Compressor study: Natural gas booster compressor

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Results are thermodynamic and curve-based estimates from the inputs and data you supply. They are not a manufacturer guarantee. Surge, choke and performance curves must come from the machine maker or from tests; nothing is invented here.

Gas and property model

Property model: PR. Molecular weight 17.845 g/mol. Pseudo-critical 201.5 K, 4624 kPa.

Component	Mole fraction	Mass fraction
Methane	0.9000	0.8091
Ethane	0.0600	0.1011
Propane	0.0200	0.0494
Nitrogen	0.0100	0.0157
Carbon dioxide	0.0100	0.0247

Single-stage compression

Quantity	Suction	Discharge
Pressure kPa(a)	1,000.0	2,200.0
Temperature C	30.0	102.5
Compressibility Z	0.9751	0.9756
Density kg/m3	7.260	12.883
Cp kJ/kg K	2.150	2.453
Heat capacity ratio k	1.3201	1.2817
Isentropic exponent	1.2877	1.2525

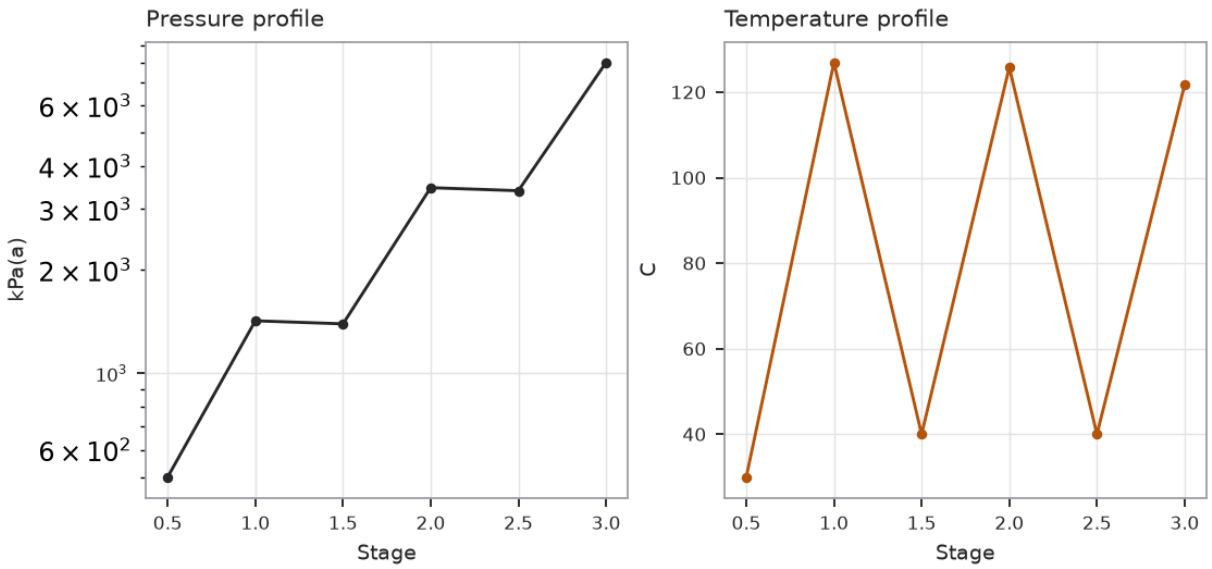
Result	Value	Result	Value
Pressure ratio	2.200	Mass flow kg/h	45,419.0
Isentropic head kJ/kg	118.44	Actual inlet flow m3/h	6,255.6
Polytropic head kJ/kg	121.39	Standard flow m3/h	60,000.0
Polytropic efficiency	0.7800	Gas power kW	1,963.4
Isentropic efficiency	0.7610	Shaft power kW	2,003.5
Discharge temperature C	102.5	Driver input kW	2,087.0
Isentropic discharge T C	87.2	Polytropic volume exponent n	1.3749

Multistage compression with intercooling

Stage	Ps kPa	Ts C	Pd kPa	Td C	Ratio	Head kJ/kg	eta_p	Power kW	Cooler Tout C	Duty kW
1	500	30.0	1,421	126.9	2.843	168.57	0.780	1,363.3	40.0	1,291.9
2	1,393	40.0	3,464	125.8	2.486	146.24	0.780	1,182.7	40.0	1,325.7
3	3,394	40.0	8,000	121.7	2.357	131.76	0.780	1,065.6	-	0.0

Mode optimum. Total gas power 3,611.6 kW against 4,536.8 kW in a single stage (saving 20.4 %). Cooling duty 2,617.6 kW. Equal-ratio reference 2.554.

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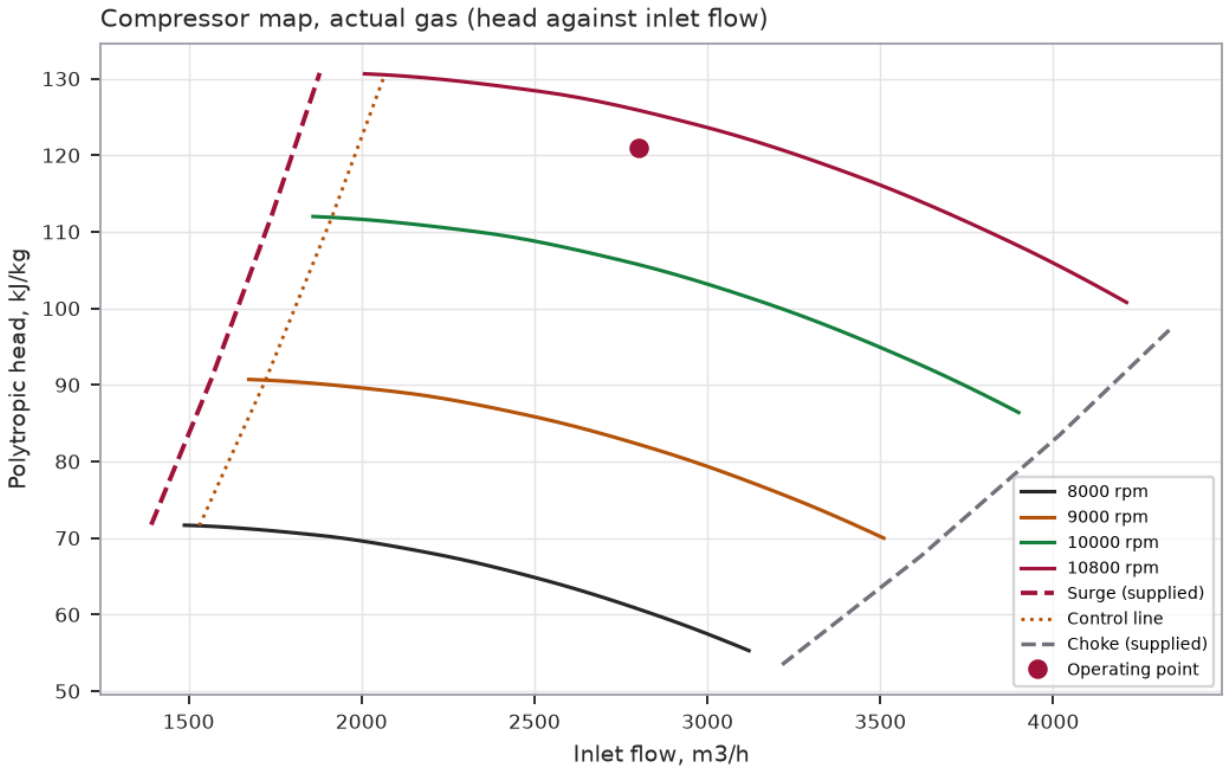


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Centrifugal compressor rating

Curves are the data you supplied for the reference gas, converted to the actual gas by the equivalent-speed (Mach similarity) method. This is an approximation that ignores Reynolds number and isentropic-exponent differences. Surge and choke appear only where supplied.

Result	Value
Speed rpm	10,610
Inlet flow m3/h	2,800.0
Polytropic head kJ/kg	120.96
Polytropic efficiency	0.8062
Discharge pressure kPa(a)	2,200.0
Discharge temperature C	100.2
Shaft power kW	864.5
Surge margin	51.7 %
Choke margin	34.3 %



Throughput study (debottlenecking)

Throughput	Flow m3/h	Speed rpm	Head kJ/kg	eta_p	Td C	Shaft kW	Surge margin	Limits reached
100 %	2,800	10,610	121.0	0.806	100.2	865	51.7 %	none
105 %	2,940	10,668	120.9	0.811	99.8	902	58.4 %	none
110 %	3,080	10,735	120.9	0.811	99.8	945	64.9 %	none
115 %	3,220	10,810	120.9	0.810	99.9	989	71.2 %	Speed 10810 rpm above maximum 10800; Curve extrapolated (unvalidated)
120 %	3,360	10,891	120.9	0.809	100.0	1,033	77.3 %	Speed 10891 rpm above maximum 10800; Curve extrapolated (unvalidated)
125 %	3,500	10,977	120.9	0.808	100.1	1,078	83.3 %	Speed 10977 rpm above maximum 10800; Curve extrapolated (unvalidated)

First limiting condition: Speed 10810 rpm above maximum 10800 at 115 % throughput.

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Reciprocating compressor rating

Stage	Ps kPa	Pd kPa	Ratio	Td C	Capacity m3/h	Displacement m3/h	eta_v	Gas power kW
1	297	805	2.711	112.8	857	1,131	0.757	92.4
2	773	2,020	2.612	121.4	336	433	0.777	90.5

Shaft power 186.7 kW; isothermal reference 132.1 kW; cooling duty 84.5 kW. Interstage pressure balance converged (mismatch 0.000 %).

Cylinder	Stage	Bore mm	Stroke mm	Acting	Capacity m3/h	eta_v	Rod load kN	Loading %
C1	1	350	250	double	856.8	0.757	50.0	25
C2	2	220	250	double	336.5	0.777	50.4	25

Capacity control steps (first stage)

Step	Capacity %	Flow m3/h	Shaft kW	Power %
Fully loaded	100.0	848	186.7	100.0
Clearance pockets open	91.3	775	170.8	91.5
Crank ends unloaded	57.5	487	109.8	58.8
Head ends unloaded	54.8	465	105.1	56.3
Speed 90 %	90.0	763	168.0	90.0
Speed 80 %	80.0	679	149.4	80.0
Speed 70 %	70.0	594	130.7	70.0

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Surge analysis

Surge flows are the maker points you supplied; none are estimated. Control line = surge flow x (1 + control margin).

Scenario	Status	Flow m3/h	Speed rpm	Surge margin	Recycle %	Mixed suction C	Extra power %
Base case	ok	2,800	10,610	51.7 %	-	-	-
Turndown to 60 %	SURGE (flow below surge)	1,700	10,589	-7.7 %	15.2	43.7	3.6
Turndown to 45 %	SURGE (flow below surge)	1,260	11,000	-34.2 %	47.3	75.3	8.9
Hot day, suction 45 C	ok	2,800	10,849	48.3 %	-	-	-
Low suction pressure 800 kPa	ok	2,800	12,118	32.8 %	-	-	-

Minimum process flow without recycle at the base duty: 14,584 kg/h (72 % of the base flow).

Recycle at the base duty: 0 kg/h; mixed suction 30.0 C; converged in 1 iteration(s).

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Compressor train

Shaft speed 10,090 rpm; shaft power 2,167 kW; recycle 0 kg/h (converged); driver loading 73 %.

Casing	Speed rpm	Ps kPa	Pd kPa	Td C	Ratio	Head kJ/kg	eta_p	Power kW	Surge margin
LP casing	10,090	980	1,754	88.5	1.789	87.9	0.702	994	124.3 %
HP casing	10,090	1,719	3,535	109.0	2.057	112.4	0.761	1,173	30.3 %

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Validation status

32 of 32 benchmark checks pass. Closed-form ideal-gas equations, CoolProp pure-gas properties, interpolation and clearance equations. No manufacturer or field test data are included, so centrifugal and reciprocating machine models are not validated against real machines.

Case	Reference	Quantity	Reference value	Result	Deviation %	Tolerance %	Status
Ideal gas isentropic	closed form T2 = T1 r^((k-1)/k)	Discharge temperature	445.7983	445.7983	-0.000	0.01	pass
Ideal gas isentropic	closed form H = k/(k-1) R T1 (r^((k-1)/k) - 1)	Isentropic head	146,455.6582	146,455.6582	-0.000	0.01	pass
Ideal gas polytropic	closed form Hp = R T1/e (r^e - 1), e = (k-1)/(k eta_p)	Polytropic head	157,244.5943	157,253.6188	0.006	0.05	pass
Ideal gas polytropic	closed form T2 = T1 r^((k-1)/(k eta_p))	Discharge temperature	508.7184	508.7304	0.002	0.05	pass
Ideal gas polytropic	closed form Hp = R T1/e (r^e - 1), e = (k-1)/(k eta_p)	Polytropic head	152,044.6427	152,053.9894	0.006	0.05	pass
Ideal gas polytropic	closed form T2 = T1 r^((k-1)/(k eta_p))	Discharge temperature	478.0732	478.0841	0.002	0.05	pass
Ideal gas isothermal	closed form w = R T ln(r)	Isothermal work	119,360.9870	119,360.9870	0.000	0.01	pass
Multistage optimum, 2 stages	theory: equal ratio is optimal for equal efficiencies and equal intercooling	Power, optimiser vs equal ratio	386,279.3652	386,279.3652	0.000	0.20	pass
Multistage ratio, 2 stages	closed form r = (Pd/Ps)^(1/N)	Stage ratio	4.0000	4.0000	0.000	0.00	pass
Multistage optimum, 3 stages	theory: equal ratio is optimal for equal efficiencies and equal intercooling	Power, optimiser vs equal ratio	353,600.1328	353,600.1328	0.000	0.20	pass
Multistage ratio, 3 stages	closed form r = (Pd/Ps)^(1/N)	Stage ratio	2.5198	2.5198	0.000	0.00	pass
Real gas isentropic: Methane	CoolProp (Helmholtz EOS)	Isentropic discharge temperature (cubic EOS accuracy, about 1 K)	386.9876	386.9320	-0.014	0.50	pass
Real gas isentropic: Methane	CoolProp (Helmholtz EOS)	Isentropic head	188,634.4101	186,726.5816	-1.011	2.50	pass
Compressibility: Methane	CoolProp (Helmholtz EOS)	Z at suction	0.9667	0.9580	-0.897	4.00	pass
Real gas isentropic: Nitrogen	CoolProp (Helmholtz EOS)	Isentropic discharge temperature (cubic EOS accuracy, about 1 K)	411.3257	410.7898	-0.130	0.50	pass
Real gas isentropic: Nitrogen	CoolProp (Helmholtz EOS)	Isentropic head	115,416.9963	115,011.9002	-0.351	2.50	pass
Compressibility: Nitrogen	CoolProp (Helmholtz EOS)	Z at suction	0.9984	0.9960	-0.241	4.00	pass
Real gas isentropic: CarbonDioxide	CoolProp (Helmholtz EOS)	Isentropic discharge temperature (cubic EOS accuracy, about 1 K)	421.2920	420.6195	-0.160	0.50	pass
Real gas isentropic: CarbonDioxide	CoolProp (Helmholtz EOS)	Isentropic head	71,271.4761	70,521.4914	-1.052	4.00	pass
Compressibility: CarbonDioxide	CoolProp (Helmholtz EOS)	Z at suction	0.9261	0.9179	-0.885	4.00	pass
Real gas isentropic: Hydrogen	CoolProp (Helmholtz EOS)	Isentropic discharge temperature (cubic EOS accuracy, about 1 K)	410.8019	412.3353	0.373	0.50	pass
Real gas isentropic: Hydrogen	CoolProp (Helmholtz EOS)	Isentropic head	1,628,559.3119	1,618,520.4855	-0.616	3.00	pass
Compressibility: Hydrogen	CoolProp (Helmholtz EOS)	Z at suction	1.0117	1.0059	-0.579	4.00	pass
Curve interpolation: linear	analytic quadratic y = 3 + 2x - 0.1x^2	y at x = 4.4	9.8640	9.8000	-0.649	1.50	pass
Curve interpolation: pchip	analytic quadratic y = 3 + 2x - 0.1x^2	y at x = 4.4	9.8640	9.8587	-0.054	1.50	pass
Curve interpolation: spline	analytic quadratic y = 3 + 2x - 0.1x^2	y at x = 4.4	9.8640	9.8606	-0.034	1.50	pass
Curve interpolation: polynomial	analytic quadratic y = 3 + 2x - 0.1x^2	y at x = 4.4	9.8640	9.8640	0.000	0.00	pass

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Case	Reference	Quantity	Reference value	Result	Deviation %	Tolerance %	Status
Recycle mixing temperature	closed form T = (m1 T1 + m2 T2) / (m1 + m2), constant cp	Mixed temperature	330.0000	330.0000	0.000	0.01	pass
Axial stage: Euler work	dh0 = lambda U^2	Stage enthalpy rise	34,543.6154	34,543.6154	0.000	0.00	pass
Axial stage: ideal-gas temperature rise	dT = lambda U^2 / cp, cp = 3.5 R	Temperature rise	34.3886	34.3849	-0.011	0.30	pass
Screw compressor: matched built-in ratio	no under- or over-compression when P2/P1 = Vi^k	Mismatch loss, %	0.0000	0.0000	0.000	0.50	pass
Reciprocating volumetric efficiency	closed form eta = 1 - C (r^(1/k) - 1)	eta_v	0.8672	0.8672	0.000	0.00	pass

Methods and limitations

Method	Status	Validity	Validation
Gas properties	implemented	gas phase, away from the critical region and the dew point	benchmarked against CoolProp for pure gases (see Validation)
Isentropic compression	implemented	gas phase	benchmarked: ideal-gas closed form and CoolProp
Polytropic compression	implemented	gas phase; constant eta_p along the path	benchmarked: ideal-gas closed form
Isothermal compression	implemented	reference process, also used for large reciprocating cylinders	benchmarked: ideal-gas closed form
Multistage compression with intercooling	implemented	equal-flow stages; no liquid condensation	benchmarked: ideal-gas equal-ratio optimum
Performance curve scaling (equivalent speed)	approximate	same machine, similar Reynolds number and isentropic exponent; speed within the tested range	affinity-law consistency tested; no manufacturer data used. Treat as an approximation, not as a real-gas validated scaling.
Surge and control lines	data-driven	only the supplied points; never extrapolated silently	none: manufacturer data governs
Reciprocating volumetric efficiency	implemented	clearance model with lumped valve loss and leakage factors you supply	benchmarked: closed-form clearance equation

References

[ptc10] ASME PTC 10 Performance Test Code on Compressors and Exhausters (definitions of head, polytropic and isentropic efficiency, equivalent-speed test conversion). Check the edition you work to.

[api617] API Standard 617 Axial and Centrifugal Compressors and Expander-compressors (data sheets, surge margin, operating range definitions). Check the edition before using any criterion.

[api618] API Standard 618 Reciprocating Compressors for Petroleum, Chemical and Gas Industry Services (cylinder and valve definitions, rod load).

[api619] API Standard 619 Rotary-type Positive-displacement Compressors.

[gpsa] GPSA Engineering Data Book, section on compressors (volumetric efficiency with clearance, multistage ratio, intercooling).

[perry] Perry's Chemical Engineers' Handbook, compressors and thermodynamics chapters (isothermal, isentropic and polytropic work).

[schultz] Schultz, J.M. (1962). The polytropic analysis of centrifugal compressors. J. Eng. Power 84(1), 69.

[huntington] Huntington, R.A. (1985). Evaluation of polytropic calculation methods for turbomachinery performance. J. Eng. Gas Turbines Power 107, 872.

[pr] Peng, D.-Y. and Robinson, D.B. (1976). A new two-constant equation of state. Ind. Eng. Chem. Fundam. 15, 59.

[srk] Soave, G. (1972). Equilibrium constants from a modified Redlich-Kwong equation of state. Chem. Eng. Sci. 27, 1197.

[coolprop] Bell, I.H. et al. (2014). Pure and pseudo-pure fluid thermophysical property evaluation and the open-source library CoolProp. Ind. Eng. Chem. Res. 53, 2498 (used as an independent reference in the benchmarks).

[lapina] Lapina, R.P. (1982). Estimating Centrifugal Compressor Performance. Gulf Publishing (similarity and gas-correction methods).

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Calculation trace: compression

Id	Quantity	Equation	Value	Unit	Ref
head_s	Isentropic head	H_s = h(T2s, P2) - h(T1, P1), s(T2s, P2) = s(T1, P1)	118,437.0000	J/kg	ptc10
head_p	Polytropic head	H_p = eta_p (h2 - h1) = int v dP along dh = v dP / eta_p	121,388.0000	J/kg	ptc10
T2	Discharge temperature	h(T2, P2) = h1 + (1 - f_loss) w	375.6660	K	ptc10
eta_s	Isentropic efficiency	eta_s = H_s / w	0.7610	-	ptc10

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Calculation trace: multistage

Id	Quantity	Equation	Value	Unit	Ref
r_eq	Equal stage pressure ratio	r = ((Pd / Ps) / prod(1 - dP_cooler))^(1/N)	2.5540	-	gpsa
s1.head_s	Isentropic head	H_s = h(T2s, P2) - h(T1, P1), s(T2s, P2) = s(T1, P1)	163,302.0000	J/kg	ptc10
s1.head_p	Polytropic head	H_p = eta_p (h2 - h1) = int v dP along dh = v dP / eta_p	168,570.0000	J/kg	ptc10
s1.T2	Discharge temperature	h(T2, P2) = h1 + (1 - f_loss) w	400.0660	K	ptc10
s1.eta_s	Isentropic efficiency	eta_s = H_s / w	0.7556	-	ptc10
s2.head_s	Isentropic head	H_s = h(T2s, P2) - h(T1, P1), s(T2s, P2) = s(T1, P1)	142,192.0000	J/kg	ptc10
s2.head_p	Polytropic head	H_p = eta_p (h2 - h1) = int v dP along dh = v dP / eta_p	146,239.0000	J/kg	ptc10
s2.T2	Discharge temperature	h(T2, P2) = h1 + (1 - f_loss) w	398.9480	K	ptc10
s2.eta_s	Isentropic efficiency	eta_s = H_s / w	0.7584	-	ptc10
s3.head_s	Isentropic head	H_s = h(T2s, P2) - h(T1, P1), s(T2s, P2) = s(T1, P1)	128,185.0000	J/kg	ptc10
s3.head_p	Polytropic head	H_p = eta_p (h2 - h1) = int v dP along dh = v dP / eta_p	131,763.0000	J/kg	ptc10
s3.T2	Discharge temperature	h(T2, P2) = h1 + (1 - f_loss) w	394.8510	K	ptc10
s3.eta_s	Isentropic efficiency	eta_s = H_s / w	0.7588	-	ptc10

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Calculation trace: recip

Id	Quantity	Equation	Value	Unit	Ref
s1.cap	Stage capacity at suction conditions	Q = sum(displacement x eta_v)	862.3130	m3/h	gpsa
s1.cap	Stage capacity at suction conditions	Q = sum(displacement x eta_v)	862.3130	m3/h	gpsa
s1.cap	Stage capacity at suction conditions	Q = sum(displacement x eta_v)	856.6950	m3/h	gpsa
s1.cap	Stage capacity at suction conditions	Q = sum(displacement x eta_v)	856.6950	m3/h	gpsa
s1.cap	Stage capacity at suction conditions	Q = sum(displacement x eta_v)	856.7840	m3/h	gpsa
s1.cap	Stage capacity at suction conditions	Q = sum(displacement x eta_v)	856.7840	m3/h	gpsa
s1.cap	Stage capacity at suction conditions	Q = sum(displacement x eta_v)	856.7840	m3/h	gpsa
s1.cap	Stage capacity at suction conditions	Q = sum(displacement x eta_v)	856.7840	m3/h	gpsa
s1.cap	Stage capacity at suction conditions	Q = sum(displacement x eta_v)	856.7840	m3/h	gpsa

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