Centrifugal Compressor Sizing

CC_Cal V3.4.1

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Profile

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Enclosed into the attachment section of this PDF file, you will find a spread sheet that is supposed to perform some calculations based on generalized data available in hand books aimed to estimate basic design data for a centrifugal compressor.

Frankly, dealing with gas thermodynamics is not the most convenient way of spending time. When it especially comes to spread sheets, it may even be more annoying because you should take care of most legwork, but not a computer. However, if you are enthusiastic enough to give it a shot, you may find following remarks helpful before getting lost into curves and tables.

1.12.5	C_p (avg)	0.41	Btu/(lb.°F)	
1.13	**C_v: Specific Heat @ Constant Volume**			
1.13.1	C_{v-1}	0.32	Btu/(lb.°F)	-> $MW.C_v = MW.C_p - 1.987$
1.13.2	C_{v-2}	0.41	Btu/(lb.°F)	
1.13.3	C_v (avg)	0.36	Btu/(lb.°F)	
1.14	**K: Specific Heat Ratio**			
1.14.1	K_{-1} (Calc.)	1.142	-	-> $K = C_p / C_v$
1.14.2	K_{-1} (Manual)		-	
1.14.3	K_{-2} (Calc.)	1.109	-	
1.14.4	K_{-2} (Manual)		-	
1.14.5	K (avg)	1.126	-	

1. Keep calm and do iteration!

The first piece of puzzle is discharge temperature (T2). To calculate T2, you need to know some gas properties that are correlated to the gas temperature. Let's read it again, you need gas properties to calculate temperature and you need that temperature for gas properties. Now what!

CENTRIFUGAL COMPRESSOR CALCULATION SHEET					
DESIGN PARAMETERS					**REMARKS**
2.2.2	Q_2		17,162.51	ft³/min | m³/hr	-> Q_{met} = (SCMH.MW.V_1)/23.65 ***or*** = Mol.MW.V1 -> ***or*** = 3600.W.V_1
2.3	**DISCHARGE TEMPERATURE**				
2.3.1	Adiabatic Compression				-> HELPING TIP
2.3.1.1	m_{-adb} (Temp. Exponent)	0.11		-	-> $m = (k-1)/k$
2.3.1.2	T_{2-adb}		335.20	°R | °K	-> $T_2 = T_1.r^m$
2.3.2	Ideal Gas				-> HELPING TIP
2.3.2.1	m_{-Id} (Temp. Exponent)	0.12		-	-> $m = ZR/C_p\eta_p$
2.3.2.2	T_{2-Id}		338.24	°R | °K	-> $T_2 = T_1.r^m$
2.3.3	Perfect Gas (Polytropic)				-> HELPING TIP
2.3.3.1	m_{-Per} (Temp. Exponent)	0.14		-	-> $m = (k-1)/(k\eta_p)$
2.3.3.2	T_{2-Per}		354.65	°R | °K	-> $T_2 = T_1.r^m$
2.3.4	Real Gas				
2.3.4.1	m_{-Real} (Temp. Exponent)			-	-> $m = (ZR/C_p)(1/\eta_p+X)$
2.3.4.2	T_{2-Real}			°R | °K	-> $T_2 = T_1.r^m$

Firstly, you may apply suction side gas properties and calculate adiabatic discharge temperature. Then by this temperature calculate compressibility (Z) and then, you will have polytropic temperature. It's time for iteration! Now repeat all steps for new polytropic temperature and keep going until you realize that calculated polytropic temperature is almost constant. (Normally it gets to the right temperature with 3 or 4 iteration)

2. Experience is the key to success!

Calculating discharge temperature, polytropic head, power consumption, and number of process stages are all quite straight forward. But, regarding compressor's speed, number of impellers, and impeller diameter, you should be more careful. By the calculation sheet, you are free to change those parameters and see how other ones change, but always there are some limits!

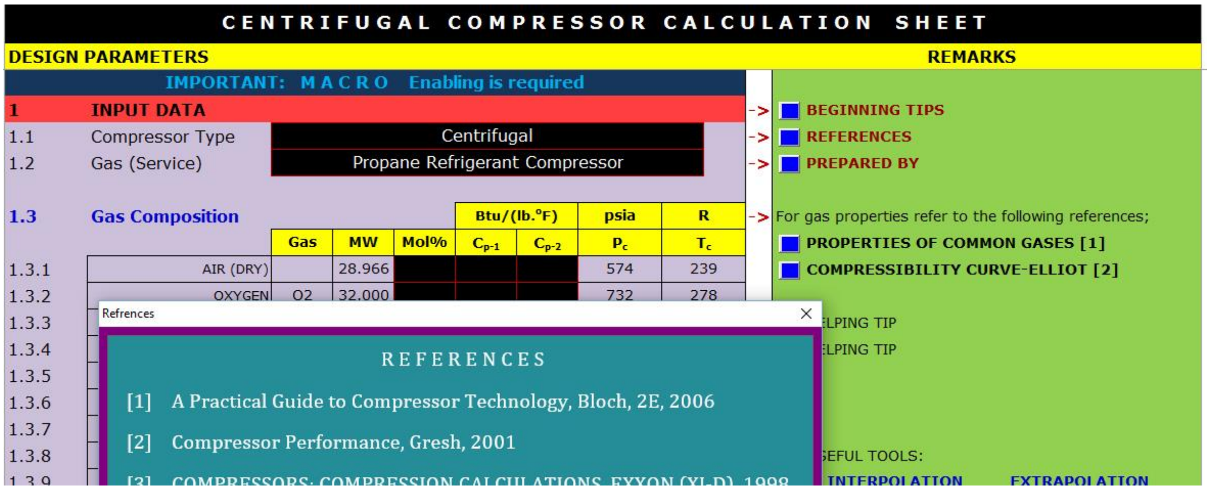
2.6	**LIMITS and STAGING**			->	HELPING TIP
2.6.1	Temperature Limit				
2.6.1.1	**T_L** (Max. allowable discharge temp.)	380.00	°R | °K	->	**TEMPERATURE LIMITS-EXXON CHART [3]**
2.6.1.2	**St_{-T}** (Expected Stage due to Temp.)	1	-		
	IMPORTANT NOTIFICATION				
	Outlet temperature is in ACCEPTABLE range.				
2.6.2	Pressure Limit				
2.6.2.1	**H_L** (Max. allowable head)	40,000	ft | m	->	**PRESSURE LIMITS-EXXON CHART [3]**
2.6.2.2	**r_L** (Max. allowable pressure ratio)		-		
2.6.2.3	**St_{-P}** (Expected Stage due to Press.)	1	-		
	IMPORTANT NOTIFICATION				
	Pressure ratio is in ACCEPTABLE range.				

In the excel sheet, there are already some factors available (flow coefficient, head coefficient, tip speed, specific speed, and Mach number) that might help you to keep changes into your control. However, I believe approved experiences could be a great asset here to broaden your horizons. If you have a vendor design available, check it for fun and see how close your estimation goes.

CENTRIFUGAL COMPRESSOR CALCULATION SHEET					
DESIGN PARAMETERS					**REMARKS**
2.8.1.4	**N** (Predicted Shaft Speed)	4,235	RPM	->	$N = N_{nominal} \sqrt{(H_{po\text{-}Total} / (W_n)(H_{m/w}))}$
2.8.2	Second Round: Optimizing wheels' number, shaft speed and wheel diameter			->	HELPING TIP
2.8.2.1	**W_n** (Optimized)	4	-		
2.8.2.2	**N** (Optimized)	4,000	RPM		
2.8.2.3	**$H_{po/w}$** (Require Head per Wheel)	2,533.14	ft | m	->	$H_{po/w} = H_{po\text{-}Total} / W_n$
2.8.2.4	**Ψ (or μ)** (Head/pres. Coefficient)	0.57	-	->	HELPING TIP
				->	**HEAD COEFFICIENT-DRESSER RAND [5]**
				->	$\Psi = H_{po}.g/u^2$ (u: tip/peripheral speed)
2.8.2.5	**D_2** (Impeller Diameter)	997	in | mm	->	$D_{(MET.)}=(59.82/N)\sqrt{(H/\Psi)}$
				->	$D_{(CUS)}=(1300/N)\sqrt{(H/\Psi)}$
2.8.2.6	**u_2** (tip speed)	208.80	ft/s | m/s	->	HELPING TIP
				->	$u_{(MET)}= \pi DN/60$
				->	$u_{(CUS)}= \pi DN/720$
2.8.2.7	**Φ** (Flow Coefficient)	0.199	-	->	HELPING TIP
				->	**FLOW COEFFICIENT-COOPER CAMERON [5]**
				->	$\Phi = Q/(\pi/4)D^2u$

3. Breaking News!

The bad news is that you have to do all calculation separately for each process stage. But be positive! This is a good opportunity to study more about centrifugal compressors. All references are available by one click.



4. CAUTION! MACROs are running all around.

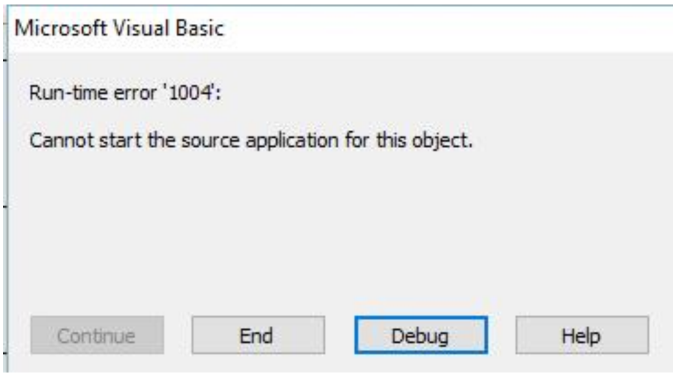
The excel sheet is running some MACROs to keep the calculations working and for reducing legwork. I give my word that they are totally harmless. So, please enable the MACROs in your excel.

5. APOLOGY! To full-access freaks! ;)

I am really sorry that everything is password protected. There's nothing secret in the file. All formulas and equations are available at the right panel. There are many connected formulas in the spread sheet and passwords are only protecting the unity against unwanted changes. However, you may feel cheerful to know that unlocking is not that much complicated nowadays!

6. Adobe PDF

There are 14 PDF documents merged into the calculation sheet. To open them, it is only possible by having Adobe PDF reader installed on your computer (it does not work with other software like Foxit Reader). I'm sorry for that, but it is Microsoft problem :) if you insert a file into Excel when your default reader is "X", later you can open it again only if you have "X" installed. However, you may [download free version of Adobe PDF from here!]



7. Recommendation!

Office documents with files inserted into them are prone to corruption. You may keep a fresh copy of the spread sheet for emergencies ;)

Example

Enclosed calculation sheet is already filled out with an example that I was working on for final check. It is presenting second stage design data for a two stage compressor (with side stream). Just for record, the whole case and its result was as follows:

Parameters	Calculated (Red)		Vendor Design (SIEMENS)		Remarks
	Stage 1	Stage 2	Stage 1	Stage 2	
Flow (kg/s)	65	204			"Grey" fields mean data are available from Purchaser and Vendor is just following
Molecular Weight	44.18		44.18	44.07	
P1 (barg)	0.8	2.9	0.77	2.85	Difference between first stage suction pressures is due to assumed pressure drop for suction strainer.
T1 (C)	-38.5	-5.65	-38.5	-4.4	Second stage suction temperature is not similar to first stage discharge temperature on account of side stream.
P2 (barg)	2.9	22			
T2 (C)	13.85	81.35	14	89	
Z Average	0.94	0.85	95.5	85.5	
Poly. Eff. (%)	81	80	84.9	84.8	
Poly. Head	59.4	99.4	61.5	104.8	
BHP (kW)	4,880	25,470	30,082		Calculated power on aggregate is 30,350
RPM	4,000		3,916		Speed should be a compromise between first and second process stages' ideal speed.
Impeller No.	2	4	6		
Impeller Dia (mm)	1090	997	1260 + 3 x 1190 + 1120 + 1060		By Vendor design, each stage's number of impeller is not clear. However, it is expected to be 2 + 4
Max. Mach	0.91		0.83		My calculation says that at higher flows, choking is expected.