

CH365 Chemical Engineering Thermodynamics

Lesson 14

Generalized Correlations for Gases and Liquids

Generalized Correlations for Gases Slide 2

Lee-Kesler Method

Byung Ik Lee and Michael Kesler,
AIChE Journal, 1975, 21(3), 511-527

Pitzer Correlation (L13)

$$Z = Z^0 + \omega Z^1 \quad (\text{Eq. 3.53})$$

simple fluids

deviation from
simple fluids:

$$\omega Z^1 = Z - Z^0$$

$$Z^0 = 1 + B^0 \frac{P_r}{T_r} \quad Z^1 = B^1 \cdot \frac{P_r}{T_r} \quad (\text{Eq. 3.60})$$

Lesson 13, Slide 5
formulas for B^0 and B^1
eqns. 3.61 and 3.62

Lee-Kesler Modification

$Z^{(r)}$: calculated for n-octane

$$Z = Z^0 + \frac{\omega}{\omega^{(r)}} (Z^{(r)} - Z^0) \quad \text{where} \quad Z^1 = \frac{(Z^{(r)} - Z^0)}{\omega^{(r)}}$$

Lee and Kesler used a modified Benedict-Webb-Rubin EOS:

$$Z = 1 + \frac{B}{V_r} + \frac{C}{V_r^2} + \frac{D}{V_r^5} + \frac{c_4}{T_r^3 V_r^2} \left(\beta + \frac{\gamma}{V_r^2} \right) \exp \left(-\frac{\gamma}{V_r^2} \right)$$

B, C, D are functions of T_r
(published in the paper)
 β, γ, c_4 , etc. are constants

Z calculated twice:

Z^0 : calculated for simple fluids

$Z^{(r)}$: calculated for n-octane

Tables: Appendix – Tables D.1-D.4, pp. 676-692

Example: Find Z for n-octane at $P_r=0.4$, $T_r=0.9$

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Table D.1: Values of Z^0 Page 677

$P_r =$	0.0100	0.0500	0.1000	0.2000	0.4000	0.6000	0.8000	1.0000
T_r								
0.30	0.0029	0.0145	0.0290	0.0579	0.1158	0.1737	0.2315	0.2892
0.35	0.0026	0.0130	0.0261	0.0522	0.1043	0.1564	0.2084	0.2604
0.40	0.0024	0.0119	0.0239	0.0477	0.0953	0.1429	0.1904	0.2379
0.45	0.0022	0.0110	0.0221	0.0442	0.0882	0.1322	0.1762	0.2200
0.50	0.0021	0.0103	0.0207	0.0413	0.0825	0.1236	0.1647	0.2056
0.55	0.9804	0.0098	0.0195	0.0390	0.0778	0.1166	0.1553	0.1939
0.60	0.9849	0.0093	0.0186	0.0371	0.0741	0.1109	0.1476	0.1842
0.65	0.9881	0.9377	0.0178	0.0356	0.0710	0.1063	0.1415	0.1765
0.70	0.9904	0.9504	0.8958	0.0344	0.0687	0.1027	0.1366	0.1703
0.75	0.9922	0.9598	0.9165	0.0336	0.0670	0.1001	0.1330	0.1656
0.80	0.9935	0.9669	0.9319	0.8539	0.0661	0.0985	0.1307	0.1626
0.85	0.9946	0.9725	0.9436	0.8810	0.0661	0.0983	0.1301	0.1614
0.90	0.9954	0.9768	0.9528	0.9015	0.7800	0.1006	0.1321	0.1630
0.93	0.9959	0.9790	0.9573	0.9115	0.8059	0.6635	0.1359	0.1664
0.95	0.9961	0.9803	0.9600	0.9174	0.8206	0.6967	0.1410	0.1705
0.97	0.9963	0.9815	0.9625	0.9227	0.8338	0.7240	0.5580	0.1779
0.98	0.9965	0.9821	0.9637	0.9253	0.8398	0.7360	0.5887	0.1844
0.99								
1.00								
1.01								
1.02								
1.05								
1.10								
1.15								
1.20								
1.30								
1.40								
1.50								
1.60								
1.70								
1.80								
1.90								
2.00								
2.20								
2.40								
2.60								
2.80								
3.00								
3.50								
4.00								

$Z^0=0.780$

$Z^1=-0.1118$

$\omega=0.400$

$$Z = Z^0 + \omega Z^1$$
$$= 0.780 + (0.400) \cdot (-0.1118)$$
$$= .7353$$

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Table D.2: Values of Z^1 Page 678

$P_r =$	0.0100	0.0500	0.1000	0.2000	0.4000	0.6000	0.8000	1.0000
T_r								
0.30	-0.0008	-0.0040	-0.0081	-0.0161	-0.0323	-0.0484	-0.0645	-0.0806
0.35	-0.0009	-0.0046	-0.0093	-0.0185	-0.0370	-0.0554	-0.0738	-0.0921
0.40	-0.0010	-0.0048	-0.0095	-0.0190	-0.0380	-0.0570	-0.0758	-0.0946
0.45	-0.0009	-0.0047	-0.0094	-0.0187	-0.0374	-0.0560	-0.0745	-0.0929
0.50	-0.0009	-0.0045	-0.0090	-0.0181	-0.0360	-0.0539	-0.0716	-0.0893
0.55	-0.0314	-0.0043	-0.0086	-0.0172	-0.0343	-0.0513	-0.0682	-0.0849
0.60	-0.0205	-0.0041	-0.0082	-0.0164	-0.0326	-0.0487	-0.0646	-0.0803
0.65	-0.0137	-0.0772	-0.0078	-0.0156	-0.0309	-0.0461	-0.0611	-0.0759
0.70	-0.0093	-0.0507	-0.1161	-0.0148	-0.0294	-0.0438	-0.0579	-0.0718
0.75	-0.0064	-0.0339	-0.0744	-0.0143	-0.0282	-0.0417	-0.0550	-0.0681
0.80	-0.0044	-0.0228	-0.0487	-0.1160	-0.0272	-0.0401	-0.0526	-0.0648
0.85	-0.0029	-0.0152	-0.0319	-0.0715	-0.0268	-0.0391	-0.0509	-0.0622
0.90	-0.0019	-0.0099	-0.0205	-0.0442	-0.1118	-0.0396	-0.0503	-0.0604
0.93	-0.0015	-0.0075	-0.0154	-0.0326	-0.0763	-0.1662	-0.0514	-0.0602
0.95	-0.0012	-0.0062	-0.0126	-0.0262	-0.0589	-0.1110	-0.0540	-0.0607
0.97	-0.0010	-0.0050	-0.0101	-0.0208	-0.0450	-0.0770	-0.1647	-0.0623
0.98	-0.0009	-0.0044	-0.0090	-0.0184	-0.0390	-0.0641	-0.1100	-0.0641
0.99	-0.0008	-0.0039	-0.0079	-0.0161	-0.0335	-0.0531	-0.0796	-0.0680
1.00	-0.0007	-0.0034	-0.0069	-0.0140	-0.0285	-0.0435	-0.0588	-0.0879
1.01	-0.0006	-0.0030	-0.0060	-0.0120	-0.0240	-0.0351	-0.0429	-0.0223
1.02	-0.0005	-0.0026	-0.0051	-0.0102	-0.0198	-0.0277	-0.0303	-0.0062
1.05	-0.0003	-0.0015	-0.0029	-0.0054	-0.0092	-0.0097	-0.0032	0.0220
1.10	0.0000	0.0000	0.0001	0.0007	0.0038	0.0106	0.0236	0.0476
1.15	0.0002	0.0011	0.0023	0.0052	0.0127	0.0237	0.0396	0.0625
1.20	0.0004	0.0019	0.0039	0.0084	0.0190	0.0326	0.0499	0.0719
1.30	0.0006	0.0030	0.0061	0.0125	0.0267	0.0429	0.0612	0.0819
1.40	0.0007	0.0036	0.0072	0.0147	0.0306	0.0477	0.0661	0.0857
1.50	0.0008	0.0039	0.0078	0.0158	0.0323	0.0497	0.0677	0.0864
1.60	0.0008	0.0040	0.0080	0.0162	0.0330	0.0501	0.0677	0.0855
1.70	0.0008	0.0040	0.0081	0.0163	0.0329	0.0497	0.0667	0.0838
1.80	0.0008	0.0040	0.0081	0.0162	0.0325	0.0488	0.0652	0.0814
1.90	0.0008	0.0040	0.0079	0.0159	0.0318	0.0477	0.0635	0.0792
2.00	0.0008	0.0039	0.0078	0.0155	0.0310	0.0464	0.0617	0.0767
2.20	0.0007	0.0037	0.0074	0.0147	0.0293	0.0437	0.0579	0.0719
2.40	0.0007	0.0035	0.0070	0.0139	0.0276	0.0411	0.0544	0.0675
2.60	0.0007	0.0033	0.0066	0.0131	0.0260	0.0387	0.0512	0.0634
2.80	0.0006	0.0031	0.0062	0.0124	0.0245	0.0365	0.0483	0.0598
3.00	0.0006	0.0029	0.0059	0.0117	0.0232	0.0345	0.0456	0.0565
3.50	0.0005	0.0026	0.0052	0.0103	0.0204	0.0303	0.0401	0.0497
4.00	0.0005	0.0023	0.0046	0.0091	0.0182	0.0270	0.0357	0.0443

Generalized Correlations for Liquids Slide 4

Rackett: $V^{\text{sat}} = V_C Z_C^{(1-T_r)^{2/7}}$ (Eq. 3.68)

$$Z^{\text{sat}} = \frac{P_r}{T_r} Z_C^{[1+(1-T_r)^{2/7}]} \quad (\text{Eq. 3.69})$$

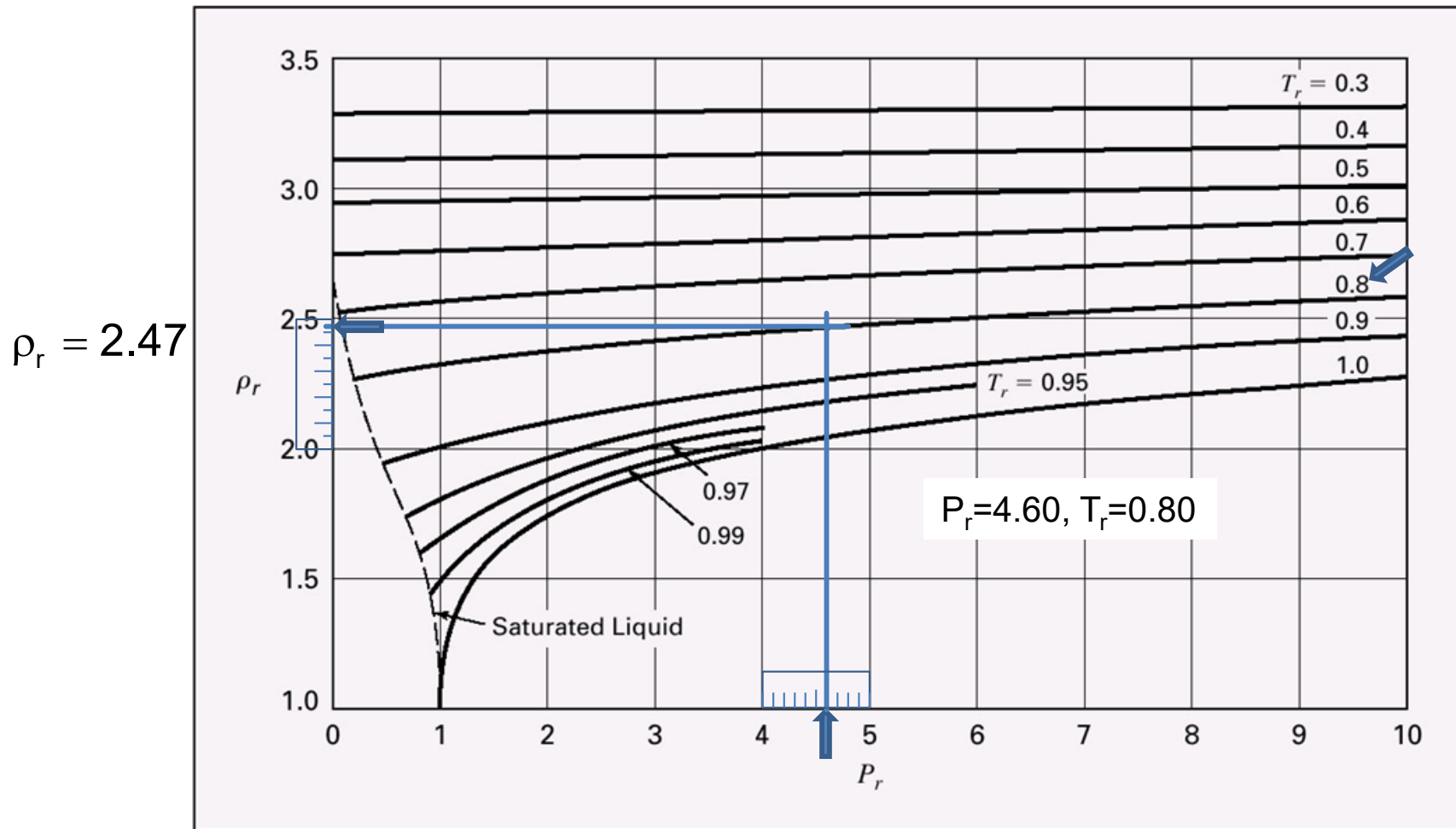


Figure 3.15: Generalized density correlation for liquids.

Lydersen, Greenkorn, and Hougen: $\rho_r \equiv \frac{\rho}{\rho_C} = \frac{V_C}{V}$ (Eq. 3.70)

Example 3.14

For ammonia at 310 K, estimate the molar volume ~~density~~ of (a) the saturated liquid and (b) the liquid at 100 bar.

(Liquids)

Example 3.14 , part b, continued

Rackett: $V^{\text{sat}} = V_C Z_C^{(1-T_r)^{2/7}}$ (Eq. 3.68) $Z^{\text{sat}} = \frac{P_r}{T_r} Z_C^{[1+(1-T_r)^{2/7}]}$ (Eq. 3.69)

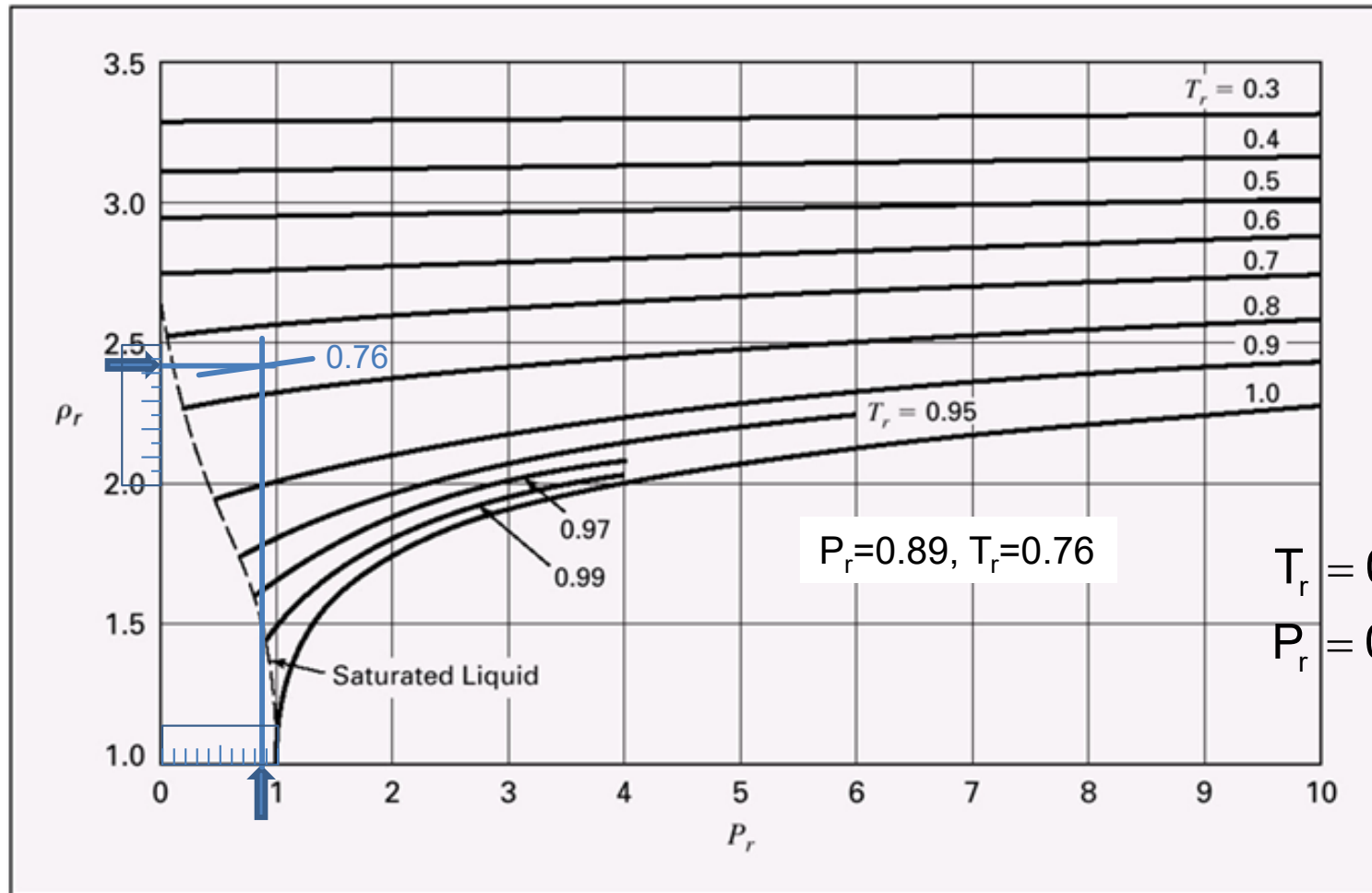


Figure 3.15. Generalized density correlation for liquids.

Lydersen, Greenkorn, and Hougen:

$$\rho_r \equiv \frac{\rho}{\rho_C} = \frac{V_C}{V} \quad (\text{Eq. 3.70})$$

Example 3.14, continued

For ammonia at 310 K, estimate the molar volume ~~density~~ of (a) the saturated liquid and (b) the liquid at 100 bar.

Homework

Problem 3.58

To a good approximation, what is the molar volume of ethanol vapor at 480 deg C and 6000 kPa? How does this result compare with the ideal gas?

Answer the problem in four parts:

(a) Lee-Kesler method.

(b) SRK equation.

(c) Ideal gas equation.

For comparison: Compare LK and SRK to IG. If either is less than IG, explain why using knowledge of IG behavior.

Online Interpolator Tool for Lee-Kesler Tables:

https://www.ajdesigner.com/phpinterpolation/bilinear_interpolation_equation.php

Lee/Kesler Method

Tables: Appendix – Tables D.1-D.4

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Table D.1: Values of Z^0 Page 664

$P_r =$	0.0100	0.0500	0.1000	0.2000	0.4000	0.6000	0.8000	1.0000
T_r	$P_r=0.975927$							
0.30	0.0029	0.0145	0.0290	0.0579	0.1158	0.1737	0.2315	0.2892
0.35	0.0026	0.0130	0.0261	0.0522	0.1043	0.1564	0.2084	0.2604
0.40	0.0024	0.0119	0.0239	0.0477	0.0953	0.1429	0.1904	0.2379
0.45	0.0022	0.0110	0.0221	0.0442	0.0882	0.1322	0.1762	0.2200
0.50	0.0021	0.0103	0.0207	0.0413	0.0825	0.1236	0.1647	0.2056
0.55	0.9804	0.0098	0.0195	0.0390	0.0778	0.1166	0.1553	0.1939
0.60	0.9849	0.0093	0.0186	0.0371	0.0741	0.1109	0.1476	0.1842
0.65	0.9881	0.9377	0.0178	0.0356	0.0710	0.1063	0.1415	0.1765
0.70	0.9904	0.9504	0.8958	0.0344	0.0687	0.1027	0.1366	0.1703
0.75	0.9922	0.9598	0.9165	0.0336	0.0670	0.1001	0.1330	0.1656
0.80	0.9935	0.9669	0.9319	0.8539	0.0661	0.0985	0.1307	0.1626
0.85	0.9946	0.9725	0.9436	0.8810	0.0661	0.0983	0.1301	0.1614
0.90	0.9954	0.9768	0.9528	0.9015	0.7800	0.1006	0.1321	0.1630
0.93	0.9959	0.9790	0.9573	0.9115	0.8059	0.6635	0.1359	0.1664
0.95	0.9961	0.9803	0.9600	0.9174	0.8206	0.6967	0.1410	0.1705
0.97	0.9963	0.9815	0.9625	0.9227	0.8338	0.7240	0.5580	0.1779
0.98	0.9965	0.9821	0.9637	0.9253	0.8398	0.7360	0.5887	0.1844
0.99	0.9966	0.9826	0.9648	0.9277	0.8455	0.7471	0.6138	0.1959
1.00	0.9967	0.9832	0.9659	0.9300	0.8509	0.7574	0.6355	0.2901
1.01	0.9968	0.9837	0.9669	0.9322	0.8561	0.7671	0.6542	0.4648
1.02	0.9969	0.9842	0.9679	0.9343	0.8610	0.7761	0.6710	0.5146
1.05	0.9971	0.9855	0.9707	0.9401	0.8743	0.8002	0.7130	0.6026
1.10	0.9975	0.9874	0.9747	0.9485	0.8930	0.8323	0.7649	0.6880
1.15	0.9978	0.9891	0.9780	0.9554	0.9081	0.8576	0.8032	0.7443
1.20	0.9981	0.9904	0.9808	0.9611	0.9205	0.8779	0.8330	0.7858
1.30	0.9985	0.9926	0.9852	0.9702	0.9396	0.9087	0.8764	0.8438
1.40	0.9988	0.9942	0.9884	0.9768	0.9534	0.9278	0.9062	0.8827
1.50	0.9991	0.9954	0.9909	0.9818	0.9636	0.9456	0.9278	0.9103
1.60	0.9993	0.9964	0.9928	0.9856	0.9714	0.9575	0.9439	0.9308
1.70	0.9994	0.9971	0.9943	0.9886	0.9775	0.9667	0.9563	0.9463
1.80	0.9995	0.9977	0.9955	0.9910	0.9823	0.9739	0.9659	0.9583
1.90	0.9996	0.9982	0.9964	0.9929	0.9861	0.9796	0.9735	0.9678
2.00	0.9997	0.9986	0.9972	0.9944	0.9892	0.9842	0.9796	0.9754
2.20	0.9998	0.9992	0.9983	0.9967	0.9937	0.9910	0.9886	0.9865
2.40	0.9999	0.9996	0.9991	0.9983	0.9969	0.9957	0.9948	0.9941
2.60	1.0000	0.9998	0.9997	0.9994	0.9991	0.9990	0.9990	0.9993
2.80	1.0000	1.0000	1.0001	1.0002	1			
3.00	1.0000	1.0002	1.0004	1.0008	1			
3.50	1.0001	1.0004	1.0008	1.0017	1			
4.00	1.0001	1.0005	1.0010	1.0021	1.0025	1.0000	1.0020	1.0115

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Table D.2: Values of Z^1 Page 665

$P_r =$	0.0100	0.0500	0.1000	0.2000	0.4000	0.6000	0.8000	1.0000
T_r	$P_r=0.975927$							
0.30	-0.0008	-0.0040	-0.0081	-0.0161	-0.0323	-0.0484	-0.0645	-0.0806
0.35	-0.0009	-0.0046	-0.0093	-0.0185	-0.0370	-0.0554	-0.0738	-0.0921
0.40	-0.0010	-0.0048	-0.0095	-0.0190	-0.0380	-0.0570	-0.0758	-0.0946
0.45	-0.0009	-0.0047	-0.0094	-0.0187	-0.0374	-0.0560	-0.0745	-0.0929
0.50	-0.0009	-0.0045	-0.0090	-0.0181	-0.0360	-0.0539	-0.0716	-0.0893
0.55	-0.0314	-0.0043	-0.0086	-0.0172	-0.0343	-0.0513	-0.0682	-0.0849
0.60	-0.0205	-0.0041	-0.0082	-0.0164	-0.0326	-0.0487	-0.0646	-0.0803
0.65	-0.0137	-0.0772	-0.0078	-0.0156	-0.0309	-0.0461	-0.0611	-0.0759
0.70	-0.0093	-0.0507	-0.1161	-0.0148	-0.0294	-0.0438	-0.0579	-0.0718
0.75	-0.0064	-0.0339	-0.0744	-0.0143	-0.0282	-0.0417	-0.0550	-0.0681
0.80	-0.0044	-0.0228	-0.0487	-0.1160	-0.0272	-0.0401	-0.0526	-0.0648
0.85	-0.0029	-0.0152	-0.0319	-0.0715	-0.0268	-0.0391	-0.0509	-0.0622
0.90	-0.0019	-0.0099	-0.0205	-0.0442	-0.1118	-0.0396	-0.0503	-0.0604
0.93	-0.0015	-0.0075	-0.0154	-0.0326	-0.0763	-0.1662	-0.0514	-0.0602
0.95	-0.0012	-0.0062	-0.0126	-0.0262	-0.0589	-0.1110	-0.0540	-0.0607
0.97	-0.0010	-0.0050	-0.0101	-0.0208	-0.0450	-0.0770	-0.1647	-0.0623
0.98	-0.0009	-0.0044	-0.0090	-0.0184	-0.0390	-0.0641	-0.1100	-0.0641
0.99	-0.0008	-0.0039	-0.0079	-0.0161	-0.0335	-0.0531	-0.0796	-0.0680
1.00	-0.0007	-0.0034	-0.0069	-0.0140	-0.0285	-0.0435	-0.0588	-0.0879
1.01	-0.0006	-0.0030	-0.0060	-0.0120	-0.0240	-0.0351	-0.0429	-0.0223
1.02	-0.0005	-0.0026	-0.0051	-0.0102	-0.0198	-0.0277	-0.0303	-0.0062
1.05	-0.0003	-0.0015	-0.0029	-0.0054	-0.0092	-0.0097	-0.0032	0.0220
1.10	0.0000	0.0000	0.0001	0.0007	0.0038	0.0106	0.0236	0.0476
1.15	0.0002	0.0011	0.0023	0.0052	0.0127	0.0237	0.0396	0.0625
1.20	0.0004	0.0019	0.0039	0.0084	0.0190	0.0326	0.0498	0.0719
1.30	0.0006	0.0030	0.0061	0.0125	0.0267	0.0479	0.0612	0.0819
1.40	0.0007	0.0036	0.0072	0.0147	0.0306	0.0477	0.0661	0.0857
1.50	0.0008	0.0039	0.0078	0.0158	0.0323	0.0497	0.0677	0.0864
1.60	0.0008	0.0040	0.0080	0.0162	0.0330	0.0500	0.0677	0.0855
1.70	0.0008	0.0040	0.0081	0.0163	0.0329	0.0497	0.0667	0.0838
1.80	0.0008	0.0040	0.0081	0.0162	0.0325	0.0488	0.0652	0.0814
1.90	0.0008	0.0040	0.0079	0.0159	0.0318	0.0477	0.0635	0.0792
2.00	0.0008	0.0039	0.0078	0.0155	0.0310	0.0464	0.0617	0.0767
2.20	0.0007	0.0037	0.0074	0.0147	0.0293	0.0437	0.0579	0.0719
2.40	0.0007	0.0035	0.0070	0.0139	0.0276	0.0411	0.0544	0.0675
2.60	0.0007	0.0033	0.0066	0.0131	0.0260	0.0387	0.0512	0.0634
2.80	0.0007	0.0032	0.0066	0.0131	0.0245	0.0365	0.0483	0.0598
3.00	0.0007	0.0031	0.0066	0.0131	0.0232	0.0345	0.0456	0.0565
3.50	0.0007	0.0030	0.0066	0.0131	0.0204	0.0303	0.0401	0.0497
4.00	0.0005	0.0023	0.0046	0.0091	0.0182	0.0270	0.0357	0.0443

Carry forward to interpolator tool

 $P_r=0.975927, T_r=1.465557$

Lee/Kesler Method

Tables: Appendix – Tables D.1-D.4

[Link to interpolator](#)

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Table D.1: Values of Z^0 Page 664

$P_r =$	0.0100	0.0500	0.1000	0.2000	0.4000	0.6000	0.8000	1.0000
T_r								
0.30	0.0029	0.0145	0.0290	0.0579	0.1158	0.1737	0.2315	0.2892
0.35	0.0026	0.0130	0.0261	0.0522	0.1043	0.1564	0.2084	0.2604
0.40	0.0024	0.0111	0.0211	0.0437	0.0904	0.1379	0.1904	0.2379
0.45	0.0022	0.0101	0.0191	0.0397	0.0847	0.1300	0.1762	0.2200
0.50	0.0021	0.0100	0.0180	0.0360	0.0800	0.1240	0.1697	0.2156
0.55	0.9804	0.0098	0.0170	0.0340	0.075927	0.1153	0.1553	0.1939
0.60	0.9849	0.0098	0.0160	0.0320	0.07476	0.11476	0.15476	0.1842
0.65	0.9881	0.937	0.0150	0.0300	0.0737	0.11415	0.15415	0.1765
0.70	0.9904	0.950	0.0140	0.0280	0.0721366	0.11366	0.15366	0.1703
0.75	0.9922	0.959	0.0130	0.0260	0.0701330	0.11330	0.15330	0.1656
0.80	0.9935	0.966	0.0120	0.0240	0.0681307	0.11307	0.15307	0.1626
0.85	0.9946	0.972	0.0110	0.0220	0.0661301	0.11301	0.15301	0.1614
0.90	0.9954	0.976	0.0100	0.0200	0.0641321	0.11321	0.15321	0.1630
0.93	0.9959	0.979	0.0090	0.0180	0.0621359	0.11359	0.15359	0.1664
0.95	0.9961	0.980	0.0080	0.0160	0.0601410	0.11410	0.15410	0.1705
0.97	0.9963	0.981	0.0070	0.0140	0.05815580	0.11558	0.15558	0.1779
0.98	0.9965	0.982	0.0060	0.0120	0.05615887	0.11587	0.15587	0.1844
0.99	0.9966	0.982	0.0050	0.0100	0.05415138	0.11613	0.15613	0.1959
1.00	0.9967	0.983	0.0040	0.0080	0.05215355	0.11655	0.15655	0.2901
1.01	0.9968	0.983	0.0030	0.0060	0.05015542	0.11697	0.15697	0.4648
1.02	0.9969	0.984	0.0020	0.0040	0.04815710	0.11710	0.15710	0.5146
1.05	0.9971	0.985	0.0010	0.0020	0.04417130	0.11730	0.15730	0.6026
1.10	0.9975	0.987	0.0000	0.0000	0.03817649	0.11764	0.15764	0.6880
1.15	0.9978	0.989	0.0000	0.0000	0.03213032	0.11832	0.15832	0.7443
1.20	0.9981	0.9904	0.9808	0.9611	0.9205	0.8779	0.8330	0.7858
1.30	0.9985	0.9926	0.9852	0.9702	0.9396	0.9087	0.8764	0.8438
1.40	0.9988	0.9942	0.9884	0.9768	0.9534	0.9278	0.9062	0.8827
1.50	0.9991	0.9947	0.9894	0.9784	0.9554	0.9296	0.9078	0.8847
1.60	0.9993	0.9949	0.9898	0.9790	0.9560	0.9300	0.9080	0.8849
1.70	0.9994	0.9950	0.9900	0.9794	0.9566	0.9306	0.9086	0.8850
1.80	0.9995	0.9951	0.9902	0.9796	0.9567	0.9307	0.9087	0.8851
1.90	0.9996	0.9952	0.9903	0.9797	0.9568	0.9308	0.9088	0.8852
2.00	0.9997	0.9953	0.9904	0.9798	0.9569	0.9309	0.9089	0.8853
2.20	0.9998	0.9954	0.9905	0.9799	0.9570	0.9310	0.9090	0.8854
2.40	0.9999	0.9955	0.9906	0.9800	0.9571	0.9311	0.9091	0.8855
2.60	1.0000	0.9956	0.9907	0.9801	0.9572	0.9312	0.9092	0.8856
2.80	1.0000	1.0000	1.0001	1.0002	1.0003	1.0004	1.0005	1.0006
3.00	1.0000	1.0002	1.0004	1.0008	1.0018	1.0030	1.0043	1.0057
3.50	1.0001	1.0004	1.0008	1.0017	1.0035	1.0055	1.0075	1.0097
4.00	1.0001	1.0005	1.0010	1.0021	1.0043	1.0066	1.0090	1.0115

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Table D.2: Values of Z^1 Page 665

$P_r =$	0.0100	0.0500	0.1000	0.2000	0.4000	0.6000	0.8000	1.0000
T_r								
0.30	-0.0008	-0.0040	-0.0081	-0.0161	-0.0323	-0.0484	-0.0645	-0.0806
0.35	-0.0009	-0.0046	-0.0093	-0.0185	-0.0370	-0.0554	-0.0738	-0.0921
0.40	-0.0010	-0.0048	-0.0096	-0.0190	-0.0380	-0.0568	-0.0758	-0.0946
0.45	-0.0009	-0.0047	-0.0094	-0.0187	-0.0375	-0.0562	-0.0745	-0.0929
0.50	-0.0009	-0.0045	-0.0091	-0.0183	-0.0369	-0.0555	-0.0736	-0.0893
0.55	-0.0314	-0.0043	-0.0087	-0.0177	-0.0357	-0.0543	-0.0724	-0.0849
0.60	-0.0205	-0.0041	-0.0082	-0.0165	-0.0346	-0.0532	-0.0713	-0.0803
0.65	-0.0137	-0.0072	-0.0144	-0.0155	-0.0335	-0.0521	-0.0699	-0.0759
0.70	-0.0093	-0.0050	-0.0100	-0.0145	-0.0324	-0.0509	-0.0681	-0.0718
0.75	-0.0064	-0.0035	-0.0070	-0.0135	-0.0313	-0.0495	-0.0661	-0.0681
0.80	-0.0044	-0.0028	-0.0056	-0.0128	-0.0302	-0.0480	-0.0648	-0.0648
0.85	-0.0029	-0.0015	-0.0030	-0.0115	-0.0291	-0.0466	-0.0622	-0.0622
0.90	-0.0019	-0.0009	-0.0018	-0.0105	-0.0279	-0.0453	-0.0604	-0.0604
0.93	-0.0015	-0.0007	-0.0014	-0.0100	-0.0272	-0.0446	-0.0602	-0.0602
0.95	-0.0012	-0.0006	-0.0012	-0.0095	-0.0267	-0.0440	-0.0607	-0.0607
0.97	-0.0010	-0.0005	-0.0010	-0.0090	-0.0262	-0.0435	-0.0623	-0.0623
0.98	-0.0009	-0.0004	-0.0009	-0.0088	-0.0260	-0.0433	-0.0641	-0.0641
0.99	-0.0008	-0.0003	-0.0008	-0.0085	-0.0258	-0.0431	-0.0680	-0.0680
1.00	-0.0007	-0.0003	-0.0007	-0.0083	-0.0256	-0.0429	-0.0687	-0.0687
1.01	-0.0006	-0.0003	-0.0006	-0.0081	-0.0254	-0.0427	-0.0723	-0.0723
1.02	-0.0005	-0.0002	-0.0005	-0.0079	-0.0252	-0.0425	-0.0762	-0.0762
1.05	-0.0003	-0.0001	-0.0003	-0.0075	-0.0247	-0.0419	-0.0802	-0.0802
1.10	0.0000	0.0000	0.0000	-0.0070	-0.0240	-0.0412	-0.0842	-0.0842
1.15	0.0002	0.0011	0.0023	-0.0062	-0.0232	-0.0404	-0.0882	-0.0882
1.20	0.0004	0.0019	0.0039	-0.0054	-0.0224	-0.0396	-0.0922	-0.0922
1.30	0.0006	0.0030	0.0061	-0.0045	-0.0215	-0.0388	-0.0962	-0.0962
1.40	0.0007	0.0036	0.0072	-0.0037	-0.0207	-0.0380	-0.1002	-0.1002
1.50	0.0008	0.0041	0.0082	-0.0029	-0.0199	-0.0372	-0.1042	-0.1042
1.60	0.0008	0.0046	0.0091	-0.0021	-0.0191	-0.0364	-0.1082	-0.1082
1.70	0.0008	0.0051	0.0097	-0.0013	-0.0183	-0.0356	-0.1122	-0.1122
1.80	0.0008	0.0056	0.0103	-0.0005	-0.0175	-0.0348	-0.1162	-0.1162
1.90	0.0008	0.0061	0.0109	0.0003	-0.0167	-0.0340	-0.1202	-0.1202
2.00	0.0008	0.0066	0.0115	0.0011	-0.0159	-0.0332	-0.1242	-0.1242
2.20	0.0007	0.0037	0.0074	0.0014	-0.0147	-0.0306	-0.1282	-0.1282
2.40	0.0007	0.0035	0.0070	0.0013	-0.0139	-0.0276	-0.1322	-0.1322
2.60	0.0007	0.0033	0.0066	0.0013	-0.0131	-0.0260	-0.1362	-0.1362
2.80	0.0006	0.0031	0.0062	0.0012	-0.0124	-0.0245	-0.1402	-0.1402
3.00	0.0006	0.0029	0.0059	0.0011	-0.0117	-0.0232	-0.1442	-0.1442
3.50	0.0005	0.0026	0.0052	0.0010	-0.0103	-0.0204	-0.1482	-0.1482
4.00	0.0005	0.0023	0.0046	0.0009	-0.0091	-0.0182	-0.1522	-0.1522

$P_r=0.975927$, $T_r=1.465557$

PS4 AAR

Quality of work is slipping for some cadets.

- 24/148 problems at 6/10 or lower for 14 cadets
- Some cadets did not compare answers to parts (a) and (b)
- Some cadets did not include sketches for 3.8
- Some cadets did not complete problem 3.30

Quality of work is slipping for some cadets.

- Courtesy email stating work will be late is appropriate professional behavior
- Avoids nasty emails and CORs from me.

Mathematica files were not attached. For future PS's:

- Save files on SharePoint
- Require printout of files and attach to PS

Sign errors on work. Compression is work done on system:

$$W > 0 \quad \Delta U \text{ increases}$$

- Compression = work done on system by surroundings
- Expansion = work done by system on surroundings

Using imaginary volume for 3.30(d):

$$a + i \cdot b \approx a \quad \text{only when} \quad |a + i \cdot b| = \sqrt{a^2 + b^2} \approx a$$