Delft University of Technology **DEPARTMENT OF AEROSPACE ENGINEERING**	
Course: Physics I (AE1240)	Course year: 1
Date: 29-06-2015	Time: 09:00-12:00
Student name and initials (capital letters):……………………………………	
Student number: ……………………………………	
Lectures you followed (cross as appropriate) ☐ Kotsonis ☐ Colonna	

Instructions

Write your answers using the blank space on the page where the problem is given.

Or use the back of the page, if necessary.

Deliver ONLY the present booklet at the end of the exam. (do not include scrap paper or any other sheet)

PLEASE TAKE NOTE OF THE PARAMETER VALUES LISTED AT THE BOTTOM OF THIS PAGE

YOU CAN USE THE OFFICIAL EQUATIONS SHEET IF DISTRIBUTED.

THE USE OF OTHER INFORMATION CARRIERS IS STRICTLY FORBIDDEN.

Problem 1: (15 points)

True or false exercise (mark with X the appropriate box after the statement)

Statement	True	False
1 – A modern petrol engine cannot be more efficient than a Carnot heat engine	x	
2 – The value of the internal energy of an ideal gas is always lower than the value of the enthalpy at a given temperature	x	
3 – A perpetual motion machine of first kind produces energy	x	
4 – The specific heat of air does not vary with the temperature		x
5 – In an adiabatic process heat is transferred from high to low temperature		x
6 – A diesel engine with high compression ratio can be more efficient than a Carnot heat engine		x
7 – An explosion can be regarded as a sudden entropy production	x	
8 – By definition c_p is always smaller than c_v		x
9 – The production of entropy in the universe is zero		x
10 – In a polytropic process the pressure can change independently of the volume		x
11 – Removing energy as heat from a closed system reduces its entropy	x	
12 – A system formed by a simple compressible substance enclosed in a constant volume cannot transfer energy as work	x	
13 – In a gas turbine engine the air enthalpy increases in the turbine		x
14 – Density is an intensive property	x	

APPENDIX

Universal gas constant: R = 8.314 J/mol · K

Gas constant for air: R_{air} = 287 J/kg · K

Specific heat at constant pressure for air: c_p = 1008 J/kg · K, c_v = 718 J/kg · K

Ratio of specific heats for air: k = 1.4

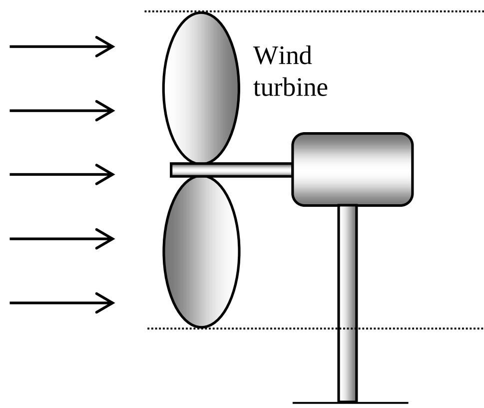
Problem 2 (10 points)

Two sites are being considered for wind power generation. In the first site, the wind blows steadily at 7 m/s for 3000 hours per year, whereas in the second site the wind blows at 10 m/s for 2000 hours per year. Assuming the wind velocity is negligible at other times for simplicity, determine which is a better site for wind power generation. Please note that you can assume the area the blades to be, A = 1 m^2.

2-16 Two sites with specified wind data are being considered for wind power generation. The site better suited for wind power generation is to be determined.

Assumptions **1**The wind is blowing steadily at specified velocity during specified times. **2** The wind power generation is negligible during other times.

Properties We take the density of air to be $\rho = 1.25$ kg/m^3 (it does not affect the final answer).



Analysis Kinetic energy is the only form of mechanical energy the wind possesses, and it can be converted to work entirely. Therefore, the power potential of the wind is its kinetic energy, which is $V^2/2$ per unit mass, and $\dot{m}V^2/2$ for a given mass flow rate. Considering a unit flow area (A = 1 m^2), the maximum wind power and power generation becomes

$$e_{\text{mech},1} = ke_1 = \frac{V_1^2}{2} = \frac{(7\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = 0.0245\text{ kJ/kg}$$

$$e_{\text{mech},2} = ke_2 = \frac{V_2^2}{2} = \frac{(10\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = 0.050\text{ kJ/kg}$$

$$\dot{W}_{\text{max},1} = \dot{E}_{\text{mech},1} = \dot{m}_1 e_{\text{mech},1} = \rho V_1 A ke_1 = (1.25\text{ kg/m}^3)(7\text{ m/s})(1\text{ m}^2)(0.0245\text{ kJ/kg}) = 0.2144\text{ kW}$$

$$\dot{W}_{\text{max},2} = \dot{E}_{\text{mech},2} = \dot{m}_2 e_{\text{mech},2} = \rho V_2 A ke_2 = (1.25\text{ kg/m}^3)(10\text{ m/s})(1\text{ m}^2)(0.050\text{ kJ/kg}) = 0.625\text{ kW}$$

since 1 kW = 1 kJ/s. Then the maximum electric power generations per year become

$$E_{\text{max},1} = \dot{W}_{\text{max},1}\Delta t_1 = (0.2144\text{ kW})(3000\text{ h/yr}) = \mathbf{643\ kWh/yr}\text{ (per m}^2\text{ flow area)}$$

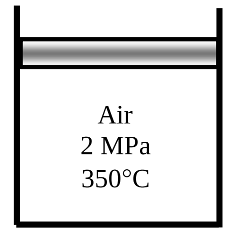
$$E_{\text{max},2} = \dot{W}_{\text{max},2}\Delta t_2 = (0.625\text{ kW})(2000\text{ h/yr}) = \mathbf{1250\ kWh/yr}\text{ (per m}^2\text{ flow area)}$$

Therefore, **second site** is a better one for wind generation.

Discussion Note the power generation of a wind turbine is proportional to the cube of the wind velocity, and thus the average wind velocity is the primary consideration in wind power generation decisions.

Problem 3 (15 points)

A piston-cylinder device contains 0.15 kg of air initially at 2 MPa and 350 ºC. The air is first expanded iso-thermally to 500 kPa, then compressed polytropically with a polytropic exponent of 1.2 to the initial pressure and finally taken at a constant pressure to the initial state. Determine the boundary work for each process and the net work of the cycle.



Solution (4-25) A piston-cylinder device contains air gas at a specified state. The air undergoes a cycle with three processes. The boundary work for each process and the net work of the cycle are to be determined.

Properties The properties of air are R = 0.287 kJ/kg.K , k = 1.4 (Table A-2a).

Analysis For the isothermal expansion process:

$$V_1 = \frac{mRT}{P_1} = \frac{(0.15\text{ kg})(0.287\text{ kJ/kg.K})(350+273\text{ K})}{(2000\text{ kPa})} = 0.01341\text{ m}^3$$

$$V_2 = \frac{mRT}{P_2} = \frac{(0.15\text{ kg})(0.287\text{ kJ/kg.K})(350+273\text{ K})}{(500\text{ kPa})} = 0.05364\text{ m}^3$$

$$W_{b,1-2} = P_1V_1\ln\left(\frac{V_2}{V_1}\right) = (2000\text{ kPa})(0.01341\text{ m}^3)\ln\left(\frac{0.05364\text{ m}^3}{0.01341\text{ m}^3}\right) = \mathbf{37.18\,kJ}$$

For the polytropic compression process:

$$P_2V_2^n = P_3V_3^n \longrightarrow (500\text{ kPa})(0.05364\text{ m}^3)^{1.2} = (2000\text{ kPa})V_3^{1.2} \longrightarrow V_3 = 0.01690\text{ m}^3$$

$$W_{b,2-3} = \frac{P_3V_3 - P_2V_2}{1-n} = \frac{(2000\text{ kPa})(0.01690\text{ m}^3) - (500\text{ kPa})(0.05364\text{ m}^3)}{1-1.2} = \mathbf{-34.86\,kJ}$$

For the constant pressure compression process:

$$W_{b,3-1} = P_3(V_1 - V_3) = (2000\text{ kPa})(0.01341 - 0.01690)\text{m}^3 = \mathbf{-6.97\,kJ}$$

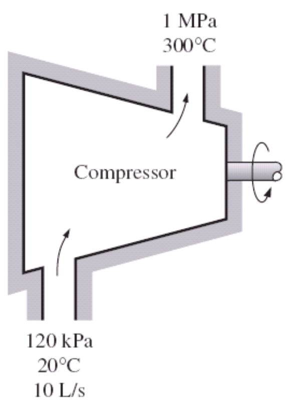
The net work for the cycle is the sum of the works for each process

$$W_{\text{net}} = W_{b,1-2} + W_{b,2-3} + W_{b,3-1} = 37.18 + (-34.86) + (-6.97) = \mathbf{-4.65\,kJ}$$

Problem 4 (15 points)

An adiabatic air compressor compresses 10 L/s of air at 120 kPa and 20 ºC to 1000 kPa and 300 ºC. Determine (a) the work required by the compressor, in kJ/kg, and (b) the power required to drive the air compressor, in kW.

An adiabatic air compressor compresses 10 L/s of air at 120 kPa and 20°C to 1000 kPa and 300°C. Determine (*a*) the work required by the compressor, in kJ/kg, and (*b*) the power required to drive the air compressor, in kW.



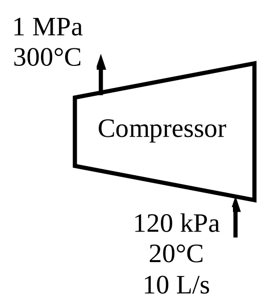
Solution (5-51) Air is compressed at a rate of 10 L/s by a compressor. The work required per unit mass and the power required are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** Air is an ideal gas with constant specific heats.

Properties The constant pressure specific heat of air at the average temperature of (20+300)/2=160°C=433 K is c_p = 1.018 kJ/kg·K (Table A-2b). The gas constant of air is R = 0.287 kPa·m^3/kg·K (Table A-1).

Analysis (*a*) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the compressor as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$



$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{W}_{\text{in}} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\dot{W}_{\text{in}} = \dot{m}(h_2 - h_1) = \dot{m}c_p(T_2 - T_1)$$

Thus,

$$w_{\text{in}} = c_p(T_2 - T_1) = (1.018\ \text{kJ/kg}\cdot\text{K})(300 - 20)\text{K} = \mathbf{285.0 kJ/kg}$$

(*b*) The specific volume of air at the inlet and the mass flow rate are

$$\boldsymbol{v}_1 = \frac{RT_1}{P_1} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(20 + 273\ \text{K})}{120\ \text{kPa}} = 0.7008\ \text{m}^3/\text{kg}$$

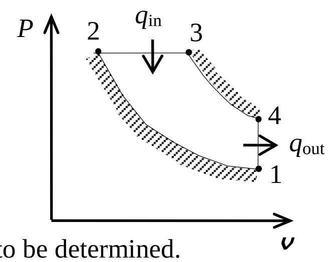
$$\dot{m} = \frac{\dot{\boldsymbol{V}}_1}{\boldsymbol{v}_1} = \frac{0.010\ \text{m}^3/\text{s}}{0.7008\ \text{m}^3/\text{kg}} = 0.01427\ \text{kg/s}$$

Then the power input is determined from the energy balance equation to be

$$\dot{W}_{\text{in}} = \dot{m}c_p(T_2 - T_1) = (0.01427\ \text{kg/s})(1.018\ \text{kJ/kg}\cdot\text{K})(300 - 20)\text{K} = \mathbf{4.068 kW}$$

Problem 5 (25 points)

An ideal Diesel cycle has a maximum cycle temperature of 2000°C and a cutoff ratio of 1.2. The state of the air at the beginning of the compression is P_1 = 95 kPa and T_1 = 15°C. This cycle is executed in a four-stroke, eight-cylinder engine with a cylinder bore of 10 cm and a piston stroke of 12 cm. The minimum volume enclosed in the cylinder is 5 percent of the maximum cylinder volume. Determine the power produced by this engine when it is operated at 1600 rpm. Use constant specific heats at room temperature.

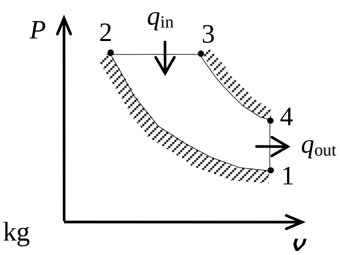


9-57 An ideal diesel cycle has a a cutoff ratio of 1.2. The power produced is to be determined.

Assumptions **1** The air-standard assumptions are applicable. **2** Kinetic and potential energy changes are negligible. **3** Air is an ideal gas with constant specific heats.

Properties The properties of air at room temperature are c_p = 1.005 kJ/kg·K, c_v = 0.718 kJ/kg·K, R = 0.287 kJ/kg·K, and k = 1.4 (Table A-2a).

Analysis The specific volume of the air at the start of the compression is



$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\,\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(288\,\text{K})}{95\,\text{kPa}} = 0.8701\,\text{m}^3/\text{kg}$$

The total air mass taken by all 8 cylinders when they are charged is

$$m = N_{\text{cyl}}\frac{\Delta V}{v_1} = N_{\text{cyl}}\frac{\pi B^2 S/4}{v_1} = (8)\frac{\pi(0.10\,\text{m})^2(0.12\,\text{m})/4}{0.8701\,\text{m}^3/\text{kg}} = 0.008665\,\text{kg}$$

The rate at which air is processed by the engine is determined from

$$\dot{m} = \frac{m\dot{n}}{N_{\text{rev}}} = \frac{(0.008665\,\text{kg/cycle})(1600/60\,\text{rev/s})}{2\,\text{rev/cycle}} = 0.1155\,\text{kg/s}$$

since there are two revolutions per cycle in a four-stroke engine. The compression ratio is

$$r = \frac{1}{0.05} = 20$$

At the end of the compression, the air temperature is

$$T_2 = T_1 r^{k-1} = (288\,\text{K})(20)^{1.4-1} = 954.6\,\text{K}$$

Application of the first law and work integral to the constant pressure heat addition gives

$$q_{\text{in}} = c_p(T_3 - T_2) = (1.005\,\text{kJ/kg}\cdot\text{K})(2273 - 954.6)\text{K} = 1325\,\text{kJ/kg}$$

while the thermal efficiency is

$$\eta_{\text{th}} = 1 - \frac{1}{r^{k-1}}\frac{r_c^k - 1}{k(r_c - 1)} = 1 - \frac{1}{20^{1.4-1}}\frac{1.2^{1.4} - 1}{1.4(1.2 - 1)} = 0.6867$$

The power produced by this engine is then

$$\begin{aligned}\dot{W}_{\text{net}} &= \dot{m}w_{\text{net}} = \dot{m}\eta_{\text{th}}q_{\text{in}} \\ &= (0.1155\,\text{kg/s})(0.6867)(1325\,\text{kJ/kg}) \\ &= \mathbf{105.1\,kW}\end{aligned}$$

Problem 6 (25 points)

A simple ideal Brayton cycle operates with air with minimum and maximum temperatures of 27°C and 727°C. It is designed so that the maximum cycle pressure is 2000 kPa and the minimum cycle pressure is 100 kPa. Determine the net work produced per unit mass of air each time this cycle is executed and the cycle's thermal efficiency. Use constant specific heats at room temperature.

Solution: A simple ideal Brayton cycle with air as the working fluid operates between the specified temperature and pressure limits. The net work and the thermal efficiency are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable. **3** Kinetic and potential energy changes are negligible. **4** Air is an ideal gas with constant specific heats.

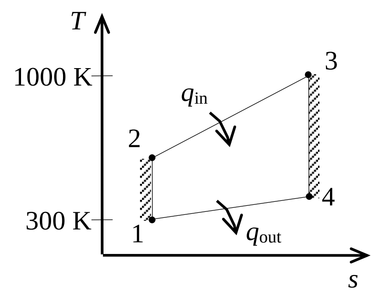
Properties The properties of air at room temperature are c_p = 1.005 kJ/kg·K and k = 1.4 (Table A-2a).

Analysis Using the isentropic relations for an ideal gas,

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (300\text{ K})\left(\frac{2000\text{ kPa}}{100\text{ kPa}}\right)^{0.4/1.4} = 706.1\text{ K}$$

Similarly,

$$T_4 = T_3\left(\frac{P_4}{P_3}\right)^{(k-1)/k} = (1000\text{ K})\left(\frac{100\text{ kPa}}{2000\text{ kPa}}\right)^{0.4/1.4} = 424.9\text{ K}$$



Applying the first law to the constant-pressure heat addition process 2-3 produces

$$q_{in} = h_3 - h_2 = c_p(T_3 - T_2) = (1.005\text{ kJ/kg}\cdot\text{K})(1000 - 706.1)\text{K} = 295.4\text{ kJ/kg}$$

Similarly,

$$q_{out} = h_4 - h_1 = c_p(T_4 - T_1) = (1.005\text{ kJ/kg}\cdot\text{K})(424.9 - 300)\text{K} = 125.5\text{ kJ/kg}$$

The net work production is then

$$w_{net} = q_{in} - q_{out} = 295.4 - 125.5 = \mathbf{169.9\text{ kJ/kg}}$$

and the thermal efficiency of this cycle is

$$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{169.9\text{ kJ/kg}}{295.4\text{ kJ/kg}} = \mathbf{0.575}$$