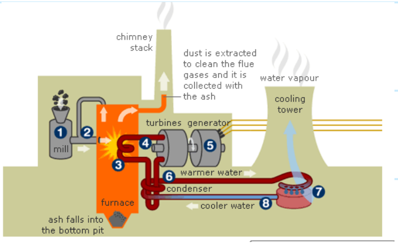
Heat Engines (p118)

Q1: A steam-cycle power station has a boiler temperature of 520°C and a condensor temperature of 21°C.
What is the maxiumum (theoretical) efficiency? (%)



Max theoretical efficiency = ideal = Carnot

Carnot efficiency: (Ideal efficiency)

$$\eta_C = 1 - \frac{T_c}{T_h}$$

where

T_h = the hot temperature (Kelvin) that the heat flows FROM

T_c = the cold temperature (Kelvin) that the heat flows TO

T_h = 520 + 273 = 793 K

T_c = 21 + 273 = 294 K

n = 1-294/793 = 0.6293 (63%)

More likely T2 = 150

Tc = 273 + 150 = 423

n = 1-423/795 = 0.4679 (47%)

Q3: Solar powered Stirling Engine: A mirror of diam 12 m focusses sunlight (599 W/m²) to achieve maximum temperature of 717°C. Air is at 21°C.

(a) Find theoretical efficiency (%)

$$\eta_C = 1 - \frac{T_c}{T_h}$$

Theoretical eff = 1-(273+21)/(273+717)

= 0.703 (70.3%)

(b) Find heat supply rate.

Heat from sun = Area of mirror * heat from sun

= Pi*6^2 * 599

= 113.097 * 599 = 67745 W

(c) Find theoretical power output.

Work Output = Heat Supplied - Heat Rejected

$\mathbf{W = Q_s - Q_R}$

So efficiency

η **= W / Q_s , So W =** η **Q**

= 0.703*67745 = 47624.735 W

Internal Combustion

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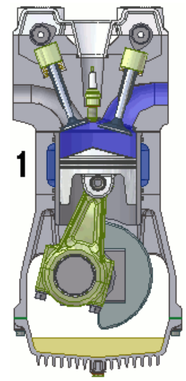

Q6: An internal combustion engine uses fuel with energy content of 37.1 MJ/kg at a rate of 4.2 kg/hour. Efficiency is 30%.

(a) What is the power output?

Heat supplied: $Q_s = mE$

m = mass/sec

= 4.2/3.600 = 1.1667 E-3 kg/s

Q_s = 1.1667E-3*37.1E6 = 43284.57 J/s (W)

W = η Q

= 0.30*43284.57 = 12985.4 Joules/s (W)

(b) What is the rate of heat generated?

$Q_S = W + Q_R$

$Q_R = Q_S - W$ = 43284.57 - 12985.4 = 30299.17 J/s (W)

Otto Cycle P-V

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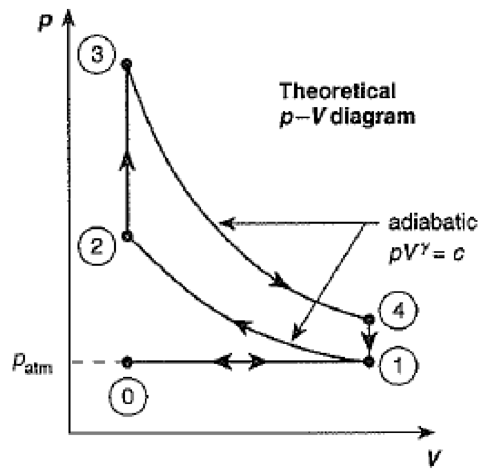


Q8: Otto cycle; Compression ratio = 8.3:1, inlet = 96.8kPa (abs) at 54°C. Heat supply = 945 kJ/kg of air.

(a) Find compression temperature T2 (K).

*Note: This question is worked out for each **kg** of air. (specific power)*

Identify the gas process.

Adiabatic compression

$$pV^n = \text{constant}$$

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

$$\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$$

Process	*Relationship between p, V, T*	*Work (W)*	*Internal-energy change ($U_2 - U_1$)*	*Heat (Q)*
constant pressure	p = constant; $\frac{V_1}{T_1} = \frac{V_2}{T_2}$	$p(V_2 - V_1)$	$mc_v(T_2 - T_1)$	$mc_p(T_2 - T_1)$
constant volume	V = constant; $\frac{p_1}{T_1} = \frac{p_2}{T_2}$	0	$mc_v(T_2 - T_1)$	$Q = U_2 - U_1$; $Q = mc_v(T_2 - T_1)$
isothermal	$T = c$; $p_1V_1 = p_2V_2$	$p_1V_1 \ln\left(\frac{V_2}{V_1}\right)$	0	$Q = W$; $Q = p_1V_1 \ln\left(\frac{V_2}{V_1}\right)$
polytropic	pV^n = constant; $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1}$; $\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$	$\frac{p_1V_1 - p_2V_2}{n-1}$	$mc_v(T_2 - T_1)$	$Q = W + U_2 - U_1$
adiabatic	as for polytropic with $n = \gamma$	as for polytropic with $n = \gamma$	$mc_v(T_2 - T_1)$	0

Convert:

T1 = 54+273.15 = 327.15 K

(V1/V2) = compression ratio

= 8.3

T2 = T1*(V1/V2)^(n-1)

T2 = 327.15*8.3^(1.4-1)

= 762.743 K (490 °C)

And... for fun...

P2 = P1*(T2/T1)^(n/(n-1))

= 96800*(762.743/327.15)^(1.4/0.4)

= 1.8732E6 Pa

(b) Find maximum temperature T3 (K).

Identify the gas process. Constant volume heating (Isochoric)

$Q = mc_v(T_3 - T_2)$

$T_3 = T_2 + Q / mc_v$

= 762.743 + 945000 / (1 * 718)

= 2078.9 K

P3 = P2*T3/T2

= 1.8732E6*2078.9/762.743

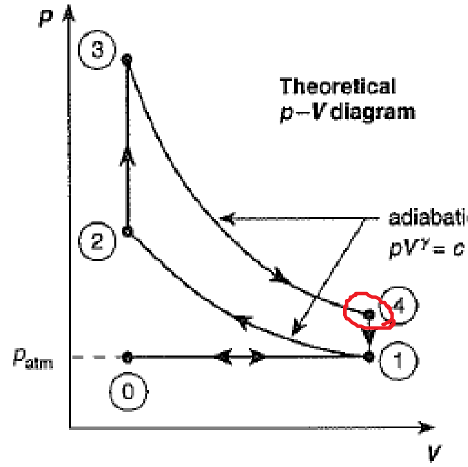
= 5.1055E6 Pa

Gas	Formula	c_p Constant Pressure Specific Heat Capacity (kJ/kgK) at 20°C	c_v Constant Volume Specific Heat Capacity (kJ/kgK) at 20°C	
Acetone		1.47	1.32	1
Acetylene	C_2H_2	1.69	1.37	1

= 5.1055E6 Pa

Acetone		1.47	1.32	1
Acetylene	C_2H_2	1.69	1.37	1
Air		**1.005**	**0.718**	**1**

Q10: (cont) Otto cycle; Compression ratio = 8.3:1, inlet = 96.8kPa (abs) at 54°C. Heat supply = 945 kJ/kg of air.
(c) Find expanded temperature T4 (K).



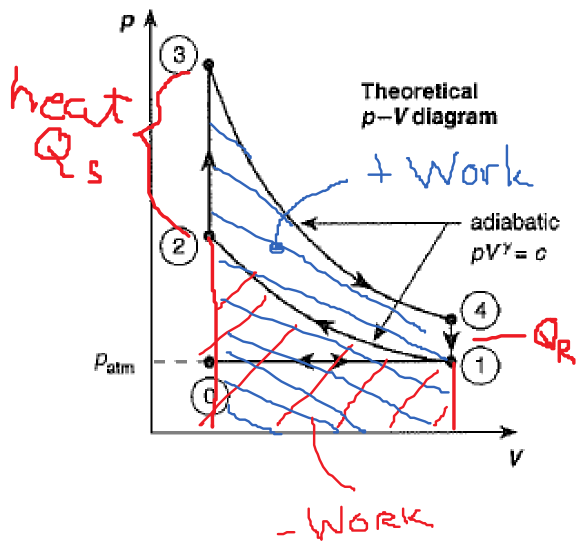
$$pV^n = \text{constant}$$
$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1}$$
$$\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$$

Adiabatic expansion...
T4 = T3*(V3/V4)^(n-1)
Expansion ratio
1/8.3 = 0.1205
T3 = 2078.899 K
So...

T4 = T3*(V3/V4)^(n-1)
= 2078.899*0.1205^0.4
= 891.7194 K

and... (for fun)
P4 = P3*(T4/T3)^(n/(n-1))
= 5.1055E6 * (891.7194/2078.9)^(1.4/0.4)
= 263888 Pa

Q11: (cont) Otto cycle; Compression ratio = 8.3:1, inlet = 96.8kPa (abs) at 54°C. Heat supply = 945 kJ/kg of air.
(d) Find indicated work (per kg of air).



Indicated power (no friction losses)
Power = Work/sec
$W_{Indicated} = W_{Expand} - W_{Compress}$
W_{Expand} = p3V3-p4V4/(n-1)
But we don't know the VOLUME!
(See example p137-138)
Use heat rejected...
$W = Q_S - Q_R$
Q_S = heat gain from 2 to 3 (const volume)
Q = 945000 J/kg (from fuel)
Q_R = heat loss from 4 to 1

		W
polytropic	$pV^n = \text{constant}$ $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1}$ $\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$	$\frac{p_1V_1 - p_2V_2}{n-1}$

$$\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$$

Q = 945000 J/kg (from fuel)

Q_R = heat loss from 4 to 1

$Q_R = mc_v(T1-T4)$

= 1 *718*(327.15 - 891.7194)

= -405361 J/kg

$W = Q_S - Q_R$

= 945000-405361

= 539639 J/kg

(e) Find theoretical efficiency (%).

$$\eta = 1 - \frac{Q_R}{Q_S} = 1 - \frac{\dot{Q}_R}{\dot{Q}_S}$$

$\eta = 1 - Q_R/Q_S$

= 1- (405361/945000) = 0.571

or...

$\eta = W/Q_S$ = 539639/ 945000 = 0.571

Steam Engine

Thursday, 17 November 2011
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Q16: A steam engine outputs 54 kW using wood (energy content 19.8 MJ/kg) at a rate of 25 kg/hour. Steam is at 520°C and cooling water is at 20°C. (a) What is the overall efficiency? (%)

$\eta = W/Q_S$

$Q_S = mE$

Q17: (cont) A steam engine outputs 54 kW using wood (energy content 19.8 MJ/kg) at a rate of 25 kg/hour. Steam is at 520°C and cooling water is at 20°C. (b) Find the maximum (theoretical) efficiency. (%)

Max theoretical efficiency = ideal = Carnot

Carnot efficiency: (Ideal efficiency)

$$\eta_C = 1 - \frac{T_c}{T_h}$$

where

T_h = the hot temperature (Kelvin) that the heat flows FROM

T_c = the cold temperature (Kelvin) that the heat flows TO

Ocean Thermal

Thursday, 17 November 2011
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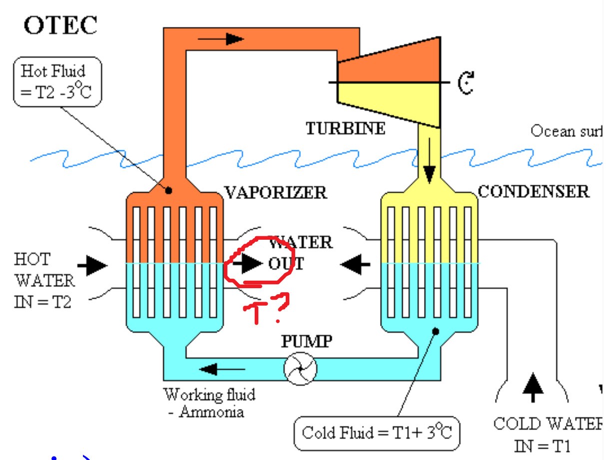
Ocean Thermal Energy Conversion (OTEC)



Q18: OTEC: Power output = 1.08 MW, T2 = 23.1°C, T1= 9.25°C. The overall plant efficiency is 44% of Carnot %. (a) Find Carnot efficiency (%). (Hint: For the working fluid, the heat exchangers miss by 3 degrees!)

$$\eta_C = 1 - \frac{T_c}{T_h}$$

Find temperatures of the Working Fluid. (Ammonia)
(This is not a gs, so we don't need to use gas process equations)

$T_C = 273+(9.25+3) = 285.25$ K

$T_H = 273+(23.1-3) = 293.1$ K

$\eta = 1-285.25/293.1 = 0.0268$ (2.68%)

$0.44*2.68 = 1.1792$ (0.01792)

Find the heat supply rate...

W , η , $\dot{Q}s$
✓ ✓ ?

From ... **$W = \eta \dot{Q}s$** (now find Qs)...

$\dot{Q}s = W/\eta$

= 1.08*1000000/0.011792

= 91646786 W (91.6 MW... Wow!)

Find hot seawater flow rate. (kg/s)

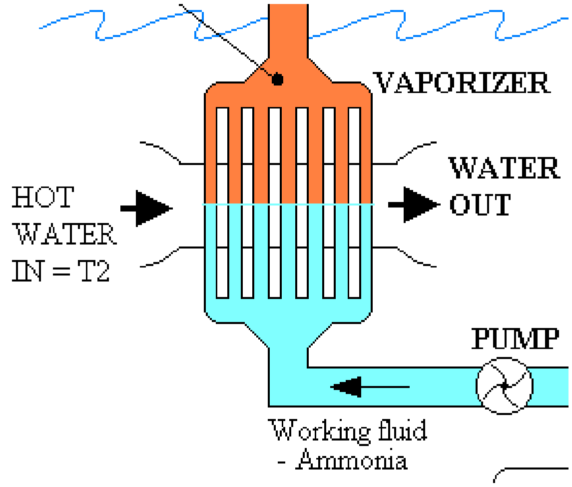
The hot seawater heats the ammonia up to within 3° of the hot incoming seawater temperature. That means the seawater itself is cooled down by 3 degrees by the time it comes out of that heat exchanger. (This assumes both fluids exit the heat exchanger at the same temperature - which is approximately correct here - not that we are told anything else anyway, so we have to assume it in this case.)

From $\dot{Q} = \dot{m}c\Delta T$

then $\dot{m} = \dot{Q}/(c\Delta T)$

$= 91646786/(4*1000*3)$

$= 7637.23$ kg/s (7.6 tonnes per sec!)



Find heat rejection rate.

$W = Q_S - Q_R$

Simply take away the work from the supplied heat. (We can also do this in rate - per second - format too)

QR = QS - W

= 91646786 - 1080000

= 90566786 W (90.5 MW)

Find cold seawater flow rate. (kg/s).

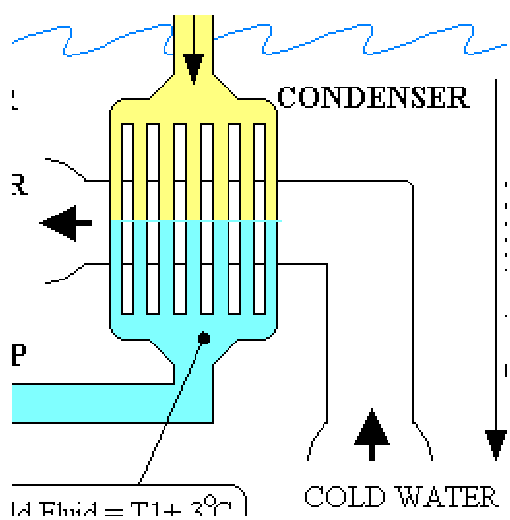
Same as the hot water (heat source), the cold seawater (heat rejector) cools the ammonia down to within 3^o of the cold incoming seawater temperature. That means the seawater itself is heated up by 3 degrees by the time it comes out of that heat exchanger. (Assuming both fluids exit the heat exchanger at the same temperature again)

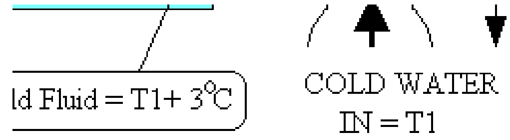
From $\dot{Q} = \dot{m}c\Delta T$

then $\dot{m} = \dot{Q}/(c\Delta T)$

$= 90566786/(4*1000*3)$

$= 7547.23$ kg/s (7.5 tonnes per sec!)




ld Fluid = T1+ 3°C
COLD WATER
IN = T1