Determining How to Set Regulators Correctly

USC Viterbi School of Engineering

SCFM to Mass Flow Rate

SCFM (Standard Cubic Feet per Minute)

$$CFM = SCFM \times \frac{P_{atm}}{P} \times \frac{T}{T_{atm}}$$

$$\dot{m} = (CFM)\rho$$

$$\rho = \frac{P}{TR} \text{ (gas)}$$

where: CFM (cubic feet per minute)

Fluid Correction Factor

$$F_G = \sqrt{\frac{SG_{ref}}{SG_{act}}}$$

where: $SG = specific\ gravity$

SG_{act} is the specific gravity of your system fluid.

$SG^{oxygen} = 1.1044$

$SG^{Nitrogen(pure)} = 0.9669$

$SG^{air} = 1.0$

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Single Engine Oxygen Mass Flow Rate to SCFM

$$SCFM = \dot{m}\frac{P}{P_{atm}}\frac{T_{atm}}{T}\frac{RT}{P}$$

$$SCFM = \dot{m}\frac{T_{atm}\,R}{P_{atm}}$$

Notice: Cylinder Pressures & Temperatures Cancel Out

Note: Don't forget about units!

(SCFM is in English units)

Note: For a better estimate take into account atmospheric temperature for the time of year

(desert has hot summers and cold winters)

For T_{atm} = 40 F (277 K) → 1190 $SCFM_{Air}$

T_{atm} = 100 F (311 K) → 1336 $SCFM_{Air}$

$$\dot{m}_O = 1.65\ {}^{lbm}/_{s}\,(0.75\ {}^{kg}/_{s})$$

$$(\tfrac{m^3}{s})_{O2} = (0.75)\tfrac{kg}{s}(298)\text{K}(259.8)\tfrac{J}{Kg-K}\left(\tfrac{1}{1.01E5}\right)\tfrac{1}{Pa} = 0.57\left(\tfrac{m^3}{s}\right)$$

$$SCFM_{O2} = (0.57)\frac{m^3}{s}\left(\frac{1^3}{0.3048^3}\right)\frac{ft^3}{m^3}\left(\frac{60}{1}\right)\frac{s}{min}$$

$$SCFM_{O2} = 1214$$

$$SCFM_{Air} = SCFM_{O2}\sqrt{\frac{SG_{02}}{SG_{air}}}$$

$$SCFM_{Air} = 1214\sqrt{\frac{1.1044}{1}}$$

$$SCFM_{Air} = 1276$$

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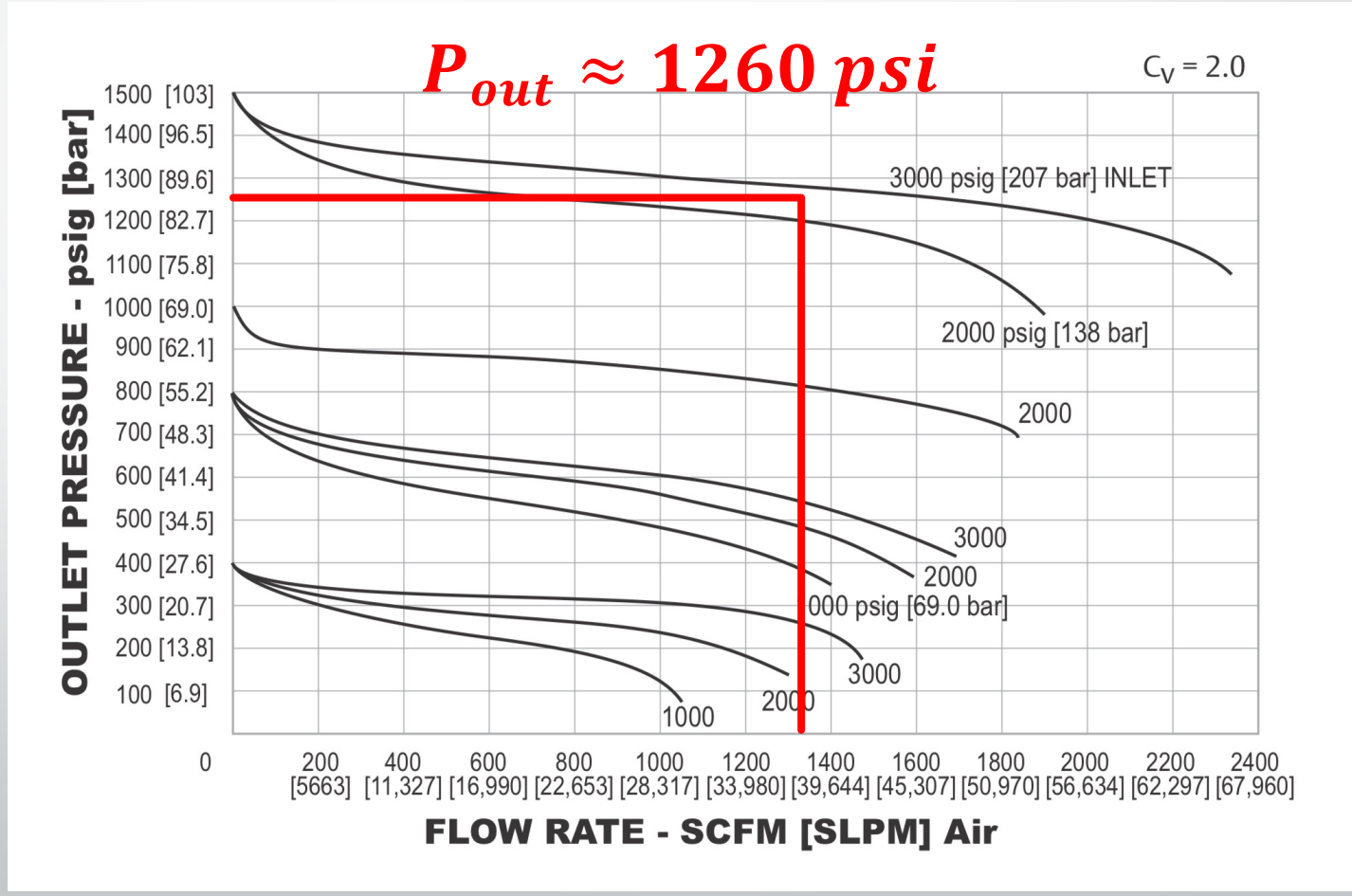
Single Engine Oxygen Regulator Set Pressure

For a cylinder pressure of 2600 psi and a desired flow rate of 1276 $SCFM_{air}$, setting the regulator to 1500 psi will result in an outlet pressure of about 1260 psi



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Determining Nitrogen Mass Flow Rate

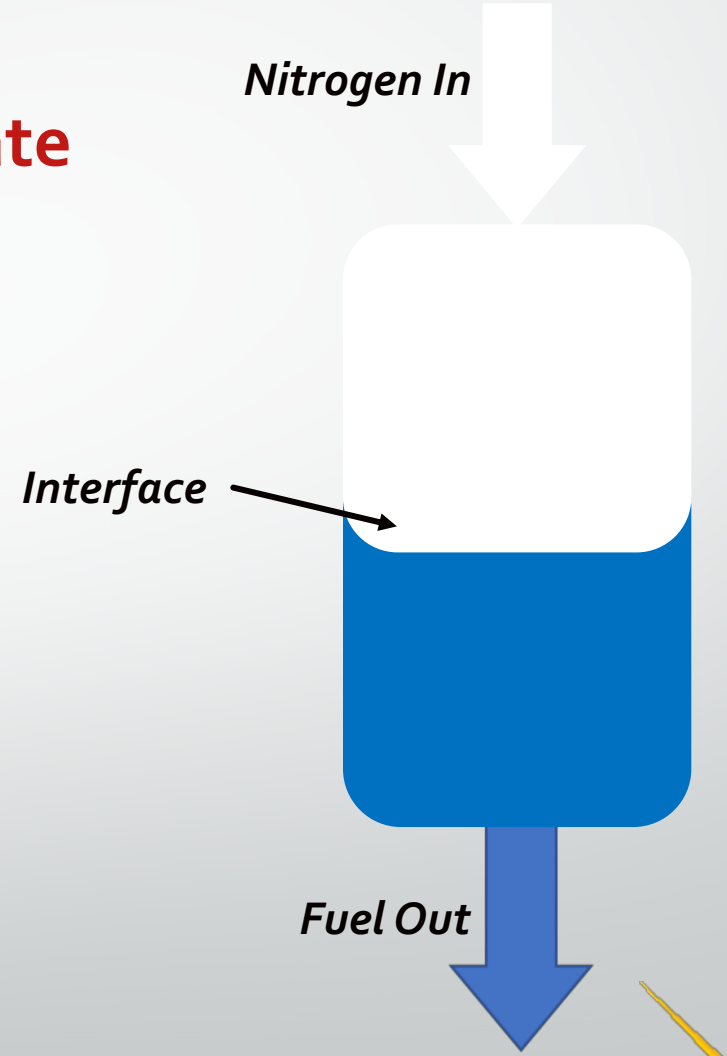
$$\boldsymbol{Volmetric\ Flow_{N,I} = Volumetric\ Flow_{F,I}}$$

$$Volmetric\ Flow = \dot{m}/\rho$$

$$\dot{m}_N/\rho_{N,I} = \dot{m}_F/\rho_{F,I}$$

$$\rho_{F=}810\ kg/m^3 \qquad P_{N,I} = \rho_{N,I} R_{N,I} T_{N,I}$$

$$\boldsymbol{\dot{m}_N = \frac{\dot{m}_F P_{N,I}}{\rho_{F,I} R_{N,I} T_{N,I}}}$$



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Single Engine Nitrogen Mass Flow Rate

$$\boldsymbol{Volmetric\ Flow_{N,I} = Volumetric\ Flow_{F,I}}$$

$$Volmetric\ Flow = \dot{m}/\rho$$

$$\dot{m}_N/\rho_{N,I} = \dot{m}_F/\rho_{F,I}$$

$\rho_{F=}810\ kg/m^3$ $\qquad P_{N,I} = \rho_{N,I} R_{N,I} T_{N,I}$

$$\boldsymbol{\dot{m}_N = \frac{\dot{m}_F P_{N,I}}{\rho_{F,I} R_{N,I} T_{N,I}}}$$

NOTE: Temperature at nitrogen interface $\boldsymbol{T_{N,I}}$ will change the require $\boldsymbol{\dot{m}_N}$ and needs to be taken into account . Also $\boldsymbol{\rho_{F,I}}$ may vary slightly

For $T_{N,I}$ = 40 F (277 K) $\rightarrow$ $\dot{m}_N$ = 0.06 $\frac{kg}{s}$

For $T_{N,I}$ = 100 F (311 K) $\rightarrow$ $\dot{m}_N$ = 0.053 $\frac{kg}{s}$

$$\boldsymbol{\dot{m}_F = 0.88\ lbm/s\ (0.4\ \frac{kg}{s})}$$

$\rho_{F=}810\ kg/m^3$

$P_{N,I} = 1450\ psi$ (10 Mpa)

$T_{N,I} = 75°F\ (297\ K)$

$R_{N,I}$ = $(296.8\ \frac{J}{Kg-K})$

$$\dot{m}_N = \frac{0.4(10E6)}{(810)(296.8)(297)}$$

$$\boldsymbol{\dot{m}_N = 0.123\ lbm/s\ (0.056\ kg/s)}$$

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Single Engine Nitrogen Mass Flow Rate to SCFM

$$SCFM = \dot{m}\frac{P}{P_{atm}}\frac{T_{atm}}{T}\frac{RT}{P}$$

$$SCFM = \dot{m}\frac{T_{atm}\,R}{P_{atm}}$$

where $T_{atm} = 298\ K \quad P_{atm} = 1.01\ \text{E5 Pa}$

Note: Don't forget about units!

(SCFM is in English units)

$$\dot{m}_N = \mathbf{0.123}\ {}^{lbm}/_{s}\ (\mathbf{0.056}\ {}^{kg}/_{s})$$

$$0.049\left(\frac{m^3}{s}\right) = (0.056)\frac{kg}{s}(298)\text{K}(296.8)\frac{J}{Kg-K}\left(\frac{1}{1.01E5}\right)\frac{1}{Pa}$$

$$SCFM_{N2} = (0.049)\frac{m^3}{s}\left(\frac{1^3}{0.3048^3}\right)\frac{ft^3}{m^3}\left(\frac{60}{1}\right)\frac{s}{min}$$

$$\boldsymbol{SCFM_{N2} = 104}$$

Note: Variations in T for the Nitrogen DOES effect the overall SCFM because it changes the required $\dot{m}_N$.

(desert has hot summers and cold winters)

For T_{atm} = 40 F (277 K) $\rightarrow$ $\dot{m}_N$= 0.06 $\frac{kg}{s}$ $\rightarrow$ 111 $SCFM_{N2}$

T_{atm} = 100 F (311 K) $\rightarrow$ $\dot{m}_N$= 0.053 $\frac{kg}{s}$ $\rightarrow$ 98 $SCFM_{N2}$

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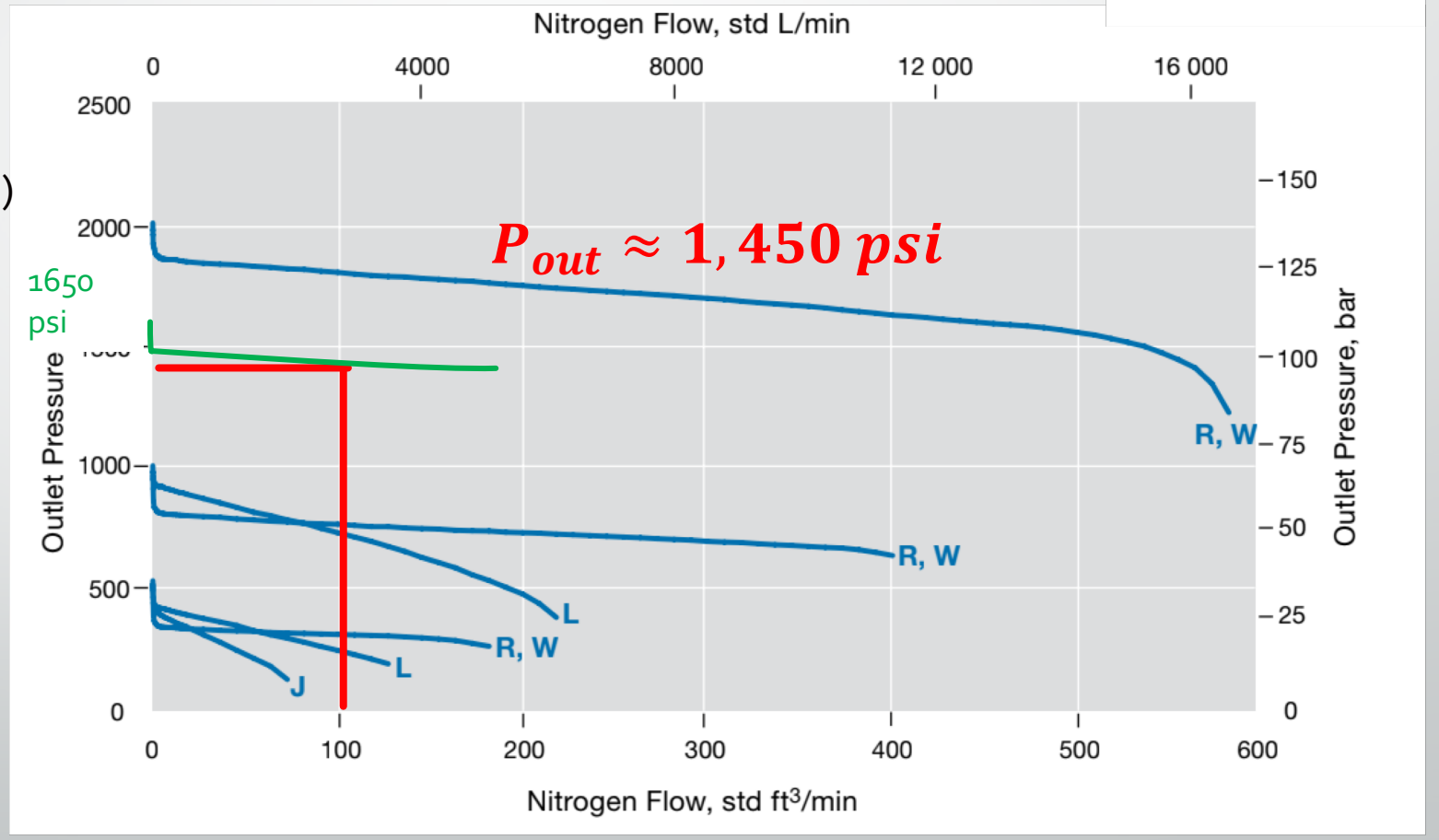
Single Engine Nitrogen Regulator Set Pressure

Desired Regulator Outlet Pressure – 1450 psi (40% pressure drop over injector and 50 psi estimated line loss)

Setting the regulator to 2,000 psi would result in a pressure drop of about 200 psi at 104 SCFM

Therefore, if we want an outlet pressure of 1,450 psi we should set the regulator to 1,650psi.



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Jessie & James Operating Condition Summary

Single Engine Operating Conditions	
$\dot{M}_{TOT} = 1.15\ kg$	$OF = 1.875$
Fuel	OX
Injector $\%P_d = 40\ \%$	*Injector* $\%P_d = 20\ \%$
Cylinder Pressure = $2600\ psi$	*Cylinder Pressure* = $2600\ psi$
$P_{regulate} = 1650\ psi$	$P_{regulate} = 1500\ psi$
$P_{supply} = 1450\ psi$	$P_{supply} = 1260\ psi$
$P_{injector} = 1400\ psi$	$P_{injector} = 1200\ psi$
$P_{chamber} = 1000\ psi$	$P_{chamber} = 1000\ psi$

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