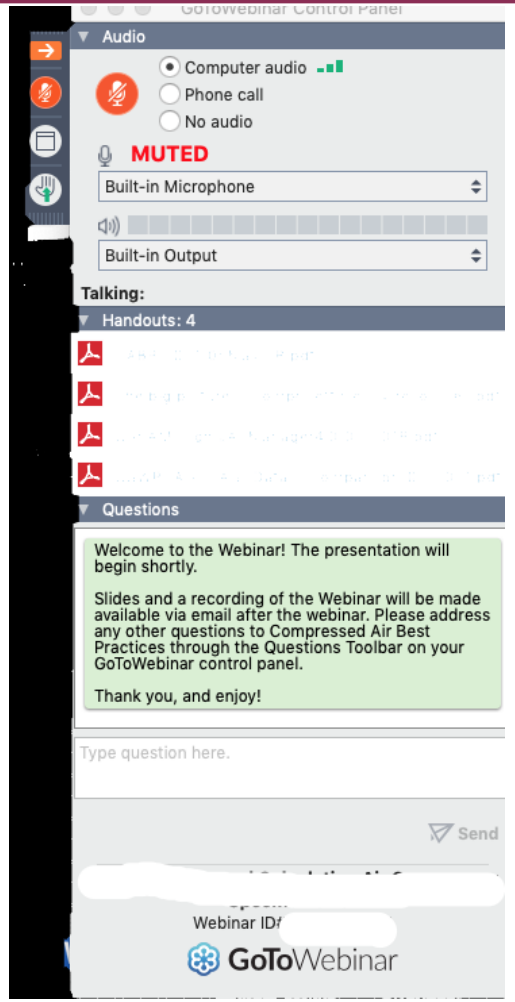
Vacuum System Fundamentals: Depth of Vacuum vs. Absolute Pressure

Andy Smiltneek
Keynote Speaker

The recording and slides of this webinar will be made available to attendees via email later today.

PDH Certificates will be e-mailed to attendees by within 2 days.

Q&A Format



- Panelists will answer your questions during the Q&A session at the end of the Webinar.

- Please post your questions in the Questions Window in your GoToWebinar interface.

- Direct all questions to Blower & Vacuum Best Practices® Magazine

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Vacuum Pumps and Vacuum Systems Consulting – Troubleshooting and Design
On a paper machine the vacuum system is the second most expensive to install and the second most expensive to run, yet is largely uncontrolled or wastefully controlled and unmanaged. Many systems were designed for the clothing technology and process control technology available decades ago. The clothing technology in particular continues to improve, yet the vacuum system is untouched. Growth Solutions Consultants provides vacuum system surveys, troubleshooting and design change recommendation to optimize the energy consumption of the machine. Capabilities include borescopic examination and orifice plate capacity checking of the pump; system mapping, and process troubleshooting.

Tissue Machine Troubleshooting
We have extensive experience with troubleshooting process problems on tissue machines.

Presentations and Training
Andy Smiltneek has presented at both Papercon and Tissue World conventions with the subjects of Liquid Ring Vacuum Pump Basics, Vacuum System Energy Savings and Press Section Water Balance. He is a co-author of the TAPPI standard for liquid ring vacuum pump testing. GSC has one hour, four hour and two day training sessions available on both management and vacuum systems; and has customized this training for corporate clients and their specific needs.

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Pulp and Paper; Heavy Industrial; Mining

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Our customers include Georgia Pacific, SCA (now Essity), Clearwater, Irving Tissue, USG, Greif, Midwest Paper and Domtar.
References are available upon request.

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All materials presented are educational. Each system is unique and must be evaluated on its own merits.

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Vacuum System Fundamentals Depth of Vacuum vs. Absolute Pressure

Introduction

Blower & Vacuum Best Practices Magazine

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About the Speakers

Andy Smiltneek
Growth Solutions Consultants

- President, Growth Solutions Consultants
- Spent 30 Years at Kimberly-Clark
- Prior Director of Tissue Machine Design with Asia Pulp and Paper in China
- Prior Technical Director at Somarakis

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Vacuum System Fundamentals: Depth of Vacuum vs. Absolute Pressure

May 11, 2023

Andy Smiltneek
President
Growth Solutions Consultants

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Pressure and Flow

November 10, 1975
Air Pressure 28.6 “Hg (adjusted to sea level)
Sustained Wind 80 mph
Gusts over 100 mph
The Edmund Fitzgerald is wrecked in Lake Superior
This is the power of 1.3”Hg vacuum
Average velocity through 9/16” hole at 1.3”Hg 120 mph

Defining Vacuum

- A space entirely devoid of matter. (Oxford dictionary)
- For our purposes, a vacuum is any pressure lower than local atmospheric

Why do we want vacuum?

- To move air through a substrate without having the material fly around!
- To create an atmosphere that allows a process to operate
- To milk cows
- To prime the pumps that hold the water out of New Orleans
- To enhance the action of geothermal wells
- To clean up creosote spilled into sand next to the Columbia River
- To make silicon chips
- And on and on

Torricelli, Pascal and Bernoulli

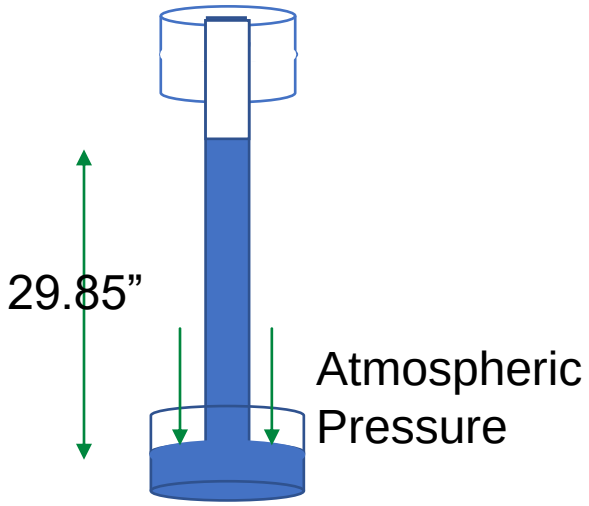
- Evangelista Torricelli (1608 – 1647) Italian
  - Invented the barometer
  - The torr as a vacuum measurement is named for him
- Blaise Pascal (1623 – 1662) French
  - Generalized Torricelli's work
  - Showed variation in atmospheric pressure
  - The pascal as a vacuum measurement is named after him
- Daniel Bernoulli (1700 – 1782) Swiss
  - Showed Relationships between pressure and velocity
  - Famous Bernoulli Principle (conservation of energy)

What did Torrecelli do?

Suppose we have a 40” long glass cylinder closed at the bottom and open at the top filled with mercury and covered with an upside-down bowl

Now we carefully and quickly rotate the cylinder and bowl

At sea level, the mercury will fall until the top of the column is 29.85 inches above the mercury pool in the bowl and the upper 10 inches will contain mercury vapor at a pressure of .07 inches of mercury



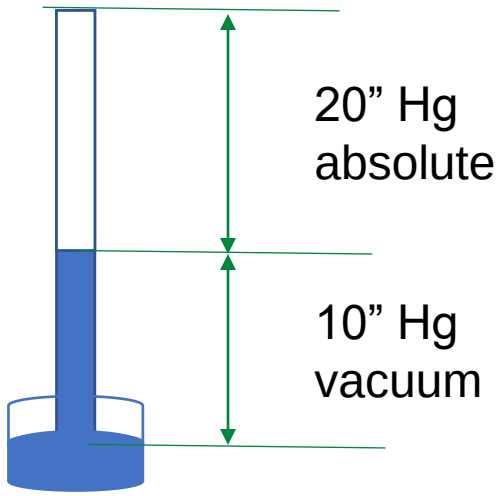
The mercury pool has atmospheric pressure (the weight of 65 miles of air) pushing on it which pushes up the mercury column; measuring the height of the column measures atmospheric pressure

If the column was water, the height would be 33.8 feet

The pressure at the bottom of the column is 14.7 psia

Measuring Vacuum

If we have a cylinder open on both ends with a mercury pool sealing the bottom end and a way to remove air from the top end, as you remove air the pressure will drop and the mercury column will rise to balance the drop in pressure. The height of the mercury column is the vacuum level, or the pressure below local atmospheric



If the column is 29.92 inches long, the height of the air from the mercury to the end of the column is the absolute pressure

Pressure Equivalents at sea level

29.92 ”Hg vacuum at sea level and 60ºF is the same as 0”Hg absolute (HgA) is the same as 0 psia is the same as 0 torr is the same as 0 bar is the same as 0 kPa

0”Hg vacuum is the same as 29.92 “Hg is the same as 14.7 psia is the same as 760 mmHg is the about the same as 760 torr is 1 bar is the same as 101.3 kPa

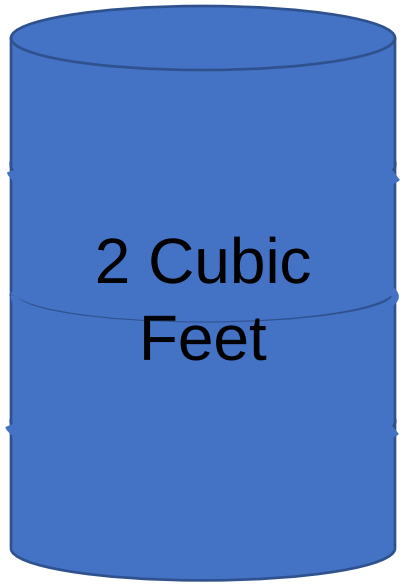
0” vacuum is the same as 0 psig (gauge pressure)

29.92”Hg is the same as 1 bar is the same as 101.3 mPa is the same as 10130mb

Vacuum Measurement Comparison Table

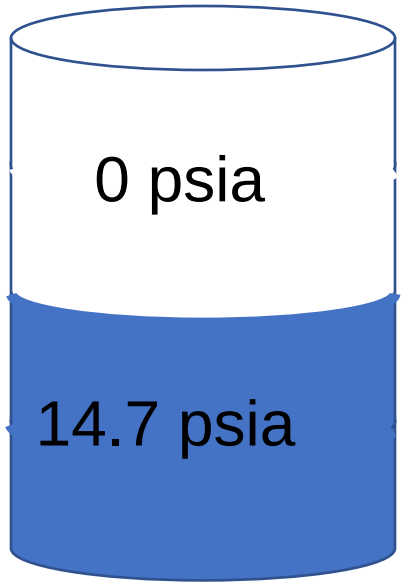
% Vacuum	Torr (approx mm Mercury; 1/760 of atmospheric)	Micron	psia (lb/in2 abs)	Inches Mercury absolute ("HgA)	Inches Mercury Gauge	kilo Pascals absolute (kPa)
0	760	760,000	14.7	29.92	0	101.3
34	500	500,000	9.7	19.7	10.22	66.7
50	380	380,000	7.3	15	14.92	50.8
61	300	300,000	5.8	11.8	18.12	40
87	100	100,000	1.93	3.94	25.98	13.3
99	7.6	7,600	0.147	0.299	29.62	1
99.999	0.01	10	0.000193	0.000394	29.9196	0.0013
100	0	0	0			

Basic Specifications - CFM

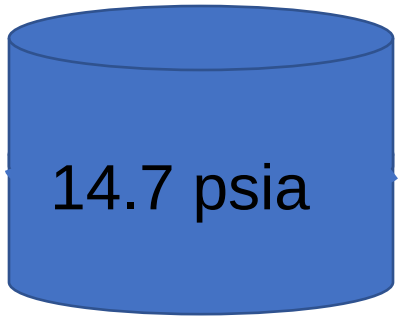


Suppose at sea level we have 2 cubic feet of air at 60ºF at 14.7 psia (29.92”HgA, 0”Hg vacuum) and 0% humidity

Basic Specifications - CFM



2 Cubic Feet

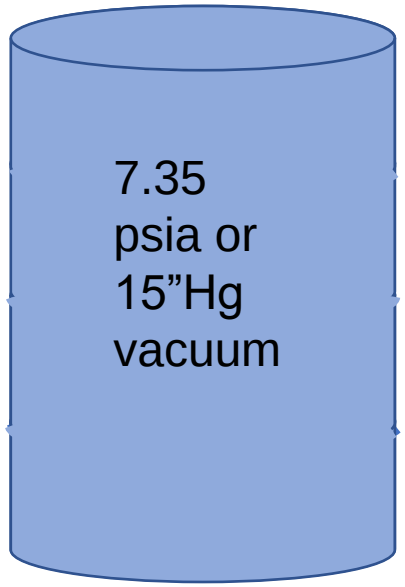


1 cubic foot

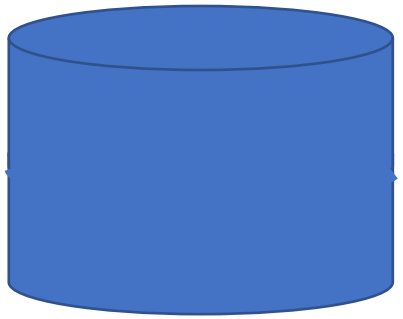
Now we remove one cubic foot of air in one minute – this is 1 CFM

Basic Specifications - CFM

The remaining air fills the whole vessel and the pressure drops in half, and we now have 3 cubic feet of air



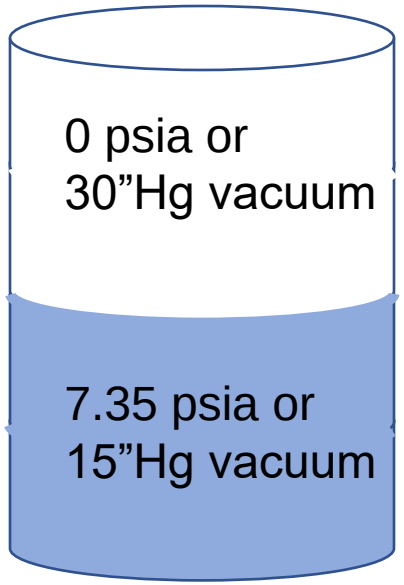
2 cubic feet



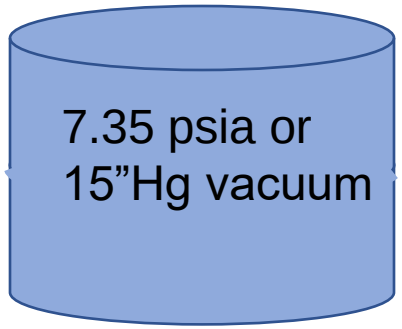
1 cubic foot

Basic Specifications - CFM

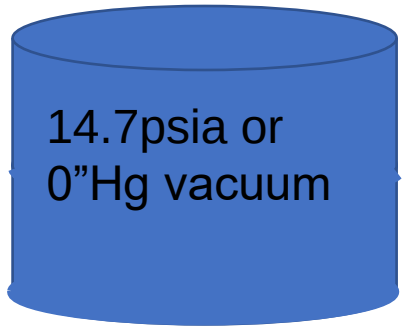
Now we remove another cubic foot of air from the vessel



2 cubic feet



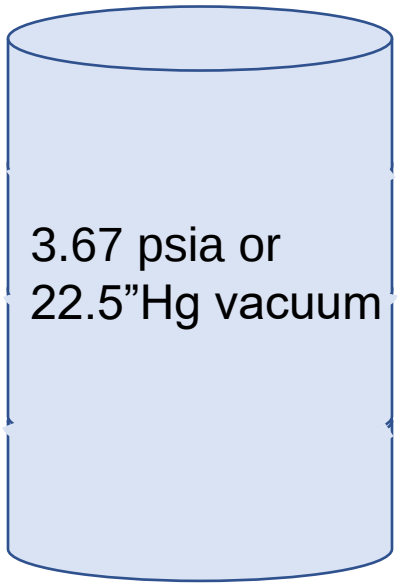
1 cubic foot



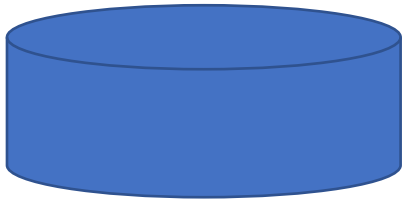
1 cubic foot

Basic Specifications - CFM

The remaining air fills the whole vessel and the pressure drops in half, and we now have 3 ½ cubic feet of air, but to discharge the air removed at 7.35 psia we must compress it to 14.7 psia

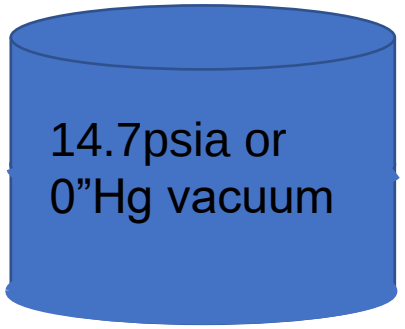


2 cubic feet



Compressed to 14.7psia or 0”Hg vacuum

1/2 cubic foot



1 cubic foot

Typical Volume Measurement Units

- Cubic feet per minute at the inlet (CFM)
- Cubic feet per minute at the discharge (ACFM)
- Cubic feet per minute corrected to standard conditions (SCFM)
- Cubic meters per minute
- Cubic meters per hour

Basic Specifications - CFM

- The vacuum pump does not pump vacuum, it is a compressor that removes air from an enclosure more quickly than air can leak in
- The vacuum pump will be rated by the air it can remove at standard conditions at the vacuum level (the pump inlet, since it is compressing the air the output in cubic feet is less than the input)
- The vacuum pump rating is usually presented in a pump curve
- The pump curve will also show the power required versus the vacuum level

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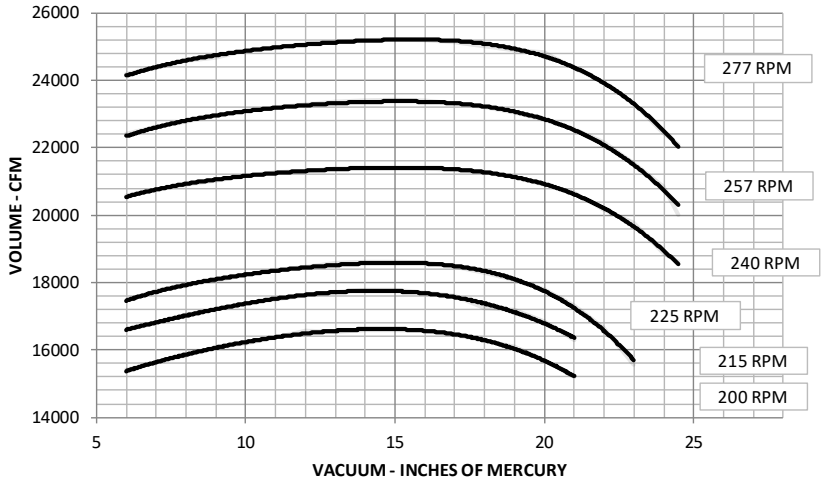
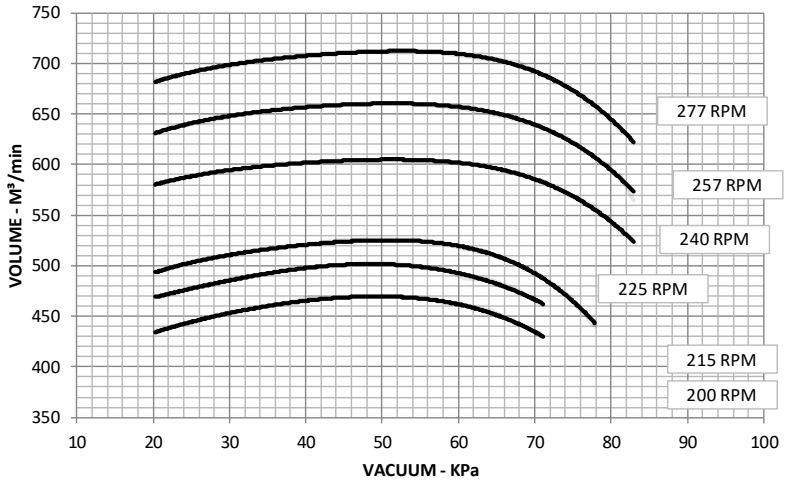
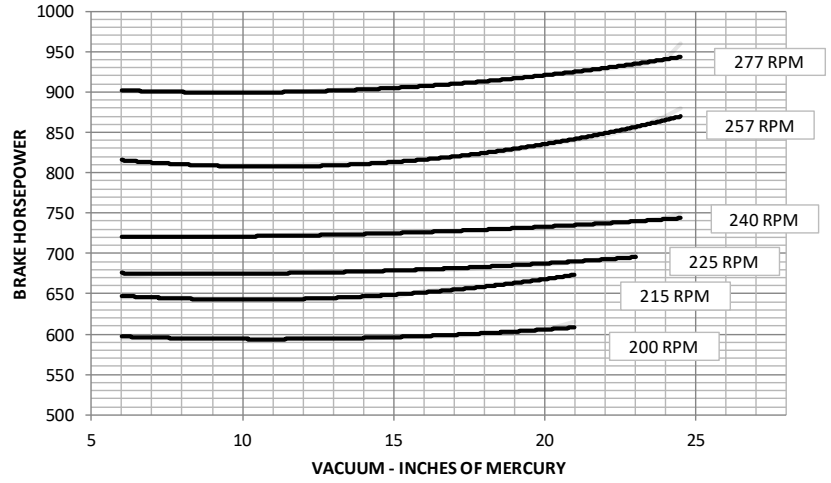
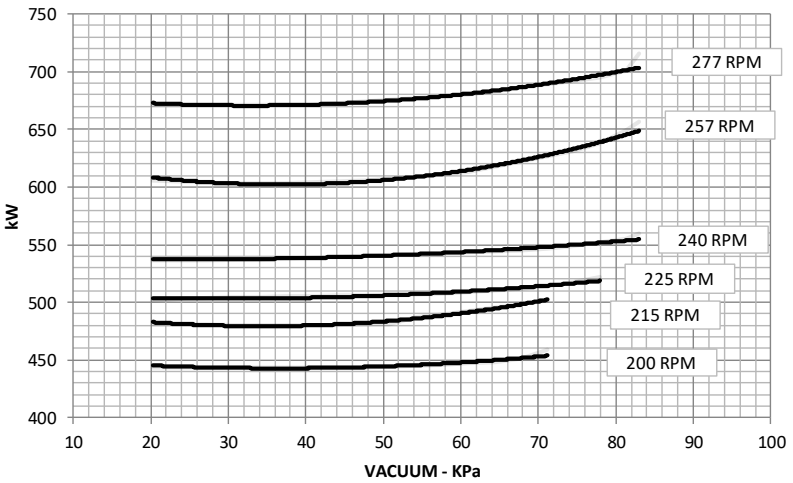
Typical Pump Curve





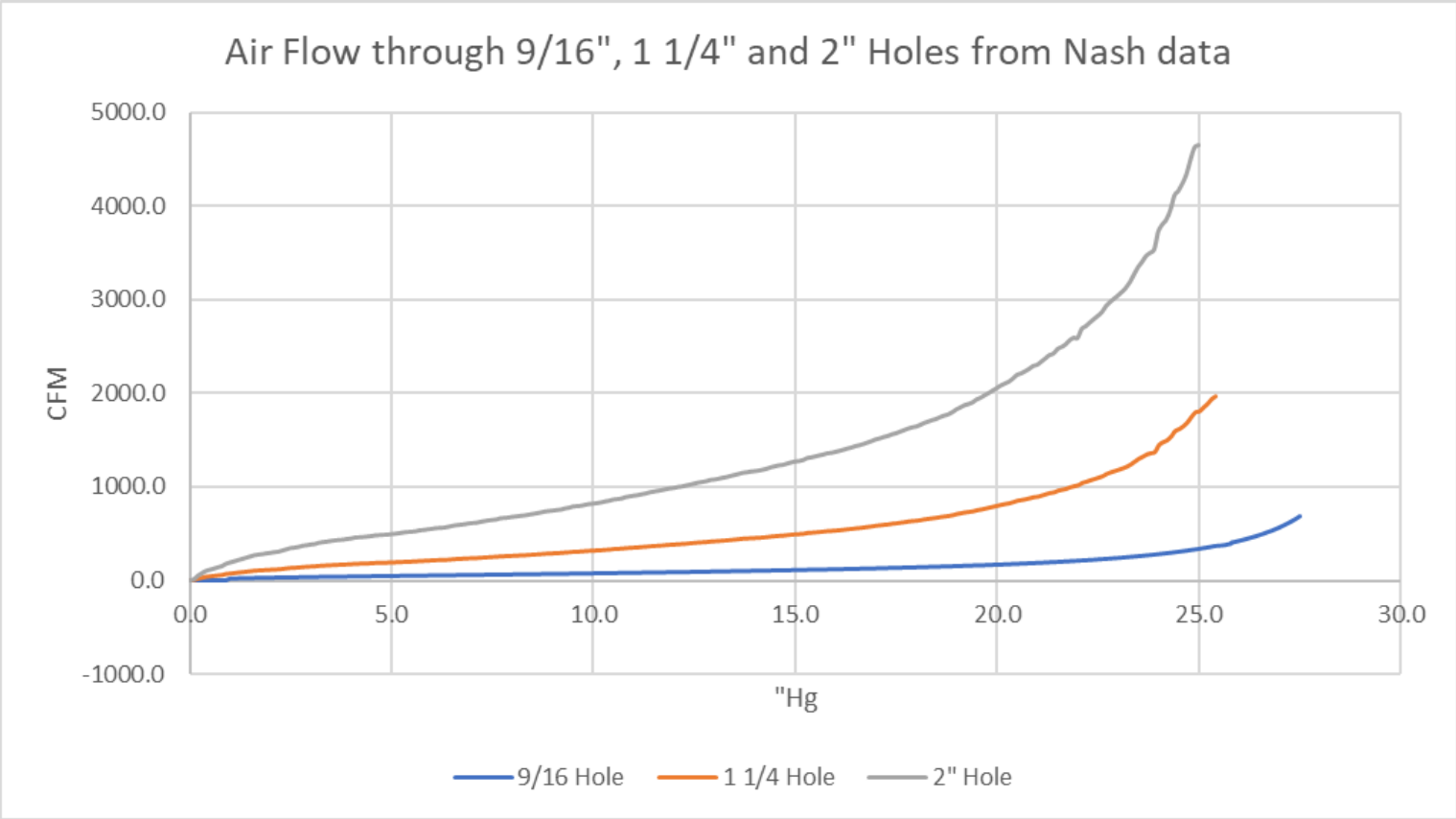


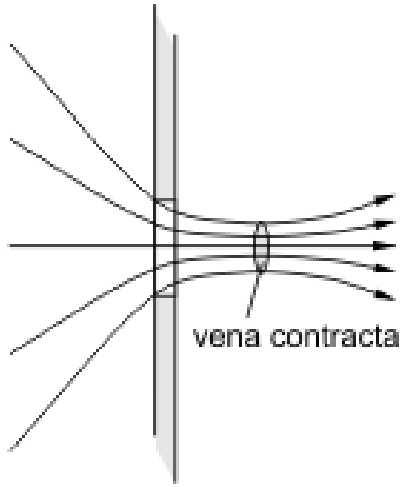


What did Bernoulli Do?

- $1/2\rho\mu^2$+P=Constant
- where P is the absolute pressure, ρ is the density of the fluid and u is its velocity
- From this equation we can derive the velocity of a fluid for any pressure drop
- People a lot smarter than me have worked with this equation to find mass flow vs pressure drop (so you can be charged for your gas and water usage, and planes can fly)

Nash flow data from 1935

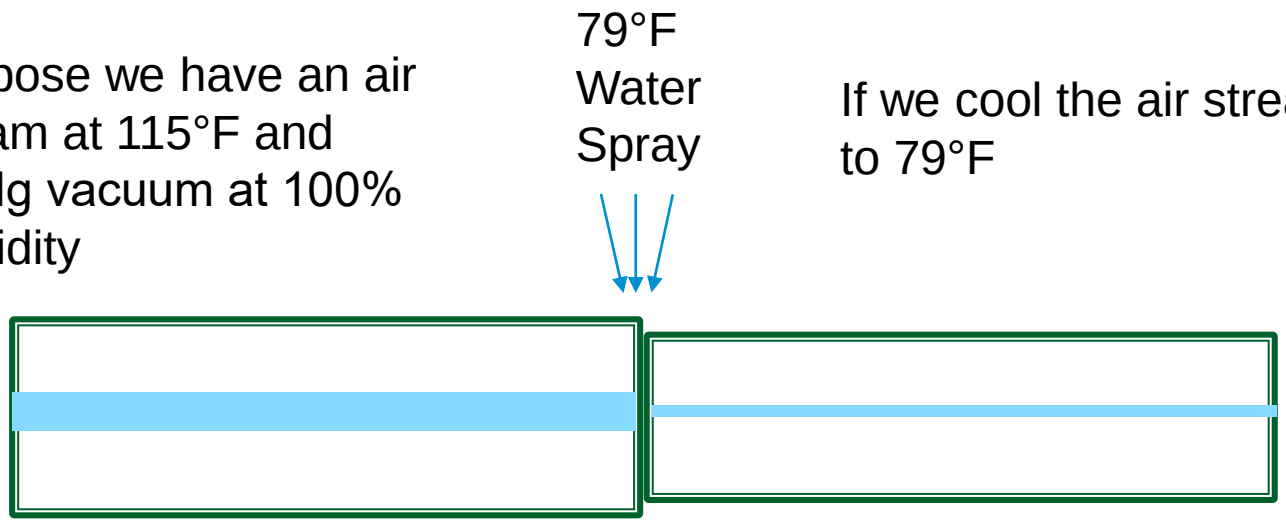




Condensation Effect

Suppose we have an air stream at 115°F and 15”Hg vacuum at 100% humidity

79°F Water Spray



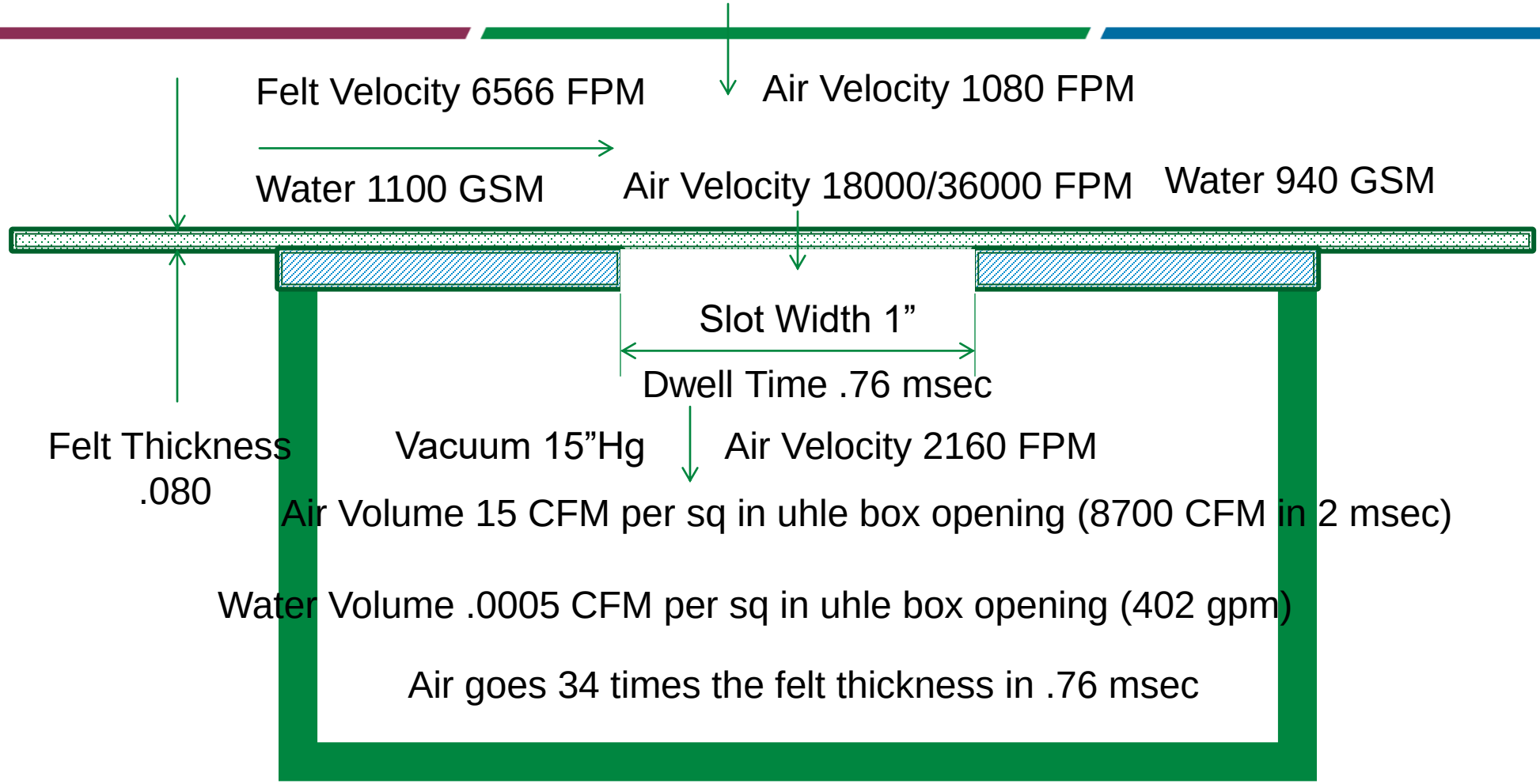
If we cool the air stream to 79°F

It will be 20% water vapor

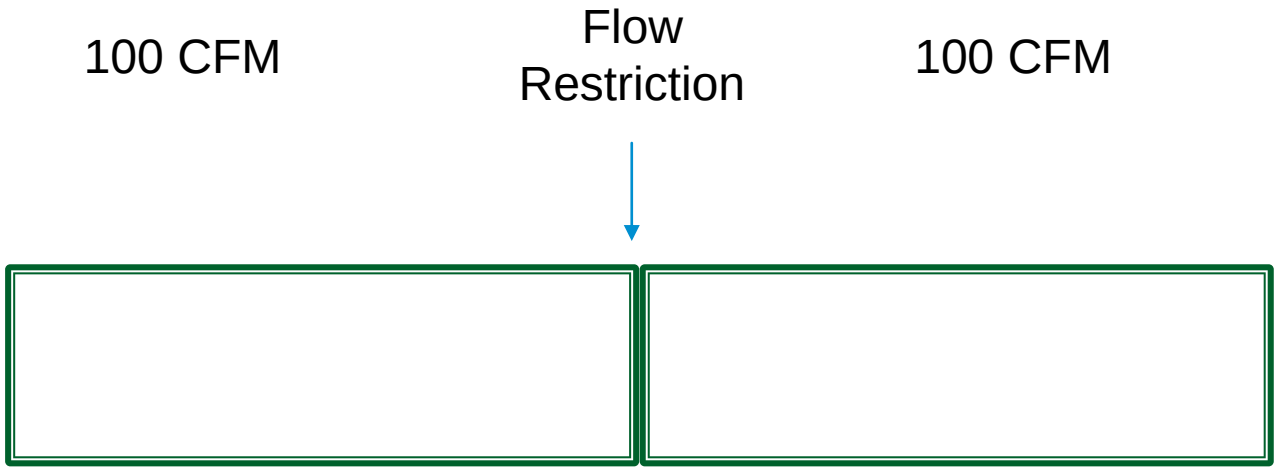
It will be 6% water vapor, with 14% of the original water vapor condensing thus decreasing the volume by 14%

This cooling is typically done with spray nozzles spraying water cooler than the air stream into the vacuum pump inlet. It effectively increases the size of the vacuum pump.
If the water is hotter than the air stream, turn it off!

Evacuation with variable resistance



Measuring Flow



There will be a pressure drop related to the flow and gas properties

If you measure the pressure drop across any restriction in a new installation, you can repeat this measurement as a regular maintenance procedure to measure the relative performance of your pump

Measuring vacuum pump performance

Orifice plate test

Liquid Ring Vacum Pump Field Test

Tested By:	Andrew Smiltneek
Date:	Tuesday, May 28, 2019
Witnessed:	
Certified:	Andrew Smiltneek
Customer :	
Customer Location:	
Pump Number:	3
Pump Manufacturer/Model:	Nash 904P2
Barometric Pressure ("Hg)	29.74
Air Temperature (°F)	91

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andys@growthsolutionsconsultants

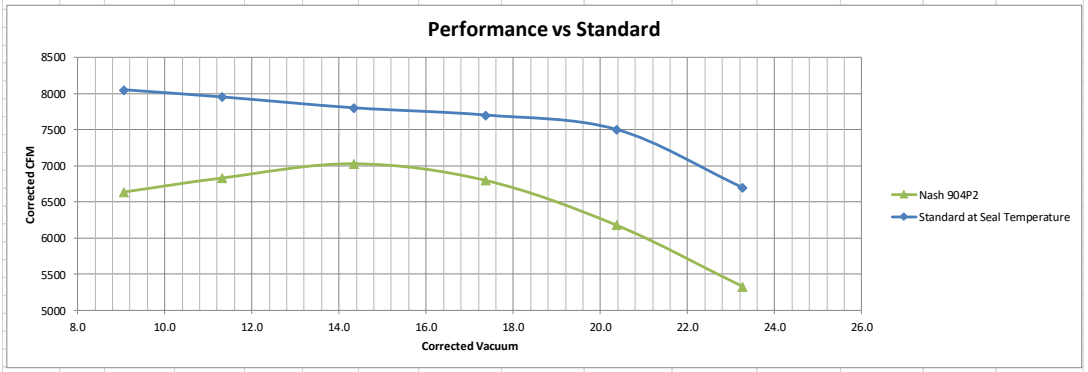
920 470 9432

84.8%

Test Point	RPM	Idle End Vacuum ("Hg)	Drive End Vacuum ("Hg)	Orifice Size	Holes Open	Seal Water Temp	Corrected Idle End Vacuum ("Hg)	Corrected Drive End Vacuum ("Hg)	Corrected Idle End Capacity (CFM)	Corrected Drive End Capacity (CFM)	Total Corrected Capacity (CFM)	Average Corrected Vacuum ("Hg)	New Pump Capacity (CFM)	% of Standard New Capacity
1	400	8.5	9.5	1.250	12	56	8.6	9.6	3143	3496	6639	9.1	8050	82.5%
2	400	11	11.5	1.250	10	56	11.1	11.6	3336	3498	6834	11.3	7950	86.0%
3	400	14	14.5	1.250	8	56	14.1	14.6	3440	3592	7032	14.3	7800	90.2%
4	400	17	17.5	1.250	6	56	17.1	17.6	3330	3473	6803	17.4	7700	88.3%
5	400	20	20.5	1.250	4	56	20.1	20.6	2994	3186	6180	20.4	7500	82.4%
6	400	23	24.5	1.250	2	56	23.0	23.5	2227	3105	5332	23.3	6700	79.6%
7	400	25	26	1.250	1	56	26.0	25.0	1734	#VALUE!	#VALUE!	25.5		#VALUE!

Note: This pump tested at an average of 84.8% of new capacity. It is the southernmost pump in the train.

Average: 84.8%



Flow guidelines

- For relatively dry air, design for 6000 fpm to minimize pressure loss
- For air with entrained water, 3500 feet per minute is recommended
- To drop the water out of the flow stream, 500 fpm is the norm.

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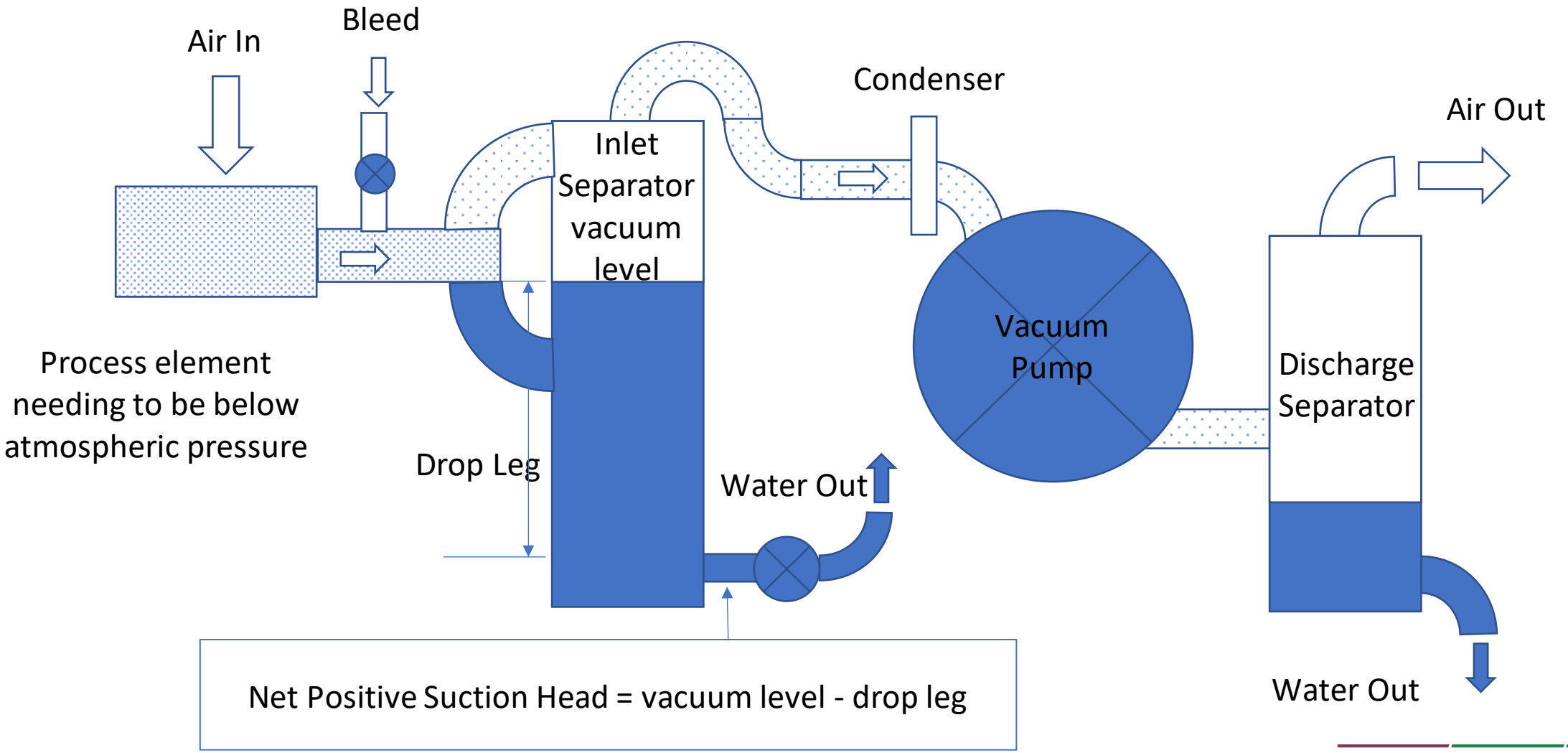
Typical Vacuum System

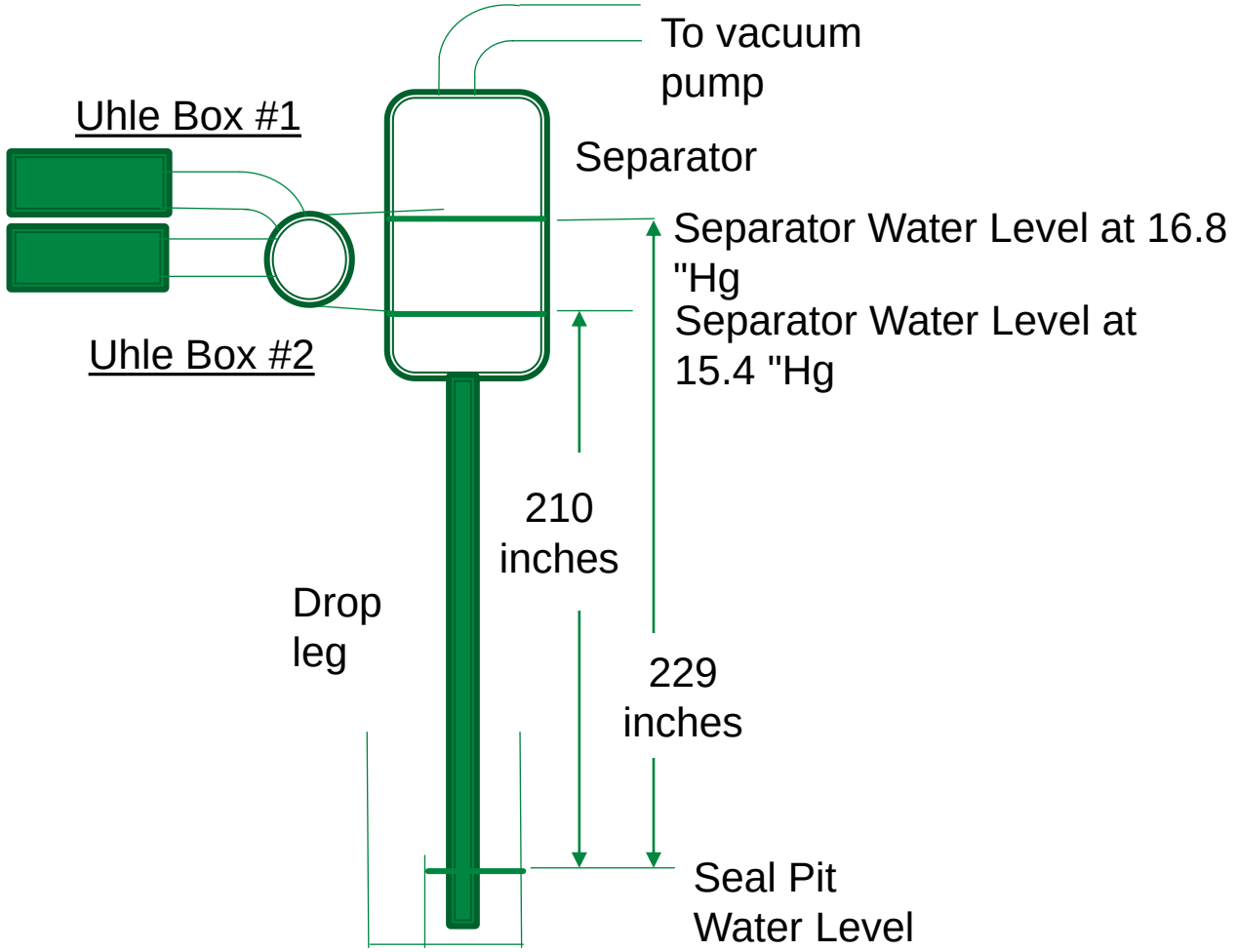


A Quick Example –Vacuum Variation

Pressure Measurement Points

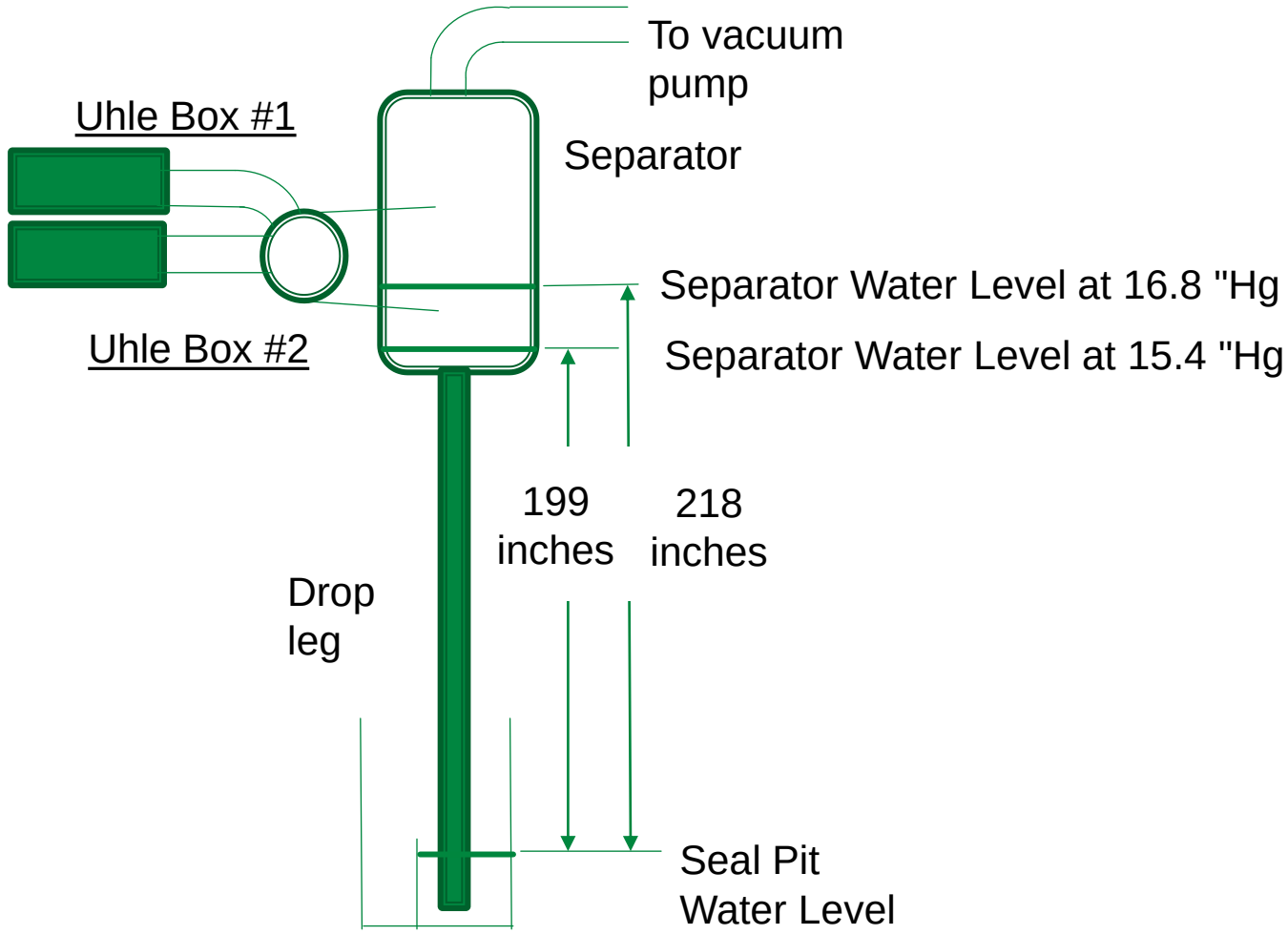
System

- When the vacuum level reached 16.8 “Hg the water coming from the uhle box almost completely blocked the air flow into the inlet separator
- The air velocity increased until the water was entrained and pulled into the vacuum pump
- The slug of water into the vacuum pump dropped the vacuum level and thus the water level in the separator
- Air flow through the uhle box increased, raising the vacuum level, and the cycle repeated every second!



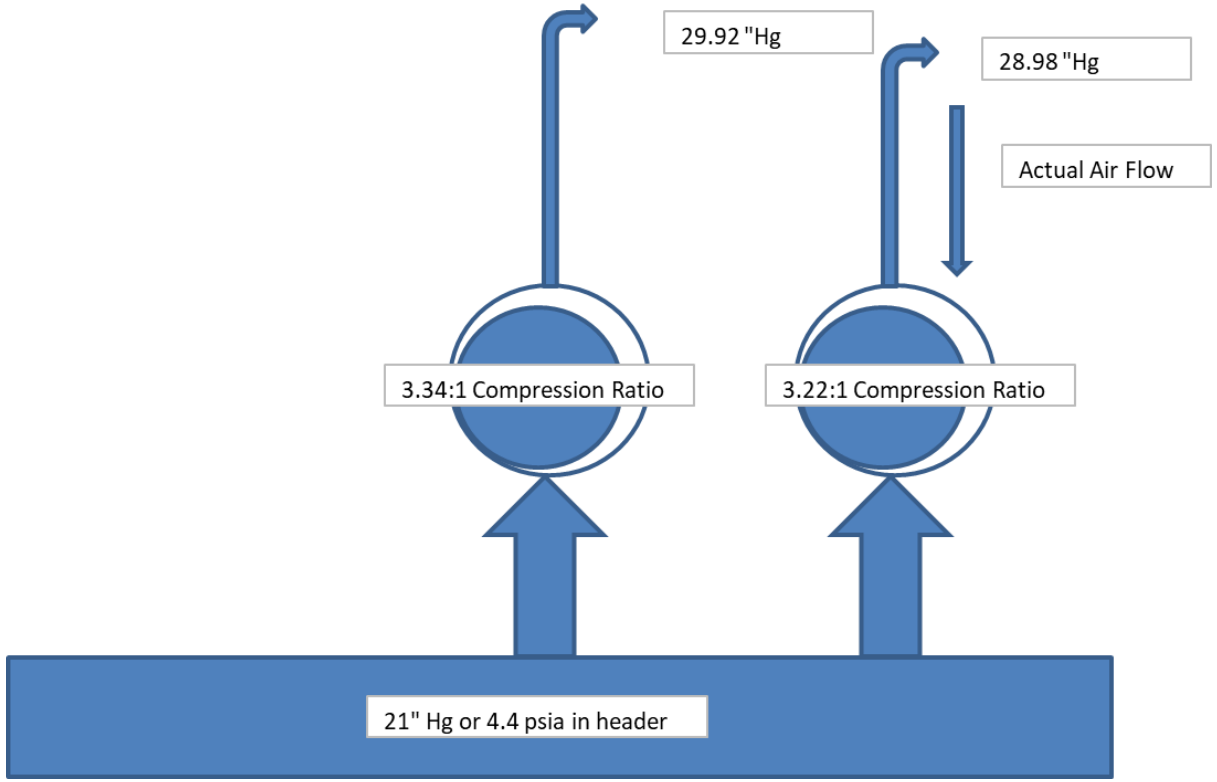
Solution

- Drop the water level in the seal box by 11 inches (fortunately this was easily done)
- The drop in seal box water level dropped the water level in the separator so the pipe could not be covered and the variation disappeared



Vacuum Pumps in Parallel

Worn or mis-applied vacuum pump example
The Living Dead Vacuum Pump
The bad pump uses as much energy but looks like a giant leak to the system



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Thinking too hard about vacuum pumps

Growth Solutions Consultants LLC

A Note About Consultants

Weather Rocks

Grandpa, Look how windy it is!

Weather Rock Operator

Questions and Critique

- And Thanks for your time
- For more information, follow my blog at the growthsolutionsconsultants.com website, much of this information is explained in more depth
- Contact me at:
- andys@growthsolutionsconsultants.com
- 920 470 9432

About the Speaker

Bryan Jensen
Rogers Machinery

- Engineered System Solutions Manager, Rogers Machinery
- 20+ years with Rogers Machinery
- Responsible for Rogers' Engineered System Solutions internationally
- Former NASA materials researcher

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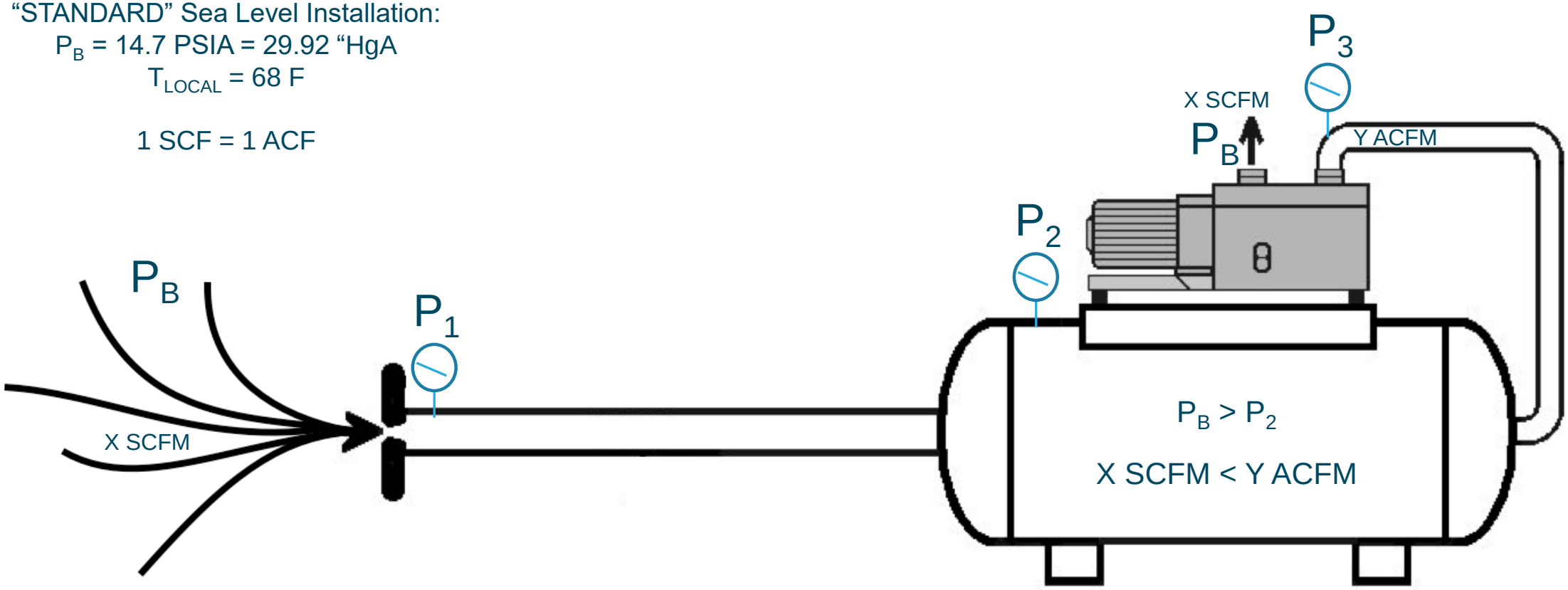
CABP dP vs. P

RVS, Performance & Sizing Process Applications

May 11, 2023

"STANDARD" Sea Level Installation:
P_B = 14.7 PSIA = 29.92 "HgA
T_{LOCAL} = 68 F

1 SCF = 1 ACF



$$P_B > P_1 > P_2 > P_3 < P_B$$

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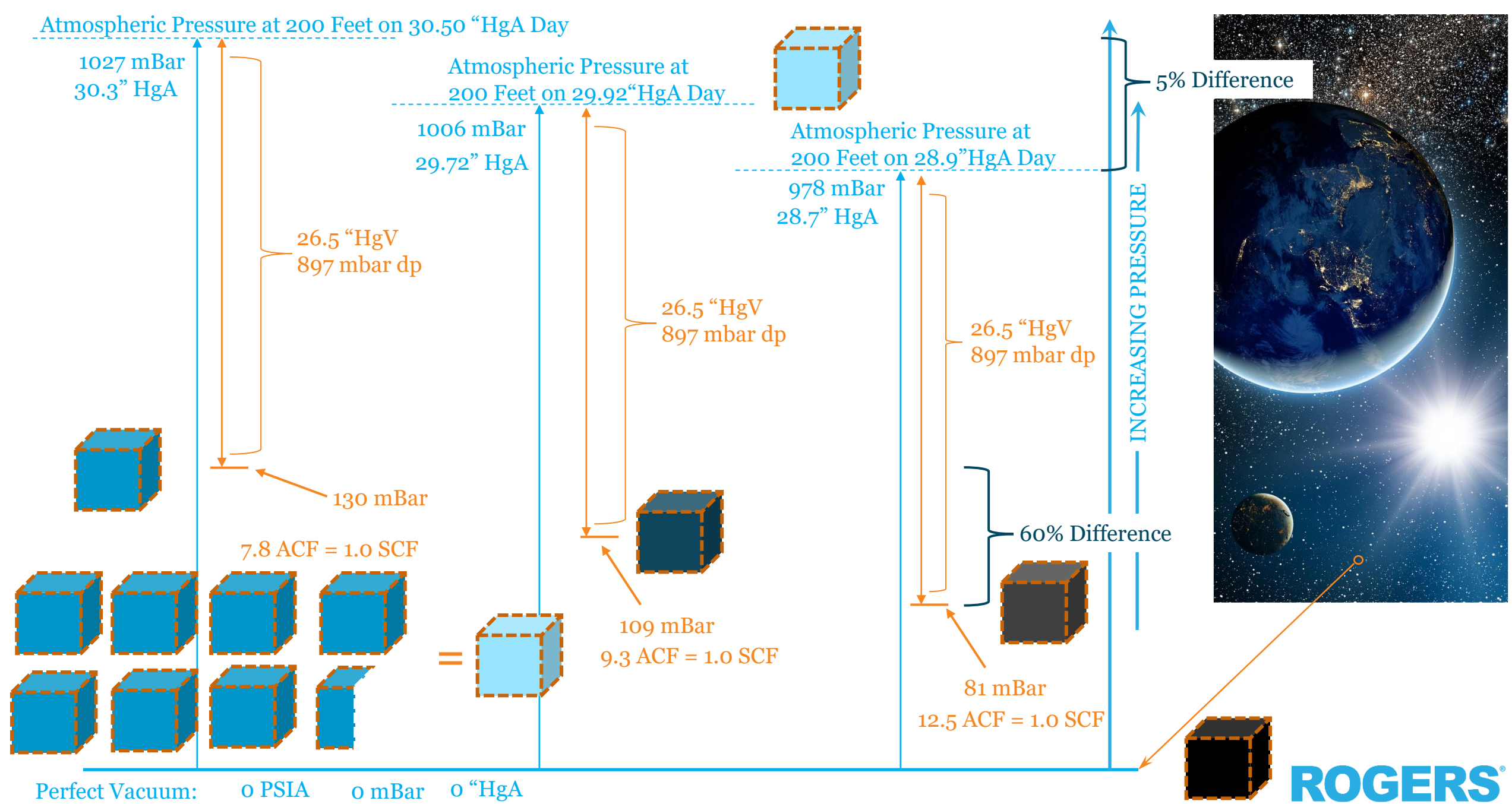
Atmospheric Pressure at 200 Feet on 30.50 "HgA Day
1027 mBar
30.3" HgA
26.5 "HgV
897 mbar dp
130 mBar
7.8 ACF = 1.0 SCF
Atmospheric Pressure at
200 Feet on 29.92"HgA Day
1006 mBar
29.72" HgA
26.5 "HgV
897 mbar dp
109 mBar
9.3 ACF = 1.0 SCF
Atmospheric Pressure at
200 Feet on 28.9"HgA Day
978 mBar
28.7" HgA
26.5 "HgV
897 mbar dp
81 mBar
12.5 ACF = 1.0 SCF
5% Difference
60% Difference
INCREASING PRESSURE
Perfect Vacuum:
0 PSIA
0 mBar
0 "HgA

P_B = 24.48 “HgA

dP = 22.8 “HgV

P_a = 1.68 ”HgA

Elevation = 5500’ Above SL

to Exhaust System

22.5 “HgV

PROCESS AREAS

Each of 5 RVS.LR

?? ACFM @ 22.8 “HgV

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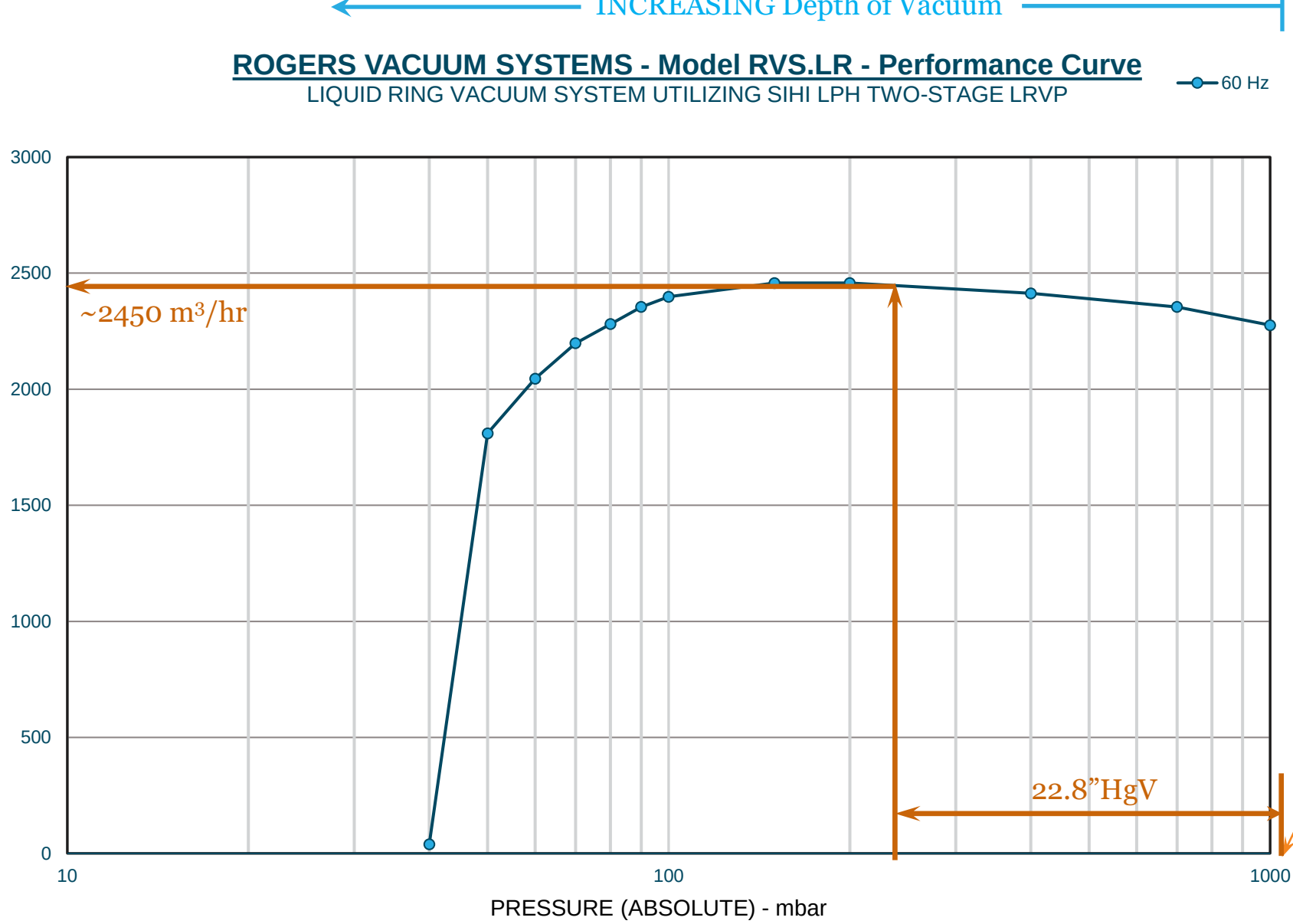
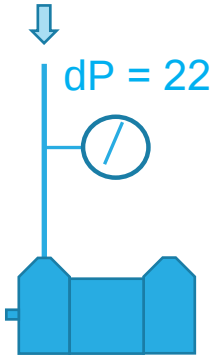
$P_{atmospheric}$ = 24.7 “HgA

INCREASING Depth of Vacuum

ROGERS VACUUM SYSTEMS - Model RVS.LR - Performance Curve

LIQUID RING VACUUM SYSTEM UTILIZING SIHI LPH TWO-STAGE LRVP





29.92(“HgA) - 22.8(“Hg) = 7.12 (“HgA)

$$\frac{7.12\ (\text{“HgA})}{29.92\ (\text{“HgA})} \times 1013.25\ (\text{mbar})$$

241 mbar

Atmospheric Pressure at Sea Level

INCREASING PRESSURE

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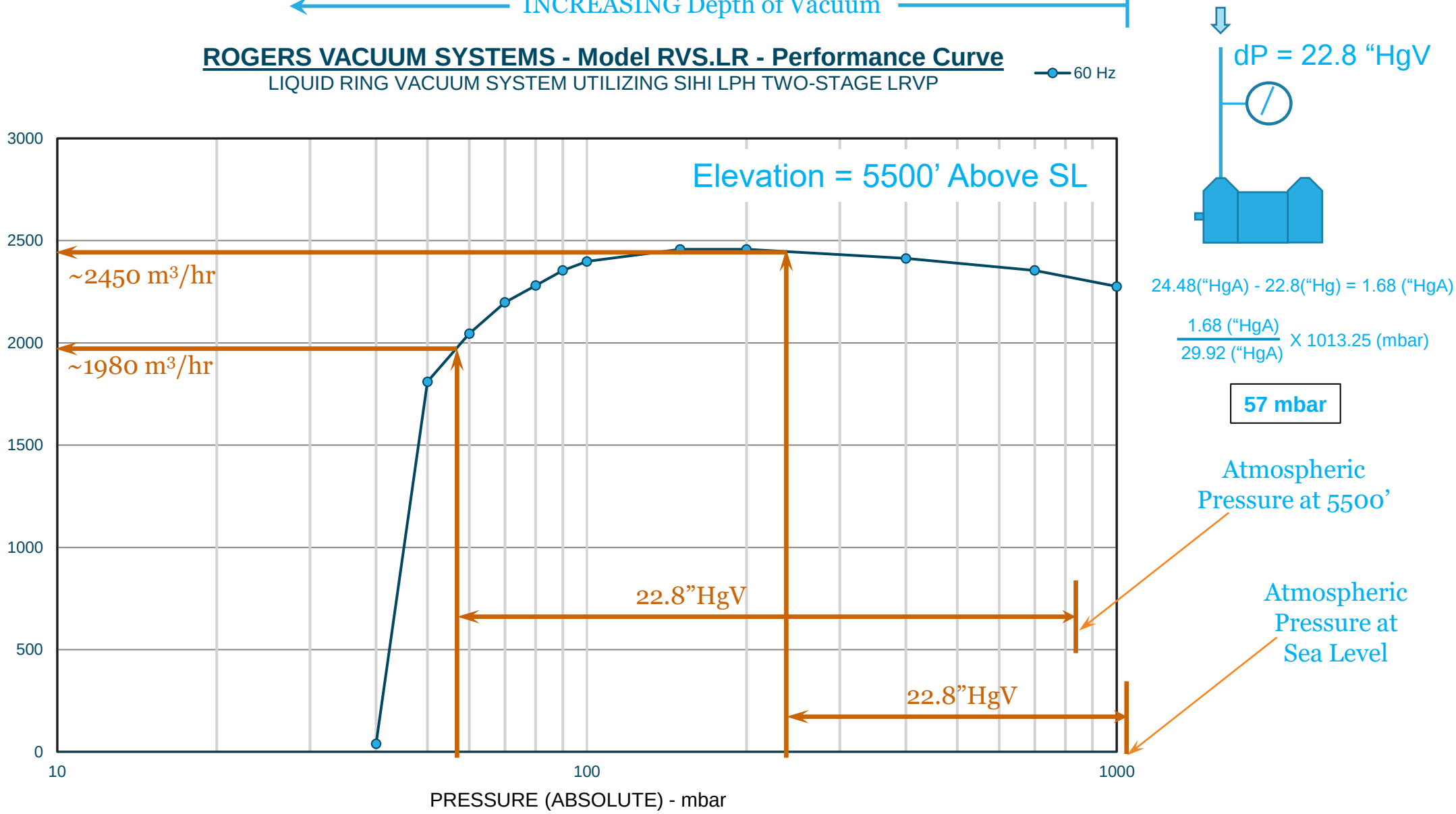
INCREASING Depth of Vacuum

ROGERS VACUUM SYSTEMS - Model RVS.LR - Performance Curve

LIQUID RING VACUUM SYSTEM UTILIZING SIHI LPH TWO-STAGE LRVP



24.48(“HgA) - 22.8(“Hg) = 1.68 (“HgA)

$$\frac{1.68\ (\text{“HgA})}{29.92\ (\text{“HgA})} \times 1013.25\ (\text{mbar})$$

57 mbar

Atmospheric Pressure at 5500’

Atmospheric Pressure at Sea Level

INCREASING PRESSURE

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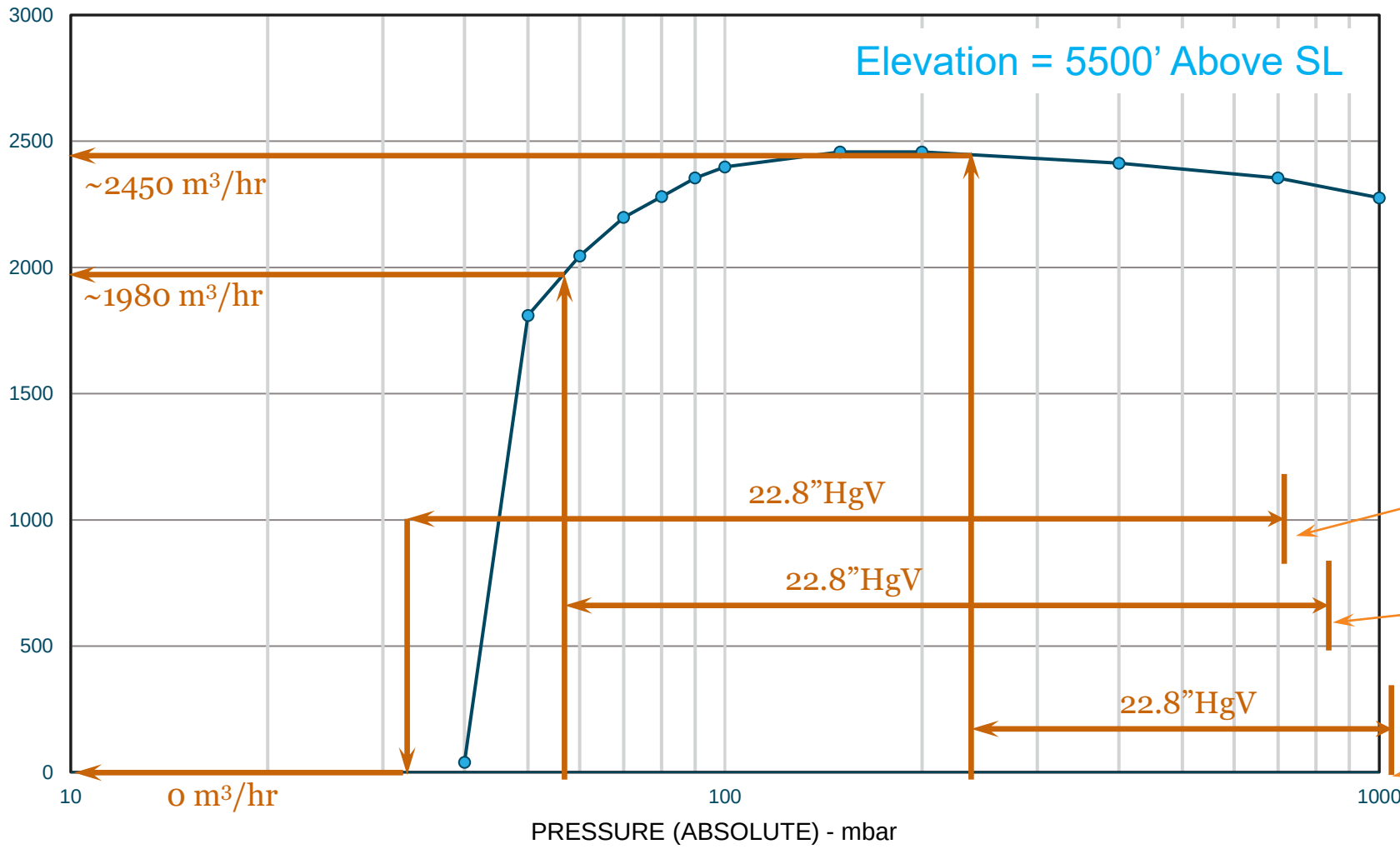
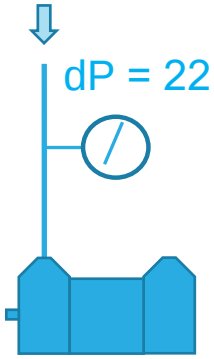
INCREASING Depth of Vacuum

ROGERS VACUUM SYSTEMS - Model RVS.LR - Performance Curve

LIQUID RING VACUUM SYSTEM UTILIZING SIHI LPH TWO-STAGE LRVP





23.78(“HgA) - 22.8(“Hg) = 0.98 (“HgA)

$$\frac{0.98\ (\text{“HgA})}{29.92\ (\text{“HgA})} \times 1013.25\ (\text{mbar})$$

33 mbar

Atmospheric Pressure at 5500’ on Low Pressure Day

Atmospheric Pressure at 5500’

Atmospheric Pressure at Sea Level

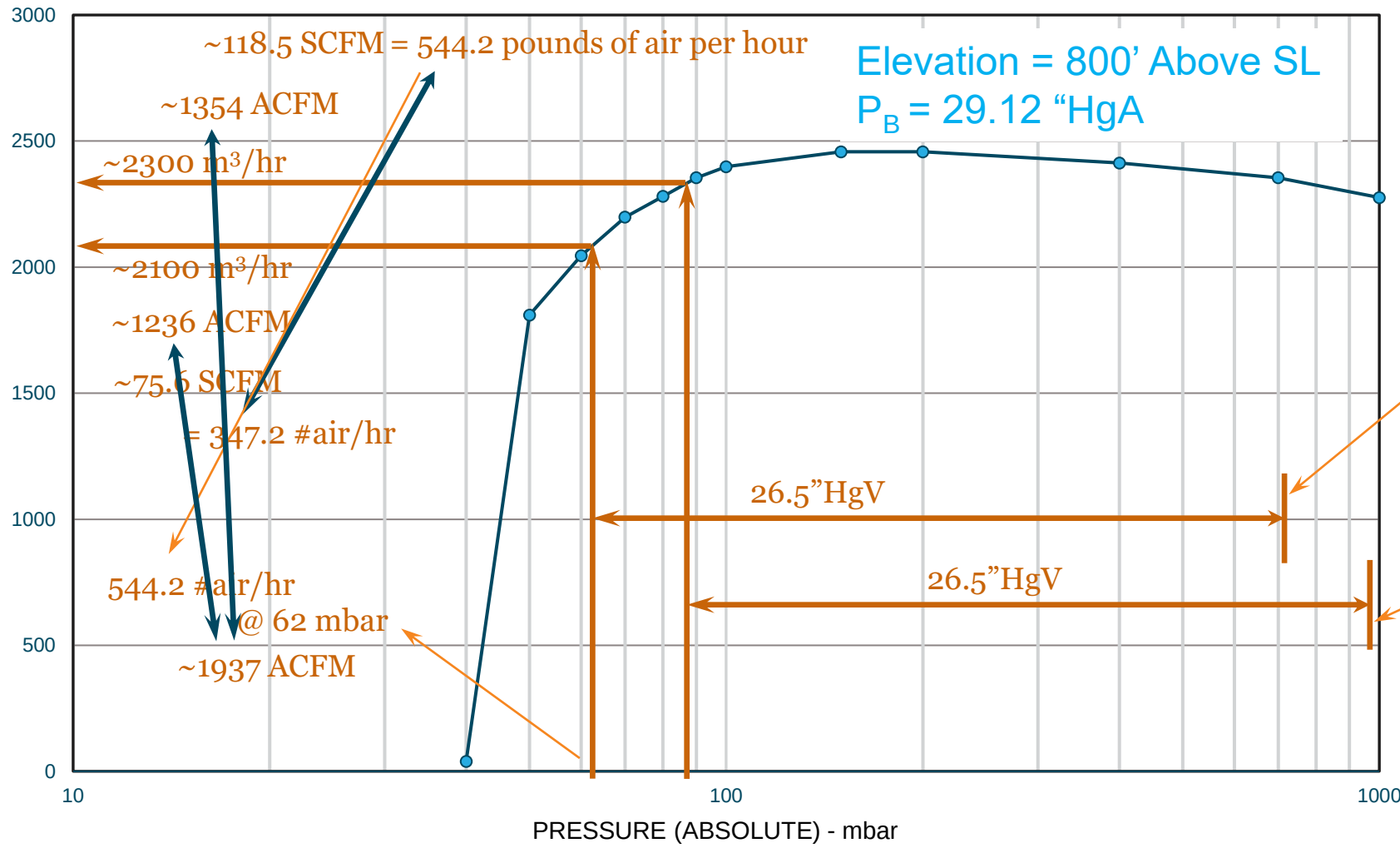
INCREASING PRESSURE

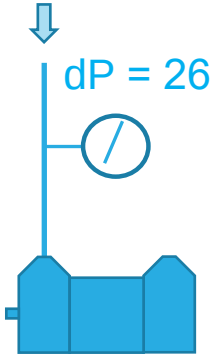
ROGERS®

INCREASING Depth of Vacuum

ROGERS VACUUM SYSTEMS - Model RVS.LR - Performance Curve

LIQUID RING VACUUM SYSTEM UTILIZING SIHI LPH TWO-STAGE LRVP





Atmospheric Pressure at 800' on Low Pressure Day

Atmospheric Pressure at 800'

INCREASING PRESSURE

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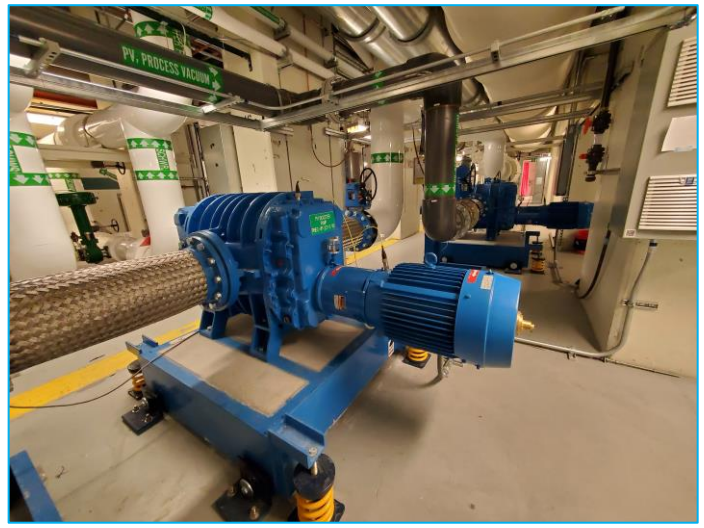
P_B = 24.48 “HgA

dP = ?? “HgV

P_a = ?? ”HgA

Elevation = 5500’ Above SL

22.5 “HgV



22.8 “HgV

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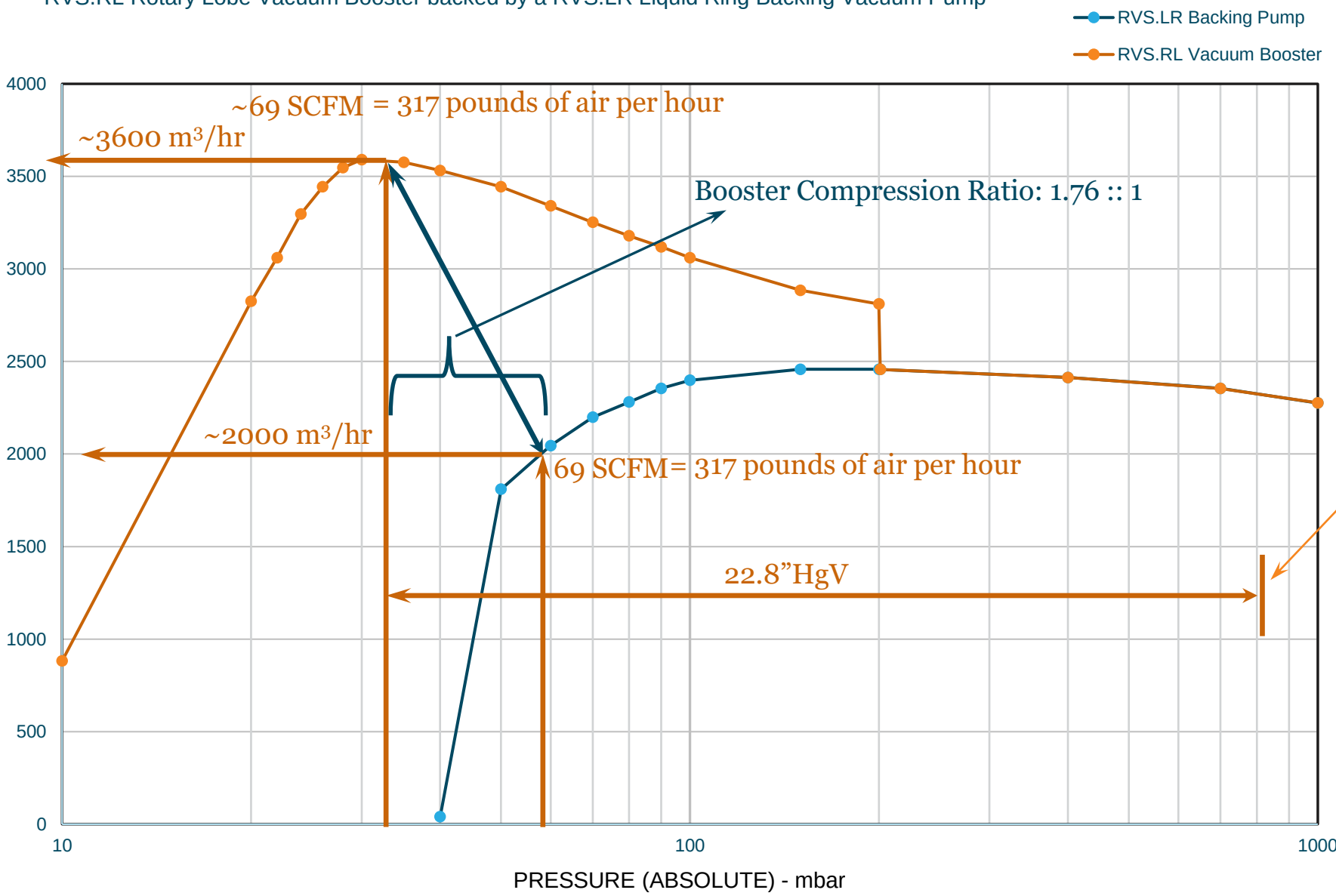
$P_{atmospheric}$ = 24.7 “HgA

ROGERS VACUUM SYSTEMS - Hybrid Vacuum System Performance Curve

RVS.RL Rotary Lobe Vacuum Booster backed by a RVS.LR Liquid Ring Backing Vacuum Pump



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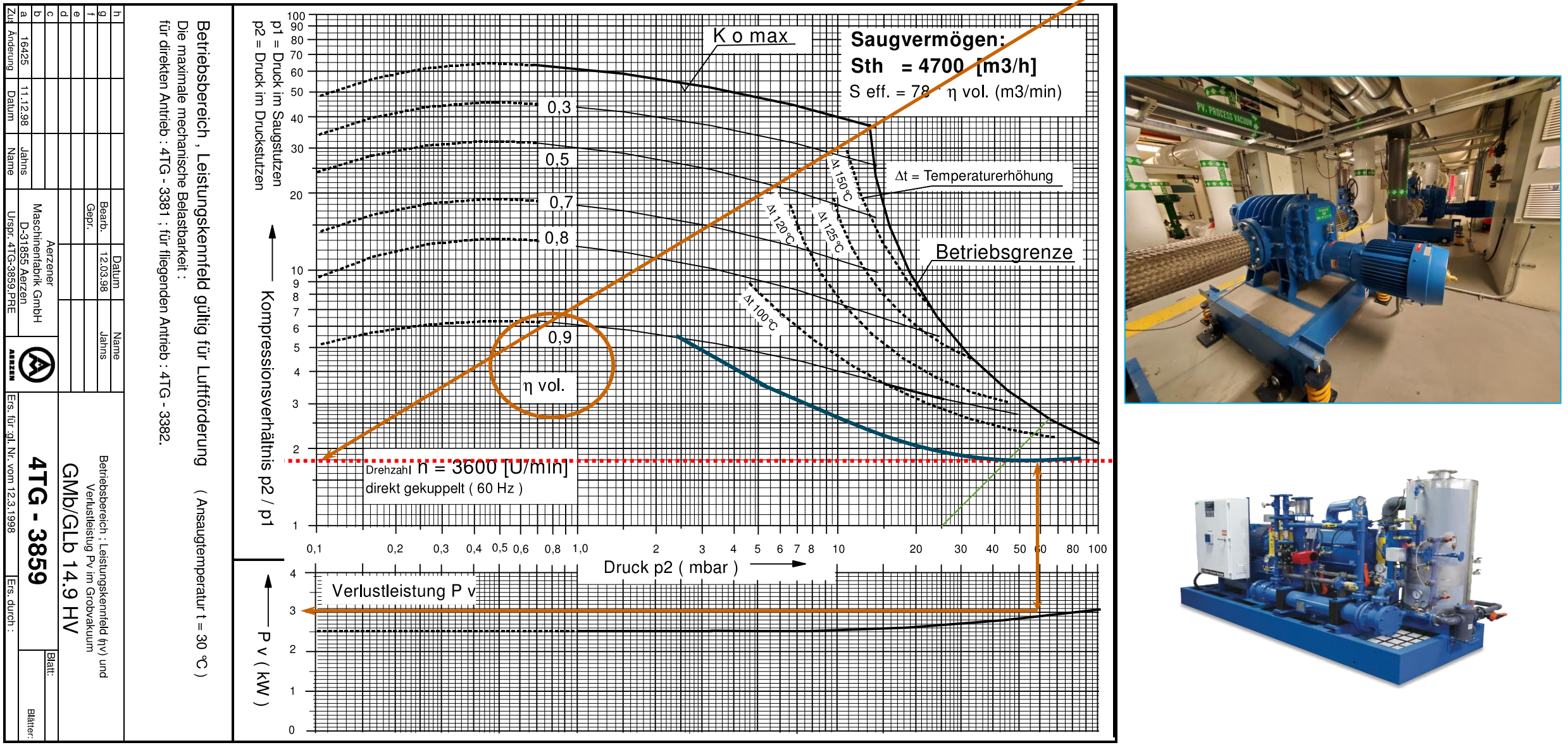
Booster Compression Ratio: 1.76 :: 1



Betriebsbereich , Leistungskennfeld gültig für Luftförderung (Ansaugtemperatur t = 30 °C)

Die maximale mechanische Belastbarkeit :

für direkten Antrieb : 4TG - 3381 ; für fliegenden Antrieb : 4TG - 3382.

Zust	Änderung	Datum	Name
a	16425	11.12.98	Jahns
b			
c			
d			
e			
f			
g			
h			

Aerzener Maschinenfabrik GmbH D-31855 Aerzen

Urspr. 4TG-3859.PRE

	Datum	Name
Bearb.	12.03.98	Jahns
Gepr.		

Betriebsbereich ; Leistungskennfeld (ηv) und Verlustleistug Pv im Grobvakuum

GMb/GLb 14.9 HV

4TG - 3859

Ers. für :gl. Nr. vom 12.3.1998

Ers. durch :

Blatt:

Blätter:

ROGERS®

$P_{atmospheric}$ = 24.7 "HgA

$P_{atmospheric}$ = 28.95 “HgA

P_{gauge} = 28.2 “HgV
$P_{absolute}$ = 0.75 “HgA
$P_{absolute}$ = 25.4 mBar
$P_{absolute}$ = 19.1 Torr
T_{design}= 75 F

$\dot{m}$=50 SCFM

A B C

50 SCFM

to ROGERS RVS.LR PVAC System

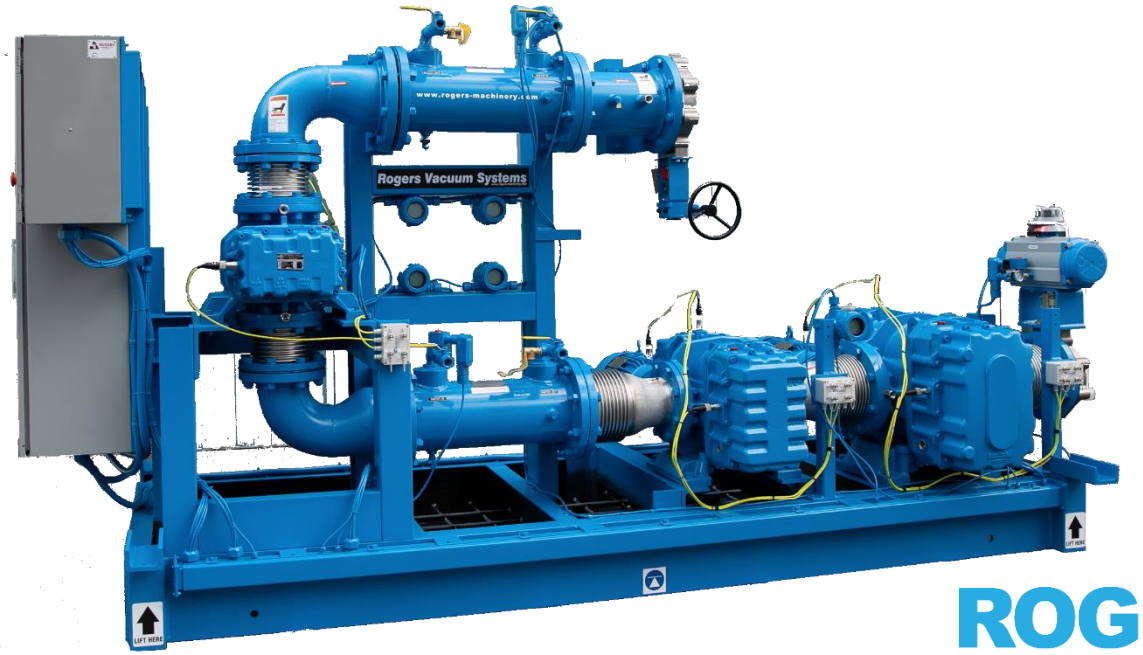
P_{gauge} = 25.1 “HgV
$P_{absolute}$ = 3.85 “HgA
T_{design}= 60 F

A B C

50 SCFM

$\dot{m}$=50 SCFM

NEW PROCESS AREA REQUIRING DEEPER VACUUM



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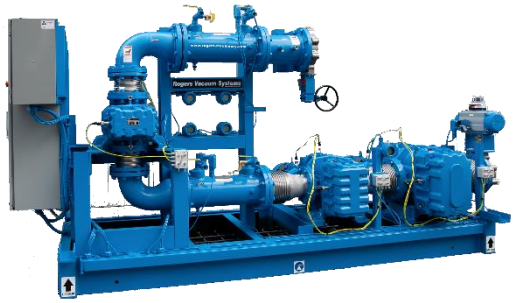
Freq

$P_{atmospheric}$ = 28.95 “HgA

Engineered System Solutions



Thank you!

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Best Practices EXPO Contest

Play for a chance to win a **FREE Full Conference Pass** to the Best Practices 2023 EXPO & Conference!! This is a $675 value! This contest is open to factory personnel, compressed air distributors, utility incentive programs and engineering firms. Exhibiting and sponsor companies are not qualified. Winners will be randomly selected from those who submitted a correct answer and notified tomorrow via email.

Please submit your answer in the upcoming poll

If you remove half of the air from an enclosed chamber initially at 30”HgA pressure, what is the final pressure and vacuum level?

A	•0
B	•3
C	•15

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*By entering you are giving permission to announce your name if you are a winner

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Vacuum System Fundamentals Depth of Vacuum vs. Absolute Pressure

Q&A

Please submit any questions through the Question Window on your GoToWebinar interface, directing them to Blower & Vacuum Best Practices Magazine. Our panelists will do their best to address your questions and will follow up with you on anything that goes unanswered during this session.

Thank you for attending!

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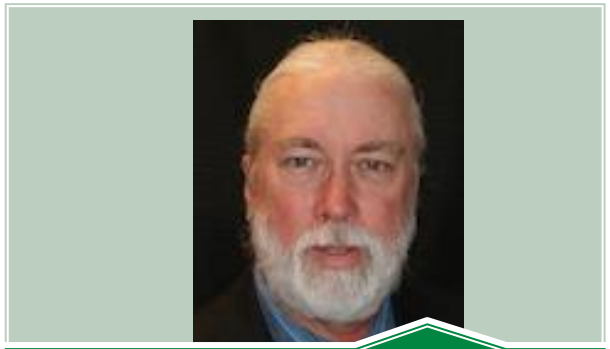
Thank you for attending!

The recording and slides of this webinar will be made available to attendees via email later today.

PDH Certificates will be e-mailed to Attendees by within 2 days

May 2023 Webinar

CTI STD-201RS Thermal Certification for Cooling System Heat Rejection Equipment Part 1: Performance Ratings



Mike Womack
Cooling Technology Institute
Keynote Speaker

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Thursday, May 18, 2023– 2:00 PM EST
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