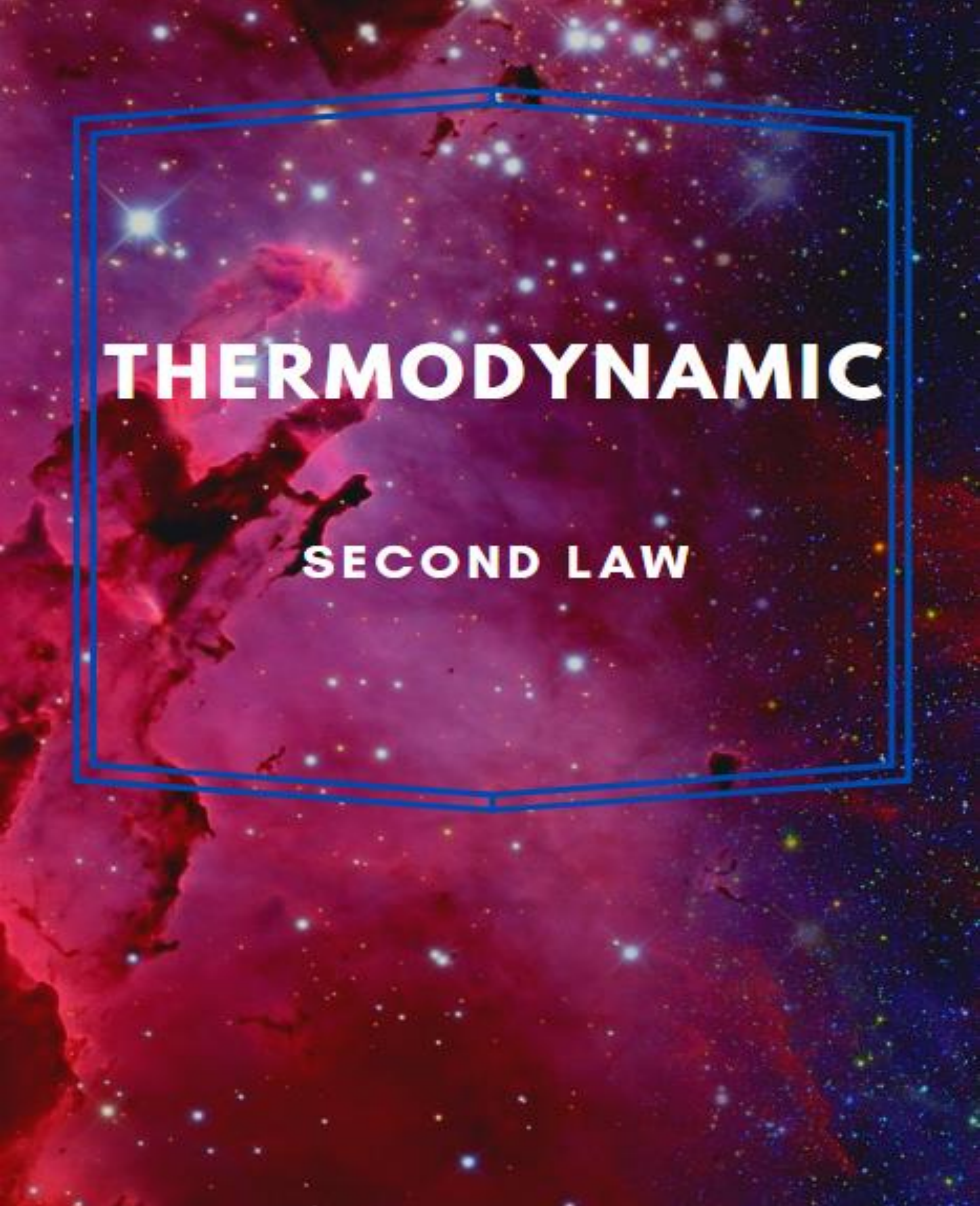

THERMODYNAMIC

SECOND LAW

NOR HISHAM | NOOR MAYAFARANIZA

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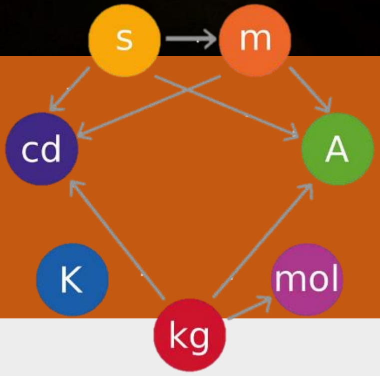
PREFACE

This books aims to students of mechanical engineering at explaining the basic concepts of thermodynamics related to heat, work, energy transformation, the characteristics for a specific thermodynamics process and contains sufficient examples to support the concepts.

The entire book is written in a simple way to enable the students understand the concepts quickly and the subject is an easy way. This book shall provide knowledge on the theory, concept and application of formula and to acquire the problem solving skills related to the respective processes.

THERMODYNAMICS
SECOND LAW

TABLE OF CONTENT



FUNDAMENTAL CONCEPTS OF THERMODYNAMICS

DEFINITION OF THERMODYNAMICS

A study about the relation between heat energy, works and the component which is all the heat energy will be converted to the works in the heat engine.

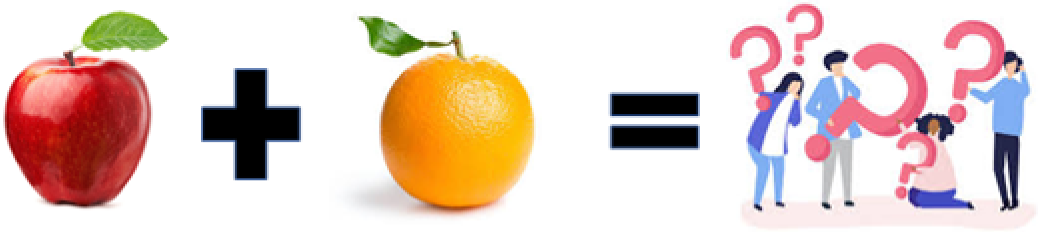
Thermodynamic :
Therme (thermo) - heat
Dynamic – mechanical movement

FUNDAMENTAL UNITS (SI)

Quantity	Unit
1. Mass, m	Kilogram (kg)
2. Time, t	Second(s)
3. Length, l	Meter (m)
4. Temperature, T	Kelvin (K) 0°C = 273K
5. Electric Current, I	Ampere (A)
6. Luminous Intensity, Iv	Candela (cd)

DIMENSIONAL HOMOGENEITY

In engineering, all equations must be dimensionally homogenous. That is, every term in an equation must have the same unit.



Answer: You can't add apples and oranges!!!

IMPERIAL UNITS

Category	Name of Unit	Measure	
Length	Inch	1/12th	ft
	Foot	1	ft
	Yard	3	ft
	Mile	5280	ft
	Nautical mile	6080	ft
Area	Acre	43,560	sq ft
Volume	Fluid ounce	1/20th	pint
	Pint	1	pint
	Quart	2	pint
	Gallon	8	pint
Weight	Ounce	1/16th	lb
	Pound	1	lb
	Stone	14	lb
	Ton	2240	lb

METRIC CONVERSIONS

1in = 25.4mm

1ft = 305mm

1yd = 0.914m

1 mile = 1.61km

1 lb (pound) = 454g

1 oz = 28.3g

DERIVED UNITS

No.	Quantity	Symbol (Unit)	Statement
1	Area	A (m^2)	
2	Volume	V (m^3)	$1m^3 = 1000L$
3	Velocity	C (m/s)	
4	Acceleration	a (m/s^2)	
5	Density	ρ (kg/m^3)	$\rho = \frac{m}{v}$; m = mass, v = volume
6	Force	F (N)	$F = ma = kg.m/s^2$
7	Pressure	P (N/m^2) = Pa	1 bar = $10^5 N/m^2$
8	Heat	Q (Joule)	1 Joule = 1Nm
9	Work	W (Joule)	1 Joule = 1Nm
10	Entropy	s	kJ/kg.K
11	Internal Energy	u	kJ/kg
12	Enthalpy	h	kJ/kg
13	Molecular weight of gas	M	kg/kmol
14	Molecular gas constant	$R_o = 8.3144$	kg/kmol.K
15	Gas constant	R	kJ/kg.K

PHYSICAL QUANTITIES

1. Force

- Formula, $F = ma$
- Unit: Newton (N)
- SI Unit: $1\ N = 1\ kg.m/s^2$

2. Energy

- Heat & Work
- Formula: $W = F \times D$
- Unit: Joule @ Nm

3. Power

- Power is the rate of energy transfer by or to system
- Formula: $P = W/t$ (J/s)
- Unit: Watt @ Nm/s

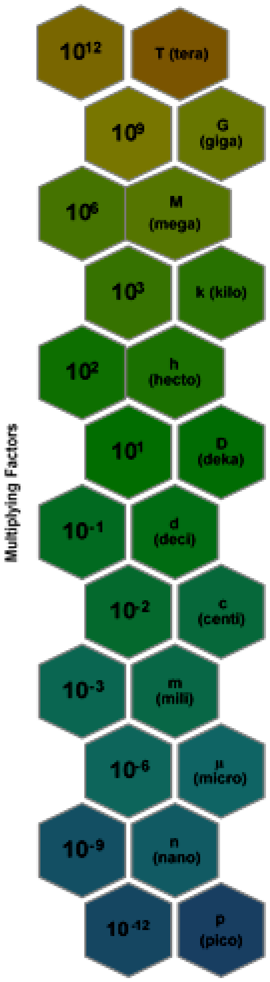
4. Pressure

- Pressure is the exerted by a fluid per unit area
- Formula: $P = F/A$
- Unit: (N/m^2), Pa @ bar

5. Density

- Density is the mass of substance per unit volume
- Unit: kg/m^3

Unit Conversions



a. 1 cm^2 >> m^2
b. 5.54 mm^3 >> m^3
c. 1.67×10^{-36}Tg >> kg
d. 25 g/mm^3 >> kg/m^3
e. 500 ml >> m^3
f. 16 m^2 >> cm^2
g. 1.2 km/m >> m/s
h. 10N/cm^2 >> kN/m^2

BASIC TERM IN THERMODYNAMICS

System

A quantity of matter or a region in space chosen for study.

Volume or any definite shape.

Divide by two:

i. Open system
ii. Closed system

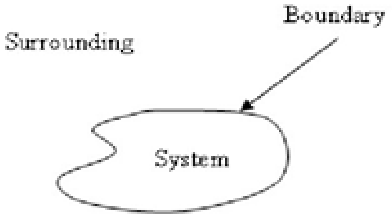
Boundry

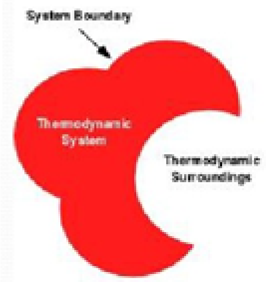
Is the surface of separation between the system and its surrounding.

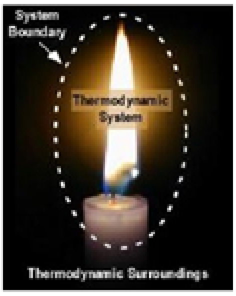
It's not take participation in any changing of the system

Surroundings

The mass or region outside the system







PROPERTIES OF SYSTEMS

Intensive Properties

Those which are independent of the size or extent of the system

Example: temperature (T), pressure (P), density (ρ).

Extensive Properties

Those whose values depend on the size or extent of the system

Example: mass (m), volume (V), internal energy (U).

Properties of Matter

			
Extensive Properties	Volume	100mL	15 mL
	Mass	99.9347 g	14.9902 g
Intensive Properties	Density	0.999 g/mL	0.999 g/mL
	Temperature	20°C	20°C

PROCESS, CYCLES AND STATE

Process

There is a change in any of the properties of the system.

A process is a transformation from one state to another.

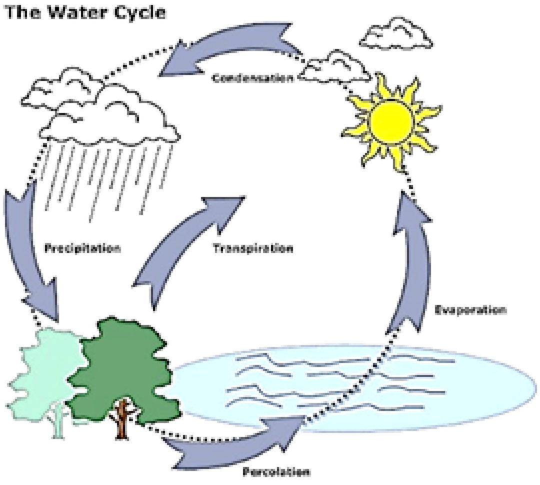
Example: Constant temperature (isothermal), Constant pressure (isobar), Constant volume, Polytrophic and adiabatic

Cycle

A system is said to have undergoes a cycle if it returns to its initial state at the end of the process.
That is, for a cycle the initial and final states are identical.

State

The condition of system as describe by its properties.
The state often can be specified by providing the values of a subset of the properties.



Example of process, cycle and state

REVERSIBLE PROCESS

A reversible process is the process in which the system and surrounding can be restored to the initial state from the final state without producing any changes in the thermodynamics properties of the universe.

In the figure, the system has undergone change from state A to state B. If the system can be restored from state B to state A, without any changes, then the process is said to be a reversible process.

In actual practices, the reversible process never occurs, thus it is an ideal or hypothetical process.

IRREVERSIBLE PROCESS

The irreversible process is also called the natural process because all the processes occurring in nature are irreversible processes. The natural process occurs due to the finite gradient between the two states of the system.

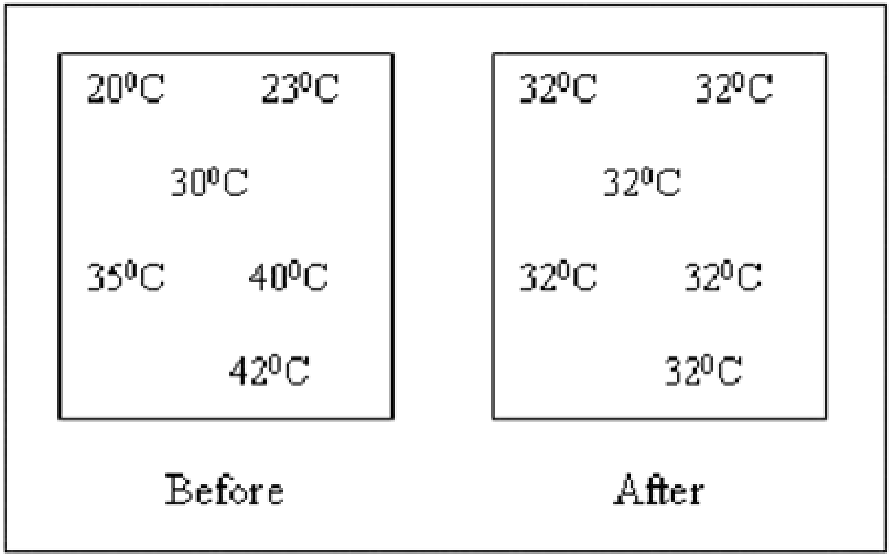
Some important points about the irreversible process:

1) In the irreversible process the initial state of the system and surroundings cannot be restored from the final state.
2) During the irreversible process the various states of the system on the path of change from initial state to final state are not in equilibrium with each other.
3) During the irreversible process the entropy of the system increases decisively and it cannot be reduced back to its initial value.

STATE AND EQUILIBRIUM

A state of balance

A system is not in thermodynamic equilibrium unless the condition of all the relevant types of equilibrium are satisfied.
Example: thermal equilibrium, mechanical equilibrium, phase equilibrium, chemical equilibrium.

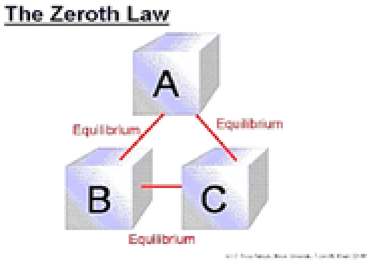


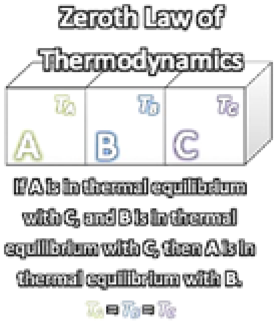
A closed system reaching thermal equilibrium

ZEROTH LAW OF THERMODYNAMICS

If two bodies are in thermal equilibrium with a third body, they also in thermal equilibrium with each other.

"the zeroth law can be restated as two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact."

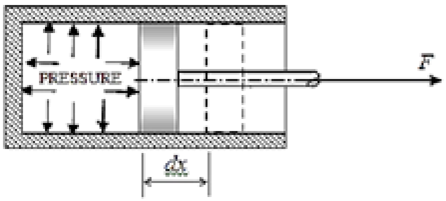




WORK TRANSFER, W

Work transfer is defined as a product of the force and the distance moved in the direction of the force.
When the boundary is moved inwards the work is done on the system by its surroundings.

Unit : Joule or Nm



$$F = pA$$

$$W = F \times dx$$

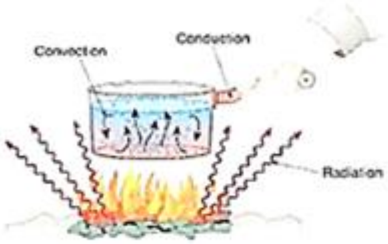
$$= F \times L$$

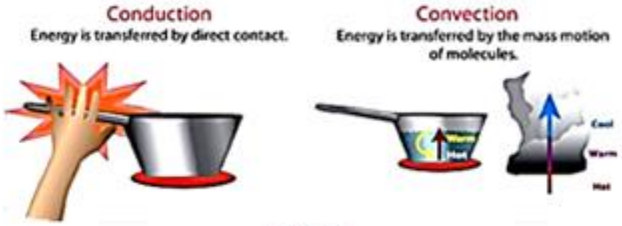
HEAT TRANSFER, Q

Heat is a form of energy which crosses the boundary of a system during a change of state produced by the difference in temperature between the system and its surroundings.

Unit : Joule or Nm

MECHANISMS OF HEAT TRANSFER

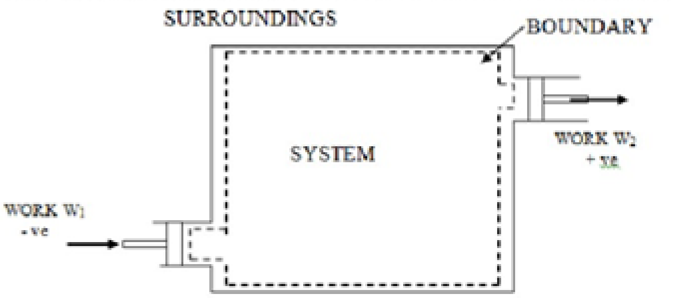




SCAN ME

SIGN CONVENTION FOR WORK TRANSFER

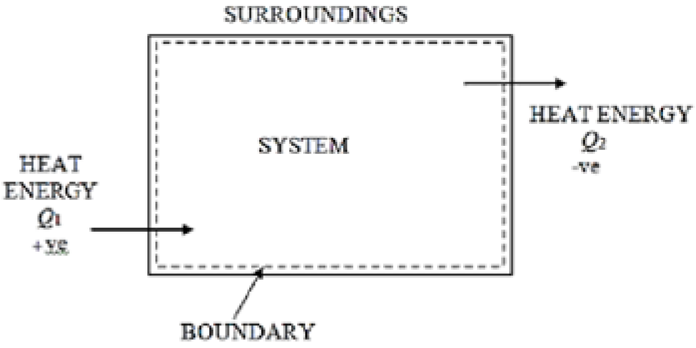
If work energy is transferred from the system to the surroundings, it is donated as positive.
If work energy is transferred from the surroundings to the system, it is donated as negative.



SIGN CONVENTION FOR HEAT TRANSFER

If heat energy flows into the system from the surroundings it is said to be positive.

If heat energy flows from the system to the surroundings it is said to be negative.



INTERNAL ENERGY, U

Sum of all the energies a fluid possesses and stores within itself.

$$\Delta U = \Delta Q - \Delta W$$

$$U2 - U1 = \Delta Q - \Delta W$$

where,

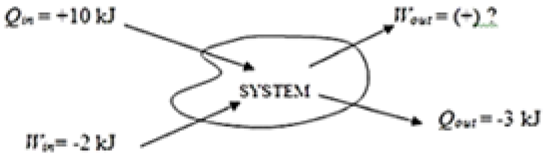
ΔQ = Heat supplied to the system

ΔW= Work done by the system.

ΔU = Change in the internal energy of the system.

If Q is positive, then there is a net heat transfer into the system, if *W* is positive, then there is work done by the system. So positive *Q* adds energy to the system and positive *W* takes energy from the system.

Unit : kJ/kg



1. Figure above shows a certain process, which undergoes a complete cycle of operations. Determine the value of the work output for a complete cycle, W_{out}.

2. A system is allowed to do work amounting to 500 kNm whilst heat energy amounting to 800 kJ is transferred into it. Find the change of internal energy and state whether it is an increase or decrease.

1. A system is allowed to do work amounting to 940 kNm whilst heat energy amounting to 480 kJ is transferred into it. Find the change of internal energy and state whether it is an increase or decrease.

    1. Sketch a diagram that consists of:
        - i. System
        - ii. Boundary
        - iii. Surroundings

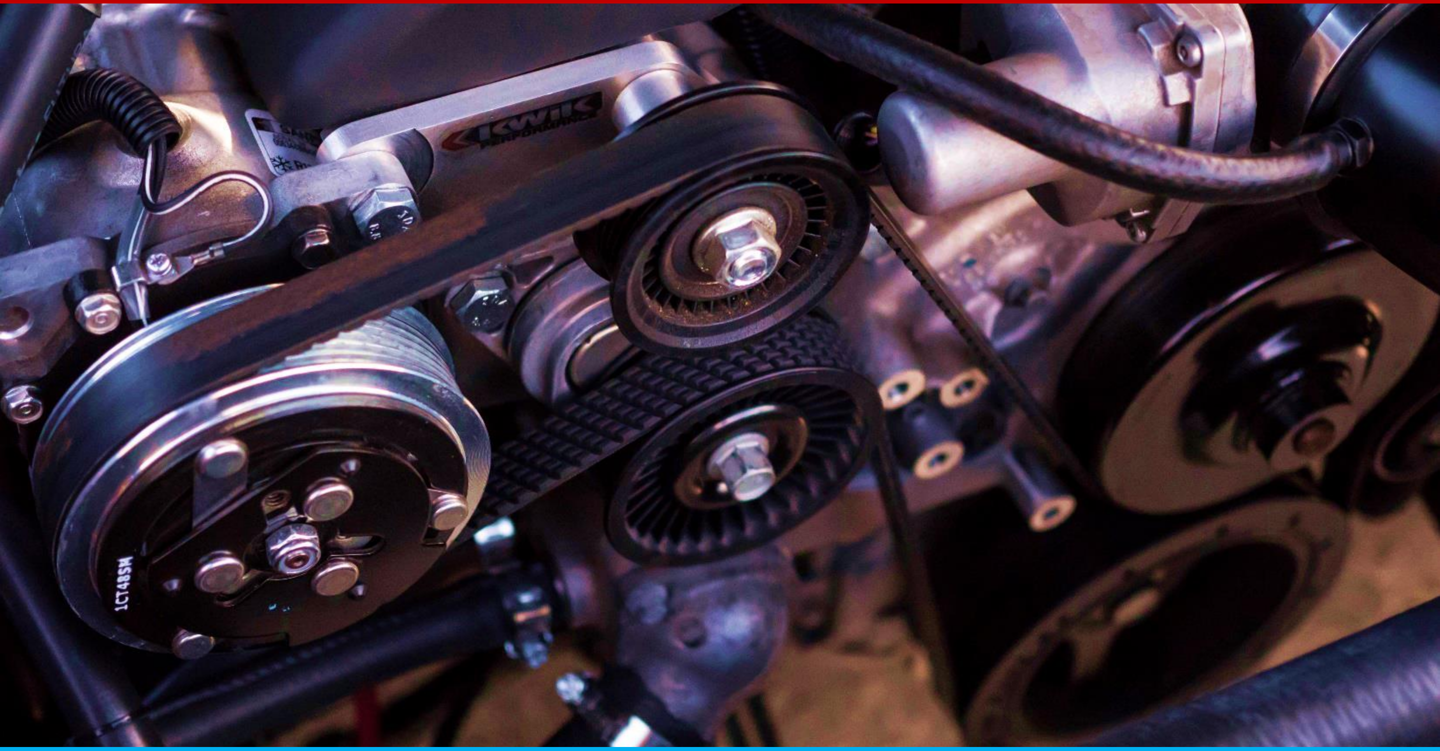
    2. Convert the following:
        - i. 2250 km/h to cm/min
        - ii. 45000 Pascal to MN/m^2
        - iii. 7 km/h to m/s
        - iv. 35 g/mm^3 to kg/m^3
        - v. 18 miligram per litre to kg/m^3

    3. List **SIX (6)** SI (International System) units and their symbols.

    4. Explain the Zeroth Law of Thermodynamics

    5. Explain briefly the equilibrium state in thermodynamics.

    6. Sketch a simple diagram showing a closed system which is already reaching a thermal equilibrium from the initial state to the final state.



SECOND LAW OF THERMODYNAMICS

Definition of Second Law Thermodynamics

“Although the net heat supplied in a cycle is equal to the net work done; the gross heat supplied must be greater than the work done; some heat must always be rejected by the system “

SCAN ME

Definition of Second Law Thermodynamics

"Although the net heat supplied in a cycle is equal to the net work done; the gross heat supplied must be greater than the work done; some heat must always be rejected by the system "

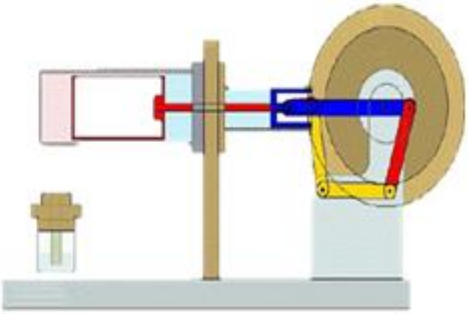
$$Q_{gross} > W_{net}$$
$$Q_1 - Q_2 = W$$

where,
Q_2= heat rejected by system

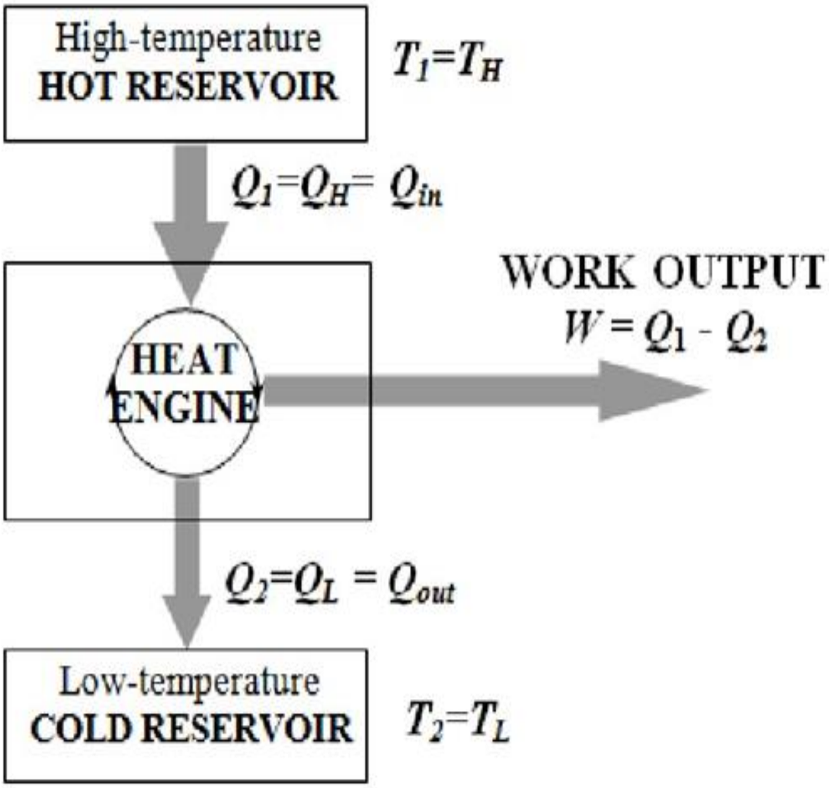
HEAT ENGINE

A heat engine is a system operating in a complete cycle and developing network from a supply of heat.
Heat engines differ considerably from one another, but all can be characterised by the following:

i. They receive heat from a high-temperature source (for example solar energy, oil furnace, nuclear reactor, steam boiler, etc.)
ii. They convert part of this heat to work (usually in the form of a rotating shaft, for example gas turbine, steam turbine, etc.)
iii. They reject the remaining waste heat to a low-temperature sink (for example the atmosphere, rivers, condenser, etc.)
iv. They operate on a cycle.



Heat Engine Diagram



Thermal Efficiency of a Heat Engine

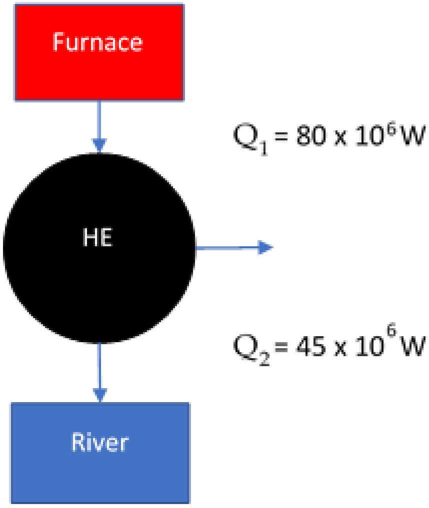
The ratio of the net work done in the cycle to the gross heat supplied in the cycle.

$$\eta = \frac{W_{out}}{Q_{in}} = \frac{W_{out}}{Q_H} = \frac{Q_1 - Q_2}{Q_1}$$

$$= 1 - \left(\frac{Q_2}{Q_1}\right) = 1 - \left(\frac{Q_L}{Q_H}\right)$$

Example

Heat is transferred to a heat engine from a furnace at a rate of 80 MW. If the rate of waste heat rejection to a nearby river is 45 MW, determine the net work done and the thermal efficiency for this heat engine.



Solution:

$$\begin{aligned} W &= Q_1 - Q_2 \\ &= 80 - 45 \\ &= 35 \text{ MW} \end{aligned}$$

$$W = Q_1 - Q_2 \; : \; 1 - \left(\frac{Q_2}{Q_1}\right)$$

$$= 1 - \left(\frac{45}{80}\right) = 0.4375$$

1. A heat engine performs 200J of work and has an efficiency of 25%. Calculate:
   i. The heat absorbed by the engine from the hot reservoir.
   ii. The heat expelled by the engine to the cold reservoir.

2. A petrol engine produces 6000J of heat from combustion and outputs 1200J of mechanical work for each cycle. Calculate the efficiency of the engine in each cycle.

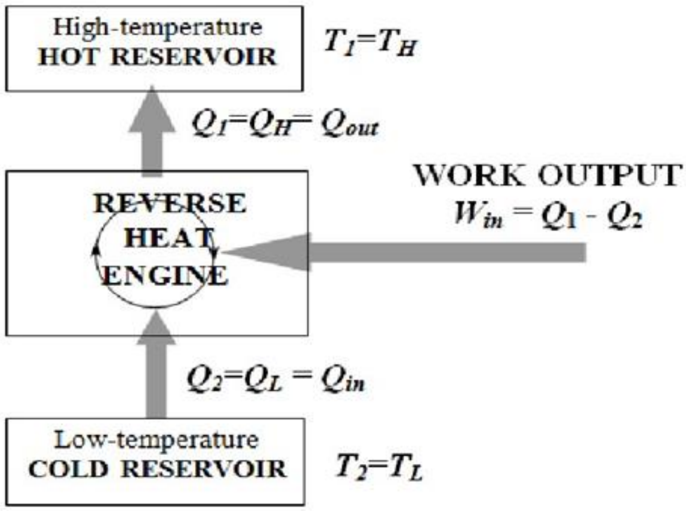
3. **3.** A steam boiler receives 2400 kJ/min of heat and produces 24 kW of power. Determine the heat that is absorbed by the river and the thermal efficiency.

REVERSE HEAT ENGINE

A thermodynamics system operating in a thermodynamics cycle which removes heat from a low temperature medium to a high temperature medium.
Divide by 2:

i. Heat Pump, HP
ii. Refrigerator, R

Reverse Heat Engine Diagram



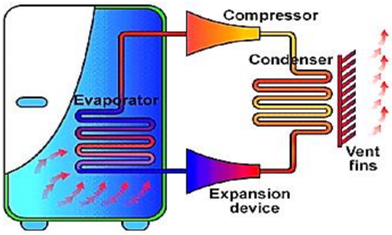
1. Refrigerator

To remove heat from the refrigerated space and to maintain the refrigerated space at low temperature.

Coefficient of Performance, **COP**$_{\text{Ref}}$

$$COP_{Ref} = \frac{Q_2}{W_{in}} = \frac{Q_L}{W_{in}} = \frac{Q_2}{Q_1 - Q_2} = \frac{Q_L}{Q_H - Q_L}$$

$$COP_{Ref} = \frac{T_2}{T_1 - T_2} = \frac{Q_2}{W_{in}}$$



2. Heat Pump

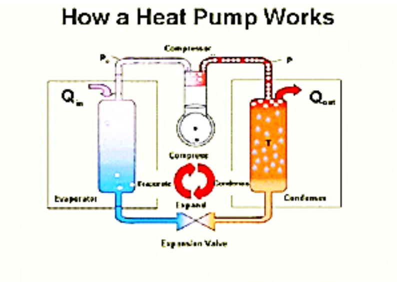
To maintain a heated space at a high temperature.

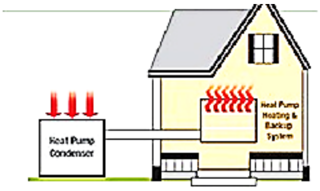
Coefficient of Performance, **COP**hp

$$COP_{HP} = \frac{Q_1}{W_{in}} = \frac{Q_H}{W_{in}} = \frac{Q_1}{Q_1 - Q_2} = \frac{Q_H}{Q_H - Q_L}$$

$$COP_{HP} = \frac{T_1}{T_1 - T_2} = \frac{Q_1}{W_{in}}$$

$$\boxed{\begin{aligned} COP_{HP} - COP_{Reff} &= 1 \\ COP_{HP} &= COP_{Reff} + 1 \end{aligned}}$$





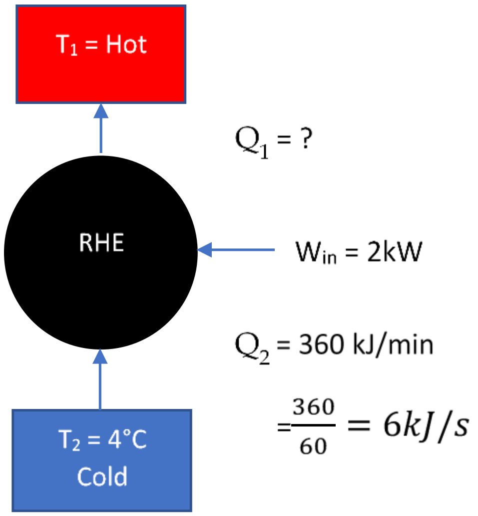
During the fall and spring: A heat pump pulls heat from outside and moves it into your home. You will need a backup heat source when temperatures are below 30 degrees F, typically mid-December through mid-February.

Example

A food compartment in refrigerator is maintain at 4˚C by removing heat from it at a rate of 360kJ/min. if the power input required is 2kW, determine:

i. the coefficient of performance of the refrigerator, COP_{Ref}
ii. the rate of heat rejection to surrounding.

Solution:



$$=\frac{360}{60} = 6kJ/s$$

i) COP_{Ref}= ?

$$COP_{Ref} = \frac{Q_2}{W_{in}} = \frac{6}{2} = 3$$

ii) $W = Q_1 - Q_2$

$Q_1 = W + Q_2$

$= 2 + 6$

$= 8$ kJ/s

$= 8 \times 60 = 480$ kJ/min

Question

1. Heat pump is used to meet the heating requirements of a house and maintain it at 20˚C. When the outdoor air temperature drop to -2˚C, the house is estimates to lose heat at rate of 80000kJ/h. If the heat pump under these conditions has a coefficient of performance, COP of 2.5, determine:

    i. The power consumed by heat pump
    ii. The rate of heat absorbed from outside

2. A domestic food freezer maintains a temperature of -10°C. The ambient air temperature is 28°C. If heat leaks into the freezer at the continuous rate of 1.65 kJ/s what is the least power necessary to pump this heat out continuously?

CARNOT CYCLE

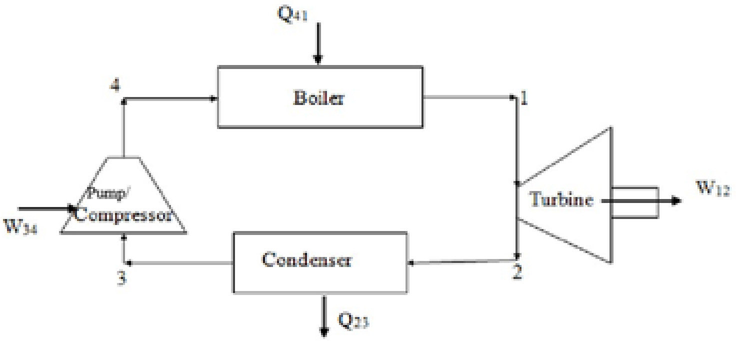
From the Second Law of Thermodynamics it can be derived that no heat engine can be more efficient than a reversible heat engine working between the same temperature limits.

Carnot, a French engineer, has shown in a paper written in 1824 that the most efficient possible cycle is one in which all the heat supplied is supplied at one fixed temperature, and all the heat rejected is rejected at a lower fixed temperature.

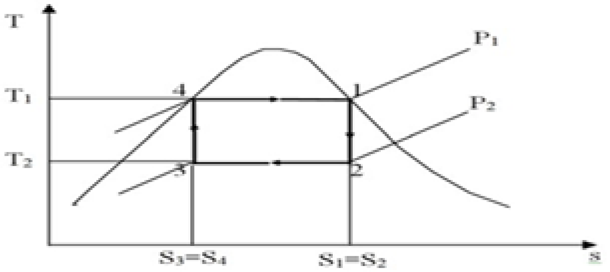
The cycle therefore consists of two isothermal processes joined by two adiabatic processes.

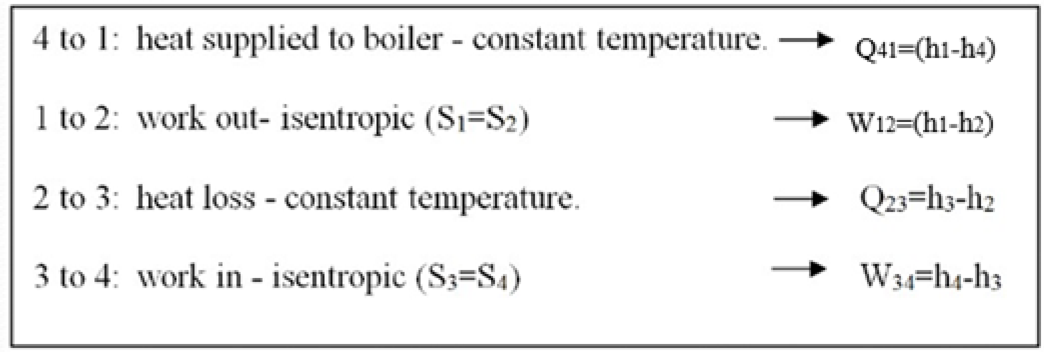
Since all processes are reversible, then the adiabatic processes in the cycle are also isentropic.

Carnot Cycle



The cycle is most conveniently represented on a T-s diagram as shown in Figure below:





4 to 1: heat supplied to boiler - constant temperature. → $Q_{41}=(h_1-h_4)$

1 to 2: work out- isentropic ($S_1=S_2$) → $W_{12}=(h_1-h_2)$

2 to 3: heat loss - constant temperature. → $Q_{23}=h_3-h_2$

3 to 4: work in - isentropic ($S_3=S_4$) → $W_{34}=h_4-h_3$

Thermal Efficient of Carnot Cycle

$$\eta_{carnot} = \frac{Net\ work\ output}{Heat\ supplied\ in\ the\ boiler} = \frac{W_{12}-W_{34}}{Q_{41}}$$

$$\eta_{carnot} = \frac{(h_1-h_2)-(h_4-h_3)}{h_1-h_4}$$

$$\eta_{carnot} = 1-\frac{T_2}{T_1}$$

Work Ratio

$$Work\ ratio, \gamma = \frac{Net\ work}{Gross\ work} = \frac{W_{12}-W_{34}}{Q_{41}}$$

$$= \frac{(h_1-h_2)-(h_4-h_3)}{h_1-h_2}$$

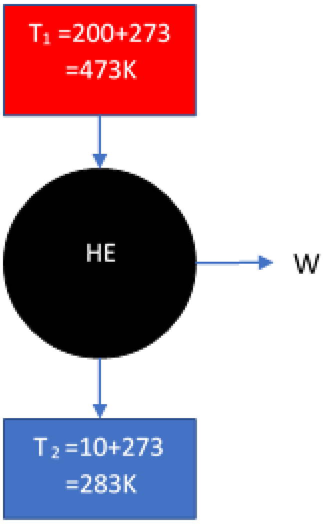
Specific Steam Consumption, SSC

$$SSC = \frac{3600}{Net\ work} = \frac{3600}{W_{nett}} = \frac{3600}{W_{12}-W_{34}}$$

$$= \frac{3600}{(h_1-h_2)-(h_4-h_3)}\ kg/kWh$$

Example

A steam power plant operates between a boiler pressure of 42 bar and a condenser pressure of 0.035 bar. Calculate for these limits the cycle efficiency and the work ratio for a Carnot cycle using wet steam.



$$\eta_{carnot} = 1 - \frac{T_2}{T_1}$$

$$\eta_{carnot} = 1 - \left(\frac{283}{473}\right) = 0.402$$

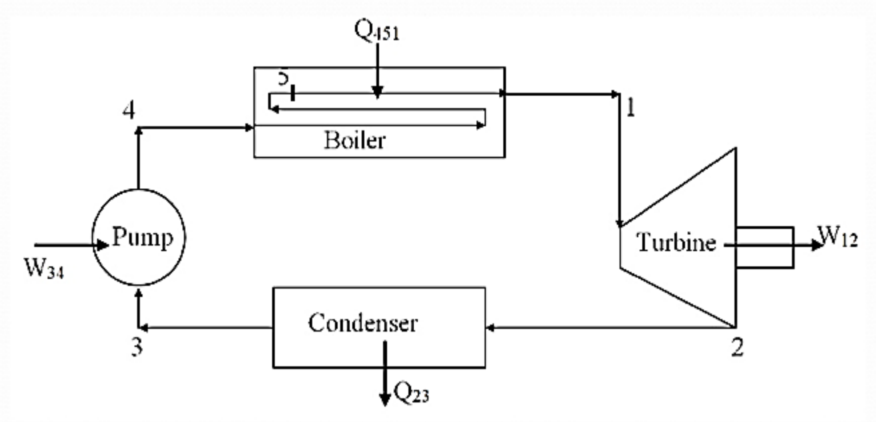
$$\eta_{carnot} = 40.2\%$$

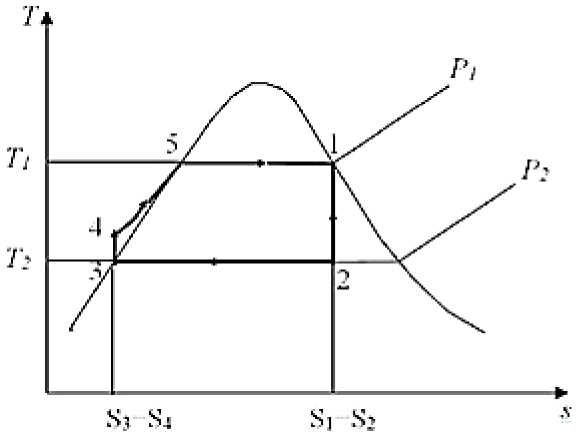
Question

1. A steam power plant operates between a boiler pressure of 40 bar and a condenser pressure of 0.045 bar. Calculate for these limits the cycle efficiency and the work ratio for a Carnot cycle using wet steam.

2. A reverse Carnot cycle air conditioner transfers heat from a house at 720 kJ/min to maintain its temperature at 21 °C. The outside temperature is 33.5°C. Find the power required to operate this air conditioner.

RANKINE CYCLE





4 to 1: heat supplied to boiler - constant temperature. → $Q_{451}=(h_1-h_4)$

1 to 2: work out- isentropic ($S_1=S_2$) → $W_{12}=(h_1-h_2)$

2 to 3: heat loss - constant temperature. → $Q_{23}=h_3-h_2$

3 to 4: work in - isentropic ($S_3=S_4$) → $W_{34}=h_4-h_3$
$=V_f(P_4-P_3)$

$V_f \approx 0.001 m^3/kg$

Thermal Efficiency of Rankine Cycle

$$\eta_R = \frac{Net\ work\ output}{Heat\ supplied\ in\ the\ boiler} = \frac{W_{12} - W_{34}}{Q_{451}}$$

$$\eta_R = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4}$$

Work Ratio for Rankine Cycle

$$Work\ ratio, \gamma = \frac{Net\ work}{Gross\ work} = \frac{W_{12} - W_{34}}{W_{12}}$$

$$= \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_2}$$

Specific Steam Consumption, SSC

$$SSC = \frac{3600}{Net\ work} = \frac{3600}{W_{nett}} = \frac{3600}{W_{12} - W_{34}}$$

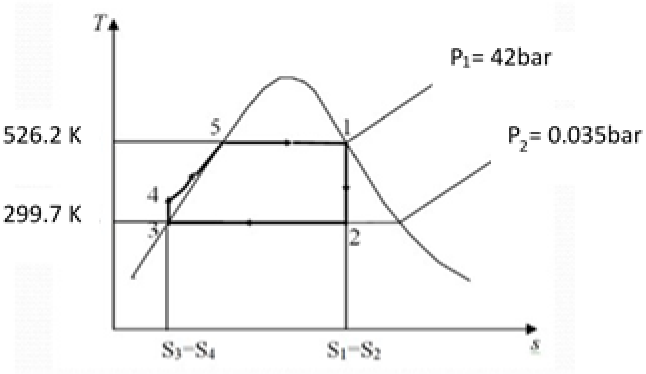
$$= \frac{3600}{(h_1 - h_2) - (h_4 - h_3)} kg/kWh$$

SCAN ME

Example

A steam power plant operates between a boiler pressure of 42 bar and a condenser pressure of 0.035 bar. Calculate for these limits the cycle efficiency, the work ratio, and the specific steam consumption for a Rankine cycle with dry saturated steam at entry to the turbine.

Solution:



$h_1 = h_g$ pada $P_1 = 42$ bar
$= 2800$ kJ/kg

$h_3 = h_f$ pada $P_2 = 0.035$ bar
$= 112$ kJ/kg

$h_2 = h_{f2} + x_2\,(h_{fg2})$
$= 112 + (0.7)(2438)$
$= 1818.6$ kJ/kg

$s_1 = s_2 = s_g$ pada $P_1 = 42$ bar
$= 6.049$ kJ/kgK

$s_2 = s_{f2} + x_2\,(s_{fg2})$
$6.049 = 0.391 + x_2\,(8.130)$
$x_2 = 0.7$

$h_4 = ?$
$W_{34} = h_4 - h_3 = V_f(P_4 - P_3)\,; P_4 = P_1 = 42\ bar;\ P_3 = P_2 = 0.035\ bar;$
$W_{34} = 0.001((42 \text{ x } 10^2) - (0.035 \text{ x } 10^2))$
$W_{34} = 4.2$ kJ/kg

$W_{34} = h_4 - h_3$
$h_4 = W_{34} + h_3$
$h_4 = 4.2 + 112$
$h_4 = 116.2\ kJ/kg$

$$\eta_R = \frac{W_{12} - W_{34}}{Q_{451}} = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4}$$

$$= \frac{(2800 - 1818.6) - (116.2 - 112)}{2800 - 116.2}$$

$$= 0.364 = 36.4\%$$

$$\gamma = \frac{W_{12} - W_{34}}{Q_{41}}$$

$$= \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_2}$$

$$= \frac{(2800 - 1818.6) - (116.2 - 112)}{2800 - 1818.6}$$

$$= 0.996$$

$$SSC = \frac{3600}{W_{12} - W_{34}}$$

$$= \frac{3600}{(h_1 - h_2) - (h_4 - h_3)}$$

$$= \frac{3600}{(2800 - 1818.6) - (116.2 - 112)}$$

$$= 3.68\ kg/kWh$$

Question

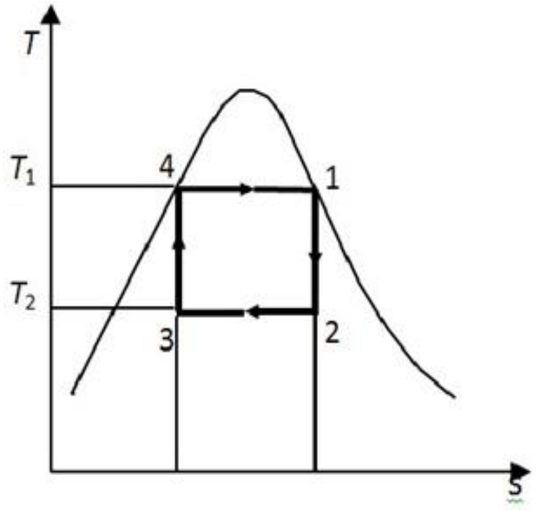
1. A steam power plant operates between a boiler pressure of 40 bar and a condenser pressure of 0.045 bar. Calculate for these limits the cycle efficiency, the work ratio, and the specific steam consumption for a Rankine cycle with dry saturated steam at entry to the turbine.

2. A steam power operates between a boiler pressure of 40 bar and condenser pressure of 0.05 bar. Calculate for these limits the cycle efficiency:
i) For a Carnot cycle using wet steam
ii) For a Rankine cycle with dry saturated steam at entry to the turbine.

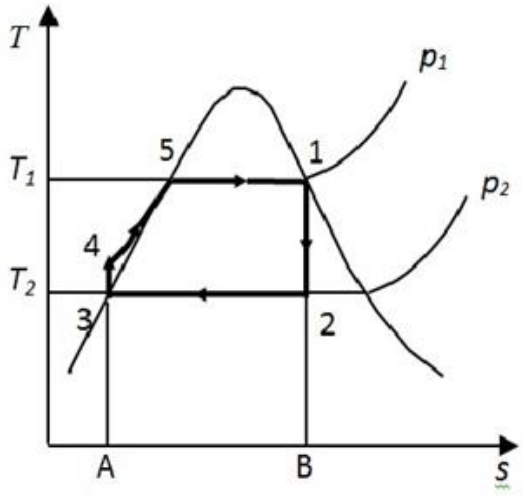
3. A steam power plant operates in the Rankine cycle with boiler pressure 36 bar and a condenser pressure of 0.045 bar. If the dry saturated steam at entry to the turbine produces the turbine work of 888 kJ/kg and feed pump work of 4.2 kJ/kg, calculate:

i) Heat supplied to the boiler.
ii) Rankine cycle efficiency
iii) Work ratio
iv) Specific steam consumption

Difference of Carnot and Rankine Cycle



Carnot cycle



Rankine cycle

NOTATION AND UNITS

a	m/s	– velocity of sound
$c_p, \tilde{c}_p$	kJ/kg K, kJ/kmol K	–specific, molar heat capacity at constant p
$c_v, \tilde{c}_v$	kJ/kg K, kJ/kmol K	–specific, molar heat capacity at constant v
$g, \tilde{g}$	kJ/kg, kJ/kmol	– specific, molar Gibbs function (h $- Ts$, $\tilde{h} - T\tilde{s}$)
$\Delta\tilde{g}^{\ominus}$, $\Delta g_f^{\ominus}$	kJ/kmol	–molar Gibbs function of reaction, of formation
$h, \tilde{h}$	kJ/kg, kJ/kmol	– specific, molar enthalpy (u $+ pv$, $\tilde{u}$ + pi?)
$\Delta\tilde{h}^{\ominus}$, $\Delta h_f^{\ominus}$	kJ/kmol	– molar enthalpy of reaction, of formation
$K^{\ominus}$, $K_f^{\ominus}$	–	– equilibrium constant, of formation
k	kW/m K	– thermal conductivity
$\tilde{m}$	kg/kmol	– molar mass
p	bar	–absolute pressure
Pr	–	– Prandtl number ($c_p\mu/k$)
$R, \tilde{R}$	kJ/kg K, kJ/kmol K	– specific, molar (universal) gas constant
$s, \tilde{s}$	kJ/kg K, kJ/kmol K	–specific, molar entropy
T	K or °C	–absolute temperature (K) or Celsius temperature (°C)
ΔT	K	–temperature interval or difference
$u, \tilde{u}$	kJ/kg, kJ/kmol	– specific, molar internal energy
$v, \tilde{v}$	m^3/kg, m^3/kmol	–specific, molar volume ($1/\rho$, $1/\tilde{\rho}$)
z	m	–geometric altitude above sea level
γ		–ratio of specific heat capacities ($c_p/c_v = \tilde{c}_p/\tilde{c}_v$)
$\bar{\lambda}$	m	–mean free path
μ	kg/m s = N s/m^2	–dynamic viscosity
ν	m^2/s	–kinematic viscosity (μ/ρ)
$\rho, \tilde{\rho}$	kg/m^3, kmol/m^3	– mass, molar density ($1/v$, $1/\tilde{v}$)

Subscripts

c –refers to a property in the critical state
f –refers to a property of the saturated liquid, or to a value of formation
g –refers to a property of the saturated vapour
fg –refers to a change of phase at constant p
i –refers to a property of the saturated solid
s –refers to a saturation temperature or pressure

Superscripts

~ – refers to a molar property (i.e. per unit amount-of-substance)
$\ominus$ –refers to a property at standard pressure $p^{\ominus} = 1$ bar (the superscript o is often used)

Saturated Water and Steam

T	p_s	v_g	h_f		h_g	s_f	s_{fg}	s_g
[°C]	[bar]	[m³/kg]		[kJ/kg]			[kJ/kg K]	
0.01	0.006112	206.1	0*	2500.8	2500.8	0†	9.155	9.155
1	0.006566	192.6	4.2	2498.3	2502.5	0.015	9.113	9.128
2	0.007054	179.9	8.4	2495.9	2504.3	0.031	9.071	9.102
3	0.007575	168.2	12.6	2493.6	2506.2	0.046	9.030	9.076
4	0.008129	157.3	16.8	2491.3	2508.1	0.061	8.989	9.050
5	0.008719	147.1	21.0	2488.9	2509.9	0.076	8.948	9.024
6	0.009346	137.8	25.2	2486.6	2511.8	0.091	8.908	8.999
7	0.01001	129.1	29.4	2484.3	2513.7	0.106	8.868	8.974
8	0.01072	121.0	33.6	2481.9	2515.5	0.121	8.828	8.949
9	0.01147	113.4	37.8	2479.6	2517.4	0.136	8.788	8.924
10	0.01227	106.4	42.0	2477.2	2519.2	0.151	8.749	8.900
11	0.01312	99.90	46.2	2474.9	2521.1	0.166	8.710	8.876
12	0.01401	93.83	50.4	2472.5	2522.9	0.180	8.671	8.851
13	0.01497	88.17	54.6	2470.2	2524.8	0.195	8.633	8.828
14	0.01597	82.89	58.8	2467.8	2526.6	0.210	8.594	8.804
15	0.01704	77.97	62.9	2465.5	2528.4	0.224	8.556	8.780
16	0.01817	73.38	67.1	2463.1	2530.2	0.239	8.518	8.757
17	0.01936	69.09	71.3	2460.8	2532.1	0.253	8.481	8.734
18	0.02063	65.08	75.5	2458.4	2533.9	0.268	8.444	8.712
19	0.02196	61.34	79.7	2456.0	2535.7	0.282	8.407	8.689
20	0.02337	57.84	83.9	2453.7	2537.6	0.296	8.370	8.666
21	0.02486	54.56	88.0	2451.4	2539.4	0.310	8.334	8.644
22	0.02642	51.49	92.2	2449.0	2541.2	0.325	8.297	8.622
23	0.02808	48.62	96.4	2446.6	2543.0	0.339	8.261	8.600
24	0.02982	45.92	100.6	2444.2	2544.8	0.353	8.226	8.579
25	0.03166	43.40	104.8	2441.8	2546.6	0.367	8.190	8.557
26	0.03360	41.03	108.9	2439.5	2548.4	0.381	8.155	8.536
27	0.03564	38.81	113.1	2437.2	2550.3	0.395	8.120	8.515
28	0.03778	36.73	117.3	2434.8	2552.1	0.409	8.085	8.494
29	0.04004	34.77	121.5	2432.4	2553.9	0.423	8.050	8.473
30	0.04242	32.93	125.7	2430.0	2555.7	0.436	8.016	8.452
32	0.04754	29.57	134.0	2425.3	2559.3	0.464	7.948	8.412
34	0.05318	26.60	142.4	2420.5	2562.9	0.491	7.881	8.372
36	0.05940	23.97	150.7	2415.8	2566.5	0.518	7.814	8.332
38	0.06624	21.63	159.1	2411.0	2570.1	0.545	7.749	8.294
40	0.07375	19.55	167.5	2406.2	2573.7	0.572	7.684	8.256
42	0.08198	17.69	175.8	2401.4	2577.2	0.599	7.620	8.219
44	0.09100	16.03	184.2	2396.6	2580.8	0.625	7.557	8.182
46	0.1009	14.56	192.5	2391.8	2584.3	0.651	7.494	8.145
48	0.1116	13.23	200.9	2387.0	2587.9	0.678	7.433	8.111
50	0.1233	12.04	209.3	2382.1	2591.4	0.704	7.371	8.075
55	0.1574	9.578	230.2	2370.1	2600.3	0.768	7.223	7.991
60	0.1992	7.678	251.1	2357.9	2609.0	0.831	7.078	7.909
65	0.2501	6.201	272.0	2345.7	2617.7	0.893	6.937	7.830
70	0.3116	5.045	293.0	2333.3	2626.3	0.955	6.800	7.755
75	0.3855	4.133	313.9	2320.8	2634.7	1.015	6.666	7.681
80	0.4736	3.408	334.9	2308.3	2643.2	1.075	6.536	7.611
85	0.5780	2.828	355.9	2295.6	2651.5	1.134	6.410	7.544
90	0.7011	2.361	376.9	2282.8	2659.7	1.192	6.286	7.478
95	0.8453	1.982	398.0	2269.8	2667.8	1.250	6.166	7.416
100	1.01325	1.673	419.1	2256.7	2675.8	1.307	6.048	7.355

† u and s are chosen to be zero for saturated liquid at the triple point.

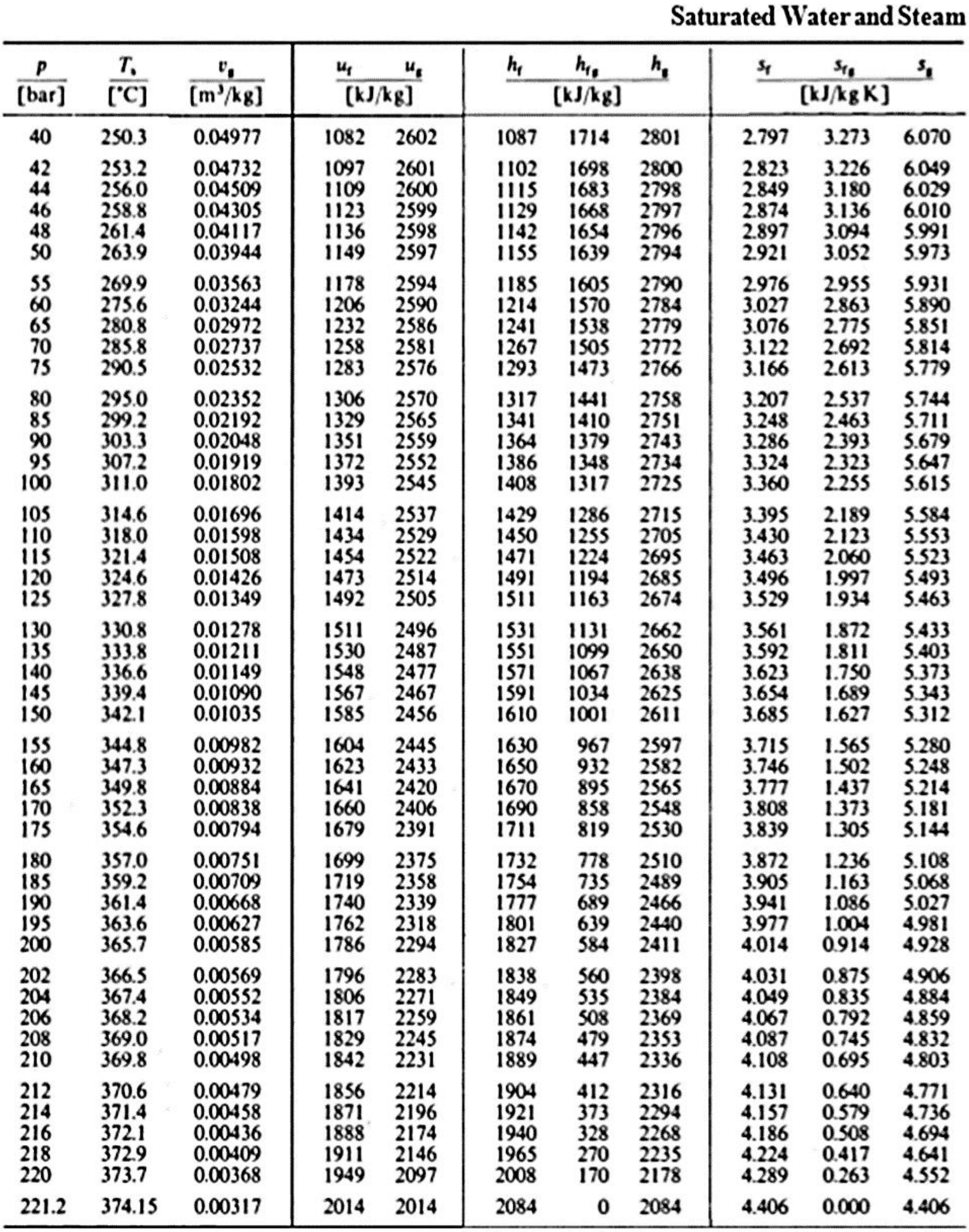
Note: values of v_f can be found on p. 10.

Saturated Water and Steam

p [bar]	T_s [°C]	v_g [m³/kg]	u_f [kJ/kg]	u_g [kJ/kg]	h_f [kJ/kg]	h_{fg} [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_{fg} [kJ/kg K]	s_g [kJ/kg K]
0.006112	0.01	206.1	0†	2375	0•	2501	2501	0†	9.155	9.155
0.010	7.0	129.2	29	2385	29	2485	2514	0.106	8.868	8.974
0.015	13.0	87.98	55	2393	55	2470	2525	0.196	8.631	8.827
0.020	17.5	67.01	73	2399	73	2460	2533	0.261	8.462	8.723
0.025	21.1	54.26	88	2403	88	2451	2539	0.312	8.330	8.642
0.030	24.1	45.67	101	2408	101	2444	2545	0.354	8.222	8.576
0.035	26.7	39.48	112	2412	112	2438	2550	0.391	8.130	8.521
0.040	29.0	34.80	121	2415	121	2433	2554	0.422	8.051	8.473
0.045	31.0	31.14	130	2418	130	2428	2558	0.451	7.980	8.431
0.050	32.9	28.20	138	2420	138	2423	2561	0.476	7.918	8.394
0.055	34.6	25.77	145	2422	145	2419	2564	0.500	7.860	8.360
0.060	36.2	23.74	152	2425	152	2415	2567	0.521	7.808	8.329
0.065	37.7	22.02	158	2427	158	2412	2570	0.541	7.760	8.301
0.070	39.0	20.53	163	2428	163	2409	2572	0.559	7.715	8.274
0.075	40.3	19.24	169	2430	169	2405	2574	0.576	7.674	8.250
0.080	41.5	18.10	174	2432	174	2402	2576	0.593	7.634	8.227
0.085	42.7	17.10	179	2434	179	2400	2579	0.608	7.598	8.206
0.090	43.8	16.20	183	2435	183	2397	2580	0.622	7.564	8.186
0.095	44.8	15.40	188	2436	188	2394	2582	0.636	7.531	8.167
0.100	45.8	14.67	192	2437	192	2392	2584	0.649	7.500	8.149
0.12	49.4	12.36	207	2442	207	2383	2590	0.696	7.389	8.085
0.14	52.6	10.69	220	2446	220	2376	2596	0.737	7.294	8.031
0.16	55.3	9.432	232	2450	232	2369	2601	0.772	7.213	7.985
0.18	57.8	8.444	242	2453	242	2363	2605	0.804	7.140	7.944
0.20	60.1	7.648	251	2456	251	2358	2609	0.832	7.075	7.907
0.22	62.2	6.994	260	2459	260	2353	2613	0.858	7.016	7.874
0.24	64.1	6.445	268	2461	268	2348	2616	0.882	6.962	7.844
0.26	65.9	5.979	276	2464	276	2343	2619	0.904	6.913	7.817
0.28	67.5	5.578	283	2466	283	2339	2622	0.925	6.866	7.791
0.30	69.1	5.228	289	2468	289	2336	2625	0.944	6.823	7.767
0.32	70.6	4.921	295	2470	295	2332	2627	0.962	6.783	7.745
0.34	72.0	4.649	302	2472	302	2328	2630	0.980	6.745	7.725
0.36	73.4	4.407	307	2473	307	2325	2632	0.996	6.709	7.705
0.38	74.7	4.189	312	2475	312	2322	2634	1.011	6.675	7.686
0.40	75.9	3.992	318	2476	318	2318	2636	1.026	6.643	7.669
0.42	77.1	3.814	323	2478	323	2315	2638	1.040	6.612	7.652
0.44	78.2	3.651	327	2479	327	2313	2640	1.054	6.582	7.636
0.46	79.3	3.502	332	2481	332	2310	2642	1.067	6.554	7.621
0.48	80.3	3.366	336	2482	336	2308	2644	1.079	6.528	7.607
0.50	81.3	3.239	340	2483	340	2305	2645	1.091	6.502	7.593
0.55	83.7	2.964	351	2486	351	2298	2649	1.119	6.442	7.561
0.60	86.0	2.731	360	2489	360	2293	2653	1.145	6.386	7.531
0.65	88.0	2.535	369	2492	369	2288	2657	1.169	6.335	7.504
0.70	90.0	2.364	377	2494	377	2283	2660	1.192	6.286	7.478
0.75	91.8	2.217	384	2496	384	2278	2662	1.213	6.243	7.456
0.80	93.5	2.087	392	2498	392	2273	2665	1.233	6.201	7.434
0.85	95.2	1.972	399	2500	399	2269	2668	1.252	6.162	7.414
0.90	96.7	1.869	405	2502	405	2266	2671	1.270	6.124	7.394
0.95	98.2	1.777	411	2504	411	2262	2673	1.287	6.089	7.376
1.00	99.6	1.694	417	2506	417	2258	2675	1.303	6.056	7.359

• $$\frac{h_f}{[\mathrm{kJ/kg}]} = \frac{p v_f}{[\mathrm{kJ/kg}]} = \frac{p}{[\mathrm{bar}]} \times \frac{10^5[\mathrm{N}]}{[\mathrm{m}^2]} \times \frac{v_f}{[\mathrm{m}^3/\mathrm{kg}]} \times \left[\frac{\mathrm{m}^3}{\mathrm{kg}}\right] \times \frac{[\mathrm{kJ}]}{10^3[\mathrm{N\,m}]} \times \frac{1}{[\mathrm{kJ/kg}]}$$

$$= \frac{p}{[\mathrm{bar}]} \times \frac{v_f}{[\mathrm{m}^3/\mathrm{kg}]} \times 10^2 = 0.006112 \times 0.0010002 \times 10^2 = 0.0006112$$



Saturated Water and Steam

p	T_s	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
[bar]	[°C]	[m³/kg]	[kJ/kg]		[kJ/kg]			[kJ/kg K]		
40	250.3	0.04977	1082	2602	1087	1714	2801	2.797	3.273	6.070
42	253.2	0.04732	1097	2601	1102	1698	2800	2.823	3.226	6.049
44	256.0	0.04509	1109	2600	1115	1683	2798	2.849	3.180	6.029
46	258.8	0.04305	1123	2599	1129	1668	2797	2.874	3.136	6.010
48	261.4	0.04117	1136	2598	1142	1654	2796	2.897	3.094	5.991
50	263.9	0.03944	1149	2597	1155	1639	2794	2.921	3.052	5.973
55	269.9	0.03563	1178	2594	1185	1605	2790	2.976	2.955	5.931
60	275.6	0.03244	1206	2590	1214	1570	2784	3.027	2.863	5.890
65	280.8	0.02972	1232	2586	1241	1538	2779	3.076	2.775	5.851
70	285.8	0.02737	1258	2581	1267	1505	2772	3.122	2.692	5.814
75	290.5	0.02532	1283	2576	1293	1473	2766	3.166	2.613	5.779
80	295.0	0.02352	1306	2570	1317	1441	2758	3.207	2.537	5.744
85	299.2	0.02192	1329	2565	1341	1410	2751	3.248	2.463	5.711
90	303.3	0.02048	1351	2559	1364	1379	2743	3.286	2.393	5.679
95	307.2	0.01919	1372	2552	1386	1348	2734	3.324	2.323	5.647
100	311.0	0.01802	1393	2545	1408	1317	2725	3.360	2.255	5.615
105	314.6	0.01696	1414	2537	1429	1286	2715	3.395	2.189	5.584
110	318.0	0.01598	1434	2529	1450	1255	2705	3.430	2.123	5.553
115	321.4	0.01508	1454	2522	1471	1224	2695	3.463	2.060	5.523
120	324.6	0.01426	1473	2514	1491	1194	2685	3.496	1.997	5.493
125	327.8	0.01349	1492	2505	1511	1163	2674	3.529	1.934	5.463
130	330.8	0.01278	1511	2496	1531	1131	2662	3.561	1.872	5.433
135	333.8	0.01211	1530	2487	1551	1099	2650	3.592	1.811	5.403
140	336.6	0.01149	1548	2477	1571	1067	2638	3.623	1.750	5.373
145	339.4	0.01090	1567	2467	1591	1034	2625	3.654	1.689	5.343
150	342.1	0.01035	1585	2456	1610	1001	2611	3.685	1.627	5.312
155	344.8	0.00982	1604	2445	1630	967	2597	3.715	1.565	5.280
160	347.3	0.00932	1623	2433	1650	932	2582	3.746	1.502	5.248
165	349.8	0.00884	1641	2420	1670	895	2565	3.777	1.437	5.214
170	352.3	0.00838	1660	2406	1690	858	2548	3.808	1.373	5.181
175	354.6	0.00794	1679	2391	1711	819	2530	3.839	1.305	5.144
180	357.0	0.00751	1699	2375	1732	778	2510	3.872	1.236	5.108
185	359.2	0.00709	1719	2358	1754	735	2489	3.905	1.163	5.068
190	361.4	0.00668	1740	2339	1777	689	2466	3.941	1.086	5.027
195	363.6	0.00627	1762	2318	1801	639	2440	3.977	1.004	4.981
200	365.7	0.00585	1786	2294	1827	584	2411	4.014	0.914	4.928
202	366.5	0.00569	1796	2283	1838	560	2398	4.031	0.875	4.906
204	367.4	0.00552	1806	2271	1849	535	2384	4.049	0.835	4.884
206	368.2	0.00534	1817	2259	1861	508	2369	4.067	0.792	4.859
208	369.0	0.00517	1829	2245	1874	479	2353	4.087	0.745	4.832
210	369.8	0.00498	1842	2231	1889	447	2336	4.108	0.695	4.803
212	370.6	0.00479	1856	2214	1904	412	2316	4.131	0.640	4.771
214	371.4	0.00458	1871	2196	1921	373	2294	4.157	0.579	4.736
216	372.1	0.00436	1888	2174	1940	328	2268	4.186	0.508	4.694
218	372.9	0.00409	1911	2146	1965	270	2235	4.224	0.417	4.641
220	373.7	0.00368	1949	2097	2008	170	2178	4.289	0.263	4.552
221.2	374.15	0.00317	2014	2014	2084	0	2084	4.406	0.000	4.406

Superheated Steam†

p/[bar] (T_s/[°C])		$\frac{T}{[°\mathrm{C}]}$	50	100	150	200	250	300	400	500
0	$u = h - RT$ at $p = 0$	v								
		u	2446	2517	2589	2662	2737	2812	2969	3132
		h	2595	2689	2784	2880	2978	3077	3280	3489
		s								
0.006112 (0.01)	v_g 206.1	v	243.9	281.7	319.5	357.3	395.0	432.8	508.3	583.8
	u_g 2375	u	2446	2517	2589	2662	2737	2812	2969	3132
	h_g 2501	h	2595	2689	2784	2880	2978	3077	3280	3489
	s_g 9.155	s	9.468	9.739	9.978	10.193	10.390	10.571	10.897	11.187
0.01 (7.0)	v_g 129.2	v	149.1	172.2	195.3	218.4	241.4	264.5	310.7	356.8
	u_g 2385	u	2446	2517	2589	2662	2737	2812	2969	3132
	h_g 2514	h	2595	2689	2784	2880	2978	3077	3280	3489
	s_g 8.974	s	9.241	9.512	9.751	9.966	10.163	10.344	10.670	10.960
0.05 (32.9)	v_g 28.20	v	29.78	34.42	39.04	43.66	48.28	52.90	62.13	71.36
	u_g 2420	u	2445	2516	2589	2662	2737	2812	2969	3132
	h_g 2561	h	2594	2688	2784	2880	2978	3077	3280	3489
	s_g 8.394	s	8.496	8.768	9.008	9.223	9.420	9.601	9.927	10.217
0.1 (45.8)	v_g 14.67	v	14.87	17.20	19.51	21.83	24.14	26.45	31.06	35.68
	u_g 2437	u	2443	2516	2588	2662	2736	2812	2969	3132
	h_g 2584	h	2592	2688	2783	2880	2977	3077	3280	3489
	s_g 8.149	s	8.173	8.447	8.688	8.903	9.100	9.281	9.607	9.897
0.5 (81.3)	v_g 3.239	v		3.420	3.890	4.356	4.821	5.284	6.209	7.134
	u_g 2483	u		2512	2585	2660	2735	2812	2969	3132
	h_g 2645	h		2683	2780	2878	2976	3076	3279	3489
	s_g 7.593	s		7.694	7.940	8.158	8.355	8.537	8.864	9.154
0.75 (91.8)	v_g 2.217	v		2.271	2.588	2.901	3.211	3.521	4.138	4.755
	u_g 2496	u		2510	2585	2659	2734	2811	2969	3132
	h_g 2662	h		2680	2779	2877	2975	3075	3279	3489
	s_g 7.456	s		7.500	7.750	7.969	8.167	8.349	8.676	8.967
1 (99.6)	v_g 1.694	v		1.696	1.937	2.173	2.406	2.639	3.103	3.565
	u_g 2506	u		2506	2583	2659	2734	2811	2968	3131
	h_g 2675	h		2676	2777	2876	2975	3075	3278	3488
	s_g 7.359	s		7.360	7.614	7.834	8.033	8.215	8.543	8.834
1.01325 (100.0)	v_g 1.673	v			1.912	2.145	2.375	2.604	3.062	3.519
	u_g 2506	u			2583	2659	2734	2811	2968	3131
	h_g 2676	h			2777	2876	2975	3075	3278	3488
	s_g 7.355	s			7.608	7.828	8.027	8.209	8.537	8.828
1.5 (111.4)	v_g 1.159	v			1.286	1.445	1.601	1.757	2.067	2.376
	u_g 2519	u			2580	2656	2733	2809	2967	3131
	h_g 2693	h			2773	2873	2973	3073	3277	3488
	s_g 7.223	s			7.420	7.643	7.843	8.027	8.355	8.646
2 (120.2)	v_g 0.8856	v			0.9602	1.081	1.199	1.316	1.549	1.781
	u_g 2530	u			2578	2655	2731	2809	2967	3131
	h_g 2707	h			2770	2871	2971	3072	3277	3487
	s_g 7.127	s			7.280	7.507	7.708	7.892	8.221	8.513
3 (133.5)	v_g 0.6057	v			0.6342	0.7166	0.7965	0.8754	1.031	1.187
	u_g 2544	u			2572	2651	2729	2807	2966	3130
	h_g 2725	h			2762	2866	2968	3070	3275	3486
	s_g 6.993	s			7.078	7.312	7.517	7.702	8.032	8.324
4 (143.6)	v_g 0.4623	$v/[\mathrm{m^3/kg}]$			0.4710	0.5345	0.5953	0.6549	0.7725	0.8893
	u_g 2554	$u/[\mathrm{kJ/kg}]$			2565	2648	2727	2805	2965	3129
	h_g 2739	$h/[\mathrm{kJ/kg}]$			2753	2862	2965	3067	3274	3485
	s_g 6.897	$s/[\mathrm{kJ/kg\,K}]$			6.929	7.172	7.379	7.566	7.898	8.191

† The entries in all tables are regarded as pure numbers and therefore the symbols for the physical quantities should be divided by the appropriate units as shown for the entries at $p/[\mathrm{bar}] = 4$. Because of lack of space, this has not been done consistently in the superheat and supercritical tables on pp. 6–9 and in the tables on pp. 11 and 23.

Superheated Steam*

$p/[\text{bar}]$ $(T_s/[^\circ\text{C}])$			$\frac{T}{[^\circ\text{C}]}$	200	250	300	350	400	450	500	600
5 (151.8)	v_g	0.3748	v	0.4252	0.4745	0.5226	0.5701	0.6172	0.6641	0.7108	0.8040
	u_g	2562	u	2644	2725	2804	2883	2963	3045	3129	3300
	h_g	2749	h	2857	2962	3065	3168	3272	3377	3484	3702
	s_g	6.822	s	7.060	7.271	7.460	7.633	7.793	7.944	8.087	8.351
6 (158.8)	v_g	0.3156	v	0.3522	0.3940	0.4344	0.4743	0.5136	0.5528	0.5919	0.6697
	u_g	2568	u	2640	2722	2801	2881	2962	3044	3128	3299
	h_g	2757	h	2851	2958	3062	3166	3270	3376	3483	3701
	s_g	6.761	s	6.968	7.182	7.373	7.546	7.707	7.858	8.001	8.267
7 (165.0)	v_g	0.2728	v	0.3001	0.3364	0.3714	0.4058	0.4397	0.4734	0.5069	0.5737
	u_g	2573	u	2636	2720	2800	2880	2961	3043	3127	3298
	h_g	2764	h	2846	2955	3060	3164	3269	3374	3482	3700
	s_g	6.709	s	6.888	7.106	7.298	7.473	7.634	7.786	7.929	8.195
8 (170.4)	v_g	0.2403	v	0.2610	0.2933	0.3242	0.3544	0.3842	0.4138	0.4432	0.5018
	u_g	2577	u	2631	2716	2798	2878	2960	3042	3126	3298
	h_g	2769	h	2840	2951	3057	3162	3267	3373	3481	3699
	s_g	6.663	s	6.817	7.040	7.233	7.409	7.571	7.723	7.866	8.132
9 (175.4)	v_g	0.2149	v	0.2305	0.2597	0.2874	0.3144	0.3410	0.3674	0.3937	0.4458
	u_g	2581	u	2628	2714	2796	2877	2959	3041	3126	3298
	h_g	2774	h	2835	2948	3055	3160	3266	3372	3480	3699
	s_g	6.623	s	6.753	6.980	7.176	7.352	7.515	7.667	7.811	8.077
10 (179.9)	v_g	0.1944	v	0.2061	0.2328	0.2580	0.2825	0.3065	0.3303	0.3540	0.4010
	u_g	2584	u	2623	2711	2794	2875	2957	3040	3124	3297
	h_g	2778	h	2829	2944	3052	3158	3264	3370	3478	3698
	s_g	6.586	s	6.695	6.926	7.124	7.301	7.464	7.617	7.761	8.028
15 (198.3)	v_g	0.1317	v	0.1324	0.1520	0.1697	0.1865	0.2029	0.2191	0.2351	0.2667
	u_g	2595	u	2597	2697	2784	2868	2952	3035	3120	3294
	h_g	2792	h	2796	2925	3039	3148	3256	3364	3473	3694
	s_g	6.445	s	6.452	6.711	6.919	7.102	7.268	7.423	7.569	7.838
20 (212.4)	v_g	0.0996	v		0.1115	0.1255	0.1386	0.1511	0.1634	0.1756	0.1995
	u_g	2600	u		2681	2774	2861	2946	3030	3116	3291
	h_g	2799	h		2904	3025	3138	3248	3357	3467	3690
	s_g	6.340	s		6.547	6.768	6.957	7.126	7.283	7.431	7.701
30 (233.8)	v_g	0.0666	v		0.0706	0.0812	0.0905	0.0993	0.1078	0.1161	0.1324
	u_g	2603	u		2646	2751	2845	2933	3020	3108	3285
	h_g	2803	h		2858	2995	3117	3231	3343	3456	3682
	s_g	6.186	s		6.289	6.541	6.744	6.921	7.082	7.233	7.507
40 (250.3)	v_g	0.0498	v			0.0588	0.0664	0.0733	0.0800	0.0864	0.0988
	u_g	2602	u			2728	2828	2921	3010	3099	3279
	h_g	2801	h			2963	3094	3214	3330	3445	3674
	s_g	6.070	s			6.364	6.584	6.769	6.935	7.089	7.368
50 (263.9)	v_g	0.0394	v			0.0453	0.0519	0.0578	0.0632	0.0685	0.0786
	u_g	2597	u			2700	2810	2907	3000	3090	3273
	h_g	2794	h			2927	3070	3196	3316	3433	3666
	s_g	5.973	s			6.212	6.451	6.646	6.818	6.975	7.258
60 (275.6)	v_g	0.0324	v			0.0362	0.0422	0.0473	0.0521	0.0566	0.0652
	u_g	2590	u			2670	2792	2893	2988	3081	3266
	h_g	2784	h			2887	3045	3177	3301	3421	3657
	s_g	5.890	s			6.071	6.336	6.541	6.719	6.879	7.166
70 (285.8)	v_g	0.0274	$v/[\text{m}^3/\text{kg}]$			0.0295	0.0352	0.0399	0.0441	0.0481	0.0556
	u_g	2581	$u/[\text{kJ/kg}]$			2634	2772	2879	2978	3073	3260
	h_g	2772	$h/[\text{kJ/kg}]$			2841	3018	3158	3287	3410	3649
	s_g	5.814	$s/[\text{kJ/kg K}]$			5.934	6.231	6.448	6.632	6.796	7.088

* See footnote on p. 6.

Superheated Steam*

p/[bar] (T_s/[°C])			T/[°C]	350	375	400	425	450	500	600	700
80 (295.0)	v_g	0.02352	$v/10^{-2}$	2.994	3.220	3.428	3.625	3.812	4.170	4.839	5.476
	h_g	2758	h	2990	3067	3139	3207	3272	3398	3641	3881
	s_g	5.744	s	6.133	6.255	6.364	6.463	6.555	6.723	7.019	7.279
90 (303.3)	v_g	0.02048	$v/10^{-2}$	2.578	2.794	2.991	3.173	3.346	3.673	4.279	4.852
	h_g	2743	h	2959	3042	3118	3189	3256	3385	3633	3874
	s_g	5.679	s	6.039	6.171	6.286	6.390	6.484	6.657	6.958	7.220
100 (311.0)	v_g	0.01802	$v/10^{-2}$	2.241	2.453	2.639	2.812	2.972	3.275	3.831	4.353
	h_g	2725	h	2926	3017	3097	3172	3241	3373	3624	3868
	s_g	5.615	s	5.947	6.091	6.213	6.321	6.419	6.596	6.902	7.166
110 (318.0)	v_g	0.01598	$v/10^{-2}$	1.960	2.169	2.350	2.514	2.666	2.949	3.465	3.945
	h_g	2705	h	2889	2989	3075	3153	3225	3360	3616	3862
	s_g	5.553	s	5.856	6.014	6.143	6.257	6.358	6.539	6.850	7.117
120 (324.6)	v_g	0.01426	$v/10^{-2}$	1.719	1.931	2.107	2.265	2.410	2.677	3.159	3.605
	h_g	2685	h	2849	2960	3052	3134	3209	3348	3607	3856
	s_g	5.493	s	5.762	5.937	6.076	6.195	6.301	6.487	6.802	7.072
130 (330.8)	v_g	0.01278	$v/10^{-2}$	1.509	1.726	1.901	2.053	2.193	2.447	2.901	3.318
	h_g	2662	h	2804	2929	3028	3114	3192	3335	3599	3850
	s_g	5.433	s	5.664	5.862	6.011	6.136	6.246	6.437	6.758	7.030
140 (336.6)	v_g	0.01149	$v/10^{-2}$	1.321	1.548	1.722	1.872	2.006	2.250	2.679	3.071
	h_g	2638	h	2753	2896	3003	3093	3175	3322	3590	3843
	s_g	5.373	s	5.559	5.784	5.946	6.079	6.193	6.390	6.716	6.991
150 (342.1)	v_g	0.01035	$v/10^{-2}$	1.146	1.391	1.566	1.714	1.844	2.078	2.487	2.857
	h_g	2611	h	2693	2861	2977	3073	3157	3309	3581	3837
	s_g	5.312	s	5.443	5.707	5.883	6.023	6.142	6.345	6.677	6.954
160 (347.3)	v_g	0.00932	$v/10^{-2}$	0.976	1.248	1.427	1.573	1.702	1.928	2.319	2.670
	h_g	2582	h	2617	2821	2949	3051	3139	3295	3573	3831
	s_g	5.248	s	5.304	5.626	5.820	5.968	6.093	6.301	6.639	6.919
170 (352.3)	v_g	0.00838	$v/10^{-2}$		1.117	1.303	1.449	1.576	1.796	2.171	2.506
	h_g	2548	h		2778	2920	3028	3121	3281	3564	3825
	s_g	5.181	s		5.541	5.756	5.914	6.044	6.260	6.603	6.886
180 (357.0)	v_g	0.00751	$v/10^{-2}$		0.997	1.191	1.338	1.463	1.678	2.039	2.359
	h_g	2510	h		2729	2888	3004	3102	3268	3555	3818
	s_g	5.108	s		5.449	5.691	5.861	5.997	6.219	6.569	6.855
190 (361.4)	v_g	0.00668	$v/10^{-2}$		0.882	1.089	1.238	1.362	1.572	1.921	2.228
	h_g	2466	h		2674	2855	2980	3082	3254	3546	3812
	s_g	5.027	s		5.348	5.625	5.807	5.950	6.180	6.536	6.825
200 (365.7)	v_g	0.00585	$v/10^{-2}$[m^3/kg]		0.768	0.995	1.147	1.270	1.477	1.815	2.110
	h_g	2411	h/[kJ/kg]		2605	2819	2955	3062	3239	3537	3806
	s_g	4.928	s/[kJ/kg K]		5.228	5.556	5.753	5.904	6.142	6.505	6.796
210 (369.8)	v_g	0.00498	$v/10^{-2}$		0.650	0.908	1.064	1.187	1.390	1.719	2.003
	h_g	2336	h		2500	2781	2928	3041	3225	3528	3799
	s_g	4.803	s		5.050	5.484	5.699	5.859	6.105	6.474	6.768
220 (373.7)	v_g	0.00368	$v/10^{-2}$		0.450	0.825	0.987	1.111	1.312	1.632	1.906
	h_g	2178	h		2300	2738	2900	3020	3210	3519	3793
	s_g	4.552	s		4.725	5.409	5.645	5.813	6.068	6.444	6.742
221.2 (374.15)	v_c	0.00317	$v/10^{-2}$	0.163	0.351	0.816	0.978	1.103	1.303	1.622	1.895
	h_c	2084	h	1637	2139	2733	2896	3017	3208	3518	3792
	s_c	4.406	s	3.708	4.490	5.398	5.638	5.807	6.064	6.441	6.739

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* See footnote on p. 6.

Note: linear interpolation is not accurate near the critical point.

REFERENCES

Kamaruzaman Daud and Roslan hashim (n.d), Module J2006. Thermodynamics 1. Mechanical Department of Malaysian Polytechnic Curriculum.

Sarimah Atan et.al (2016), Thermodynamics, 1st Edition, Polytechnic Approach, Politeknik Nilai.

Yunus Cengel, Michael Boles (2010) Thermodynamics: An Engineering Approach with Student Resources DVD. McGraw Hill.

Rajput, R.K. (2010) A Textbook of Engineering Thermodynamics, 4th Edition, Laxmi Publication (P) Ltd.

Nag, P.K. (2010) Basic And Applied Thermodynamics, 2nd Edition, Tata McGraw Hill Education Private Limited.

Gupta, S.C. (2006), Thermodynamics, Dorling Kindersley(India) Pvt. Ltd Easteop, T. D &McConkey.(2006) Applied Thermodynamics For Engineering Technologist , 5thEdition, Pearson & Prentice Hall, Singapore.

John P. O'Connell, J.M. Haile (2005) Thermodynamics: Fundamentals Of Applications, Cambridge University Press.

Sonntag, R. E.,Borgnakke, C., and Van Wylen, G. J., (2003) Fundamentals Of Thermodynamics, 6th Edition, John Wiley & Sons, Inc.

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