



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

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**FINAL EXAMINATION**  
**JULY 2025 SEMESTER SESSION**

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**SUBJECT CODE** : LED22503

**SUBJECT TITLE** : FUNDAMENTAL THERMODYNAMICS

**PROGRAMME NAME** : DET IN ELECTRICAL AND ELECTRONICS (MARINE)  
(FOR MPU: PROGRAMME LEVEL)

**TIME / DURATION** : 09.00 AM – 12.00 PM  
(3 HOURS)

**DATE** : 16 DECEMBER 2025

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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 consists of **TWO (2) Sections**; Section A and Section B.
3. Answer **ALL** questions in Section A. For Section B, answer **TWO (2) questions ONLY**.
4. Please write your answers on the answer booklet provided.
5. Answer all questions in English language **ONLY**.
6. Answer should be written in blue or black ink except for sketches, graphic and illustration.
7. Thermodynamics Table of Properties and Formula has been appended for your reference.

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**THERE ARE 7 PAGES OF QUESTIONS, INCLUDING 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 basic concept of thermodynamics to systems and processes.

(a) Define the following:

- i. Closed system
- ii. Open system
- iii. Adiabatic system

(6 marks)

(b) Convert the following units:

- i. 3500 liter/min into  $\text{m}^3/\text{s}$
- ii. 50 psi into kPa
- iii.  $0.5 \text{ lbm}/\text{ft}^3$  into  $\text{kg}/\text{m}^3$

(6 marks)

(c) A deep-sea diver descends into a freshwater lake and experiences a gauge pressure of 100,000 kPa. Given that the atmospheric pressure at the surface is 101 kPa and the density of freshwater is  $1000 \text{ kg}/\text{m}^3$ , determine the:

- i. depth ( $h$ ) of the diver in meters.
- ii. absolute pressure, ( $P_{\text{abs}}$ ) acting on the diver in kPa

(5 marks)

(3 marks)

**Question 2**

With reference to forms of energy and energy transfer of a system.

(a) Define the following:

- i. Potential energy
- ii. Flow energy
- iii. Mechanical energy,

(6 marks)

(b) A piston-cylinder device containing water is being heated, causing the piston to rise. During this heating process:

- 200 kJ of heat is transferred to the water,  $Q_{in}$ .
- 20 kJ of heat is lost to the surroundings,  $Q_{out}$ .
- The vapor does 25 kJ of work as it expands,  $W_{out}$ .

Calculate the change in the internal energy of the water for this process.

(6 marks)

(c) A river flows toward a reservoir at an average velocity of 2 m/s ( $V$ ) with a volume flow rate of 15 m<sup>3</sup>/s ( $\dot{V}$ ) at a location 600 m ( $z$ ) above the reservoir surface (height of waterfall). Determine the:

- i. total mechanical energy ( $e_{mech}$ ) of the river water per unit mass and

(2 marks)

- ii. power generation potential ( $\dot{E}$ ) of the water flow at that location, assuming the water could be fully utilized for power generation for dam.

(6 marks)

**Question 3**

With reference to Laws of thermodynamics, energies, systems, pure substance properties and entropy.

(a) Define the following terms:

- i. Compressed liquid
- ii. Saturated liquid
- iii. Saturated vapor

(6 marks)

(b) A closed, well-insulated vessel contains water at a pressure of 175 kPa and an internal energy of 1400 kJ/kg.

i. Based on the given properties, determine the phase of the water (compressed liquid, saturated mixture, or superheated vapor).

(3 marks)

ii. Explain briefly how you determined the phase using thermodynamic property tables.

(3 marks)

(c) Complete Table 1 below of thermodynamics properties for water. Show all the calculations involved. Use the following abbreviations where needed:

- CL – Compressed (Subcooled) liquid
- SL – Saturated liquid
- SM – Saturated Mixture
- SV – Saturated Vapor
- SHV – Superheated Vapor
- NA – Not applicable

Table 1: Thermodynamics properties for water

P (kPa)	T(°C)	u, kJ/kg	h, kJ/kg	Phase Description	Quality (x)
400	(a)	(b)	3000	(c)	(d)
5000	80	(e)	(f)	(g)	(h)

(8 marks)

**SECTION B (Total: 40 marks)**

**INSTRUCTION: Answer only TWO questions.**

**Please use the answer booklet provided.**

**Question 4**

With reference to Laws of thermodynamics, energies, systems, pure substance properties and entropy.

(a) Match each region or phase (Column A) with its correct description name (Column B)

Column A: Regions / Phases		Column B: Descriptions
i. Subcooled Liquid		A. Substance is in fully liquid and is about to vaporize
ii. Saturated liquid		B. Substance is in both liquid and vapor phases
iii. Saturated Mixture (Liquid + Vapor)		C. Substance is fully liquid, and is not about to vaporize
iv. Saturated Vapor		D. Substance is fully vapor and not about to condense
v. Superheated Vapor		E. liquid and gas phases are indistinguishable
vi. Critical Point		F. A vapor that is about to condense

(6 marks)

- (b) A 500-liter rigid tank contains 3 kg of air at 25°C. The atmospheric pressure is 97 kPa. Match each term or value from the situation with its correct description. Write the letter of your answer (A – F) in the space provided next to each number.

Column A		Column B: Descriptions
i. Rigid tank		A. Temperature used to calculate the pressure of the air inside the tank
ii. 500 liters		B. Subtracted from the absolute pressure to calculate the gauge pressure
iii. 3 kg of air		C. Volume of the air stored in the tank
iv. 25°C		D. Mass used to determine air density or specific volume
v. Atmospheric pressure (97kPa)		E. Pressure measured relative to atmospheric pressure
vi. Gauge pressure		F. Indicates that the volume of the system remains constant

(6 marks)

- (c) A mass of 0.1 kg of helium is contained in a rigid vessel with a volume of 0.2 m<sup>3</sup>, and the pressure is measured to be 350 kPa. The vessel is heated until the pressure is 700 kPa.

i. Determine the initial temperature,  $T_1$  (K). (3 marks)

ii. Determine the final temperature,  $T_2$  (K). (3 marks)

iii. Calculate the change in temperature of helium,  $\Delta T$  (in °C and K) (2 marks)

**Question 5**

With reference to Laws of thermodynamics, energies, systems, pure substance properties and entropy.

Air enters a 28-cm pipe steadily with the following inlet and exit conditions. Air is heated as it flows as shown in Figure 1.

Inlet (State 1):

Pressure  $P_1 = 200$  kPa  
 Temperature  $T_1 = 20^\circ\text{C}$   
 Velocity  $V_1 = 5$  m/s  
 Diameter,  $D_1 = 28$  cm

Exit (State 2):

Pressure  $P_2 = 180$  kPa  
 Temperature  $T_2 = 40^\circ\text{C}$   
 Diameter,  $D_2 = 28$  cm

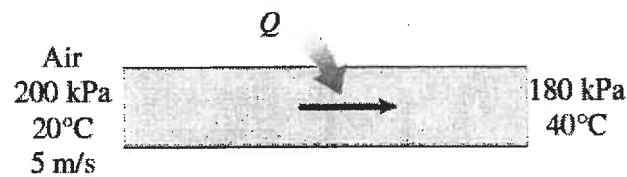


Figure 1: Air flow steadily in pipe

Determine the following:

- (a) volume flowrate at the inlet pipe,  $\dot{V}_1$  ( $\text{m}^3/\text{s}$ ) (5 marks)
- (b) mass flowrate of air,  $\dot{m}$  (kg/s) (7 marks)
- (c) velocity at the exit,  $V_2$  (m/s) (5 marks)
- (d) volume flowrate at the exit,  $\dot{V}_2$  ( $\text{m}^3/\text{s}$ ) (3 marks)

**Question 6**

With reference to the second law of thermodynamics to cyclic devices.

(a) A heat pump and a refrigerator operate on the same basic reversed Carnot cycle but serve different purposes.

- i. Explain the working principle of a heat pump and a refrigerator, highlighting the direction of heat transfer and the role of each main component in the cycle.

(6 marks)

- ii. Explain the similarities and differences between a heat pump and a refrigerator in terms of their function, purpose, and performance (COP).

(6 marks)

(b) An air conditioner removes heat steadily from a house at a rate of 750 kJ/min ( $Q_L$ ), while drawing electric power at a rate of 5.25 kW ( $W_{in}$ ). Determine:

- i. the COP of this air conditioner and,

(3 marks)

- ii. rate of heat transfer to the outside air,  $Q_H$  (kW).

(5 marks)

**END OF EXAMINATION PAPER**



## THERMODYNAMICS FORMULAE

<b>First Law of Thermodynamics</b>
$\text{Quality, } x = \frac{m_g}{m_{total}} = \frac{v - v_f}{v_{fg}}$ $v = v_f + (x)v_{fg}; \quad u = u_f + (x)u_{fg}; \quad h = h_f + (x)h_{fg}$
<p><b>Mass total,</b></p> $m_{total} = m_f + m_g$
<p><b>Ideal gas equation</b></p> $PV = mRT; \quad Pv = RT$ $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
<p><b>General Energy Balance</b></p> $E_{in} - E_{out} = \Delta E_{system}$
$\Delta E_{system} = \Delta U + \Delta KE + \Delta PE$
<p><b>Energy Balance for a closed system, constant volume process</b></p> $Q - W = \Delta U + \Delta KE + \Delta PE$ <p><i>Ideal gas:</i> <math>Q - W = mc_v(T_2 - T_1)</math></p>
<p><b>Energy Balance for a constant pressure process</b></p> $W_b + \Delta U = \Delta H$ $Q - W_{other} = \Delta H + \Delta KE + \Delta PE$ <p><i>Ideal gas:</i> <math>Q - W = mc_p(T_2 - T_1)</math></p>
<p><b>Conservation of mass and energy equations for steady-flow process</b></p> $\sum \dot{m}_{in} = \sum \dot{m}_{out}$ $\dot{Q} - \dot{W} = \sum_{out} \dot{m} [h + V^2/2 + gz] - \sum_{in} \dot{m} [h + V^2/2 + gz]$ $\dot{Q}_{in} + \dot{W}_{in} + \dot{m} \left( h_1 + \frac{V_1^2}{2} + gz_1 \right) = \dot{Q}_{out} + \dot{W}_{out} + \dot{m} \left( h_2 + \frac{V_2^2}{2} + gz_2 \right)$
<p><b>Boundary work (<math>P = \text{constant}</math>), <math>W_b = mP_0(v_2 - v_1)</math></b></p>
<p><b>Boundary work (<math>T = \text{constant}</math>), <math>W_b = P_1V_1 \ln \left( \frac{V_2}{V_1} \right)</math></b></p>
<p><b>Polytropic Process, <math>PV^n = C</math></b></p> <p><b>Boundary work (Polytropic), <math>W_b = \frac{P_1V_1 - P_2V_2}{1-n}</math></b></p>

**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**

$$s_2 = s_1$$

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

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

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

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

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

### 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

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

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

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

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

### Rankine Cycle

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

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

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

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

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

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

### 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

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

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

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

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

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

## 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 lbm/ft <sup>3</sup> = 0.036127 lbm/in <sup>3</sup> 1 lbm/in <sup>3</sup> = 1728 lbm/ft <sup>3</sup> 1 kg/m <sup>3</sup> = 0.062428 lbm/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>†</sup> = 4.184 J 1 IT cal <sup>†</sup> = 4.1868 J 1 Cal <sup>†</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>5</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 lbm · 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>6</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 lbm 1 lbm = 0.45359237* kg 1 ounce = 28.3495 g 1 slug = 32.174 lbm = 14.5939 kg 1 short ton = 2000 lbm = 907.1847 kg
Power, heat transfer rate	1 W = 1 J/s 1 kW = 1000 W = 1.341 hp 1 hp <sup>‡</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>†</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	$T(\text{K}) = T(^{\circ}\text{C}) + 273.15$ $\Delta T(\text{K}) = \Delta T(^{\circ}\text{C})$	$T(\text{R}) = T(^{\circ}\text{F}) + 459.67 = 1.8 T(\text{K})$ $T(^{\circ}\text{F}) = 1.8 T(^{\circ}\text{C}) + 32$ $\Delta T(^{\circ}\text{F}) = \Delta T(\text{R}) = 1.8 \Delta T(\text{K})$
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	$R_u = 8.31447 \text{ kJ}/\text{kmol} \cdot \text{K}$ $= 8.31447 \text{ kPa} \cdot \text{m}^3/\text{kmol} \cdot \text{K}$ $= 0.0831447 \text{ bar} \cdot \text{m}^3/\text{kmol} \cdot \text{K}$ $= 82.05 \text{ L} \cdot \text{atm}/\text{kmol} \cdot \text{K}$ $= 1.9858 \text{ Btu}/\text{lbmol} \cdot \text{R}$ $= 1545.37 \text{ ft} \cdot \text{lbf}/\text{lbmol} \cdot \text{R}$ $= 10.73 \text{ psia} \cdot \text{ft}^3/\text{lbmol} \cdot \text{R}$
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 $0^{\circ}\text{C}$ 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	$h_{fg} = 2256.5 \text{ kJ}/\text{kg}$ $= 970.12 \text{ Btu}/\text{lbm}$