Key

Exam No. 2 **CBE 150A** **Spring 2014** **Eldridge**

Problem No. 1 (30 pts)

Contaminated nitrogen from a semiconductor fabrication unit enters a blower and is compressed to 25 psia. It then flows through a packed bed where trace hydrocarbon is removed. After leaving the bed, the purified nitrogen is discharge to the atmosphere. If the flow to the bed is 150,800 ft^3/hr at 15 psia and 70 F what is the required diameter of the carbon bed ?

Data: Bed particles: 4 X 8 mesh, sphericity = 0.75, void fraction = 0.4, bed length = 10 ft.
Nitrogen viscosity at 70 F = 0.018 cP.

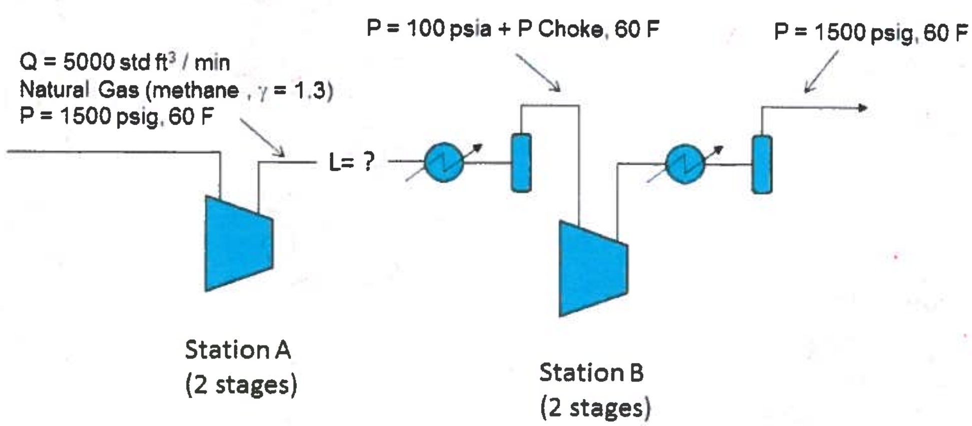
Problem No. 2 (30 pts)

Nitrogen (γ =1.4) is flowing through a nozzle such that the Mach number is 2.4 where the flow area is 25 cm^2. Assuming the flow is isentropic, determine the flow area and velocity (ft/s) at the location where the Mach number is 1.2. Reservoir conditions: P = 500 psia, T = 200 °C

Problem No. 3 (40 pts)

A natural gas (primarily methane, γ = 1.3, μ = 0.01 cP) pipeline is to be designed to transport gas at a rate of 5000 scfm (standard conditions are P = 1atm and 60 F). The steel pipe is to be 6 inch ID and the maximum pressure that the compressor can develop is 1500 psig. The compressor stations are to be located in the pipeline at the point at which the suction pressure for the compressors is 100 psi above that at which choked flow will occur. If the design temperature for the pipeline is 60 F, the compressors are 60 percent efficient, and the compressor stations each operate with two stages and interstage cooling to 60 F, determine:

a) The proper distance (L) between compressor stations in miles.
b) The optimum interstage pressure and the compression ratio for each compression stage.
c) The total horsepower required for each compressor station.



Exam No. 2 Make-up **CBE 150A** **Spring 2014** **Eldridge**

Problem No. 1 (30 pts)

Contaminated nitrogen from a semiconductor fabrication unit enters a blower and is compressed. It then flows through a packed bed where trace hydrocarbons are removed. After leaving the bed, the purified nitrogen is discharge to the atmosphere at 14.7 psia. If the flow to the bed is 280,000 std ft^3/hr (1 atm and 60 °F) what is the required discharge pressure of the blower ? The bed operates at 70 °F.

Data: Bed particles: 4 X 8 mesh, sphericity = 0.75, void fraction = 0.4, bed length = 10 ft.
Nitrogen viscosity at 70 F = 0.018 cP. Bed inside diameter = 4 ft.

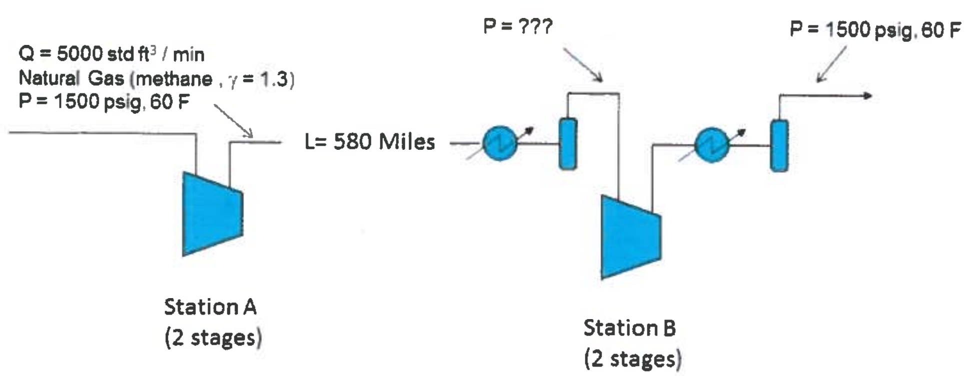
Problem No. 2 (30 pts)

Nitrogen (γ =1.4) is flowing through a nozzle such that the Mach number is 2.4 where the flow area is 25 cm^2. Assuming the flow is isentropic, determine the flow area and velocity (ft/s) at the location where the Mach number is 1.2. Reservoir conditions: P = 500 psia, T = 200 °F

Problem No. 3 (40 pts)

A natural gas (primarily methane, γ = 1.3, μ = 0.01 cP) pipeline is to be designed to transport gas at a rate of 5000 scfm (standard conditions are P = 1atm and 60 F). The steel pipe is to be 6 inch ID and the maximum pressure that the compressor can develop is 1500 psig. Two identical compressor stations are to be located in the pipeline 580 miles apart. If the design temperature for the pipeline is 60 F, the compressors are 60 percent efficient, and the compressor stations each operate with two stages and interstage cooling to 60 F, determine:

a) The arrival pressure at the compressor station.
b) The optimum interstage pressure and the compression ratio for each compression stage.
c) The total horsepower required for each compressor station.



Problem #1

N_2 $P_{Avg} = \frac{25+15}{2} = 20\,psiA$

$\dot{Q}\ \frac{ft^3}{min}$ at $20\,psiA$

$= \left(\frac{15}{20}\right)(150,800) = 113,100\ \frac{ft^3}{hr}$

$\left(31.4\ \frac{ft^3}{s}\right)$

$\mu = 0.018\,cP$

$\rho = \frac{20\,psiA\left(28\frac{lb}{lbmol}\right)}{10.73\ \frac{ft^3\,psiA}{lbmol\,R}(530R)} = 0.098\ \frac{lb}{ft^3}$

4X8 Mesh $d_p^{Avg} = 3.53mm = 1.16\times10^{-2}\,ft$

$\frac{\Delta P}{L} = \frac{10\,lbf}{in^2(10ft)}\frac{144in^2}{ft^2} = \frac{144\,lbf}{ft^2\,ft}$

Term 1

$$\frac{150\,V_0\left[0.018cP\left(\frac{6.719\times10^{-4}\frac{lbm}{ft\,s}}{cP}\right)\right]\left(\frac{(1-0.40)^2}{(0.40)^3}\right)}{(0.75)^2(1.16\times10^{-2}ft)^2}$$

$= 4.186\ \frac{lbf\,s}{ft^4}\ V_0$

Term 2

$$\frac{1.75\left(0.098\frac{lb}{ft^3}\right)(V_0)^2(1-0.40)}{0.75(1.16\times10^{-2}ft)(0.40)^3}$$

$= 184.8\ \frac{lbm}{ft^4}\left(\frac{lbf\,s^2}{32.2\,lbm\,ft}\right)\ V_0^2$

$= 5.739\ V_0^2$

$$5.735\, V_o^2 + 4.186\, V_o - 144 = \phi$$

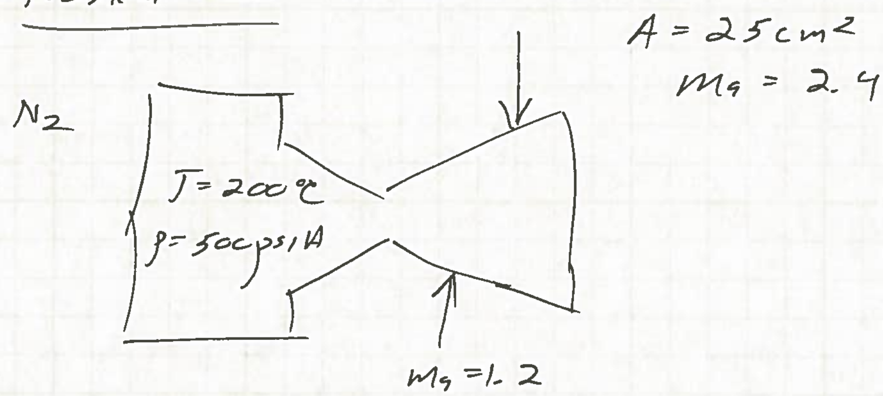
$$V_o = 4.658\ \frac{ft}{s}$$

$$CSA = 113{,}100\ \frac{ft^3}{hr}\left(\frac{1\,hr}{3600\,s}\right)\left(\frac{1\,s}{4.658\,ft}\right)$$

$$CSA = 6.745\ ft^2 = \frac{\pi D^2}{4}$$

$$D = 2.9\ ft$$

Problem #2



$T = 391.8\ F \quad (851.8\ R)$

$Ma = 2.4 \qquad \frac{A}{A^*} = 2.4031 \qquad A^* = \frac{25\,cm^2}{2.4031} = 10.4\,cm^2$

At $Ma = 1.2 \qquad \frac{T}{T_0} = 0.7764 \qquad \frac{A}{A^*} = 1.0304$

$A = 10.4(1.0304) = 10.7\,cm^2 \quad (0.0115\ ft^2)$

$T = 851.8(0.7764) = 661.3\ R$

$$U_{sonic} = \sqrt{\frac{(1.4)\left(\frac{1545.3\ ft\,lbf}{lbmol\,R}\right)(661.3R)\left(\frac{32.2\ ft\,lbm}{lbf\,s^2}\right)}{28\ \frac{lbm}{lbmol}}}$$

$U_{sonic} = 1282.5\ \frac{ft}{s}$

$U = 1.2\left(1282.5\ \frac{ft}{s}\right) = 1539\ \frac{ft}{s}$

$\left(469\ \frac{m}{s}\right)$

Eqn Solution:

$$U^2 = 2\left[\frac{\frac{1545.3\ ft\,lbf}{lbmol\,R}(851.8R)\left(\frac{32.2\ ft\,lbm}{lbf\,s^2}\right)}{28\ lb/lbmol}\right]\left(\frac{1.4}{0.4}\right)$$

$$* (1 - 0.7764)$$

$$v^2 = 2365289 \ \frac{ft^2}{s^2}$$

$$v = 1539 \ \frac{ft}{s} \ \checkmark$$

Problem #3

$$G = \frac{5000\ ft^3}{min}\left(\frac{1\ mol}{379.5\ ft^3}\right)\left(\frac{16\ lb}{lbmol}\right)\left(\frac{1}{0.1964\ ft^2}\right)\left(\frac{1\ min}{60\ s}\right)$$

$$A = \frac{\pi (0.5)^2}{4} = 0.1964\ ft^2$$

$$G = 17.9\ \frac{lbm}{ft^2 s} = G_{max} \text{ at Choked Conditions}$$

$$G = G_{max} = \sqrt{P_2\ \rho_2} = P_2 \sqrt{\frac{MW}{RT}}$$

$$17.9\ \frac{lbm}{ft^2 s} = \sqrt{\frac{16\ \frac{lbm}{lbmol}\left(\frac{lbf\ s^2}{32.2\ lbm\ ft}\right)}{\frac{1545.3\ ft\ lbf}{lbmol\ R}\left(520 R\right)}}\ (P_2)$$

$$P_2 = 4.91\ \frac{lbf}{in^2} \text{ at choke}$$

$$P_{op} = 100 + 4.9 = 104.9\ \frac{lbf}{in^2}$$

Find L

$$N_{Re} = \frac{DG}{\mu}$$

$$N_{Re} = \frac{0.5\ ft\left(17.9\ \frac{lbm}{ft^2 s}\right)}{0.01\ cP\left(6.7197 \times 10^{-4}\ \frac{lbm}{ft\text{-}s}\right)}$$

$$N_{Re} = 1.332 \times 10^6$$

✓

Steel Pipe $\frac{k}{D} = \frac{0.00015\ ft}{0.5\ ft} = 0.0003$

$$f = 0.00389$$

$$\left(17.9 \frac{lb_m}{ft^2 s}\right)^2 = \frac{\dfrac{16\ lb_m}{lbmol}\left(P_1^2 - P_2^2\right)}{\dfrac{1545\ ft\,lb_f}{lbmol\ R}\left(520R\right)} \Bigg/ \left[\frac{4\left(0.00389\right)L}{0.5\ ft} - \ln\left(\frac{P_2}{P_1}\right)\right]$$

$$\left[(P_1)^2 - (P_2)^2\right]$$

$$\left[\frac{1515\ lb_f}{in^2}\left(\frac{144\ in^2}{ft^2}\right)\right]^2 - \left[\frac{104.9\ lb_f}{in^2}\left(\frac{144\ in^2}{ft^2}\right)\right]^2$$

$$= 4.736 \times 10^{10}\ \frac{lb_f^2}{ft^4}$$

$$\frac{320.4\ lb_m^2}{ft^4 s^2} = \frac{943191 \dfrac{lb_m}{ft\,lb_f}\left(\dfrac{32.2\ ft\,lb_m}{lb_f\ s^2}\right)\left(\dfrac{lb_f^2}{ft^4}\right)}{\dfrac{0.0311\ L}{ft}}$$

A) $\boxed{L = 577 \text{ miles}}$

B) $\sqrt{\dfrac{1515}{105}} \doteq 3.80$

$$105 \xrightarrow{①} 400 \xrightarrow{②} 1515$$

$\Delta \hat{H}_1^{IDEAL} = (1545 - 1445)\ \frac{BTU}{lb}$ $\left(100\ \frac{BTU}{lb}\right)$

$\Delta \hat{H}_2^{IDEAL} = (1555 - 1455)\ \frac{BTU}{lb}$ $\left(100\ \frac{BTU}{lb}\right)$

[60% Efficiency]

#1 $\frac{100 \ BTU/lb}{0.60} \stackrel{?}{=} 167 \ \frac{BTU}{lb}$ $\qquad \hat{H}'_{ACT} = 1380 \ \frac{BTU}{lb}$

$T_{ACT} = 340°F$ OK

#2 $\frac{100}{0.60} = 167 \ \frac{BTU}{lb}$

Stg 1

$$\dot{m} = \frac{5000 \ ft^3}{min}\left(\frac{1 \ lbmol}{379.5 \ ft^3}\right)\left(\frac{16 \ lb}{1 \ lbmol}\right)\left(\frac{1 \ min}{60 \ s}\right)$$

$$\dot{m} = 3.513 \ \frac{lb}{s}$$

$$\text{Power } (P) \text{ (Total)} = \frac{3.513 \ lb}{s}\left(\frac{334 \ BTU}{lb}\right)\left(\frac{3600 \ s}{hr}\right)\left(\frac{1 \ Hp}{2544.5 \ \frac{BTU}{hr}}\right)$$

$$P \stackrel{\sim}{=} 1660 \ Hp$$

Eqn Solution

$$P_{Total} = \hat{W}\dot{m} = \frac{\overset{\text{Stgs}}{2}\left(3.513 \ \frac{lb}{s}\right)(520 \ R)\left(1545.3 \ \frac{ft \ lbf}{lbmol \ R}\right)(1.3)}{(1.3 - 1.0)\left(16 \ \frac{lb}{lbmol}\right)}\left[\left(3.8\right)^{\left(\frac{1.3-1.0}{1.3}\right)} - 1\right]$$

$$P = \frac{551782 \ \frac{ft \ lbf}{s}}{(0.60) \ \frac{550 \ ft \ lbf}{s} / Hp} = \boxed{1672 \ Hp}$$

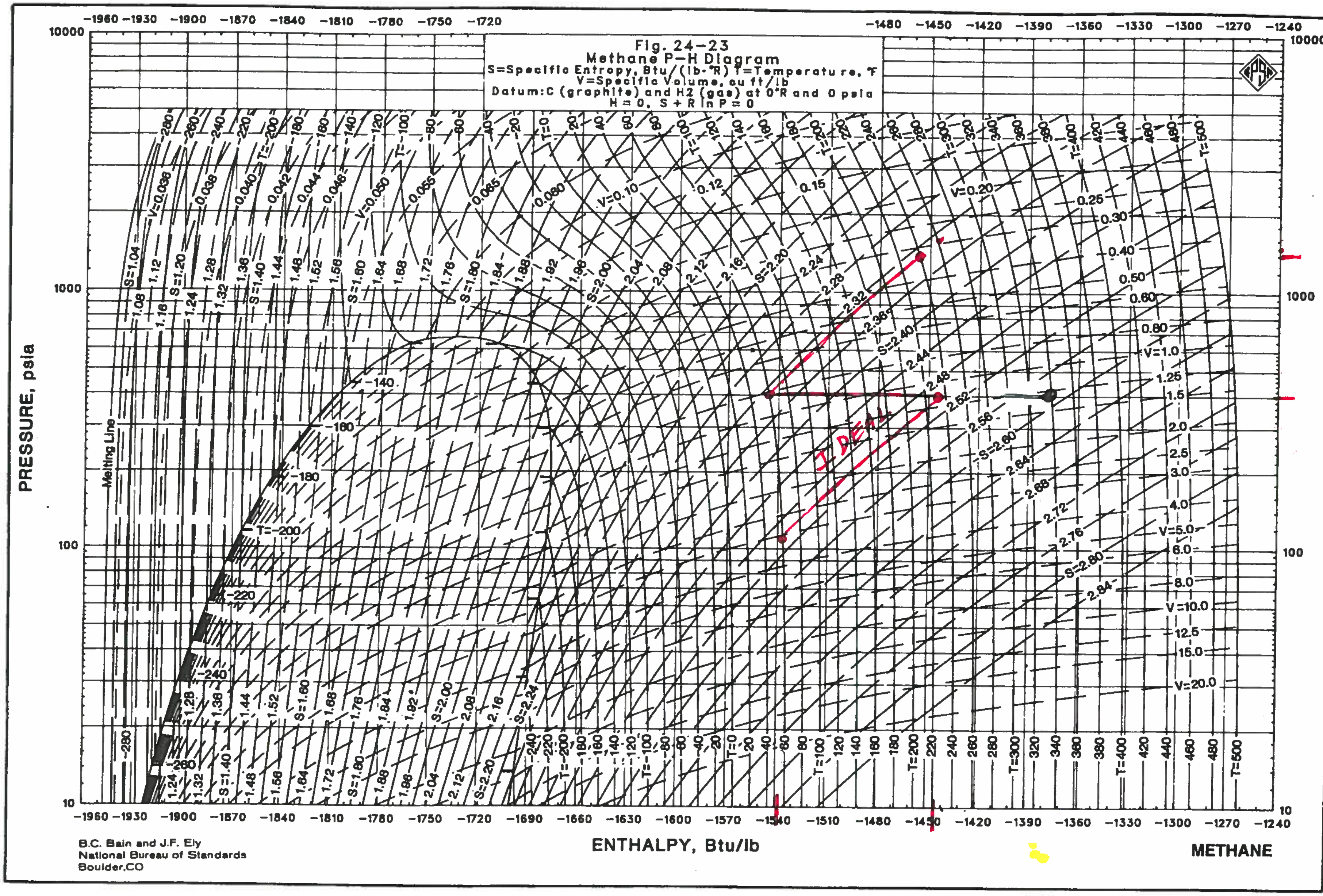


Fig. 24-23
Methane P-H Diagram
S=Specific Entropy, Btu/(lb·°R) T=Temperature, °F
V=Specific Volume, cu ft/lb
Datum: C (graphite) and H2 (gas) at 0°R and 0 psia
H = 0, S + R ln P = 0
PRESSURE, psia
ENTHALPY, Btu/lb
Melting Line
IDEAL
B.C. Bain and J.F. Ely
National Bureau of Standards
Boulder, CO
METHANE