Techniques and Insights for Optimizing Reciprocating Compressors

by Dwayne A. Hickman

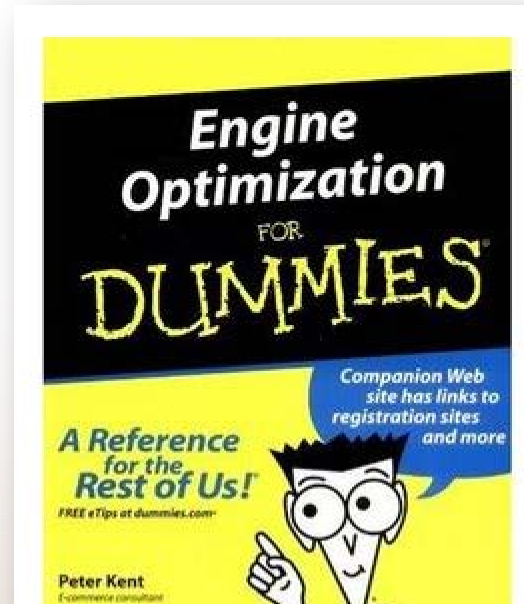
Optimizing Reciprocating Compressors

- **Engine/Motor**
- **Compressor**
- **Coolers**
- **Scrubbers**
- **Piping**
- **Acoustics**
- **Vibrations**
- **Torsional Forces**
- **Etc.**

Optimizing any one part may have no real impact on the entire system!

Optimizing Reciprocating Compressors

- **Engine**
  - **Emissions**
  - **Power**
  - **Fuel Consumption**
  - **Maintenance Costs**
  - **Down Time**

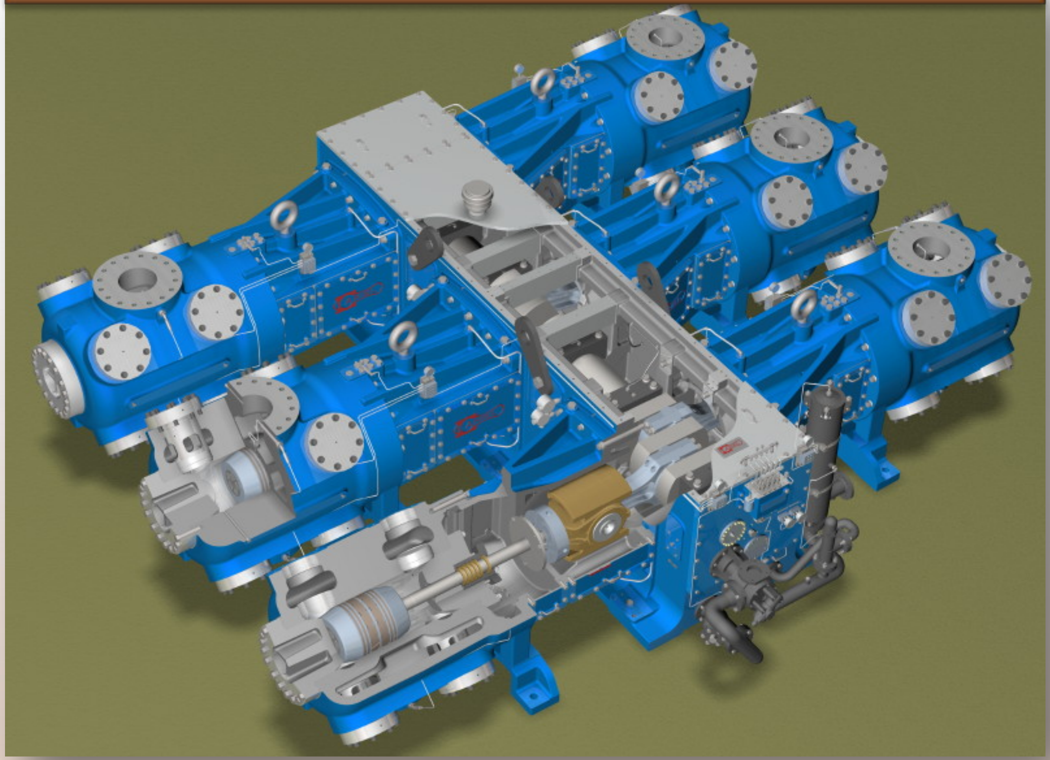


I'm NOT an Engine Expert!

Optimizing Reciprocating Compressors

- **Coolers**
- **Scrubbers**
- **Piping**
- **Acoustics**
- **Vibrations**
- **Torsional Forces**

I only know Compressors!



Optimizing Reciprocating Compressors

- Compressor
  - Valves
  - Unloading
  - Process/Control
  - Maximize Flow
  - Safety
  - Ratios
  - Discharge Temperatures
  - Minimize Power
  - Minimize Pressure Drops

Compressor Optimization

- **Myth #1: More Power means More Flow.**
- **Myth #2: Higher Compression Ratios mean Higher Rod Loads**
- **Myth #3: Higher Compression Ratios mean More Power Required**
- **Myth #4: Higher Suction Pressures means more Flow, and thus More Required Power**
- **Myth #5: If new valves reduce power at same conditions, then they must be better than the previous ones.**

- **Compressor**
  - Frames
  - Cylinders
  - Valves
  - Unloading Devices
  - And Driver

And then these follow…

- Compression Ratios
- Discharge Temperatures
- Minimize Power
- Minimize Pressure Drops
- Process Control
- Safety
- Flexible Operating Map

Consider these, →

← when changing these.

- **Compressor**
  - Frames
  - Cylinders
  - Valves
  - Unloading Devices
  - And Driver

And then these follow…

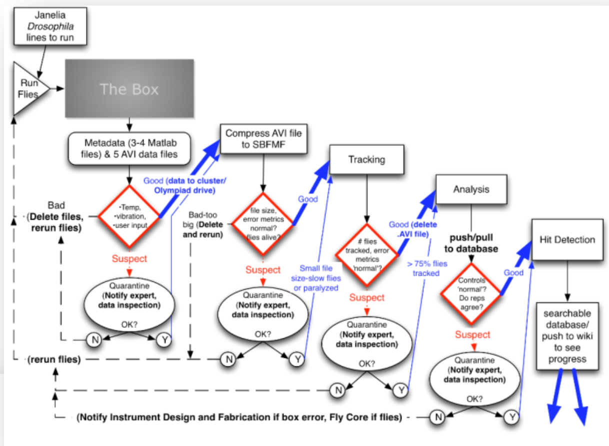
- Compression Ratios
- Discharge Temperatures
- Minimize Power
- Minimize Pressure Drops
- Process Control
- Safety
- Flexible Operating Map

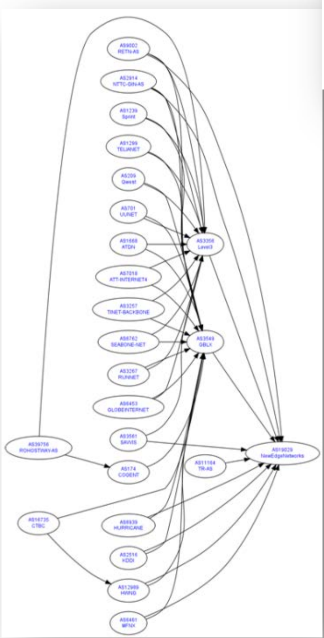
← Once installed, these, now determine these. →

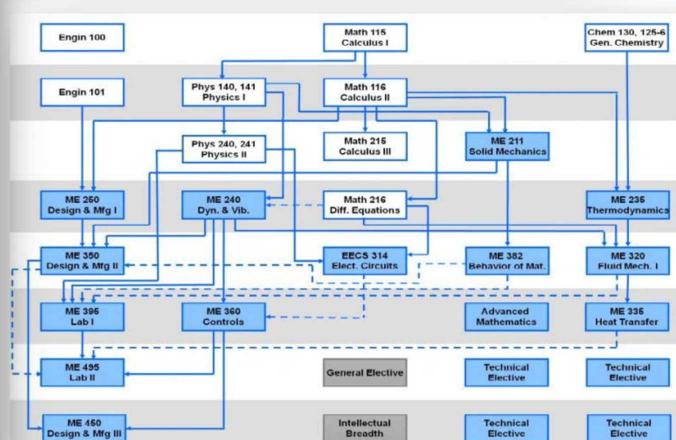
Today, for new units I'm going to cover:

- Staging
- Frames & Cylinders
- Flexibility
- Costs
- Efficiencies
- Unloading

Lists of *What to Consider* are handy, but I want to know *How to Actually Do It*!







First, Size Unit to the Process.

You need to know:

- **Gases Involved**
- **Desired Flow Rates**
- **Expected Operating Ranges**
  - **Pressures and Temperatures**
- **Emissions Limits, when applicable**
- **General level of Unit Turndown**

Many Packagers do not auto-size well. Use their results as a starting place.

Initial Goals:

- Estimate required Power
  - Pick highest of multiple design points
  - Consider a 5% increase at design flow
- Select smallest frame
- Avoid Tandem Cylinders
- Minimize use of High-Pressure Cylinders

Sample Case for 100% Hydrogen Gas

Design Points:

- **Ps=100 psig, Pd=350, Flow=8.5 MMscfd**
- **Ps=120 psig, Pd=375, <u>Flow=9.2 MMscfd</u>**
- **Ps= 80 psig, Pd=350, Flow=7.3 MMscfd**

OEM Auto-Size Estimates vary from 600 HP to about 800 HP, and that this should be either a 1-stage or a 2-stage unit.

Sample Case

OEM software would tend to size the initial design point, or the Max Flow case point, as single-stage models.

If so, then the user is in trouble on the 3rd design point, which requires two stages to keep the discharge temperatures less than OEM allowed.

Sample Case

Therefore, first required option to optimize the unit is to make sure it is properly configured to safely operate at the expected pressure ratios.

It's not optimized if it cannot run!

#1 Identify Correct Number of Stages

Sample Case

Next, it must safely meet flow objectives.

It's not optimized if it cannot achieve the flow objectives for which it was purchased!

#2 Identify Correct Cylinders Sizes and Speed

Sample Case

Review multiple design points. Select those cylinder sizes that achieve highest flow case.

If OEM's software handles multiple design points, let it do the grunt work.

Keep in mind that it is usually easy to turndown a unit to obtain LESS flow. *Getting more flow after the frame, cylinders and the driver chosen is NOT VERY LIKELY!*

Sample Case

Next, review unloading options to turndown the unit to achieve key design points.

It's not optimized if you have to throttle inlet gas, or recycle discharge gas to meet daily station flow objectives!

#3 Indentify Correct Type and Amount of Unloading Required

Sample Case

Next, review unit safety over entire operating map.

It's not optimized if you cannot run it where you need to run it!

#4 Find out where the proposed unit <u>can</u>, and <u>cannot</u> run.

Sample Case

Next, is the unit mechanical safe? Torsional, Vibration, Acoustic Issues?

It's not optimized if running it leads to cracks or breaks in: pipes, foundations, tubing, etc.!

#5 Indentify risks related to these items.

This item can be expensive so often done last, and only on the ideal unit selected.

Sample Case

Next, is the unit affordable?

A major constraint is cost. If unit is not within cost goals, then it is not an ideal unit to the end-user.

#6 Review items to lower costs that have minimum impact on unit performance.

Sample Case

When a packager says "This is the right unit for you", you might want to interpret that like when a car dealer says "This is the right car for you."

Likely, it is the "right" unit for them: to make money, to get stock out of inventory, to reduce their fleet of *those* types of units, etc.

OK, let's do a real run-through with this 100% H_2 Gas.

Free OEM Software is available for sizing reciprocating compressors from Ariel, Arrow Engine, Dresser-Rand, Knox Western, LeROI, GE Oil & Gas, and others.

Time limits me to using just one OEM Software Package!

Sample Case

Design Points (Specified Flows are Inlet Flows)

	Error(s)			
HP	Power			
MMscfd	Est'd Flow			
MMscfd	Req'd Flow	8.5	9.2	7.3
psiG	Ps	100	120	80
psiG	Pd	350	375	350
	Speed			
deg F	Ts-1	80.0	80.0	80.0
deg F	Ts-2	120.0	120.0	120.0
deg F	Ts-3	120.0	120.0	120.0
deg F	Ts-4	120.0	120.0	120.0
deg F	Ts-5	120.0	120.0	120.0
deg F	Ts-6	120.0	120.0	120.0
	Service	1	1	1

Estimated Required Power/Unit: 786.9 HP

Performance/Sizing based on running 1 parallel unit(s).

Suggested Unit Staging: 2

If you JUST sized to 1st point, then a single stage with 700 HP suggested.

We enter our three design points.

Based on these three points, software suggests that we develop a 2-stage model, and we'll need upwards of 790 HP.

Sample Case

Auto-Sizing: Estimates of Bore Sizes per Stage, for Various Hardware Arrangements Considered During Auto-Size

ID#	Frame	Stroke	rRPM	Throws	Layout	Stg1 Bore-in	Stg2 Bore-in	Stg3 Bore-in	Stg4 Bore-in	Stg5 Bore-in	Stg6 Bore-in
365	DS502	5		2	2/1-2/1-x-x-x-x	11.625	9.625				
366	DS502	5		2	2/1-2/1-x-x-x-x	12.625	9.625				
367	DS502	5		2	1/2-1/2-x-x-x-x	12.375	9.625				
368	DS502	5		2	1/2-1/2-x-x-x-x	11.875	9.375				
369	DS502	5		2	1/2-1/2-x-x-x-x	12.750	9.375				
370	DS602	6		2	1-2-x-x-x-x	12.500	9.875				
371	DS602	6		2	1-2-x-x-x-x	12.000	9.625				
372	DS602	6		2	1-2-x-x-x-x	12.875	9.750				
373	DS602	6		2	2/1-2/1-x-x-x-x	12.500	10.000				
374	DS602	6		2	2/1-2/1-x-x-x-x	11.875	9.750				
375	DS602	6		2	2/1-2/1-x-x-x-x	12.875	9.875				
376	DS602	6		2	1/2-1/2-x-x-x-x	12.625	9.750				
377	DS602	6		2	1/2-1/2-x-x-x-x	12.125	9.625				
378	DS602	6		2	1/2-1/2-x-x-x-x	13.000	9.625				
379	DS504	5		4	2-1-2-1-x-x	8.750	6.875				
380	DS504	5		4	2-1-2-1-x-x	8.375	6.750				
381	DS504	5		4	2-1-2-1-x-x	9.000	6.750				
382	DS504	5		4	2-1-1-1-x-x	7.125	9.750				
383	DS504	5		4	2-1-1-1-x-x	6.875	9.500				
384	DS504	5		4	2-1-1-1-x-x	7.375	9.500				
385	DS504	5		4	2/1-2/1-2/1-2/1-x-x	8.625	7.125				
386	DS504	5		4	2/1-2/1-2/1-2/1-x-x	8.250	6.875				
387	DS504	5		4	2/1-2/1-2/1-2/1-x-x	8.875	7.000				
388	DS504	5		4	1/2-1/2-1/2-1/2-x-x	8.875	6.750				
389	DS504	5		4	1/2-1/2-1/2-1/2-x-x	8.500	6.625				
390	DS504	5		4	1/2-1/2-1/2-1/2-x-x	9.125	6.625				

Print List

Table details frames reviewed during Auto-Size, and the estimated cylinder bore sizes per stage based on user-specified flow rates, and current Auto-Sizing options. Layout format of 'x-x-x-x-x-x' indicates which stage cylinders are on which throw. Example: 2-1-2-1-3-4 means Stage-2 cylinders are on Throws #1 & #3 of a 6-Throw 4-Stage Frame.

Close

Software reviews 1000's of potential solutions.

Sample Case

Of those 1000's of possibilities, 455 may be useful.

Reviewing potential solutions: 64 of 455

Of those, the top 100 are listed.

1	A354	3.50	1800	800	7.500 : (2)	9.000 : (1)	7.500 : (2)	9.000 : (1)
2	A354	3.50	1800	800	7.500 : (2)	9.500 : (1)	7.500 : (2)	9.500 : (1)
3	A354	3.50	1800	800	7.250 : (2)	9.000 : (1)	7.250 : (2)	9.000 : (1)
4	DS602	6.00	1200	1200	11.750 : (1)	9.750 : (2)		
5	DS602	6.00	1200	1200	12.750 : (1)	9.750 : (2)		
6	DS602	6.00	1200	1200	12.000 : (1)	9.750 : (2)		
7	DS602	6.00	1200	1200	13.000 : (1)	9.750 : (2)		
8	A354	3.50	1800	800	7.250 : (2)	9.500 : (1)	7.250 : (2)	9.500 : (1)
9	DS602	6.00	1200	1200	11.750 : (1)	10.000 : (2)		
10	DS602	6.00	1200	1200	12.500 : (1)	10.000 : (2)		
11	DS602	6.00	1200	1200	12.750 : (1)	10.000 : (2)		
12	DS602	6.00	1200	1200	12.000 : (1)	10.000 : (2)		
13	DS602	6.00	1200	1200	13.000 : (1)	10.000 : (2)		
14	DS602	6.00	1200	1200	13.000 : (1)	10.250 : (2)		
15	A354	3.50	1800	800	7.750 : (2)	9.500 : (1)	7.750 : (2)	9.500 : (1)
16	A354	3.50	1800	800	7.750 : (2)	9.000 : (1)	7.750 : (2)	9.000 : (1)
17	ES602	6.00	1200	2400	12.000 : (1)	9.750 : (2)		
18	ES602	6.00	1200	2400	13.000 : (1)	9.750 : (2)		
19	ES702	7.00	1000	2400	12.000 : (1)	9.750 : (2)		
20	ES702	7.00	1000	2400	13.000 : (1)	9.750 : (2)		
21	FS602	6.00	1200	2400	13.000 : (1)	9.750 : (2)		

Sample Case

Now, the big question is "Which one out of the 100 is *The Best*?"

Of course, the answer is "*It depends!*"

Sample Case

1	A354	3.50	1800	800	7.500 : (2)	9.000 : (1)	7.500 : (2)	9.000 : (1)
2	A354	3.50	1800	800	7.500 : (2)	9.500 : (1)	7.500 : (2)	9.500 : (1)
3	A354	3.50	1800	800	7.250 : (2)	9.000 : (1)	7.250 : (2)	9.000 : (1)
4	DS602	6.00	1200	1200	11.750 : (1)	9.750 : (2)		
5	DS602	6.00	1200	1200	12.750 : (1)	9.750 : (2)		
6	DS602	6.00	1200	1200	12.000 : (1)	9.750 : (2)		
7	DS602	6.00	1200	1200	13.000 : (1)	9.750 : (2)		
8	A354	3.50	1800	800	7.250 : (2)	9.500 : (1)	7.250 : (2)	9.500 : (1)
9	DS602	6.00	1200	1200	11.750 : (1)	10.000 : (2)		
10	DS602	6.00	1200	1200	12.500 : (1)	10.000 : (2)		
11	DS602	6.00	1200	1200	12.750 : (1)	10.000 : (2)		
12	DS602	6.00	1200	1200	12.000 : (1)	10.000 : (2)		
13	DS602	6.00	1200	1200	13.000 : (1)	10.000 : (2)		
14	DS602	6.00	1200	1200	13.000 : (1)	10.250 : (2)		
15	A354	3.50	1800	800	7.750 : (2)	9.500 : (1)	7.750 : (2)	9.500 : (1)
16	A354	3.50	1800	800	7.750 : (2)	9.000 : (1)	7.750 : (2)	9.000 : (1)
17	ES602	6.00	1200	2400	12.000 : (1)	9.750 : (2)		
18	ES602	6.00	1200	2400	13.000 : (1)	9.750 : (2)		
19	ES702	7.00	1000	2400	12.000 : (1)	9.750 : (2)		
20	ES702	7.00	1000	2400	13.000 : (1)	9.750 : (2)		
21	FS602	6.00	1200	2400	13.000 : (1)	9.750 : (2)		

OK, so software ideally selected the most meaningful combinations of Frames and Cylinders, configured for 2-Stage.

Also, required driver size estimated.

Sample Case

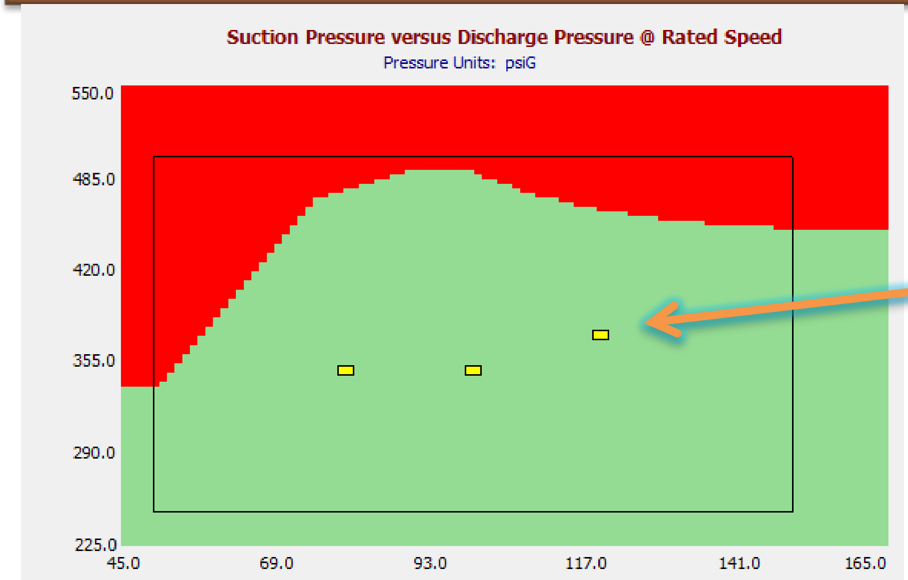
1	A354	3.50	1800	800	7.500 : (2)	9.000 : (1)	7.500 : (2)	9.000 : (1)
2	A354	3.50	1800	800	7.500 : (2)	9.500 : (1)	7.500 : (2)	9.500 : (1)
3	A354	3.50	1800	800	7.250 : (2)	9.000 : (1)	7.250 : (2)	9.000 : (1)
4	DS602	6.00	1200	1200	11.750 : (1)	9.750 : (2)		
5	DS602	6.00	1200	1200	12.750 : (1)	9.750 : (2)		
6	DS602	6.00	1200	1200	12.000 : (1)	9.750 : (2)		
7	DS602	6.00	1200	1200	13.000 : (1)	9.750 : (2)		
8	A354	3.50	1800	800	7.250 : (2)	9.500 : (1)	7.250 : (2)	9.500 : (1)
9	DS602	6.00	1200	1200	11.750 : (1)	10.000 : (2)		
10	DS602	6.00	1200	1200	12.500 : (1)	10.000 : (2)		
11	DS602	6.00	1200	1200	12.750 : (1)	10.000 : (2)		
12	DS602	6.00	1200	1200	12.000 : (1)	10.000 : (2)		
13	DS602	6.00	1200	1200	13.000 : (1)	10.000 : (2)		
14	DS602	6.00	1200	1200	13.000 : (1)	10.250 : (2)		
15	A354	3.50	1800	800	7.750 : (2)	9.500 : (1)	7.750 : (2)	9.500 : (1)
16	A354	3.50	1800	800	7.750 : (2)	9.000 : (1)	7.750 : (2)	9.000 : (1)
17	ES602	6.00	1200	2400	12.000 : (1)	9.750 : (2)		
18	ES602	6.00	1200	2400	13.000 : (1)	9.750 : (2)		
19	ES702	7.00	1000	2400	12.000 : (1)	9.750 : (2)		
20	ES702	7.00	1000	2400	13.000 : (1)	9.750 : (2)		
21	FS602	6.00	1200	2400	13.000 : (1)	9.750 : (2)		

So now what? Pick one based on fewer throws, small cylinders, lower price???

Remove Low & High Flow Cases. 100 to 46.

Remove low Map Coverage. 46 to 35.

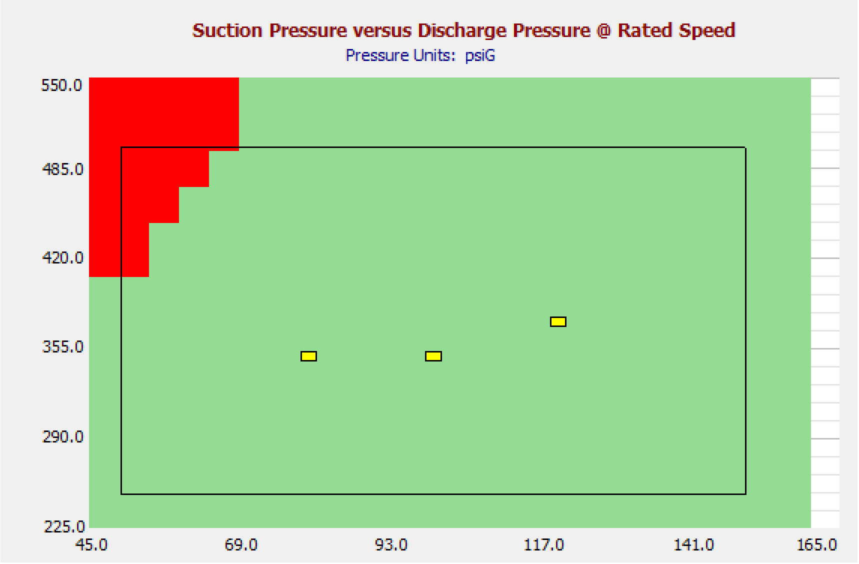
Sample Case: Unit Flexibility

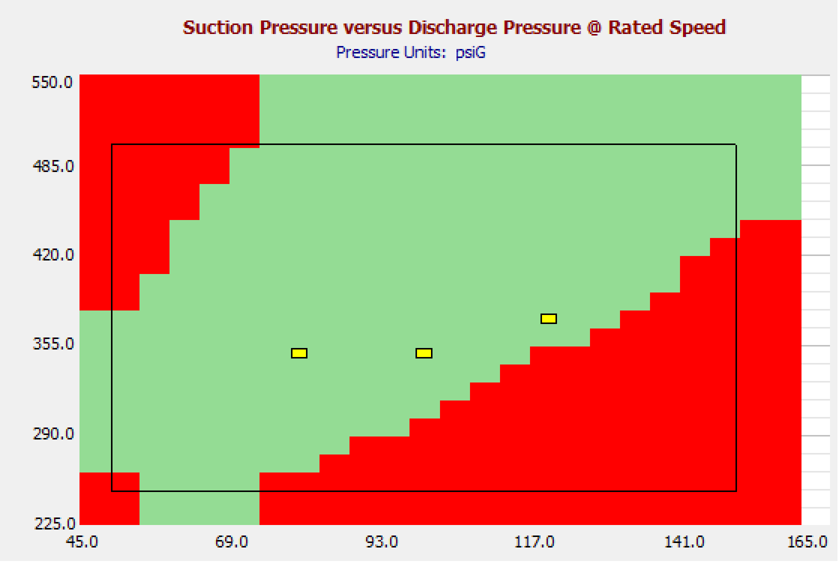


Design Points used when sizing the unit.

This can be done by reviewing a particular combination (frame + cylinders) over what part of the defined operating map that that combination is even potentially useful.

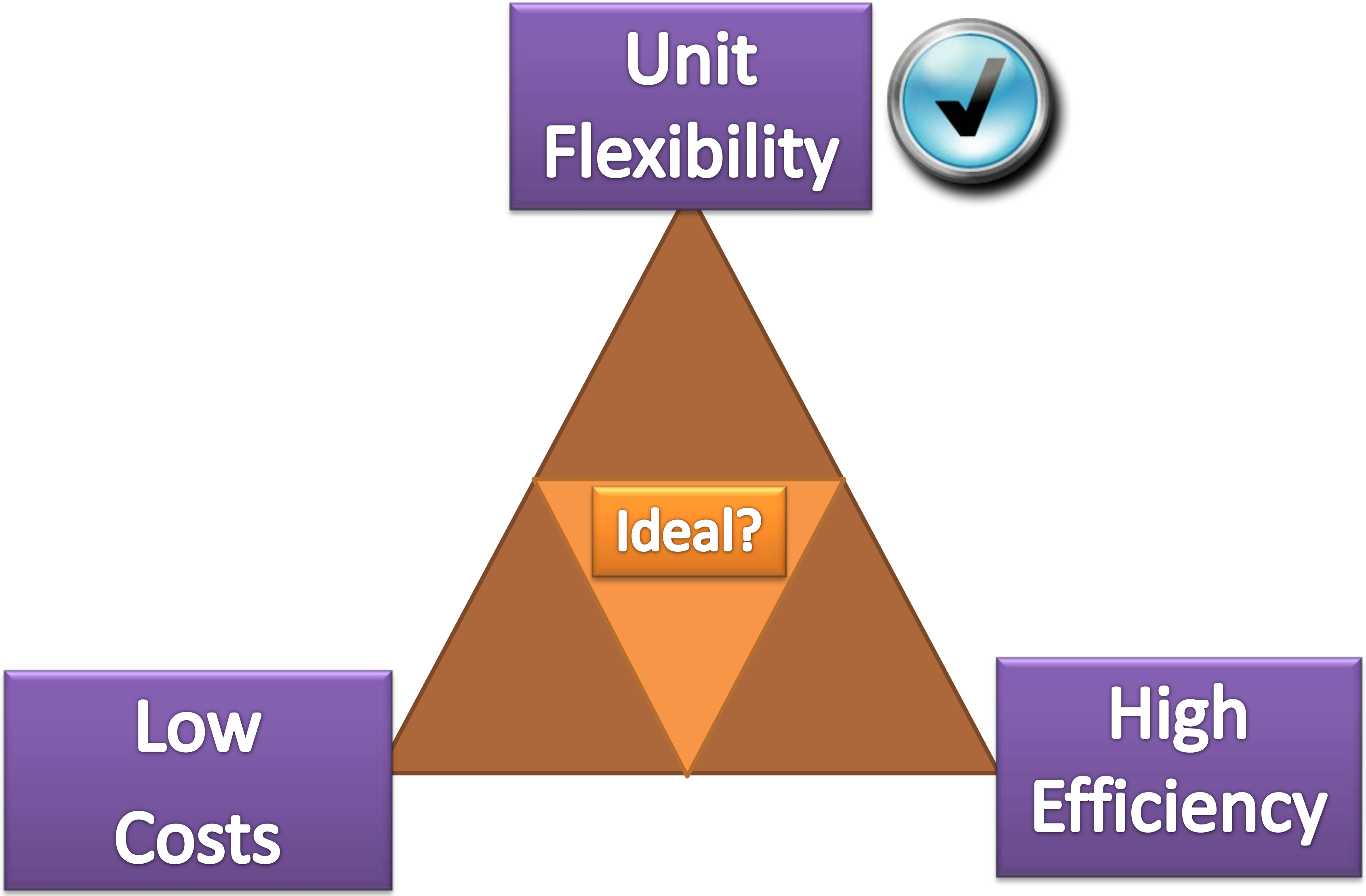
The Good and The Bad





This can be done by reviewing all unit configurations (frame + cylinders) to identify what part of the defined operating map each combination is potentially useful.

Sample Case

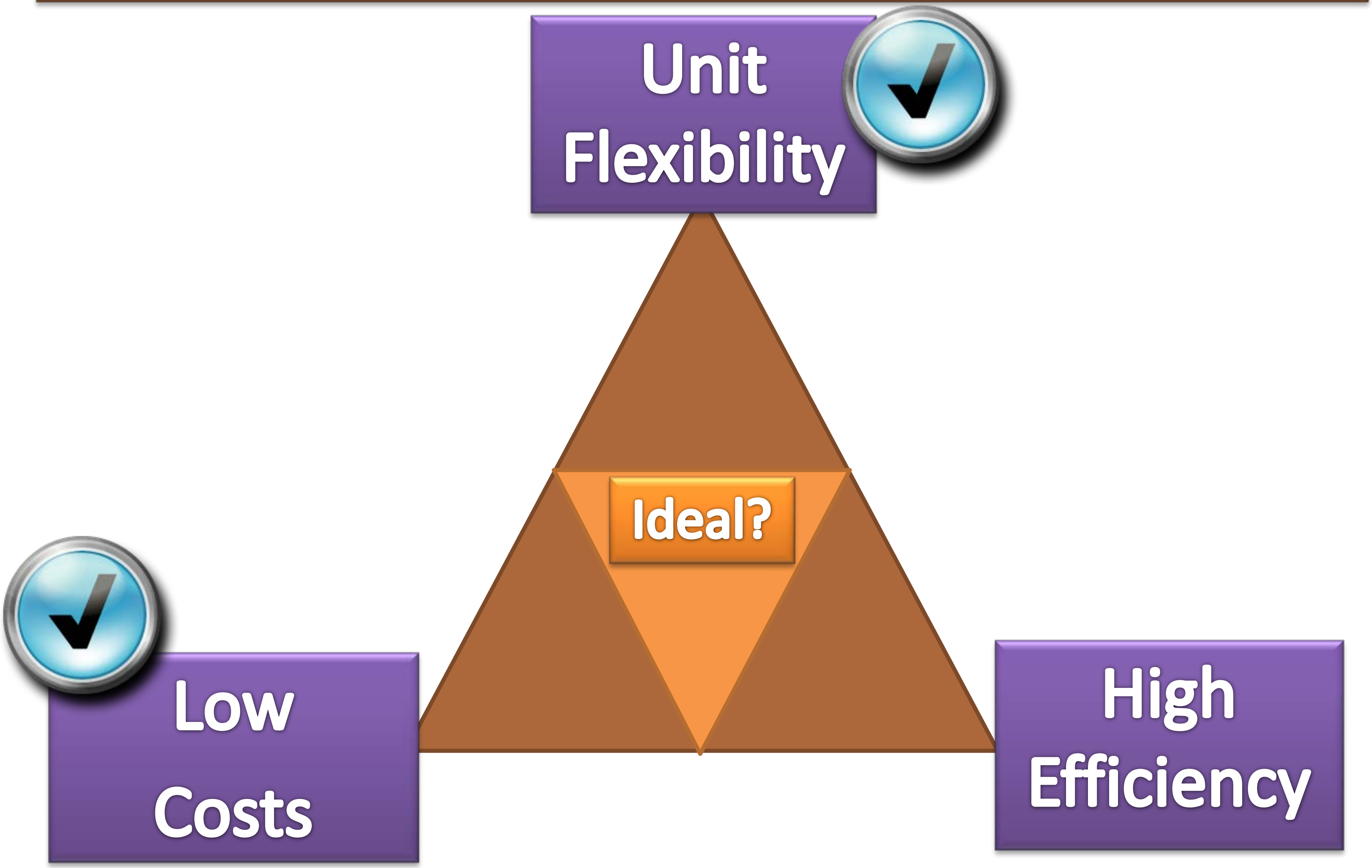


Reduced Number of Potential Units

From the list of 35 configurations that are acceptable, remove high price items:

No.	GE Frame	Stroke	Rated Speed	Rated Load	Throw-1 Bore [Stg]	Throw-2 Bore [Stg]	Throw-3 Bore [Stg]	Throw-4 Bore [Stg]	Throw-5 Bore [Stg]	Throw-6 Bore [Stg]
1	FS602	6.00	1200	2400	13.000 : (1)	9.750 : (2)	$206 K			
2	ES602	6.00	1200	2400	12.500 : (1)	10.250 : (2)				
3	ES602	6.00	1200	2400	12.750 : (1)	10.500 : (2)				
4	ES602	6.00	1200	2400	12.750 : (1)	10.250 : (2)				
5	FS702	7.00	1000	2400	13.000 : (1)	9.750 : (2)				
6	ES702	7.00	1000	2400	12.500 : (1)	10.000 : (2)				
7	ES702	7.00	1000	2400	12.750 : (1)	10.000 : (2)				
8	FS602	6.00	1200	2400	12.500 : (1)	10.250 : (2)				
9	FS602	6.00	1200	2400	12.750 : (1)	10.000 : (2)				
10	FS602	6.00	1200	2400	12.500 : (1)	10.000 : (2)	$209 K			
11	FS602	6.00	1200	2400	12.750 : (1)	10.250 : (2)				
12	FS602	6.00	1200	2400	13.000 : (1)	10.000 : (2)				
13	FS702	7.00	1000	2400	12.750 : (1)	10.250 : (2)				
14	FS702	7.00	1000	2400	12.750 : (1)	10.000 : (2)				
15	FS702	7.00	1000	2400	13.000 : (1)	10.000 : (2)				
16	FS702	7.00	1000	2400	12.500 : (1)	10.250 : (2)				
17	FS702	7.00	1000	2400	12.500 : (1)	10.000 : (2)				
18	DS604	6.00	1200	2400	7.000 : (2)	9.000 : (1)	7.000 : (2)	9.000 : (1)		
19	DS604	6.00	1200	2400	7.250 : (2)	8.750 : (1)	7.250 : (2)	8.750 : (1)		
20	DS604	6.00	1200	2400	9.750 : (2)	7.500 : (1)	7.500 : (1)	7.500 : (1)	$311 K	
21	DS604	6.00	1200	2400	9.750 : (2)	7.250 : (1)	7.250 : (1)	7.250 : (1)		
22	DS604	6.00	1200	2400	10.000 : (2)	7.500 : (1)	7.500 : (1)	7.500 : (1)		
23	DS604	6.00	1200	2400	10.000 : (2)	7.250 : (1)	7.250 : (1)	7.250 : (1)		
24	ES604	6.00	1200	4800	9.750 : (2)	7.250 : (1)	7.250 : (1)	7.250 : (1)		
25	ES604	6.00	1200	4800	7.250 : (2)	9.000 : (1)	7.250 : (2)	9.000 : (1)	$354 K	
26	FS604	6.00	1200	4800	7.250 : (2)	9.000 : (1)	7.250 : (2)	9.000 : (1)		
27	FS604	6.00	1200	4800	7.500 : (2)	9.000 : (1)	7.500 : (2)	9.000 : (1)		
28	ES604	6.00	1200	4800	10.000 : (2)	7.250 : (1)	7.250 : (1)	7.250 : (1)		
29	ES604	6.00	1200	4800	10.000 : (2)	7.500 : (1)	7.500 : (1)	7.500 : (1)		
30	ES704	7.00	1000	4800	7.250 : (2)	9.000 : (1)	7.250 : (2)	9.000 : (1)		
31	FS704	7.00	1000	4800	7.250 : (2)	9.000 : (1)	7.250 : (2)	9.000 : (1)		
32	ES704	7.00	1000	4800	10.000 : (2)	7.500 : (1)	7.500 : (1)	7.500 : (1)		
33	ES704	7.00	1000	4800	10.250 : (2)	7.500 : (1)	7.500 : (1)	7.500 : (1)		
34	FS604	6.00	1200	4800	10.250 : (2)	7.500 : (1)	7.500 : (1)	7.500 : (1)	$365 K	
35	FS704	7.00	1000	4800	10.250 : (2)	7.500 : (1)	7.500 : (1)	7.500 : (1)		
36										

Sample Case



Reduced Number of Potential Units

From the list of 17 configurations that are acceptable, remove less efficient ones:

No.	GE Frame	Stroke	Rated Speed	Rated Load	Throw-1 Bore [Stg]	Throw-2 Bore [Stg]
1	FS602	6.00	1200	2400	13.000 : (1)	9.750 : (2)
2	ES602	6.00	1200	2400	12.500 : (1)	10.250 : (2)
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	FS702	7.00	1000	2400	12.500 : (1)	10.250 : (2)
17	FS702	7.00	1000	2400	12.500 : (1)	10.000 : (2)

This part takes some effort and some time. But, at least you know your efforts are being applied only to units that have already passed flexibility and cost requirements.

Reduced Number of Potential Units

Efficiency may relate to any of these:

- **Power / Unit of Flow (e.g. BHP/MM)**
  - **Lower is better!**
- **Isentropic (measure of valve and friction efficiencies)**
  - **Higher is better!**
- **Emissions from Engine**
- **And others.**

Reduced Number of Potential Units

Power / Unit of Flow

Load per Flow: Ps versus Pd table based on average Suct. Temps, varying speed

Calculations based on unit's current Torque limit, average Suction Temperatures, varying speed and specified unloading settings.

Region to Map:

Ps - Min: 50 psiG   Pd - Min: 250 p

Ps - Max: 150 psiG   Pd - Max: 500 p

Pd (Discharge)

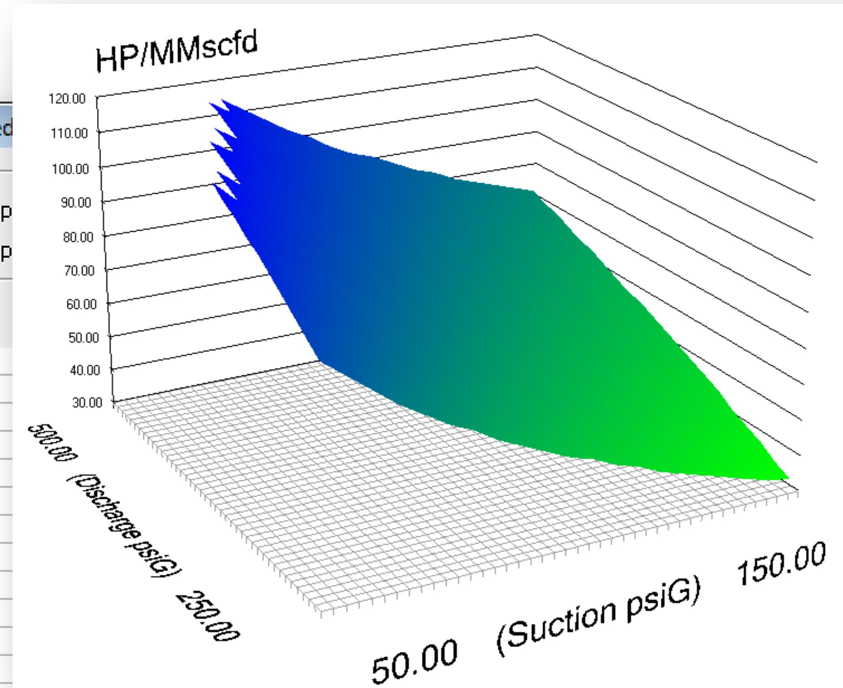
Table of Unit's Load per Flow Results

Pd \ Ps	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0	105.0	110.0	115.0	120.0	125.0	130.0	135.0	140.0	145.0	150.0
500						115	111	107	103	100	96										
488					117	113	109	105	102	98	95										
475					116	111	107	103	100	96	93										
463					114	109	105	102	98	95	91										
450				116	112	108	104	100	96	93	90										
438				115	110	106	102	98	94	91	88										
425			117	113	108	104	100	96	92	89	86										
413			115	111	106	102	98	94	91	87	84										
400			113	108	104	100	96	92	89	85	82										
388		116	111	106	102	98	94	90	87	83	80										
375		114	109	104	100	95	92	88	84	81	78										
363	118	112	107	102	97	93	89	86	82	79	76										
350	115	109	104	99	95	91	87	84	80	77	74	71	68	66	63	61	59	57	55	53	51
338	113	107	102	97	93	89	85	81	78	75	72	69	66	64	61	59	57	55	53	51	49
325	110	104	99	95	90	86	83	79	76	72	69	67	64	61	59	57	54	52	50	48	47
313	108	102	97	92	88	84	80	77	73	70	67	64	62	59	57	55	52	50	48	46	45
300	105	99	94	90	85	81	78	74	71	68	65	62	59	57	54	52	50	48	46	44	42
288	102	97	92	87	83	79	75	72	68	65	62	60	57	55	52	50	48	46	44	42	40
275	99	94	89	84	80	76	72	69	66	63	60	57	54	52	50	47	45	43	41	39	38
263	96	91	86	81	77	73	70	66	63	60	57	54	52	49	47	45	43	41	39	37	35
250	93	88	83	78	74	70	67	63	60	57	54	52	49	47	44	42	40	38	36	34	33

☑ Run all points at current speed: 1000

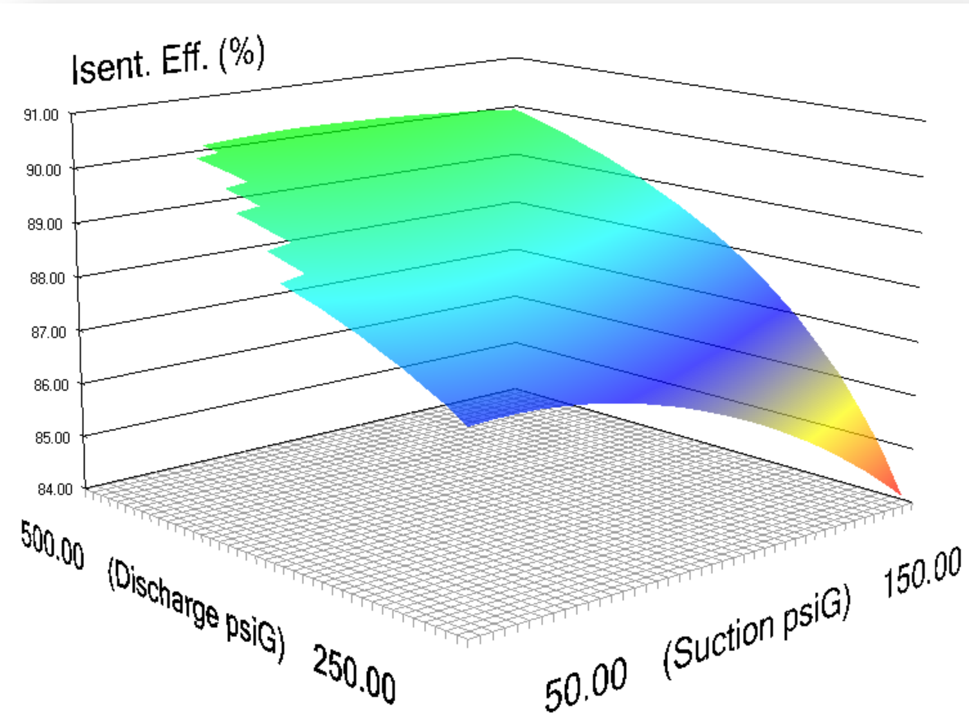
Ps (Suction)

Load/Flow Units: HP/MMscfd



Reduced Number of Potential Units

Isentropic Efficiency



us Pd (for current VVCP and End Deactivation settings)

250 psiG
500 psiG

Formatting:
Decimals: 2
Font Size: 7

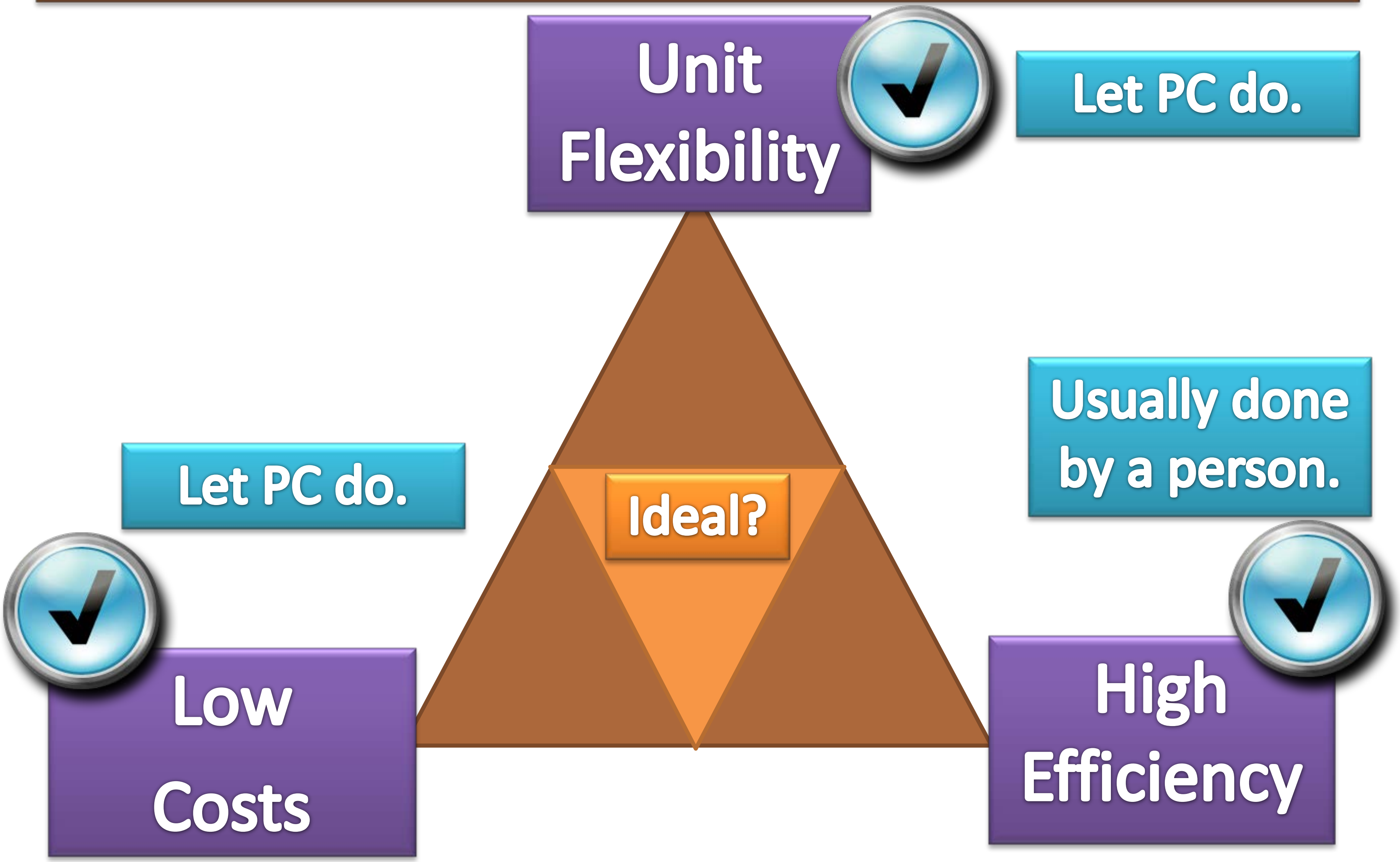
Update Table
Close
Print
Ref: Unit (All Stage
Plot Data 3-D
Copy

lax Loads

	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0	105.0	110.0	115.0	120.0	125.0	130.0	135.0	140.0	145.0	150.0
											90.20	90.19	90.18	90.17	90.15	90.13	90.10	90.07	90.04	90.00	89.96
											90.12	90.12	90.11	90.09	90.07	90.04	90.01	89.98	89.94	89.90	89.86
											90.04	90.03	90.01	89.99	89.97	89.94	89.91	89.87	89.83	89.79	89.74
											89.95	89.94	89.92	89.90	89.87	89.84	89.80	89.76	89.72	89.67	89.62
											89.85	89.84	89.82	89.79	89.76	89.72	89.68	89.64	89.59	89.54	89.48
											89.76	89.74	89.71	89.68	89.65	89.61	89.56	89.52	89.46	89.41	89.35
											89.65	89.62	89.60	89.56	89.52	89.48	89.43	89.37	89.32	89.25	89.19
											89.54	89.51	89.48	89.44	89.39	89.34	89.29	89.23	89.17	89.10	89.03
											89.41	89.38	89.34	89.30	89.25	89.19	89.13	89.07	89.00	88.92	88.84
											89.28	89.25	89.20	89.16	89.10	89.04	88.97	88.90	88.82	88.74	88.65
											89.14	89.09	89.04	88.99	88.93	88.86	88.78	88.70	88.62	88.53	88.43
											88.99	88.94	88.88	88.82	88.75	88.68	88.59	88.50	88.41	88.31	88.21
											88.81	88.76	88.70	88.63	88.55	88.46	88.37	88.27	88.17	88.05	87.94
											88.64	88.58	88.51	88.43	88.34	88.24	88.14	88.03	87.91	87.79	87.66
											88.43	88.36	88.28	88.19	88.09	87.98	87.87	87.74	87.61	87.47	87.32
313	88.34	88.41	88.45	88.47	88.48	88.47	88.45	88.41	88.36	88.30	88.22	88.14	88.05	87.95	87.84	87.71	87.58	87.44	87.30	87.14	86.97
300	88.17	88.24	88.27	88.29	88.29	88.27	88.24	88.19	88.13	88.06	87.97	87.88	87.77	87.65	87.53	87.39	87.24	87.08	86.91	86.73	86.54
288	88.01	88.06	88.09	88.10	88.09	88.07	88.03	87.97	87.90	87.81	87.71	87.60	87.48	87.35	87.21	87.05	86.88	86.70	86.51	86.31	86.09
275	87.81	87.86	87.88	87.88	87.86	87.82	87.77	87.70	87.61	87.51	87.40	87.27	87.13	86.98	86.82	86.64	86.44	86.23	86.01	85.77	85.52
263	87.62	87.65	87.66	87.65	87.62	87.57	87.51	87.42	87.32	87.20	87.07	86.93	86.77	86.59	86.40	86.19	85.97	85.73	85.47	85.20	84.90
250	87.38	87.40	87.40	87.38	87.33	87.27	87.19	87.09	86.96	86.83	86.67	86.50	86.31	86.11	85.88	85.64	85.38	85.09	84.79	84.46	84.11

Ps (Suction)

Sample Case


Unit Flexibility
Let PC do.
Ideal?
Usually done by a person.
Let PC do.
Low Costs
High Efficiency

Optimizing Compressors: Via Unloading Hardware

OK, now how much unloading do we need versus how much can be achieved? What problems may arise because of the unloading options selected?

- Rod Loads
- Pin Non-reversals
- Crank Pin Forces
- Parasitic Losses
- Pulsations/Vibrations
- High Discharge Temps
- High Pressure Drops
- Low Vol. Efficiency

Optimizing Compressors: Via Unloading Hardware

Generally, there are five types of actions for unloading (changing its load or its flow) a unit:

- **Pinch/Throttle Suction Pressure**
- **Recycle Gas back to Inlet**
- **Change Unit Speed**
- **Add More Clearance**
- **Deactivate Ends**

Unloading Actions

– **Pinch Suction Pressure:**

  – Wastes Energy
  – Requires your compressor to add that energy back to the gas

– **Recycle Gas:**

  – Wastes Energy
  – Compressor keeps re-compressing the same gas

It's not optimized if it wastes money!

Unloading Actions

- **Change Unit Speed:**
  - Excellent Flow Control
    - Smooth Control
  - Poor Load Control
    - Rated Torque Varies with Speed
  - Contributes to Vibration, and Pulsation
  - Engine Fuel Eff. best at Rated Speed
  - VFD Motors can cost A LOT
  - Affects all throws, all stages

Unloading Actions

- <u>Add More Clearance:</u>
  - Most Efficient Way to Unload Both Load and Flow (*not good for low ratio apps*)
  - Generally does not affect pulsation or torsional issues too much
  - Clearance added by VVCPs, Front Head Pockets, Valve Cap Pockets, Plugs, Body Pockets, Valve Spacers, etc.
  - Affects only those cylinder ends with clearance devices added

Unloading Actions

- **Deactivate Ends:**
  - **Allows for large changes in load and flow**
  - **Good for low and high ratio applications**
  - **May have adverse effects on pulsation and torsional issues**
  - **Adverse effects on rod loads, pin non-reversals, and pressure drops**
  - **Accomplished via plug, finger-type, or radial unloaders, pulling valves, or bypass**

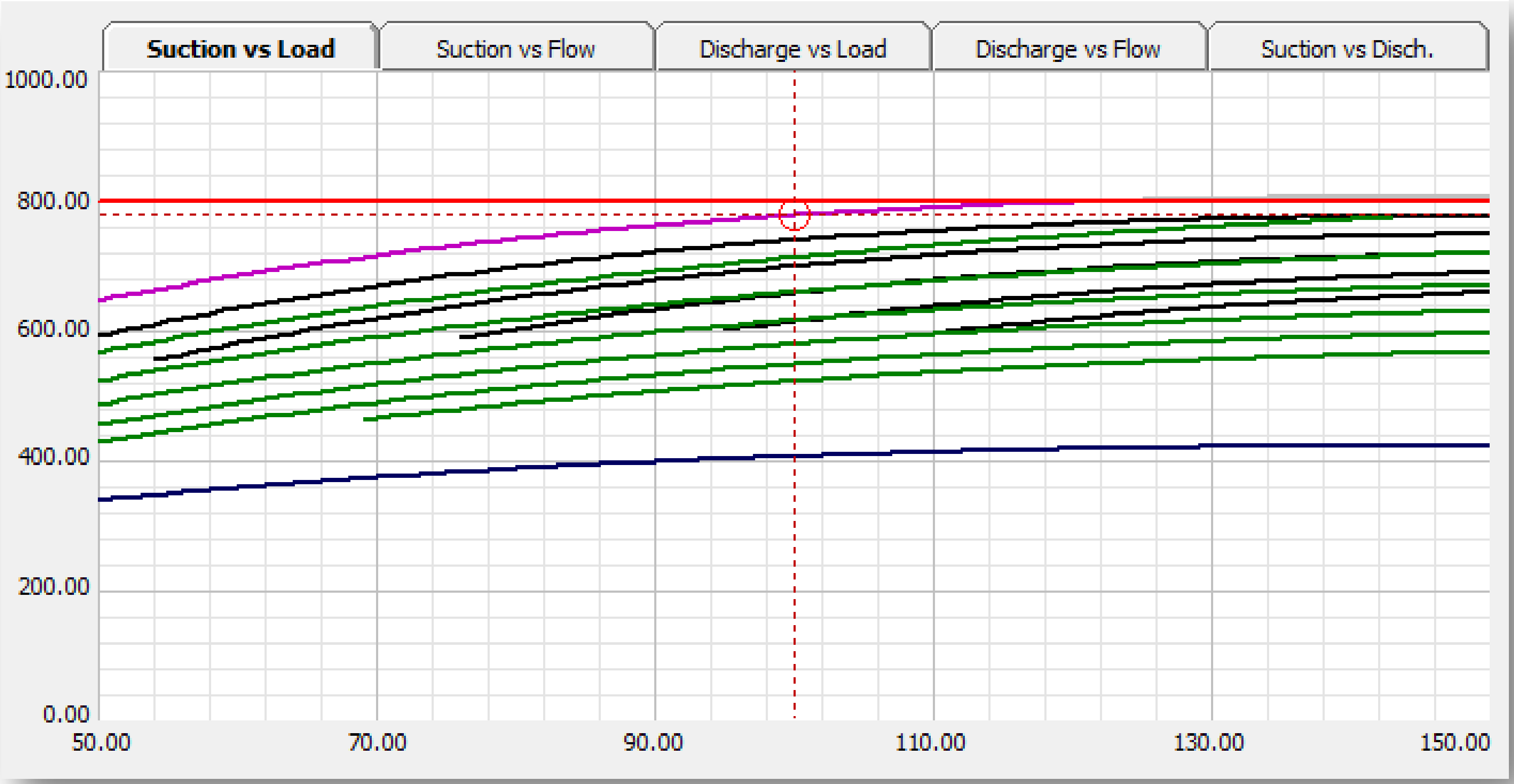
Unloading Actions (Load or Flow)

Rule of Thumb and Order of Use:

1. Use **Clearance** for noticeable changes
2. Use **Speed** for fine tuning
3. Use **End Deactivators** for large changes
4. **Pinch Suction** if 1-3 do not solve issue
5. **Recycle Gas** if 1-4 do not solve issue
6. **Shut Down** unit if recycle fails to help, or recycling too long

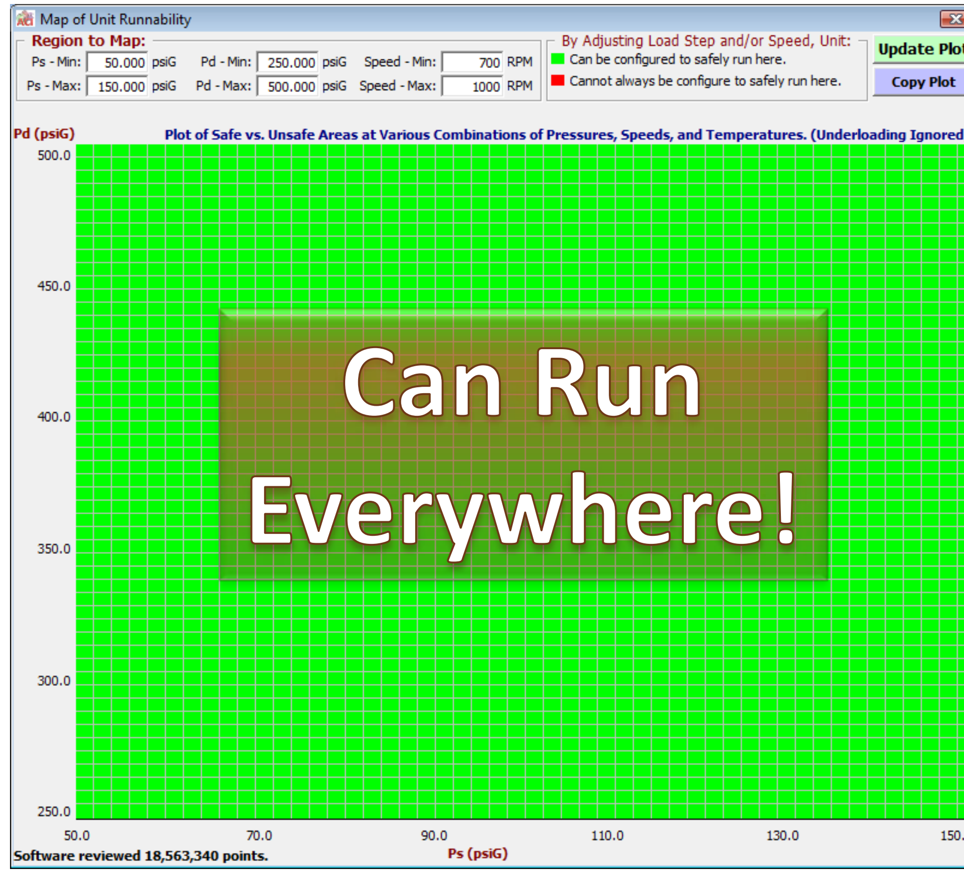
Unloading Actions

Based on Clearance and End Deactivation, the curves hint to what map is covered.



Unloading Actions

But to know where unit really can operate, millions of operating points need to be checked. All pressures vs. all speeds vs. all unloading configurations vs. various suction gas temperatures.



18.5 Million Points Later

Final Actions

Rule of Thumb and Order of Use:

1. Check for Torsional Concerns
2. Check for Pulsation/Acoustic/Vibration and Mechanical Concerns
3. Do required dampening devices for pulsations (orifice plates et al) create significant pressure drops?
4. Can automation/control panel properly model unit, and model any safety limits?