



**UNIVERSITI KUALA LUMPUR**  
**Malaysian Institute of Marine Engineering Technology**

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**FINAL EXAMINATION**  
**FEBRUARY 2025 SEMESTER SESSION**

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<b>SUBJECT CODE</b>	<b>: LMD25202</b>
<b>SUBJECT TITLE</b>	<b>: APPLIED THERMODYNAMICS</b>
<b>PROGRAMME NAME</b> (FOR MPU: PROGRAMME LEVEL)	<b>: DIPLOMA OF ENGINEERING TECHNOLOGY IN MARINE ENGINEERING</b>
<b>TIME / DURATION</b>	<b>: 09.00 AM - 11.30 AM (2 HOURS 30 MINUTES)</b>
<b>DATE</b>	<b>: 1 JULY 2025</b>

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**INSTRUCTIONS TO CANDIDATES**

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1. Please read **CAREFULLY** the instructions given in the question paper.
2. This question paper has information printed on both sides of the paper.
3. This question paper consists of **TWO (2)** sections; Section A and Section B.
4. Answer **ALL** question in Section A, and **TWO (2)** questions **ONLY** in Section B.
5. Please write your answers on this answer booklet provided.
6. Answer **ALL** questions in English language **ONLY**.
7. Answer should be written in blue or black ink except for sketching, graphic and illustration.
8. Steam Table of Properties and Formula has been appended for your reference.

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**THERE ARE 5 PAGES OF QUESTIONS, EXCLUDING THIS PAGE.**

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**SECTION A (Total: 60 marks)**

**INSTRUCTION: Answer ALL questions.  
Please use the answer booklet provided.**

**Question 1**

With reference to energy transfer in the marine heat engine cycle and ideal gases cycle:

- (a) Define the following:
- i. Compression ratio (2 marks)
  - ii. Stroke (2 marks)
  - iii. Bore (1 mark)

- (b) Differentiate Stirling cycle and Ericsson cycle based on the following criteria as shown in Table 1(b).

Table 1(b): Differences of Stirling and Ericsson cycle.

Criteria	Stirling Cycle	Ericsson Cycle
Thermodynamics Processes (4 marks)		
Pressure – volume (P-v) diagram (3 marks)		

- (c) Reciprocating engines are classified as spark ignition (SI) engines and compression ignition (CI) engines. Sketch and label the expansion stroke for both SI and CI engines. (8 marks)

**Question 2**

With reference to energy transfer in the vapor power cycle of marine steam turbine engine:

- (a) Describe any TWO (2) main components of steam power plant having a Rankine cycle. (5 marks)
- (b) A simple ideal Rankine cycle was modified by superheating the steam to a high temperature at a turbine. Identify its effect (*decrease, increase or remains constant*) after modification on the following:
- i. Pump work input,  $w_{pump,in}$  (1 mark)
  - ii. Moisture content at turbine exit (1 mark)
  - iii. Cycle efficiency,  $\eta_{th}$  (1 mark)
  - iv. Sketch and label both the original and the modified cycles on the same temperature entropy (T-s) diagram. (4 marks)
- (c) Steam power plant operates on simple ideal Rankine cycle with water as the working fluid. Complete Table 2(c) by showing all the calculations involved.

Table 2(c): Thermodynamic properties of simple ideal Rankine cycle

State	Pressure, (kPa)	Phases exist	Enthalpy, h (kJ/kg)	Energy transfer (kJ/kg)
1	12.352	(i)	209.34	$w_{pump,in}$ (ii)
2	3500	Compressed liquid	212.87	$q_{in} = 2892.03$
3	3500	(iii)	(iv)	$w_{turb,out}$ (v)
4	12.352	Saturated mixture	2131.61	$q_{out} = 1922.26$

(8 marks)

**Question 3**

With reference to energy transfer in the marine refrigeration cycle:

- (a) List THREE (3) energy sources for the heat pump system. (3 marks)
- (b) i. List TWO (2) types of secondary refrigerant. (2 marks)  
 ii. Identify THREE (3) properties of refrigerant used in marine refrigeration systems. (3 marks)
- (c) Explain FOUR (4) usage of expansion device instead of isentropic turbine in ideal vapor compression refrigeration cycle. (4 marks)
- (d) Air enters the compressor of an ideal gas refrigeration cycle at 70°C ( $T_1$ ) and 70 kPa ( $P_1$ ) and the turbine at 47°C ( $T_3$ ) and 210 kPa ( $P_3$ ). Assuming variable specific heats is used, complete Table 3(d) by showing all calculations involved.

Table 3(d): Properties of gas refrigeration cycle

Processes	Pressure P, kPa	Enthalpy h, kJ/kg	Relative pressure, $P_r$
1 - 2	70	350.49	2.379
2 - 3	$P_2$ (i)	$h_2$ (ii)	7.137
3 - 4	210	$h_3$ (iii)	$P_{r3}$ (iv)
4 - 1	$P_3$ (v)	233.608	0.5792

(8 marks)

SECTION B (Total: 40 marks)

INSTRUCTION: Answer only TWO (2) questions.

Please use the answer booklet provided.

Question 4

With reference to the problem solving of marine heat engine cycle and ideal gases cycle:

A four-cylinder spark ignition engine operating on the ideal Otto cycle as shown in Figure 4 has a compression ratio, ( $r$ ) of 10.5 and has a maximum volume ( $V$ ) of 0.004 m<sup>3</sup>. At the beginning of the compression process, the air is at 98 kPa ( $P_1$ ), 37°C ( $T_1$ ), and the maximum temperature of the cycle is 2100K ( $T_3$ ). Assume the constant specific heats and the isentropic processes are used for air.

(Given  $R = 0.287 \frac{kJ}{kg.K}$ ;  $c_v = 0.718 \frac{kJ}{kg.K}$ )

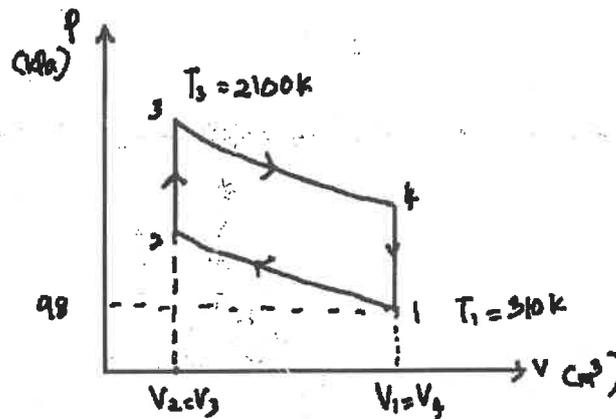


Figure 4: P-v diagram of an ideal Otto cycle

- (a) Identify FOUR (4) processes involved in this cycle as shown in Figure 4. (5 marks)
- (b) Calculate the following:
  - i. The temperature at the end of compression process ( $T_2$ ). (2 marks)
  - ii. The pressure at the end of the heat addition process ( $P_3$ ). (5 marks)
  - iii. The amount of heat added ( $Q_{in}$ ) to this cycle, in kJ unit. (8 marks)

**Question 5**

With reference to the problem solving of Rankine cycle for marine steam turbine engines:

A simple ideal Rankine cycle with water as the working fluid operated between the pressure limits of 3 MPa ( $P_3 = P_2$ ), in the boiler and 30 kPa ( $P_4 = P_1$ ), in the condenser. The temperature at the turbine inlet is 600°C ( $T_3$ ).

- (a) Explain FIVE (5) reasons the turbine inlet condition is in superheated steam rather than saturated steam for this cycle. (5 marks)
- (b) Calculate the following:
- The moisture content at the exit turbine. (6 marks)
  - The heat added to the cycle, ( $q_{in}$ ) in kJ/kg unit. (9 marks)

**Question 6**

With reference to the problem solving of marine refrigeration cycle:

The following data were obtained from a refrigerator which operates on an ideal vapor compression refrigeration cycle by using refrigerant-134a (R-134a) as working fluid.

Condenser pressure ( $P_2 = P_3$ ) = 0.8 MPa

Evaporator pressure ( $P_4 = P_1$ ) = 0.14 MPa

- (a) Sketch and label a temperature – entropy (T-s) diagram of an ideal vapor compression refrigeration cycle. (5 marks)
- (b) Calculate the following:
- The heat absorbed ( $q_L$ ) from the cold medium in kJ/kg unit. (5 marks)
  - The refrigerator coefficient of performance, ( $COP_R$ ). (10 marks)

**END OF EXAMINATION PAPER**



## THERMODYNAMICS FORMULAE

### First Law of Thermodynamics

$$\text{Quality, } x = \frac{m_g}{m_{total}} = \frac{v - v_f}{v_{fg}}$$

$$v = v_f + (x)v_{fg}; \quad u = u_f + (x)u_{fg}; \quad h = h_f + (x)h_{fg}$$

#### Mass total,

$$m_{total} = m_f + m_g$$

#### Ideal gas equation

$$PV = mRT; \quad Pv = RT$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

#### General Energy Balance

$$E_{in} - E_{out} = \Delta E_{system}$$

$$\Delta E_{system} = \Delta U + \Delta KE + \Delta PE$$

#### Energy Balance for a closed system, constant volume process

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

$$\text{Ideal gas: } Q - W = mc_v(T_2 - T_1)$$

#### Energy Balance for a constant pressure process

$$W_b + \Delta U = \Delta H$$

$$Q - W_{other} = \Delta H + \Delta KE + \Delta PE$$

$$\text{Ideal gas: } Q - W = mc_p(T_2 - T_1)$$

#### Conservation of mass and energy equations for steady-flow process

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

$$\dot{Q} - \dot{W} = \sum_{out} \dot{m} [h + V^2/2 + gz] - \sum_{in} \dot{m} [h + V^2/2 + gz]$$

$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m} \left( h_1 + \frac{V_1^2}{2} + gz_1 \right) = \dot{Q}_{out} + \dot{W}_{out} + \dot{m} \left( h_2 + \frac{V_2^2}{2} + gz_2 \right)$$

$$\text{Boundary work (} P = \text{constant), } W_b = mP_0(v_2 - v_1)$$

$$\text{Boundary work (} T = \text{constant), } W_b = P_1V_1 \ln \left( \frac{V_2}{V_1} \right)$$

#### Polytropic Process, $PV^n = C$

$$\text{Boundary work (Polytropic), } W_b = \frac{P_1V_1 - P_2V_2}{1-n}$$

**Mass flow rate**

$$\dot{m} = \rho AV = \rho \dot{V} = \frac{\dot{V}}{v}$$

**Volume flow rate**

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

**Thermal efficiency of a Heat Engine**

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

**Coefficient of Performance of a Refrigerator and Heat Pump**

$$COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L}$$

**Carnot Heat Engine**

$$\eta_{th,Carnot} = \eta_{th,rev} = 1 - \frac{T_L}{T_H}$$

**Carnot Refrigerators and Heat Pumps**

$$COP_{R,carnot} = \frac{1}{\frac{T_H}{T_L} - 1}$$

$$COP_{HP,carnot} = \frac{1}{1 - \frac{T_L}{T_H}}$$

**Isentropic Process (Cold-air standard)**

$$s_2 = s_1$$

$$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^{k-1}$$

$$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$

$$\left(\frac{P_2}{P_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^k$$

$$\left(\frac{P_2}{P_1}\right)_{s=\text{const.}} = \frac{P_{r2}}{P_{r1}}$$

$$\left(\frac{v_2}{v_1}\right)_{s=\text{const.}} = \frac{v_{r2}}{v_{r1}}$$

### Power Cycles

$$\text{Compression ratio, } r = \frac{V_{\max}}{V_{\min}} = \frac{V_{BDC}}{V_{TDC}} = \frac{V_1}{V_2} = \frac{v_1}{v_2} = \frac{v_{r1}}{v_{r2}}$$

$$MEP = \frac{W_{net}}{V_{\max} - V_{\min}} = \frac{w_{net}}{v_{\max} - v_{\min}} = \frac{w_{net}}{v \left(1 - \frac{1}{r}\right)}$$

### Otto Cycle

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_{exit} - h_{inlet}$$

$$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$$

$$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$

$$\text{Thermal efficiency, } \eta_{th,Otto} = \frac{W_{net}}{Q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

$$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}} = \text{cold-air standard}$$

### Diesel Cycle

$$q_{in} = w_{b,out} + (u_3 - u_2) = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$$

$$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$

$$\text{Cutoff ratio, } r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$$

$$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}} \left[ \frac{r_c^k - 1}{k(r_c - 1)} \right] = \text{cold-air standard}$$

### Joule-Brayton Cycle

$$q_{in} = w_{b,out} + (u_3 - u_2) = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$$

$$q_{out} = h_4 - h_1 = c_p(T_4 - T_1)$$

$$\text{Pressure ratio, } r_p = \frac{P_2}{P_1} = \frac{P_{r2}}{P_{r1}}$$

$$\eta_{th,Brayton} = 1 - \frac{1}{r_p^{\frac{k-1}{k}}} = \text{cold-air standard}$$

### Rankine Cycle

$$w_{pump,in} = h_2 - h_1 = v_1(P_2 - P_1)$$

$$q_{in} = h_3 - h_2$$

$$w_{turb,out} = h_3 - h_4$$

$$q_{out} = h_4 - h_1$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

$$w_{net} = q_{in} - q_{out} = w_{turb,in} - w_{pump,in}$$

### Reheat Rankine Cycle

$$\text{Total heat input, } q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$$

$$q_{out} = h_6 - h_1$$

$$w_{turb,out} = w_{turb,I} + w_{turb,II} = (h_3 - h_4) + (h_5 - h_6)$$

### Refrigeration Cycle

$$W_{net,out} = Q_H - Q_L$$

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

$$COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{h_2 - h_3}{h_2 - h_1}$$

$$COP_{HP} = COP_R + 1$$

### Combustion

$$\text{Air Fuel Ratio (AF)} = \frac{m_{air}}{m_{fuel}} = \frac{(NM)_{air}}{(NM)_C + (NM)_{H_2}}$$

# Conversion Factors

DIMENSION	METRIC	METRIC/ENGLISH
Acceleration	1 m/s <sup>2</sup> = 100 cm/s <sup>2</sup>	1 m/s <sup>2</sup> = 3.2808 ft/s <sup>2</sup> 1 ft/s <sup>2</sup> = 0.3048* m/s <sup>2</sup>
Area	1 m <sup>2</sup> = 10 <sup>4</sup> cm <sup>2</sup> = 10 <sup>6</sup> mm <sup>2</sup> = 10 <sup>-6</sup> km <sup>2</sup>	1 m <sup>2</sup> = 1550 in <sup>2</sup> = 10.764 ft <sup>2</sup> 1 ft <sup>2</sup> = 144 in <sup>2</sup> = 0.09290304* m <sup>2</sup>
Density	1 g/cm <sup>3</sup> = 1 kg/L = 1000 kg/m <sup>3</sup>	1 g/cm <sup>3</sup> = 62.428 lbf/ft <sup>3</sup> = 0.036127 lbf/in <sup>3</sup> 1 lbf/in <sup>3</sup> = 1728 lbf/ft <sup>3</sup> 1 kg/m <sup>3</sup> = 0.062428 lbf/ft <sup>3</sup>
Energy, heat, work, internal energy, enthalpy	1 kJ = 1000 J = 1000 N · m = 1 kPa · m <sup>3</sup> 1 kJ/kg = 1000 m <sup>2</sup> /s <sup>2</sup> 1 kWh = 3600 kJ 1 cal <sup>1</sup> = 4.184 J 1 IT cal <sup>1</sup> = 4.1868 J 1 Cal <sup>f</sup> = 4.1868 kJ	1 kJ = 0.94782 Btu 1 Btu = 1.055056 kJ = 5.40395 psia · ft <sup>3</sup> = 778.169 lbf · ft 1 Btu/lbm = 25.037 ft <sup>2</sup> /s <sup>2</sup> = 2.326* kJ/kg 1 kJ/kg = 0.430 Btu/lbm 1 kWh = 3412.14 Btu 1 therm = 10 <sup>9</sup> Btu = 1.055 × 10 <sup>5</sup> kJ (natural gas)
Force	1 N = 1 kg · m/s <sup>2</sup> = 10 <sup>5</sup> dyne 1 kgf = 9.80665 N	1 N = 0.22481 lbf 1 lbf = 32.174 lbf · ft/s <sup>2</sup> = 4.44822 N
Heat flux	1 W/cm <sup>2</sup> = 10 <sup>4</sup> W/m <sup>2</sup>	1 W/m <sup>2</sup> = 0.3171 Btu/h · ft <sup>2</sup>
Heat transfer coefficient	1 W/m <sup>2</sup> · °C = 1 W/m <sup>2</sup> · K	1 W/m <sup>2</sup> · °C = 0.17612 Btu/h · ft <sup>2</sup> · °F
Length	1 m = 100 cm = 1000 mm = 10 <sup>9</sup> μm 1 km = 1000 m	1 m = 39.370 in = 3.2808 ft = 1.0926 yd 1 ft = 12 in = 0.3048* m 1 mile = 5280 ft = 1.6093 km 1 in = 2.54* cm
Mass	1 kg = 1000 g 1 metric ton = 1000 kg	1 kg = 2.2046226 lbf 1 lbf = 0.45359237* kg 1 ounce = 28.3495 g 1 slug = 32.174 lbf = 14.5939 kg 1 short ton = 2000 lbf = 907.1847 kg
Power, heat transfer rate	1 W = 1 J/s 1 kW = 1000 W = 1.341 hp 1 hp <sup>f</sup> = 745.7 W	1 kW = 3412.14 Btu/h = 737.56 lbf · ft/s 1 hp = 550 lbf · ft/s = 0.7068 Btu/s = 42.41 Btu/min = 2544.5 Btu/h = 0.74570 kW 1 boiler hp = 33,475 Btu/h 1 Btu/h = 1.055056 kJ/h 1 ton of refrigeration = 200 Btu/min
Pressure	1 Pa = 1 N/m <sup>2</sup> 1 kPa = 10 <sup>3</sup> Pa = 10 <sup>-3</sup> MPa 1 atm = 101.325 kPa = 1.01325 bars = 760 mm Hg at 0°C = 1.03323 kgf/cm <sup>2</sup> 1 mm Hg = 0.1333 kPa	1 Pa = 1.4504 × 10 <sup>-4</sup> psia = 0.020886 lbf/ft <sup>2</sup> 1 psi = 144 lbf/ft <sup>2</sup> = 6.894757 kPa 1 atm = 14.696 psia = 29.92 in Hg at 30°F 1 in Hg = 3.387 kPa
Specific heat	1 kJ/kg · °C = 1 kJ/kg · K = 1 J/g · °C	1 Btu/lbm · °F = 4.1868 kJ/kg · °C 1 Btu/lbmol · R = 4.1868 kJ/kmol · K 1 kJ/kg · °C = 0.23885 Btu/lbm · °F = 0.23885 Btu/lbm · R

\*Exact conversion factor between metric and English units.

<sup>1</sup>Calorie is originally defined as the amount of heat needed to raise the temperature of 1 g of water by 1°C, but it varies with temperature. The international steam table (IT) calorie (generally preferred by engineers) is exactly 4.1868 J by definition and corresponds to the specific heat of water at 15°C. The thermochemical calorie (generally preferred by physicists) is exactly 4.184 J by definition and corresponds to the specific heat of water at room temperature. The difference between the two is about 0.06 percent, which is negligible. The capitalized Calorie used by nutritionists is actually a kilocalorie (1000 IT calories).

DIMENSION	METRIC	METRIC/ENGLISH
Specific volume	$1 \text{ m}^3/\text{kg} = 1000 \text{ L}/\text{kg} = 1000 \text{ cm}^3/\text{g}$	$1 \text{ m}^3/\text{kg} = 16.02 \text{ ft}^3/\text{lbm}$ $1 \text{ ft}^3/\text{lbm} = 0.062428 \text{ m}^3/\text{kg}$
Temperature	$T(\text{K}) = T(^{\circ}\text{C}) + 273.15$ $\Delta T(\text{K}) = \Delta T(^{\circ}\text{C})$	$T(\text{R}) = T(^{\circ}\text{F}) + 459.67 = 1.8T(\text{K})$ $T(^{\circ}\text{F}) = 1.8 T(^{\circ}\text{C}) + 32$ $\Delta T(^{\circ}\text{F}) = \Delta T(\text{R}) = 1.8 \Delta T(\text{K})$
Thermal conductivity	$1 \text{ W}/\text{m} \cdot ^{\circ}\text{C} = 1 \text{ W}/\text{m} \cdot \text{K}$	$1 \text{ W}/\text{m} \cdot ^{\circ}\text{C} = 0.57782 \text{ Btu}/\text{h} \cdot \text{ft} \cdot ^{\circ}\text{F}$
Velocity	$1 \text{ m}/\text{s} = 3.60 \text{ km}/\text{h}$	$1 \text{ m}/\text{s} = 3.2808 \text{ ft}/\text{s} = 2.237 \text{ mi}/\text{h}$ $1 \text{ mi}/\text{h} = 1.46667 \text{ ft}/\text{s}$ $1 \text{ mi}/\text{h} = 1.6093 \text{ km}/\text{h}$
Volume	$1 \text{ m}^3 = 1000 \text{ L} = 10^6 \text{ cm}^3 (\text{cc})$	$1 \text{ m}^3 = 6.1024 \times 10^4 \text{ in}^3 = 35.315 \text{ ft}^3$ $= 264.17 \text{ gal (U.S.)}$ $1 \text{ U.S. gallon} = 231 \text{ in}^3 = 3.7854 \text{ L}$ $1 \text{ fl ounce} = 29.5735 \text{ cm}^3 = 0.0295735 \text{ L}$ $1 \text{ U.S. gallon} = 128 \text{ fl ounces}$
Volume flow rate	$1 \text{ m}^3/\text{s} = 60,000 \text{ L}/\text{min} = 10^6 \text{ cm}^3/\text{s}$	$1 \text{ m}^3/\text{s} = 15,850 \text{ gal}/\text{min (gpm)} = 35.315 \text{ ft}^3/\text{s}$ $= 2118.9 \text{ ft}^3/\text{min (cfm)}$

\*Mechanical horsepower. The electrical horsepower is taken to be exactly 746 W.

### Some Physical Constants

Universal gas constant	$R_u = 8.31447 \text{ kJ}/\text{kmol} \cdot \text{K}$ $= 8.31447 \text{ kPa} \cdot \text{m}^3/\text{kmol} \cdot \text{K}$ $= 0.0831447 \text{ bar} \cdot \text{m}^3/\text{kmol} \cdot \text{K}$ $= 82.05 \text{ L} \cdot \text{atm}/\text{kmol} \cdot \text{K}$ $= 1.9858 \text{ Btu}/\text{lbmol} \cdot \text{R}$ $= 1545.37 \text{ ft} \cdot \text{lb}/\text{lbmol} \cdot \text{R}$ $= 10.73 \text{ psia} \cdot \text{ft}^3/\text{lbmol} \cdot \text{R}$
Standard acceleration of gravity	$g = 9.80665 \text{ m}/\text{s}^2$ $= 32.174 \text{ ft}/\text{s}^2$
Standard atmospheric pressure	$1 \text{ atm} = 101.325 \text{ kPa}$ $= 1.01325 \text{ bar}$ $= 14.696 \text{ psia}$ $= 760 \text{ mm Hg (0}^{\circ}\text{C)}$ $= 29.9213 \text{ in Hg (32}^{\circ}\text{F)}$ $= 10.3323 \text{ m H}_2\text{O (4}^{\circ}\text{C)}$
Stefan-Boltzmann constant	$\sigma = 5.6704 \times 10^{-8} \text{ W}/\text{m}^2 \cdot \text{K}^4$ $= 0.1714 \times 10^{-8} \text{ Btu}/\text{h} \cdot \text{ft}^2 \cdot \text{R}^4$
Boltzmann's constant	$k = 1.380650 \times 10^{-23} \text{ J}/\text{K}$
Speed of light in vacuum	$c_o = 2.9979 \times 10^8 \text{ m}/\text{s}$ $= 9.836 \times 10^8 \text{ ft}/\text{s}$
Speed of sound in dry air at 0°C and 1 atm	$c = 331.36 \text{ m}/\text{s}$ $= 1089 \text{ ft}/\text{s}$
Heat of fusion of water at 1 atm	$h_{if} = 333.7 \text{ kJ}/\text{kg}$ $= 143.5 \text{ Btu}/\text{lbm}$
Enthalpy of vaporization of water at 1 atm	$h_{fg} = 2256.5 \text{ kJ}/\text{kg}$ $= 970.12 \text{ Btu}/\text{lbm}$