UNIVERSITEIT VAN JOHANNESBURG/
UNIVERSITY OF JOHANNESBURG

TRD 2B21

DATE	:	**2016**
TIME	:	
VENUE	:	

COURSE	: ENGINEERING		**TIME**	: 3 hours
SUBJECT	: THERMODYNAMICS 2B		**MARKS**	: 100
EXAMINERS	: N Janse van Rensburg			
	: D Madyira			

This paper consists of 7 pages and an appendix

- *Requirements: Calculator.*
- *This examination is closed book.*
- *Answer all questions.*
- *Formula sheet on page 4*
- *Tables and figures attached in appendix.*

QUESTION 1 [20]

1.1 Find the missing properties among T, P, v, u, h and x (if applicable), give the phase of the substance, and indicate the states relative to the two-phase region in a T-v diagram, for R-134a at

1.1.1 $T = 40°\text{C}, h = 400\ kJ/kg$ [4]

1.1.2 $T = 13°C, v = 0.3\ m^3/kg.$ [8]

1.2 A piston cylinder contains $0.1\ kg$ air at $100\ kPa$, $400\ K$ which goes through a polytropic compression process with $n = 1.3$ to a pressure of $300\ kPa$.

1.2.1 Find the final volume and temperature [4]

1.2.2 How much work has the air done in the process? [4]

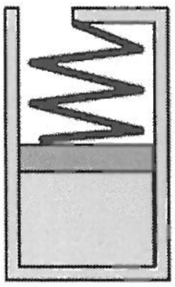
QUESTION 2 [16]

A piston cylinder arrangement, shown in the figure below, with a linear spring contains R-134a at 15°C, x = 0.6 and a volume of 0.02 m^3. It is heated to 60°C at which point the specific volume is 0.03002 m^3/kg.

2.1. Illustrate the process on a P-v diagram. [4]

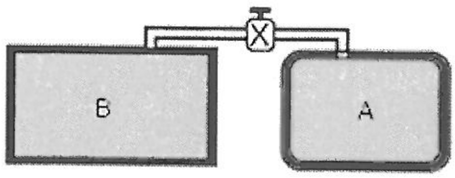
2.2. Evaluate the continuity and energy equation for this process. [2]

2.3. Determine the work and heat transfer during the process. [10]



QUESTION 3 [20]

A $1\ m^3$ tank containing air at 25°C and $500\ kPa$ is connected through a valve to another tank containing $4\ kg$ of air at 60°C and $200\ kPa$. Now the valve is opened and the entire system reaches thermal equilibrium with the surroundings at 20°C. Assume constant specific heat at 25°C and determine the final pressure and the heat transfer.



QUESTION 4 [20]

The refrigerant R-134a is used as the working fluid in a conventional heat pump cycle. Saturated vapour enters the compressor of this unit at $10°C$; its exit temperature from the compressor is measured and found to be $85°C$. If the compressor exit is at $2\ MPa$

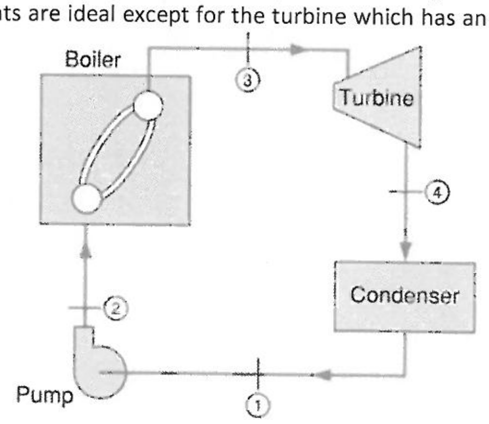
4.1 Illustrate the actual cycle and the isentropic compressor cycle on a T-s diagram [5]

4.2 What is the compressor's isentropic efficiency? [10]

4.3 Determine the COP of the cycle [5]

QUESTION 5 [24]

A steam power plant operates with a high pressure of 5 MPa and has a boiler exit temperature of 600°C receiving heat from a 700°C source. The ambient at 20°C provides cooling for the condenser so it can maintain 45°C inside. All the components are ideal except for the turbine which has an exit state with a quality of 97%.



5.1 Illustrate the cycle on a *T-s* diagram [4]

5.2 Find the work and heat transfer in all components per kg water [14]

5.3 Find the rate of entropy generation per kg water in the boiler/heat source setup [6]

Formulas

Control volumes and units

$$P = \frac{F}{A}$$

$$v = \frac{V}{m}$$

$$\rho = \frac{m}{V}$$

$$\Delta P = \rho g H$$

$$T[\mathrm{K}] = T[^\circ\mathrm{C}] + 273.15$$
$$T[\mathrm{R}] = T[\mathrm{F}] + 459.67$$
$$F = ma$$

$$a = \frac{d^2x}{dt^2} = \frac{d\mathbf{V}}{dt}$$

$$\mathbf{V} = \frac{dx}{dt}$$

Pure substance behaviour

$$x = m_{\mathrm{vap}}/m$$
$$1 - x = m_{\mathrm{liq}}/m$$
$$v = (1 - x)v_f + xv_g$$
$$P\text{–}v\text{–}T$$
$$Pv = RT \qquad PV = mRT = n\bar{R}T$$
$$\bar{R} = 8.3145 \text{ kJ/kmol K}$$
$$R = \bar{R}/M$$

$$Pv = ZRT$$

$$P_r = \frac{P}{P_c} \qquad T_r = \frac{T}{T_c}$$

Energy transfers

$$W = \int_1^2 F\,dx = \int_1^2 P\,dV = \int_1^2 \mathcal{S}\,dA = \int_1^2 T\,d\theta$$
$$w = W/m$$
$$\dot{W} = F\mathbf{V} = P\dot{V} = T\omega$$
$$\text{Velocity } \mathbf{V} = r\omega,$$
$$PV^n = \text{constant} \quad \text{or} \quad Pv^n = \text{constant}$$

$${}_1W_2 = \frac{1}{1-n}(P_2V_2 - P_1V_1) \quad (\text{if } n \neq 1)$$

$${}_1W_2 = P_1V_1 \ln\frac{V_2}{V_1} \quad (\text{if } n = 1)$$

$$\dot{Q} = -kA\frac{dT}{dx}$$
$$k \quad (\mathrm{W/m\ K})$$
$$\dot{Q} = hA\,\Delta T$$
$$h(\mathrm{W/m^2\ K})$$
$$\dot{Q} = \epsilon\sigma A(T_s^4 - T_{\mathrm{amb}}^4) \quad (\sigma = 5.67 \times 10^{-8}\ \mathrm{W/m^2\ K^4})$$

$${}_1Q_2 = \int \dot{Q}\,dt \approx \dot{Q}_{\mathrm{avg}}\,\Delta t$$

Energy equations

$$E = U + \text{KE} + \text{KE} = mu + \frac{1}{2}m\mathbf{V}^2 + mgZ$$

$$\text{KE} = \frac{1}{2}m\mathbf{V}^2$$

$$\text{KE} = mgZ$$

$$e = u + \frac{1}{2}\mathbf{V}^2 + gZ$$

$$h \equiv u + Pv$$

$$u = u_f + xu_{fg} = (1-x)u_f + xu_g$$

$$h = h_f + xh_{fg} = (1-x)h_f + xh_g$$

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v ; C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

$$C = C_v = C_p$$

$$u_2 - u_1 = C(T_2 - T_1)$$

$$h_2 - h_1 = u_2 - u_1 + v(P_2 - P_1)$$

$$h = h_f + v_f(P - P_{sat}); u \cong u_f$$

$$h = u + Pv = u + RT$$

$$C_v = \frac{du}{dT}; C_p = \frac{dh}{dT} = C_v + R$$

$$u_2 - u_1 = \int C_v\, dT \cong C_v(T_2 - T_1)$$

$$h_2 - h_1 = \int C_p\, dT \cong C_p(T_2 - T_1)$$

$$\dot{E} = \dot{Q} - \dot{W}$$

$$E_2 - E_1 = {}_1Q_2 - {}_1W_2$$

$$m(e_2 - e_1) = m(u_2 - u_1) + \frac{1}{2}m(\mathbf{V}_2^2 - \mathbf{V}_1^2) + mg(Z_2 - Z_1)$$

$$E = m_A e_A + m_B e_B + m_C e_C + \cdots$$

$$\dot{V} = \int \mathbf{V}\, dA = A\mathbf{V}$$

$$\dot{m} = \int \rho \mathbf{V}\, dA = \rho A\mathbf{V} = A\mathbf{V}/v$$

$$\dot{W}_{\text{flow}} = P\dot{V} = \dot{m}Pv$$

$$\dot{m}_{\text{C.V.}} = \sum \dot{m}_i - \sum \dot{m}_e$$

$$\dot{E}_{\text{C.V.}} = \dot{Q}_{\text{C.V.}} - \dot{W}_{\text{C.V.}} + \sum \dot{m}_i h_{\text{tot}\,i} - \sum \dot{m}_e h_{\text{tot}\,e}$$

$$h_{\text{tot}} = h + \frac{1}{2}\mathbf{V}^2 + gZ = h_{\text{stagnation}} + gZ$$

$$\sum \dot{m}_i = \sum \dot{m}_e \quad (\text{in} = \text{out})$$

$$\dot{Q}_{\text{C.V.}} + \sum \dot{m}_i h_{\text{tot}\,i} = \dot{W}_{\text{C.V.}} + \sum \dot{m}_e h_{\text{tot}\,e} \quad (\text{in} = \text{out})$$

$$q = \dot{Q}_{\text{C.V.}}/\dot{m} \quad (\text{steady state only})$$

$$w = \dot{W}_{\text{C.V.}}/\dot{m} \quad (\text{steady state only})$$

$$q + h_{\text{tot}\,i} = w + h_{\text{tot}\,e} \quad (\text{in} = \text{out})$$

$$m_2 - m_1 = \sum m_i - \sum m_e$$
$$E_2 - E_1 = {}_1Q_2 - {}_1W_2 + \sum m_i h_{\text{tot } i} - \sum m_e h_{\text{tot } e}$$
$$E_2 - E_1 = m_2(u_2 + \frac{1}{2}\mathbf{V}_2^2 + gZ_2) - m_1(u_1 + \frac{1}{2}\mathbf{V}_1^2 + gZ_1)$$
$$h_{\text{tot } e} = h_{\text{tot exit average}} \approx \frac{1}{2}(h_{\text{tot } e1} + h_{\text{tot } e2})$$

Second law

$$W_{\text{HE}} = Q_H - Q_L; \qquad \eta_{\text{HE}} = \frac{W_{\text{HE}}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$
$$W_{\text{HP}} = Q_H - Q_L; \qquad \beta_{\text{HP}} = \frac{Q_H}{W_{\text{HP}}} = \frac{Q_H}{Q_H - Q_L}$$
$$W_{\text{REF}} = Q_H - Q_L; \qquad \beta_{\text{REF}} = \frac{Q_L}{W_{\text{REF}}} = \frac{Q_L}{Q_H - Q_L}$$
$$\eta_{\text{HE}} = \frac{W_{\text{HE}}}{Q_H} \le \eta_{\text{Carnot HE}} = 1 - \frac{T_L}{T_H}$$
$$\beta_{\text{HP}} = \frac{Q_H}{W_{\text{HP}}} \le \beta_{\text{Carnot HP}} = \frac{T_H}{T_H - T_L}$$
$$\beta_{\text{REF}} = \frac{Q_L}{W_{\text{REF}}} \le \beta_{\text{Carnot REF}} = \frac{T_L}{T_H - T_L}$$
$$\dot{Q} = C\,\Delta T$$
$$\oint \frac{dQ}{T} \le 0$$
$$ds = \frac{dq}{T} + ds_{\text{gen}}; \qquad ds_{\text{gen}} \ge 0$$
$$\dot{S}_{\text{c.m.}} = \sum \frac{\dot{Q}_{\text{c.m.}}}{T} + \dot{S}_{\text{gen}}$$
$$m(s_2 - s_1) = \int_1^2 \frac{\delta Q}{T} + {}_1S_{2\text{ gen}}; \qquad {}_1S_{2\text{ gen}} \ge 0$$
$$\Delta S_{\text{net}} = \Delta S_{\text{cm}} + \Delta S_{\text{surr}} = \Delta S_{\text{gen}} \ge 0$$
$$W_{\text{lost}} = \int T\,dS_{\text{gen}}$$
$${}_1W_2 = \int P\,dV - W_{\text{lost}}$$
$$T\,ds = du + P\,dv$$
$$T\,ds = dh - v\,dP$$
$$s_2 - s_1 = \int \frac{du}{T} = \int C\frac{dT}{T} = C\ln\frac{T_2}{T_1}$$
$$s_T^0 = \int_{T_0}^{T} \frac{C_{p0}}{T}\,dT$$
$$s_2 - s_1 = s_{T2}^0 - s_{T1}^0 - R\ln\frac{P_2}{P_1}$$
$$s_2 - s_1 = C_{p0}\ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}$$
$$s_2 - s_1 = C_v\ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1}$$
$$k = C_{p0}/C_{v0}$$

$Pv^n =$ constant; $\quad PV^n =$ constant

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n = \left(\frac{v_1}{v_2}\right)^n = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{n-1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$\frac{v_2}{v_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} = \left(\frac{T_1}{T_2}\right)^{\frac{1}{n-1}}$$

$${}_1w_2 = \frac{1}{1-n}(P_2v_2 - P_1v_1) = \frac{R}{1-n}(T_2 - T_1)$$

$${}_1w_2 = P_1v_1 \ln\frac{v_2}{v_1} = RT_1 \ln\frac{v_2}{v_1} = RT_1 \ln\frac{P_1}{P_2}$$

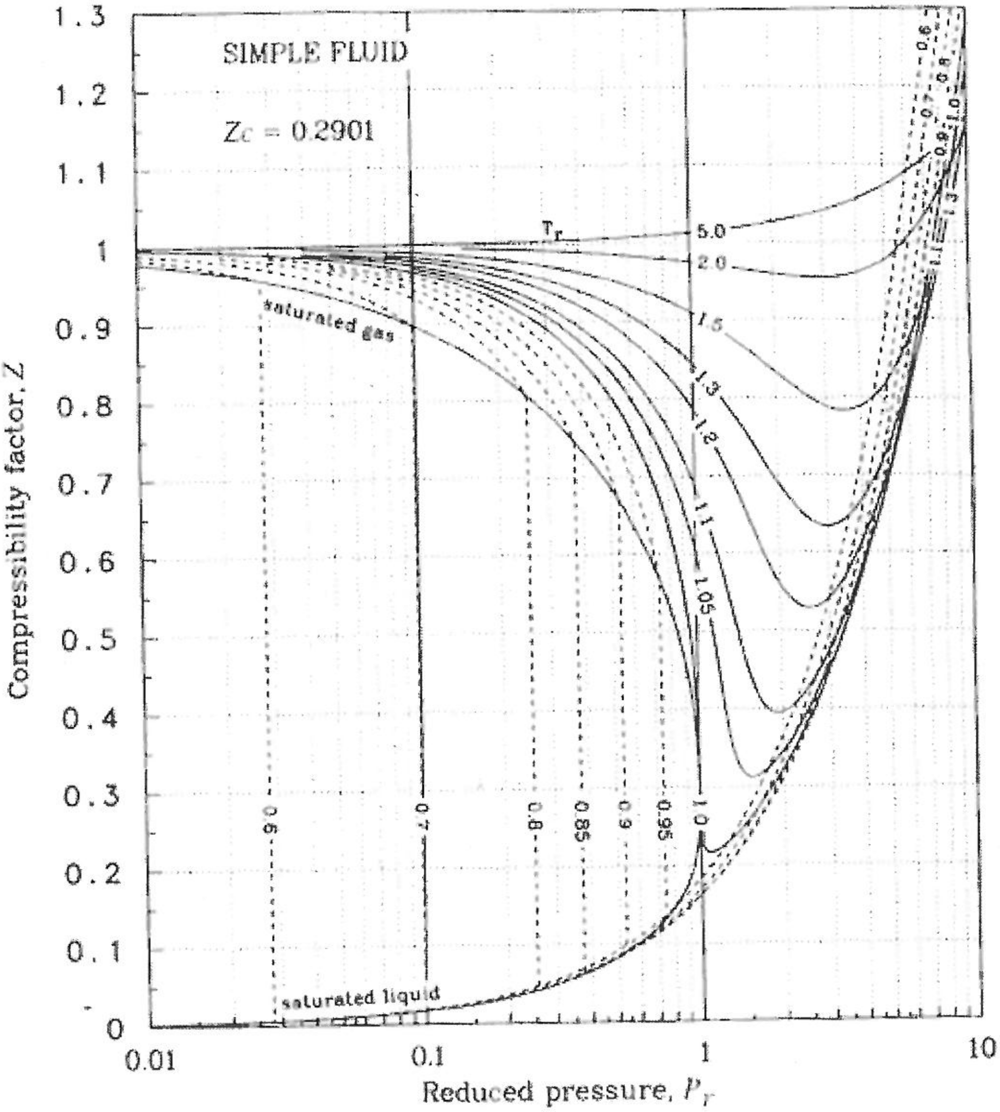


FIGURE D.1 Lee–Kesler simple fluid compressibility factor.

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This paper consists of 7 pages and an appendix

- Benodigdhede: Sakrekenaar.
  Requirements: Calculator.
- Hierdie eksamen is toeboek.
  This examination is closed book.
- Beantwoord alle vrae.
  Answer all questions.
- Formuleblad voorsien op bladsy 5
  Formula sheet on page 5
- Tabelle en grafieke aangeheg in bylaag.
  Tables and figures attached in appendix.

QUESTION 1 [30]

1.1 Find the missing properties P, T, v, u and x and identify the phases on a P-v diagram for: [16]

	P	T	v	U	x
Water	5000 kPa			2999.64 kJ/kg	
Ammonia		50°C	0.07506 m^3/kg		
Ammonia	1200 kPa	28°C			
R-134a		20°C		350 kJ/kg	

1.2 Consider a Carnot-cycle heat pump with R-410a as the working fluid. Heat is rejected from the R-410a at 40°C, during which process the R-410a changes from saturated vapour to saturated liquid. The heat is transferred to the R-410a at -5°C.

1.2.1 Show the cycle on a T–s diagram. [2]

1.2.2 List the four basic processes of a Carnot-cycle. [4]

1.2.3 Find the quality of the R-410a at the beginning and end of the isothermal heat addition process at -5°C. [4]

1.2.4 Determine the efficiency of the cycle. [4]

QUESTION 2 [14]

In a reversible process, nitrogen is compressed in a cylinder from 100 kPa and 20°C to 500kPa. During this process the relationship between the pressure and the volume $PV^{1.3}$ is constant.

2.1 Determine the temperature at state 2 [4]

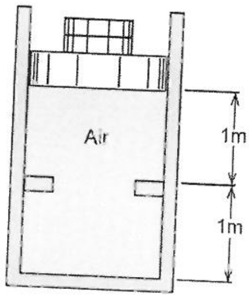
2.2 Calculate the work done during this process [5]

2.3 Find the heat transfer during this process [5]

QUESTION 3

[16]

A piston/cylinder arrangement shown below initially contains air at 150 kPa, 400°C. The setup is allowed to cool to the ambient temperature of 20°C.



3.1 What is the final pressure in the cylinder? [4]
3.2 Is the piston resting on the stops in the final state? [2]
3.3 Illustrate the process on a $P - v$ diagram [4]
3.4 What is the specific work done by the air during this process? [6]

QUESTION 4

[10]

A 1-L capsule of water at 700 kPa, 150°C is placed in a larger insulated and otherwise evacuated vessel. The capsule bursts and its contents fill the entire volume. If the final pressure should not exceed 125 kPa, what should the vessel volume be?

QUESTION 5 [30]

5.1 A simple steam power plant shown in Figure 6.1 runs on a Rankine cycle. List the four processes in this cycle. [4]

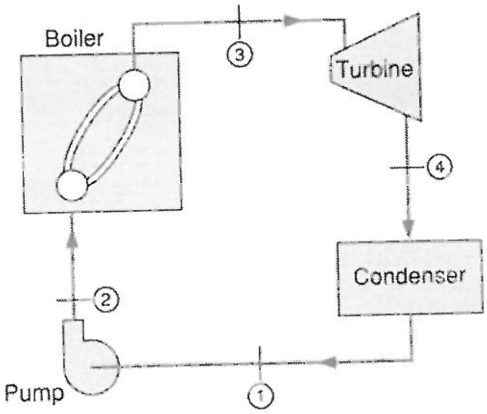


Figure 6.1. A simple steam power plant

5.2 A utility runs a Rankine cycle with water exiting the boiler at 3.0 MPa. The cycle operates at a high temperature of 450°C and a low of 45°C, respectively. [26]

5.2.1 Illustrate the process on a T-s diagram. [2]
5.2.2 What is the operating pressure of the condenser? [2]
5.2.3 Determine the specific work and heat transfer in each component. [14]
5.2.4 Find the cycle efficiency. [4]
5.2.5 Find the Carnot efficiency for the cycle. [4]

Formulas

Control volumes and units

$$P = \frac{F}{A}$$

$$v = \frac{V}{m}$$

$$\rho = \frac{m}{V}$$

$$\Delta P = \rho g H$$

$$T[\text{K}] = T[^\circ\text{C}] + 273.15$$
$$T[\text{R}] = T[\text{F}] + 459.67$$
$$F = ma$$

$$a = \frac{d^2x}{dt^2} = \frac{d\mathbf{V}}{dt}$$

$$\mathbf{V} = \frac{dx}{dt}$$

Pure substance behaviour

$x = m_{\text{vap}}/m$

$1 - x = m_{\text{liq}}/m$

$v = (1 - x)v_f + xv_g$

P--v--T

$Pv = RT \qquad PV = mRT = n\bar{R}T$

$\bar{R} = 8.3145$ kJ/kmol K

$R = \bar{R}/M$

$Pv = ZRT$

$$P_r = \frac{P}{P_c} \qquad T_r = \frac{T}{T_c}$$

Energy transfers

$$W = \int_1^2 F\,dx = \int_1^2 P\,dV = \int_1^2 \mathcal{S}\,dA = \int_1^2 T\,d\theta$$

$w = W/m$

$\dot{W} = F\mathbf{V} = P\dot{V} = T\omega$

Velocity $\mathbf{V} = r\omega$,

$PV^n = \text{constant}$ or $Pv^n = \text{constant}$

$${}_1W_2 = \frac{1}{1-n}(P_2V_2 - P_1V_1) \quad (\text{if } n \neq 1)$$

$${}_1W_2 = P_1V_1 \ln\frac{V_2}{V_1} \quad (\text{if } n = 1)$$

$$\dot{Q} = -kA\frac{dT}{dx}$$

k (W/m K)

$\dot{Q} = hA\,\Delta T$

h(W/m^2 K)

$\dot{Q} = \epsilon\sigma A(T_s^4 - T_{\text{amb}}^4) \quad (\sigma = 5.67 \times 10^{-8}\ \text{W/m}^2\,\text{K}^4)$

$${}_1Q_2 = \int \dot{Q}\,dt \approx \dot{Q}_{\text{avg}}\,\Delta t$$

Energy equations

$$E = U + \text{KE} + \text{KE} = mu + \frac{1}{2}m\mathbf{V}^2 + mgZ$$

$$\text{KE} = \frac{1}{2}m\mathbf{V}^2$$

$$\text{KE} = mgZ$$

$$e = u + \frac{1}{2}\mathbf{V}^2 + gZ$$

$$h \equiv u + Pv$$

$$u = u_f + xu_{fg} = (1-x)u_f + xu_g$$

$$h = h_f + xh_{fg} = (1-x)h_f + xh_g$$

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v; C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

$$C = C_v = C_p$$

$$u_2 - u_1 = C(T_2 - T_1)$$

$$h_2 - h_1 = u_2 - u_1 + v(P_2 - P_1)$$

$$h = h_f + v_f(P - P_{\text{sat}}); u \cong u_f$$

$$h = u + Pv = u + RT$$

$$C_v = \frac{du}{dT}; C_p = \frac{dh}{dT} = C_v + R$$

$$u_2 - u_1 = \int C_v\,dT \cong C_v(T_2 - T_1)$$

$$h_2 - h_1 = \int C_p\,dT \cong C_p(T_2 - T_1)$$

$$\dot{E} = \dot{Q} - \dot{W}$$

$$E_2 - E_1 = {}_1Q_2 - {}_1W_2$$

$$m(e_2 - e_1) = m(u_2 - u_1) + \frac{1}{2}m(\mathbf{V}_2^2 - \mathbf{V}_1^2) + mg(Z_2 - Z_1)$$

$$E = m_A e_A + m_B e_B + m_C e_C + \cdots$$

$$\dot{V} = \int \mathbf{V}\,dA = A\mathbf{V}$$

$$\dot{m} = \int \rho\,\mathbf{V}\,dA = \rho A\mathbf{V} = A\mathbf{V}/v$$

$$\dot{W}_{\text{flow}} = P\dot{V} = \dot{m}Pv$$

$$\dot{m}_{\text{C.V.}} = \sum \dot{m}_i - \sum \dot{m}_e$$

$$\dot{E}_{\text{C.V.}} = \dot{Q}_{\text{C.V.}} - \dot{W}_{\text{C.V.}} + \sum \dot{m}_i h_{\text{tot}\,i} - \sum \dot{m}_e h_{\text{tot}\,e}$$

$$h_{\text{tot}} = h + \frac{1}{2}\mathbf{V}^2 + gZ = h_{\text{stagnation}} + gZ$$

$$\sum \dot{m}_i = \sum \dot{m}_e \quad \text{(in = out)}$$

$$\dot{Q}_{\text{C.V.}} + \sum \dot{m}_i h_{\text{tot}\,i} = \dot{W}_{\text{C.V.}} + \sum \dot{m}_e h_{\text{tot}\,e} \quad \text{(in = out)}$$

$$q = \dot{Q}_{\text{C.V.}}/\dot{m} \quad \text{(steady state only)}$$

$$w = \dot{W}_{\text{C.V.}}/\dot{m} \quad \text{(steady state only)}$$

$$q + h_{\text{tot}\,i} = w + h_{\text{tot}\,e} \quad \text{(in = out)}$$

$$m_2 - m_1 = \sum m_i - \sum m_e$$
$$E_2 - E_1 = {}_1Q_2 - {}_1W_2 + \sum m_i h_{\text{tot } i} - \sum m_e h_{\text{tot } e}$$
$$E_2 - E_1 = m_2(u_2 + \frac{1}{2}\mathbf{V}_2^2 + gZ_2) - m_1(u_1 + \frac{1}{2}\mathbf{V}_1^2 + gZ_1)$$

$$h_{\text{tot } e} = h_{\text{tot exit average}} \approx \frac{1}{2}(h_{\text{hot } e1} + h_{\text{tot } e2})$$

Second law

$$W_{\text{HE}} = Q_H - Q_L; \qquad \eta_{\text{HE}} = \frac{W_{\text{HE}}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$
$$W_{\text{HP}} = Q_H - Q_L; \qquad \beta_{\text{HP}} = \frac{Q_H}{W_{\text{HP}}} = \frac{Q_H}{Q_H - Q_L}$$
$$W_{\text{REF}} = Q_H - Q_L; \qquad \beta_{\text{REF}} = \frac{Q_L}{W_{\text{REF}}} = \frac{Q_L}{Q_H - Q_L}$$

$$\eta_{\text{HE}} = \frac{W_{\text{HE}}}{Q_H} \le \eta_{\text{Carnot HE}} = 1 - \frac{T_L}{T_H}$$
$$\beta_{\text{HP}} = \frac{Q_H}{W_{\text{HP}}} \le \beta_{\text{Carnot HP}} = \frac{T_H}{T_H - T_L}$$
$$\beta_{\text{REF}} = \frac{Q_L}{W_{\text{REF}}} \le \beta_{\text{Carnot REF}} = \frac{T_L}{T_H - T_L}$$
$$\dot{Q} = C\,\Delta T$$

$$\oint \frac{dQ}{T} \le 0$$
$$ds = \frac{dq}{T} + ds_{\text{gen}}; \qquad ds_{\text{gen}} \ge 0$$

$$\dot{S}_{\text{c.m.}} = \sum \frac{\dot{Q}_{\text{c.m.}}}{T} + \dot{S}_{\text{gen}}$$

$$m(s_2 - s_1) = \int_1^2 \frac{\delta Q}{T} + {}_1S_{2\,\text{gen}}; \qquad {}_1S_{2\,\text{gen}} \ge 0$$

$$\Delta S_{\text{net}} = \Delta S_{\text{cm}} + \Delta S_{\text{surr}} = \Delta S_{\text{gen}} \ge 0$$

$$W_{\text{lost}} = \int T\,dS_{\text{gen}}$$
$${}_1W_2 = \int P\,dV - W_{\text{lost}}$$
$$T\,ds = du + P\,dv$$
$$T\,ds = dh - v\,dP$$

$$s_2 - s_1 = \int \frac{du}{T} = \int C\frac{dT}{T} = C \ln \frac{T_2}{T_1}$$

$$s_T^0 = \int_{T_0}^{T} \frac{C_{p0}}{T}\,dT$$
$$s_2 - s_1 = s_{T2}^0 - s_{T1}^0 - R \ln \frac{P_2}{P_1}$$
$$s_2 - s_1 = C_{p0} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$
$$s_2 - s_1 = C_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$
$$k = C_{p0}/C_{v0}$$

$Pv^n = \text{constant}; \qquad PV^n = \text{constant}$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n = \left(\frac{v_1}{v_2}\right)^n = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{n-1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$\frac{v_2}{v_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} = \left(\frac{T_1}{T_2}\right)^{\frac{1}{n-1}}$$

$${}_1w_2 = \frac{1}{1-n}(P_2v_2 - P_1v_1) = \frac{R}{1-n}(T_2 - T_1)$$

$${}_1w_2 = P_1v_1 \ln\frac{v_2}{v_1} = RT_1 \ln\frac{v_2}{v_1} = RT_1 \ln\frac{P_1}{P_2}$$

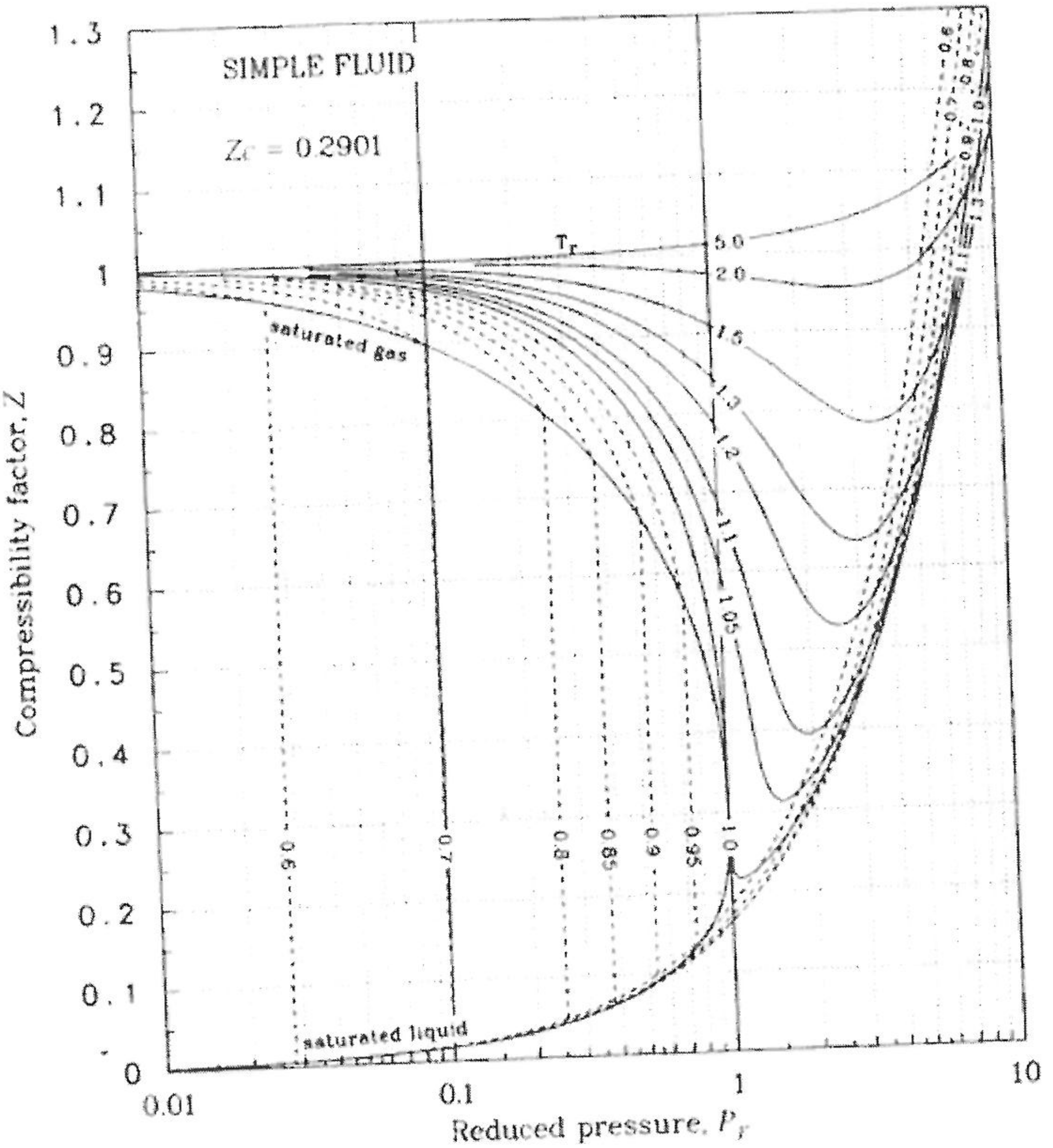


FIGURE D.1 Lee–Kesler simple fluid compressibility factor.