UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
FEBRUARY 2025 SEMESTER SESSION

SUBJECT CODE	: **LMD14203**
SUBJECT TITLE	: **APPLIED THERMODYNAMICS**
PROGRAMME NAME (FOR MPU: PROGRAMME LEVEL)	: **DIPLOMA OF ENGINEERING TECHNOLOGY IN MARINE ENGINEERING**
TIME / DURATION	: **09.00AM - 12.00PM** **(3 HOURS)**
DATE	: **1 JULY 2025**

INSTRUCTIONS TO CANDIDATES

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 of black ink except for sketching, graphic and illustration.

8. Steam Table of Properties and Formula has been appended for your reference.

THERE ARE 5 PAGES OF QUESTIONS, EXCLUDING THIS PAGE.

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, η_{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 m³. 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 are used for air. (Given $R = 0.287 \frac{kJ}{kg.K}$; $c_v = 0.718 \frac{kJ}{kg.K}$)
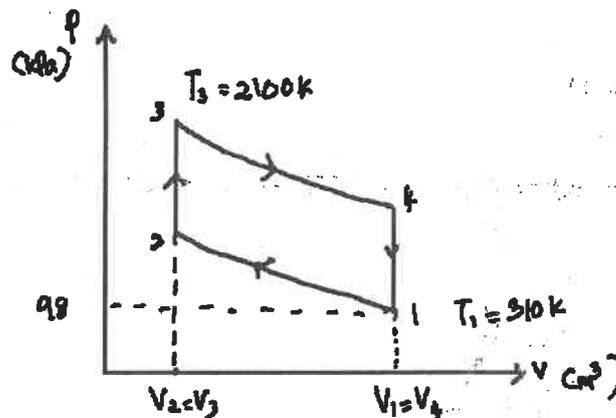

Figure 4: P-v diagram of an ideal Otto cycle

(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 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), in the boiler and 30 kPa (P_4), 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:

i. The moisture content at the exit turbine.

(6 marks)

ii. 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) = 0.8 MPa

Evaporator pressure (P_4)= 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:

i. The heat absorbed (q_L) from the cold medium in kJ/kg unit.

(5 marks)

ii. The refrigerator coefficient of performance, (COP_R).

(10 marks)

END OF EXAMINATION PAPER

THERMODYNAMICS FORMULAE

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

Mass flow rate
$$\dot{m} = \rho A V = \rho \dot{V} = \frac{\dot{V}}{v}$$
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)
$$s_2 = s_1$$
$$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^{k-1}$$
$$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$
$$\left(\frac{P_2}{P_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^{k}$$

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

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

Power Cycles

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

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

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	$1 \text{ m/s}^2 = 100 \text{ cm/s}^2$	$1 \text{ m/s}^2 = 3.2808 \text{ ft/s}^2$ $1 \text{ ft/s}^2 = 0.3048^* \text{ m/s}^2$
Area	$1 \text{ m}^2 = 10^4 \text{ cm}^2 = 10^6 \text{ mm}^2 = 10^{-6} \text{ km}^2$	$1 \text{ m}^2 = 1550 \text{ in}^2 = 10.764 \text{ ft}^2$ $1 \text{ ft}^2 = 144 \text{ in}^2 = 0.09290304^* \text{ m}^2$
Density	$1 \text{ g/cm}^3 = 1 \text{ kg/L} = 1000 \text{ kg/m}^3$	$1 \text{ g/cm}^3 = 62.428 \text{ lbm/ft}^3 = 0.036127 \text{ lbm/in}^3$ $1 \text{ lbm/in}^3 = 1728 \text{ lbm/ft}^3$ $1 \text{ kg/m}^3 = 0.062428 \text{ lbm/ft}^3$
Energy, heat, work, internal energy, enthalpy	$1 \text{ kJ} = 1000 \text{ J} = 1000 \text{ N} \cdot \text{m} = 1 \text{ kPa} \cdot \text{m}^3$ $1 \text{ kJ/kg} = 1000 \text{ m}^2/\text{s}^2$ $1 \text{ kWh} = 3600 \text{ kJ}$ $1 \text{ cal}^\dagger = 4.184 \text{ J}$ $1 \text{ IT cal}^\dagger = 4.1868 \text{ J}$ $1 \text{ Cal}^\dagger = 4.1868 \text{ kJ}$	$1 \text{ kJ} = 0.94782 \text{ Btu}$ $1 \text{ Btu} = 1.055056 \text{ kJ}$ $\quad = 5.40395 \text{ psia} \cdot \text{ft}^3 = 778.169 \text{ lbf} \cdot \text{ft}$ $1 \text{ Btu/lbm} = 25,037 \text{ ft}^2/\text{s}^2 = 2.326^* \text{ kJ/kg}$ $1 \text{ kJ/kg} = 0.430 \text{ Btu/lbm}$ $1 \text{ kWh} = 3412.14 \text{ Btu}$ $1 \text{ therm} = 10^5 \text{ Btu} = 1.055 \times 10^5 \text{ kJ}$ $\quad$ (natural gas)
Force	$1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2 = 10^5 \text{ dyne}$ $1 \text{ kgf} = 9.80665 \text{ N}$	$1 \text{ N} = 0.22481 \text{ lbf}$ $1 \text{ lbf} = 32.174 \text{ lbm} \cdot \text{ft/s}^2 = 4.44822 \text{ N}$
Heat flux	$1 \text{ W/cm}^2 = 10^4 \text{ W/m}^2$	$1 \text{ W/m}^2 = 0.3171 \text{ Btu/h} \cdot \text{ft}^2$
Heat transfer coefficient	$1 \text{ W/m}^2 \cdot {}^\circ\text{C} = 1 \text{ W/m}^2 \cdot \text{K}$	$1 \text{ W/m}^2 \cdot {}^\circ\text{C} = 0.17612 \text{ Btu/h} \cdot \text{ft}^2 \cdot {}^\circ\text{F}$
Length	$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} = 10^6 \text{ }\mu\text{m}$ $1 \text{ km} = 1000 \text{ m}$	$1 \text{ m} = 39.370 \text{ in} = 3.2808 \text{ ft} = 1.0926 \text{ yd}$ $1 \text{ ft} = 12 \text{ in} = 0.3048^* \text{ m}$ $1 \text{ mile} = 5280 \text{ ft} = 1.6093 \text{ km}$ $1 \text{ in} = 2.54^* \text{ cm}$
Mass	$1 \text{ kg} = 1000 \text{ g}$ $1 \text{ metric ton} = 1000 \text{ kg}$	$1 \text{ kg} = 2.2046226 \text{ lbm}$ $1 \text{ lbm} = 0.45359237^* \text{ kg}$ $1 \text{ ounce} = 28.3495 \text{ g}$ $1 \text{ slug} = 32.174 \text{ lbm} = 14.5939 \text{ kg}$ $1 \text{ short ton} = 2000 \text{ lbm} = 907.1847 \text{ kg}$
Power, heat transfer rate	$1 \text{ W} = 1 \text{ J/s}$ $1 \text{ kW} = 1000 \text{ W} = 1.341 \text{ hp}$ $1 \text{ hp}^\dagger = 745.7 \text{ W}$	$1 \text{ kW} = 3412.14 \text{ Btu/h}$ $\quad = 737.56 \text{ lbf} \cdot \text{ft/s}$ $1 \text{ hp} = 550 \text{ lbf} \cdot \text{ft/s} = 0.7068 \text{ Btu/s}$ $\quad = 42.41 \text{ Btu/min} = 2544.5 \text{ Btu/h}$ $\quad = 0.74570 \text{ kW}$ $1 \text{ boiler hp} = 33,475 \text{ Btu/h}$ $1 \text{ Btu/h} = 1.055056 \text{ kJ/h}$ $1 \text{ ton of refrigeration} = 200 \text{ Btu/min}$
Pressure	$1 \text{ Pa} = 1 \text{ N/m}^2$ $1 \text{ kPa} = 10^3 \text{ Pa} = 10^{-3} \text{ MPa}$ $1 \text{ atm} = 101.325 \text{ kPa} = 1.01325 \text{ bars}$ $\quad = 760 \text{ mm Hg at } 0^\circ\text{C}$ $\quad = 1.03323 \text{ kgf/cm}^2$ $1 \text{ mm Hg} = 0.1333 \text{ kPa}$	$1 \text{ Pa} = 1.4504 \times 10^{-4} \text{ psia}$ $\quad = 0.020886 \text{ lbf/ft}^2$ $1 \text{ psi} = 144 \text{ lbf/ft}^2 = 6.894757 \text{ kPa}$ $1 \text{ atm} = 14.696 \text{ psia} = 29.92 \text{ in Hg at } 30^\circ\text{F}$ $1 \text{ in Hg} = 3.387 \text{ kPa}$
Specific heat	$1 \text{ kJ/kg} \cdot {}^\circ\text{C} = 1 \text{ kJ/kg} \cdot \text{K} = 1 \text{ J/g} \cdot {}^\circ\text{C}$	$1 \text{ Btu/lbm} \cdot {}^\circ\text{F} = 4.1868 \text{ kJ/kg} \cdot {}^\circ\text{C}$ $1 \text{ Btu/lbmol} \cdot \text{R} = 4.1868 \text{ kJ/kmol} \cdot \text{K}$ $1 \text{ kJ/kg} \cdot {}^\circ\text{C} = 0.23885 \text{ Btu/lbm} \cdot {}^\circ\text{F}$ $\quad = 0.23885 \text{ Btu/lbm} \cdot \text{R}$

*Exact conversion factor between metric and English units.

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

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

Some Physical Constants

Universal gas constant	$R_u = 8.31447\ kJ/kmol \cdot K$ $\quad = 8.31447\ kPa \cdot m^3/kmol \cdot K$ $\quad = 0.0831447\ bar \cdot m^3/kmol \cdot K$ $\quad = 82.05\ L \cdot atm/kmol \cdot K$ $\quad = 1.9858\ Btu/lbmol \cdot R$ $\quad = 1545.37\ ft \cdot lbf/lbmol \cdot R$ $\quad = 10.73\ psia \cdot ft^3/lbmol \cdot R$
Standard acceleration of gravity	$g = 9.80665\ m/s^2$ $\quad = 32.174\ ft/s^2$
Standard atmospheric pressure	$1\ atm = 101.325\ kPa$ $\quad = 1.01325\ bar$ $\quad = 14.696\ psia$ $\quad = 760\ mm\ Hg\ (0°C)$ $\quad = 29.9213\ in\ Hg\ (32°F)$ $\quad = 10.3323\ m\ H_2O\ (4°C)$
Stefan–Boltzmann constant	$\sigma = 5.6704 \times 10^{-8}\ W/m^2 \cdot K^4$ $\quad = 0.1714 \times 10^{-8}\ Btu/h \cdot ft^2 \cdot R^4$
Boltzmann's constant	$k = 1.380650 \times 10^{-23}\ J/K$
Speed of light in vacuum	$c_0 = 2.9979 \times 10^8\ m/s$ $\quad = 9.836 \times 10^8\ ft/s$
Speed of sound in dry air at 0°C and 1 atm	$c = 331.36\ m/s$ $\quad = 1089\ ft/s$
Heat of fusion of water at 1 atm	$h_{if} = 333.7\ kJ/kg$ $\quad = 143.5\ Btu/lbm$
Enthalpy of vaporization of water at 1 atm	$h_{fg} = 2256.5\ kJ/kg$ $\quad = 970.12\ Btu/lbm$