler**				
15	First Stage Volume flow	Qs	m3/hr	65073	
16	Cylinder intake pressure	ps'	barA	0.97	
17	Cylinder exhaust pressure	pd'	barA	41.2	
18	Pressure ratio (p_D / p_S)	r'_{TOTAL}	-	42.474	
19	(k-1)/k		-	0.2857	
20	k/(k-1)		-	3.500	
25	**Check number of stage due to max. temp**				
21	Max. temperature	t_{MAX}	^{O}C	150	See Chapter VI.
22		T_{MAX}	^{O}K	423	
23	Max. pressure ratio	r_{MAX-T}	-	2.87	Equation (11)
24	Is r > r_{MAX} or need intercooler ?			**Yes**	
25	Total Hydrodynamic head	H_{TOTAL}	m	63634	Eq. 8.
26	**Expected minimum adiabatic vol. eff.**	η_{V-A}		0.850	
27	Max. clearance space vol.		%	13.35	Eq. A.3. If need intercooler, use r = r_{max-T}, otherwise use r_{Total}
28	Clearance space volume	c	%	10	Fill < max.at expected eff.
29	Volumetric efficiency	η_V		0.843	Eq. A.3 and A.4.

	Item	Symbol	Unit	Quantity	Note
1	Supply efficiency	λ/η_V		0.949	Eq. A.5.
2	Required piston capacity	Qp	m3/hr	81326.7	Eq. A.6 and A.7.
3	Max. hydr. Head for each stage	$H_{STG-MAX}$	m	11656	Eq. A.6.
4	Preliminary number of stage	i_{CAL}		5	= Htotal / Hstg-max
5	GHP			15170	
6	Mechanical efficiency			0.95	
7	BHP			15969	
8	**Frame BHP selection**			**Casing I**	**Casing II**
9	Selected frame BHP			8000	9200 See frame BHP table near preliminary BHP in line 7
10	No. of frame			1	1 Frame BHP data
11	No. of throw per frame			10	6 Frame BHP data
12	Stroke length			508	400 Frame BHP data
13	No. of compression acting			2	2 Frame BHP data
14	Crankshaft speed			277	375 Frame BHP data
15	Max. diameter			1130	1000 Frame BHP data
16	Max. H per throw for frame			3213.3	6158.9 Eq.A.11

	Detail calculation	CASING I			CASING II				Note
18		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	
19	**G** (kg/hr)	70000	70000	70000	70000	70000	70000	70000	70000	
20	Max. H per stage for parallel throws	3213.3	3213.3	3213.3	6158.9	6158.9	6158.9	6158.9	6158.9	= line 16
21	Last cylinder exhaust press. (barA)	41.2	41.2	41.2	41.2	41.2	41.2	41.2	41.2	
22	Cyl. intake pressure, **ps'** (barA)	0.97	1.341	1.803	2.270	3.985	7.072	12.627	22.627	Eq. A8
23	Suction temperature, **ts** (C)	40.0	70.3	100.6	45.0	45.0	45.0	45.0	45.0	
24	**Ts** (K)	313.0	343.3	373.6	318.0	318.0	318.0	318.0	318.0	
25	Max. discharge temp., **td** max. (C)	**150**	150	150	150	150	150	150	150	Chapter 6
26	**Td** max. (C)	423.0	423.0	423.0	423.0	423.0	423.0	423.0	423.0	
27	**MW**	28.00	28.00	28	28	28	28	28	28	
28	**Rs** = 8.314/MW	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	
29	p_{CR}	33.7	33.7	33.7	33.7	33.7	33.7	33.7	33.7	
30	T_{CR}	126.7	126.7	126.7	126.7	126.7	126.7	126.7	126.7	
31	$p_R = p_{RED} = p / p_{CR}$	0.03	0.040	0.05	0.07	0.12	0.21	0.37	0.67	Appendix B
32	$T_R = T_{RED} = T / T_{CR}$	2.47	2.710	2.95	2.51	2.51	2.51	2.51	2.51	
33	Z_S	1	1	1	1	1	1	1	1	
34	MCp_S (kJ/kgmol.K)	29.19	# 29.2	29.2	29.2	29.2	29.2	29.2	29.2	
35	**k** = MCp/(MCp-8.314)	1.40	1.398	1.398	1.398	1.398	1.398	1.398	1.398	

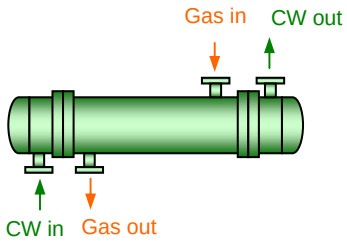
	Detail calculation (cont)	CASING I			CASING II					Note
		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	
1	**Cp_S** = R.k /(k-1), (kJ/kg.K)	1.04	1.043	1.043	1.043	1.043	1.043	1.043	1.043	
2	**DS_S** = 100.ps / (Z.R.Ts), (kg/m3)	1.1	1.3	1.6	2.4	4.2	7.5	13.4	24.0	Eq. 3 up to 7
3	**Q_S** = G / DSs, (m3/hr)	65072.7	53238.4	43073	29130.2	16591.5	9349.0	5235.6	2921.9	
4	**Q_N** (Nm3/h)	56028	56028	56028	56028	56028	56028	56028	56028	
5	**(k-1)/k**	0.286	0.285	0.285	0.285	0.285	0.285	0.285	0.285	
6	**k/(k-1)**	3.500	3.511	3.511	3.511	3.511	3.511	3.511	3.511	
7	**Due to max. temperature**									
8	Pressure ratio, **r '** due to max. temp.	2.869	2.081	1.547	2.723	2.723	2.723	2.723	1.821	Eq. 11, Eq. A.10
9	**Due to max. frame BHP**									
10	Max. **r'** due to max. frame BHP	1.382	1.345	1.314	1.800	1.800	1.800	1.800	1.800	
11	Selected **r'**	**1.382**	**1.345**	**1.314**	**1.800**	**1.800**	**1.800**	**1.800**	**1.800**	
12	Discharge pressure, **pd** (barA)	1.341	1.803	2.370	4.085	7.172	12.727	22.727	40.723	
13	Cylinder exhaust pressure, **pd'** (barA)	1.381	1.857	2.441	4.207	7.387	13.109	23.408	41.945	Eq. A8 for 3 % loss
14	Clearance space volume, **c** (%)	10	10	10	10	10	10	10	10	
15	Volumetric efficiency, **η_V**	0.925	0.928	0.929	0.900	0.900	0.900	0.900	0.900	Eq. A4
16	Supply efficiency, **λ/η_V**	0.989	0.990	0.991	0.977	0.977	0.977	0.977	0.977	Eq. A5
17	Required piston capacity, **Qp** (m3)	71120.3	57980.5	46770.8	33109.8	18858.2	10626.2	5950.9	3321.1	Eq. A7
18	Preliminary Piston speed (m/s)	5	**5**	**5**	**5**	**5**	**5**	**5**	**5**	
19	Stroke length, **L** (mm)	**508**	508	508	400	400	400	400	400	
20	No. of compression acting	2	2	2	2	2	2	2	2	
21	No. of throw for each stage, **z**	**5**	3 **3**	**2**	**2**	**1**	**1**	**1**	**1**	Max = 16
22	Crankshaft speed, **N** (RPM)	**277**	277	277	375	375	375	375	375	Adjust if U > 6 m/s
23	Piston speed, **U** (m/s)	4.7	4.7	4.7	5.0	5.0	5.0	5.0	5.0	Eq. 12, **max. 6 m/s**
24	Piston displacement vol./stroke, m^3	0.428	0.581	0.704	0.368	0.419	0.236	0.132	0.074	
25	Piston diameter, **D** (mm)	**1034.7**	1206.1	1326.8	1081.2	1154.0	866.2	648.2	484.3	Shall be < max. dia
26	Hydrodynamic head, **H** (m)	3213.3	3213.3	3213.3	6158.9	6158.9	6158.9	6158.9	6158.9	Eq. 8
27	**GHP**	**669**	**688**	**686**	**1375**	**1375**	**1375**	**1375**	**1375**	**Eq. 9**
31	Exhaust temp before cooler, **td** (C)	**70.3**	**100.6**	**130.8**	**102.9**	**102.9**	**102.9**	**102.9**	**102.9**	Eq. 10
28	Need intercooler ?	**No**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	
29	If "Yes", outlet gas temp. (C)	45	45	45	45	45	45	45	45	
30	Pres. drop at inter/stg cooler (bar)	0.10	0.10	0.10	0.100	0.100	0.100	0.100	0.100	
32	Compression continue ?	**Continue**	**Continue**	**Continue**	**Continue**	**Continue**	**Continue**	**Continue**	**Finish**	
33	**Total Adiabatic Compression GHP** (kW)	8919.89								
34	Adiabatic eff, when isn' t fully adiabatic	0.90								See figure below
35	Mechanical efficiency	0.945								Fig. A4
36	**Total BHP** (kW)	**10488**								
37	C.W. each cooler (ton/hr)	0.0	# 0.0	52.9	101	101	101	101	0	For Δt water = 10 C
38	Total C.W. required (ton/hr)	458.6								



Cooling water consumption is calculated with following equation :

$$G_{WI} = \frac{(0.001)\, G_{gas} . Cp_{gas} . \Delta t_{gas}}{4.17\, \Delta t_W}$$ in ton/hr, Ggas in kg/hr, Cpgas in kJ/kg.K, Δt in C

temperature difference of C.W. is about 8 - 10 degree centigrade and Cp = 4.17 kJ/kg.K



Intercooler and interstagecooler :
$T_{GAS\ OUT}$ - $T_{CW\ OUT}$ shall be higher than 5 C

C.W. consumption for water jacket surrounding cylinder can be calculated by equation :
GHP in kW, Δt in C. K is percentage of gas heat loss and friction heat of piston comparing to GHP, i.e. 0.2

$$G_{WJW} = \frac{3.6\ K\ .GHP}{4.17\ \ \Delta\ t_W}$$ in ton/hr

When intercooler and cooling system for cylinder are applied, adiabatic efficiency is near to 1.0

Frame Power Data

Frame power (kW)	Max. dia. Dmax (mm)	Max. no. throw Z	Stroke length, L (mm)	Crank max. speed N (RPM)	Power per throw (kW)
150		2	100		75
300		4	150		75
600		4	200		150
1200		4	250		300
2000		6	300		333
3000		6	350		500
170	350	2	150	1000	85
540	650	4	150	1200	135
790		4	200	750	198
930		4	200	750	233
260		4	178	600	65
650	765	4	230	500	163
1100		4	230	500	275
2100		6	230	514	350
3000		6	315	400	500
4600		6	315	428	767
5500		6	400	300	917
10000		6	400	300	1667
370	400	4	220	700	93
600	500	4	260	600	150
1000	650	4	260	600	250
2600	1000	6	320	500	433
3700	1000	6	360	500	617
5100	1000	6	400	500	850
6600	1000	6	400	375	1100
9200	1000	6	400	375	1533

Frame power (kW)	Max. dia. Dmax (mm)	Max. no. throw Z	Stroke length, L (mm)	Crank max. speed N (RPM)	Power per throw (kW)
8800	1000	12	430	400	733
18000		12	430	360	1500
1500	830	10	267	514	150
3000	1130	10	356	360	300
4400	1130	10	356	360	440
8000	1130	10	508	277	800
15000	1130	10	508	277	1500

RECIPROCATING COMPRESSOR CALCULATION SHEET
WITHOUT INTERCOOLER

Gas properties, flowrate and conditions

Red color cells are inputs or given datas

1	Gas name	Synthese gas				
	Item or symbol	Quantity	Unit	Item or symbol	Quantity	Unit
2	Suction pressure, ps	27	bar A	Discharge pressure, pd	70	bar A
3	Suction temperature, ts	32	°C			
4	Ts	305	°K	p_{CR}	19	bar A
5	MW	8.91	kg/kgmol	T_{CR}	60	°K
6	k_S	1.402		$p_R = p / p_{CR}$	1.42	
7	R_S	0.933	kJ/kg.°K	$T_R = T / T_{CR}$	5.08	
8	DSs	9.487	kg/m3	Z_S	1.003	
9	MCp	29	kJ/kgmol.°K	Cp_S	3.25	kJ/kg
10	G	120000	kg/hr	G_{mol}	13468	kgmol/hr
11	Q_S	12649	m^3/hr	Q_N	301764	Nm^3/hr
12						

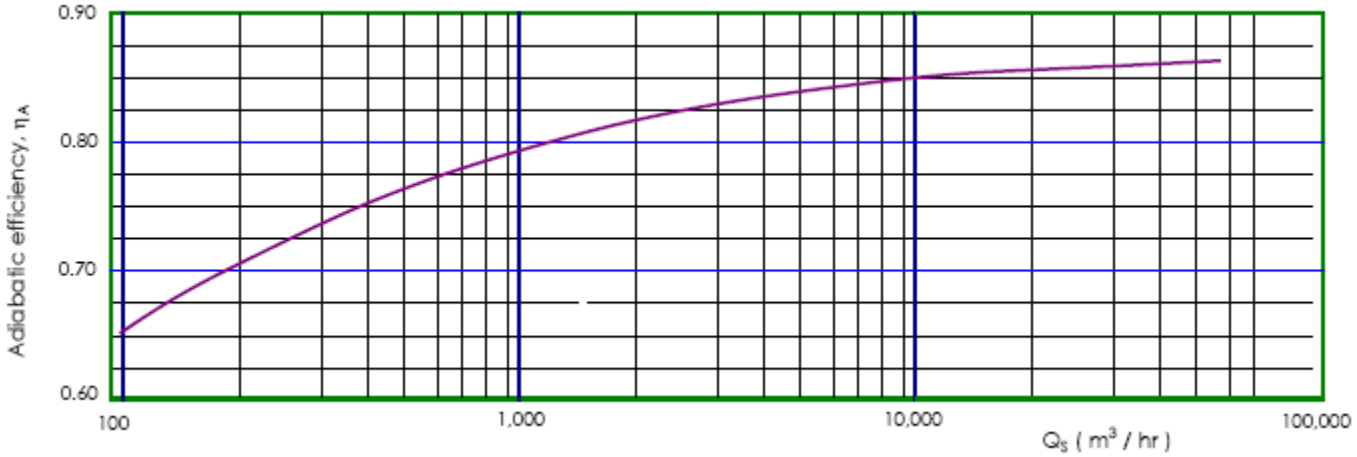
Compressor Calculation Sheet

	Item	Symbol	Unit	Quantity	Note
13	***Preliminary Calculation***				
14	**Check whether need intercooler**				
15	First Stage Volume flow	Qs	m3/hr	12649	
16	Cylinder intake pressure	ps'	barA	26.19	
17	Cylinder exhaust pressure	pd'	barA	72.1	
18	Pressure ratio (p_D / p_S)	r'_{TOTAL}	-	2.753	
19	(k-1)/k		-	0.2867	
20	k/(k-1)		-	3.488	
25	**Check number of stage due to max. temp**				
21	Max. temperature	t_{MAX}	°C	150	See Chapter VI.
22		T_{MAX}	°K	423	
23	Max. pressure ratio	r_{MAX-T}	-	3.13	Equation (11)
24	Is $r > r_{MAX}$ or need interstage cooler ?			**No**	
25	Total Hydrodynamic head	H_{TOTAL}	m	34190	Eq. 8.
26	**Expected minimum adiabatic vol. eff.**			0.850	
27	Max. clearance space vol.		%	14.16	Eq. A.3. If need intercooler, use $r = r_{max-T}$, otherwise use r_{Total}
28	Clearance space volume	c	%	10	< max.at expected eff.
29	Volumetric efficiency	η_V		0.831	Eq. A.3 and A.4.

	Item	Symbol	Unit	Quantity	Note
1	Supply efficiency	λ/η_V		0.942	Eq. A.5.
2	Required piston capacity	Qp	m3/hr	16160.4	Eq. A.6 and A.7.
3	Max. hydr. Head for each stage	$H_{STG-MAX}$	m	39268	Eq. A.6.
4	Preliminary number of stage	i_{CAL}		1	= Htotal / Hstg-max
5	GHP			14284	
6	Mechanical efficiency			0.95	
7	BHP			15036	
8	**Frame BHP selection**			**Casing I**	
9	Selected frame BHP			18000	See frame BHP table near preliminary BHP in line 7
10	No. of frame			1	Frame BHP data
11	No. of throw per frame			12	Frame BHP data
12	Stroke length			508	Frame BHP data
13	No. of compression acting			2	Frame BHP data
14	Crankshaft speed			277	Frame BHP data
15	Max. diameter			1130	Frame BHP data
16	Max. H per throw			3490.3	Eq.A.11

	Detail calculation	CASING I									
18		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10
19	**G** (kg/hr)	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000
20	Max. H per stage for parallel throws	3490.3	3490.3	3490.3	3490.3	3490.3	3490.3	3490.3	3490.3	3490.3	3490.3
21	Last cylinder exhaust press. (barA)	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1
22	Cyl. intake pressure, **ps'** (barA)	26.19	29.468	33.040	36.912	41.097	45.610	50.467	55.682	61.272	67.251
23	Suction temperature, **ts** (C)	32.0	42.5	53.0	63.5	73.9	84.4	94.9	105.4	115.9	126.4
24	**Ts** (K)	305.0	315.5	326.0	336.5	346.9	357.4	367.9	378.4	388.9	399.4
25	Max. discharge temp., **td** max. (C)	**150**	150	150	150	150	150	150	150	150	150
26	**Td** max. (C)	423.0	423.0	423.0	423.0	423.0	423.0	423.0	423.0	423.0	423.0
27	**MW**	8.91	8.91	9	9	9	9	9	9	9	9
28	**Rs** = 8.314/MW	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
29	p_{CR}	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
30	T_{CR}	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
31	$p_R = p_{RED} = p / p_{CR}$	1.38	1.551	1.74	1.94	2.16	2.40	2.66	2.93	3.22	3.54
32	$T_R = T_{RED} = T / T_{CR}$	5.08	5.258	5.43	5.61	5.78	5.96	6.13	6.31	6.48	6.66
33	Z_S	1.003	1	1	1	1	1	1	1	1	1
34	MCp_S (kJ/kgmol.K)	29.00	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1
35	**k** = MCp/(MCp-8.314)	1.40	1.400	1.400	1.400	1.400	1.400	1.400	1.400	1.400	1.400

	Detail calculation (cont)	CASING I									
		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10
1	**Cp_S** = R.k /(k-1), (kJ/kg.K)	3.25	3.266	3.266	3.266	3.266	3.266	3.266	3.266	3.266	3.266
2	**DSs** = 100.ps / (Z.R.Ts), (kg/m3)	9.5	10.0	10.9	11.8	12.7	13.7	14.7	15.8	16.9	18.0
3	**Q_S** = G / DSs, (m3/hr)	12648.8	11987.9	11047	10206.5	9452.8	8774.8	8162.9	7609.2	7106.6	6649.4
4	**Q_N** (Nm3/h)	301764	301764	301764	301764	301764	301764	301764	301764	301764	301764
5	**(k-1)/k**	0.287	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286
6	**k/(k-1)**	3.488	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500
7	**Due to max. temperature**										
8	Pressure ratio, **r '** due to max. temp.	2.753	2.447	2.182	1.953	1.754	1.581	1.429	1.295	1.177	1.072
9	**Due to max. frame BHP**										
10	Max. **r'** due to max. frame BHP	1.125	1.121	1.117	1.113	1.110	1.106	1.103	1.100	1.098	1.095
11	Selected **r'**	**1.125**	**1.121**	**1.117**	**1.113**	**1.110**	**1.106**	**1.103**	**1.100**	**1.098**	**1.072**
12	Discharge pressure, **pd** (barA)	29.468	33.040	36.912	41.097	45.610	50.467	55.682	61.272	67.251	72.107
13	Cylinder exhaust pressure, **pd'** (barA)	30.352	34.032	38.019	42.330	46.978	51.981	57.353	63.110	69.268	74.270
14	Clearance space volume, **c** (%)	10	10	10	10	10	10	10	10	10	10
15	Volumetric efficiency, **η_V**	0.942	0.942	0.942	0.942	0.943	0.943	0.943	0.943	0.943	0.945
16	Supply efficiency, **λ/η_V**	0.996	0.996	0.996	0.997	0.997	0.997	0.997	0.997	0.997	0.998
17	Required piston capacity, **Qp** (m3)	13483.6	12774.2	11767.0	10867.6	10061.5	9336.8	8683.0	8091.6	7555.1	7051.2
18	Preliminary Piston speed (m/s)	5	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
19	Stroke length, **L** (mm)	**508**	508	508	508	508	508	508	508	508	508
20	No. of compression acting	2	2	2	2	2	2	2	2	2	2
21	No. of throw for each stage, **z**	1	1	1	1	1	1	1	1	1	1
22	Crankshaft speed, **N** (RPM)	**277**	277	277	277	277	277	277	277	277	277
23	Piston speed, **U** (m/s)	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
24	Piston displacement vol./stroke, m^3	0.406	0.384	0.354	0.327	0.303	0.281	0.261	0.243	0.227	0.212
25	Piston diameter, **D** (mm)	**1007.4**	980.6	941.1	904.5	870.3	838.3	808.5	780.4	754.1	728.5
26	Hydrodynamic head, **H** (m)	3490.3	3490.3	3490.3	3490.3	3490.3	3490.3	3490.3	3490.3	3490.3	2674.9
27	**GHP**	**1212**	**1253**	**1252**	**1252**	**1251**	**1251**	**1251**	**1250**	**1250**	**955**
31	Exhaust temp before cooler, **td** (C)	**42**	**53**	**63**	**74**	**84**	**95**	**105**	**116**	**126**	**134**
28	Need intercooler ?	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**
29	If "Yes", outlet gas temp. (C)	45	45	45	45	45	45	45	45	45	45
30	Pres. drop at inter/stg cooler (bar)	0.10	0.10	0.10	0.100	0.100	0.100	0.100	0.100	0.100	0.100
31	Compression continue ?	**Continue**	**Continue**	**Continue**	**Continue**	**Continue**	**Continue**	**Continue**	**Continue**	**Continue**	**Finish**
32	**Total Adiabatic Compression GHP** (kW)	12177.40									
33	Adiabatic eff, when isn' t fully adiabatic	0.85									
34	Mechanical efficiency	0.945									
35	**Total BHP** (kW)	**15160**									
36	C.W. each cooler (ton/hr)	0.0	0.0	0.0	0	0	0	0	0	0	0
37	Total C.W. required (ton/hr)	0.0									



Interpretation of adiabatic efficiency from literature (0.65 for small, 0.80 for medium, 0.85 and higher for large reciprocating compressor) when the compressor doesn't work in fully adiabatic compression. Qs is suction flow at first stage of the compressor. When intercoolers and water jacket are applied, adiabatic efficiency higher than above figure.

BHP = GHP /(η_A . η_M)