Oefeningen Thermodynamica

# Hoofdstukken 1-2

## Oefening 1

P1V1 = n1RT1

P2V2 = n2RT2

Volume hoeveelheid gas in de fles blijft hetzelfde bij verwarmen. Er geld dus :

Dat is een druk toename met een factor 4 !!

## Oefening 2

Oppervlakte deksel = A1 = Pi \* R2 = 0,09 pi

Oppervlak gewichtjes = A2 = Pi \* r2 = 2,25 x 10^-6 Pi

Druk atmosfeer is 1013 hPa

Inwendige druk over heel A1 = P inw = 200 kPa

Druk van het gewichtje : Pgew = F/ A2 = m g / A2

Inwendige druk moet gelijk zijn aan atmosferische druk + druk van het gewichtje (op dit punt zal het blokje net niet omhoog gaan door inwendige druk)

P atm + P gew = P inw

1013 hPa + m g / A2 = 200 kPa

De enige onbekende is m en deze kunnen we dus berekenen

m = 71 g

## Oefening 3

*Een hamster loopt in een rad en trekt zo een gewicht van 200 g 41,55 m omhoog. Door het harde rennen, produceert hij 5,0 J lichaamswarmte. Wat is de verandering in inwendige energie van de hamster onder deze omstandigheden ?*

Gegeven:

* m = 0,2 kg
* h = 41,55 m
* Q = 5,0 J

De hamster levert potentiële energie gelijk aan m.g.h en levert 5,0 J warmte.

## Oefening 4

***Geg:*** k = 12\*10³ kN/cm

Δx = 5 cm

D1 = 7 cm

D2 = 5 cm

p2 = 8 MPa

p3 = 0.3 MPa

***Gevr:*** p1

***Opl:***

F2+F3-F1=-Fv

## Oefening 5

*Gasballons worden gevuld met helium (ongeveer 7 keer lichter dan lucht). De kracht die de ballon omhoog stuwt, wordt als volgt bepaald: Fb = ρlucht .g.Vballon  
Twee ballonvaarders van elk 70 kg willen opstijgen in een ballon met een diameter van 10 meter.  
Gevraagd:*

1. *Wat is de versnelling van de ballon op het moment dat alle kabels worden losgelaten?  
   (ρlucht = 1,16 kg/m³)*
2. *Wat is de maximale massa die deze ballon de hoogte in kan nemen?*

1. We beschouwen de ballon als gewichtloos, waardoor het totale gewicht gelijk is aan dat van de 2 ballonvaarders, namelijk 140 kg. De kracht Fb die de ballon omhoog stuwt, moet gelijk zijn aan m\*a.

2. De opwaartse kracht is gelijk aan 5958,3 N.

## Oefening 8

***Geg:*** h1 = 0.2 m

h2 = 0.3 m

h3 = 0.46 m

patm = 1.030\*105 Pa

ρwater = 1000 kg/m3

ρolie = 850 kg/m³

ρHg= 13600 kg/m³

***Gevr:*** p

***Opl:***

## Oefening 11

*Een skilift van 1 km lang brengt de skiërs 200 m omhoog. De stoeltjes hangen 20 meter uit elkaar. De lift draait met een snelheid van 10 km/u.*

1. *Als de gemiddelde massa van elk stoeltje (met 3 skiërs in) 250 kg is, wat is dan het vermogen, nodig om de lift draaiende te houden ?*
2. *Wat is het vermogen, nodig om de lift in 5 seconden vanuit stilstand op kruissnelheid te brengen ?*

Gegeven:

* l = 1000 m
* h = 200 m
* x = 20 m
* v = 2,78 m/s

1. m = 250 kg en 1000 m/20 m = 50 stoeltjes maar eigenlijk 51 want je rekent de ‘eindpunten’ mee.  
De berekeningen zijn echter voor 50 stoeltjes, aangezien we daar pas later zijn achtergekomen.  
🡪 totale massa = 12 500 kg  
Voor het vermogen geldt volgende formule:

De geleverde arbeid is gelijk aan de potentiële energie door het omhoog brengen van de liften.

De tijd die de lift erover doet om de liften 200 m hoger te brengen, is gelijk aan:

Het vermogen, nodig om de lift draaiende te houden, is dus gelijk aan 68 179,5 W.

2. We maken gebruik van de formule voor kinetische energie, om het benodigde vermogen te bepalen.

Als je deze kinetische energie nu deelt door de gewenste 5 seconden, bekom je een vermogen van   
9 660,5 W.

Ik weet eerlijk gezegd wel niet meer waarom we in het eerste geval de potentiële energie gebruikten, en in het tweede geval kinetische energie. ’t Is niet dat die verschillende uitwerkingen op hetzelfde neerkomen ..

## Oefening 15

*Een oude 75 pk motor met een efficiëntie van 91,0 % wordt vervangen door een nieuwe motor met hetzelfde vermogen, maar met een efficiëntie van 95,4 %... Als de motor voor 100 % belast blijft (net als z’n voorganger), hoeveel minder warmte wordt dan afgegeven door de nieuwe motor dan door de oude ?*

Gegeven:

* P = 75 pk = 745\*75 W = 55 875 W
* η = 91,0 % 🡪 95,4 %

Er is 4,4% \* 55 875 W = 2458,5 J/s minder verlies in de vorm van warmte.

## Oefening 16

*Een stoommachine wordt aangedreven via een boiler die 3,8.106 kJ/u verbruikt. De verbrandingsefficiëntie van de boiler is 0,7. De boiler wordt eens goed onder handen genomen tot de efficiëntie 0,8 is.De boiler werkt met tussenpozen in het totaal 1500 uur per jaar. Als de energiekost 4,12€ per 106kJ per eenheid kost, hoeveel euro werd er dan bespaard door het onderhoud van de boiler?*

Gegeven:

* P = 3,8.106 kJ/u = 1 055 555,55 J/s
* η = 70% 🡪 80%
* 1500 u/j = 5 400 000 s
* 4,12€/109 J

We berekenen eerste de totale kosten voor een efficiëntie van 100%.  
Als de boiler in totaal 5 400 000 s (per jaar) werkt, dan verbruikt hij in totaal:

De totaalkosten lopen dan op tot:

Als de efficiëntie 70% bedraagt, dan wordt dus 70% van de verbruikte 5,7 \* 1012 J omgezet naar energie die verbruikt kan worden door de stoommachine. De output van de boiler is dan 3,99 \* 1012 J. De verspilde energie is ongeveer gelijk aan 1,7 \* 1012 J. De prijs om zoveel energie op te wekken, is 7004€.

Voor een efficiëntie van 80% is de output van de boiler gelijk aan 4,56 \* 1012 J. Nu gaat er slechts 1,14 \* 1012 J verloren. De prijs hiervoor bedraagt 4696,8 euro.

Dankzij het onderhoud word er jaarlijks dus 2307,2 euro bespaard.

## Oefening 20

🡪als er een x gegeven is, dan weet je dat je in het gebied L+G zit

2)

🡪geldt ook voor enthalpie en inwendige energie

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| T (°C) | P (kPa) | h (kJ/kg) | x | Fase (n) |
| 120.21 (A-5) | 200 | 1692.533 (2) | 0.7 | L+G |
| 140 | 361.53 (A-4)(\*) | 1800 | 0.56 (2) | L+G |
| 177.66 | 950 | 752.74 | 0.0 | L (verz.) |
| 80 (A-4) | 500 (\*\*) | 335.02 | 0.0 | L (onverz.) |
| 350 | 800 | 3162.2 (\*\*\*) | 0.0 | G |

(\*)Eerst kijken of je goed zit!

🡪enthalpie checken

🡪enthalpie tussen hf en hg

🡺L+G

(\*\*)Druk is veel hoger dan 47.416

🡪L (zie P,v-grafiek in boek. Als het G zou zijn, in andere tabel gaan kijken)

(\*\*\*)Ligt niet tussen hf en hg

🡺overheated

## Oefening 22

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| T (°C) | P (kPa) | h (kJ/kg) | x | Fase (n) |
| 21.55 | 600 | 180 | 0.5 (2) | L+G |
| -10 | 200.74 | 162.126 (2) | 0.6 (2) | L+G |
| -14 | 500 | 33.55 (\*) | 0.0 | L (onverz.) |
| 70 | 1200 | 300.61 | 0.0 | G |
| 44 | 1130.7 | 272.95 | 1.0 | G (verz.) |

(\*)

# Hoofdstuk 4

## Oefening 4.26

A saturated water mixture contained in a spring-loaded piston-cylinder device is cooled until it is saturated liquid at a specified temperature. The work done during this process is to be determined.

***Assumptions*** The process is quasi-equilibrium.

***Analysis*** The initial state is saturated mixture at 1 MPa. The specific volume at this state is (Table A-5),

*P*

*v*

2

1

1 MPa



The final state is saturated liquid at 100°C (Table A-4)



Since this is a linear process, the work done is equal to the area under the process line 1-2:



The negative sign shows that the work is done on the system in the amount of 5.34 kJ.

## Oefening 4.40

Geg: 1) A: gas, m = 2 kg, p = 1 MPa, T = 300°C

B: saturated liquid-vapor, m = 3 kg, T = 150°C, x=0.5

2) p = 300 kPa

Gevr: a) T en x in situatie 2

b) warmteverlies

Opl:

a) A: Tabel A-6:

🡪

B: Tabel A-4:

🡪

🡺

🡪

* Kijk in tabel A-6: v komt niet voor in P=0.30 MPa
* Kijk in tabel A-5: v valt tussen vf en vg
* T=133.52°C

b) Tabel A-5:

Tabel A-6:

Tabel A-4:

-

Of

## Oefening 4.41

34,0 minuten

## Oefening 4.67

***Geg:*** 1 kg O2

Opwarming van 25°C naar 300°C

***Gevr:*** warmtetransfer?

a) V = constant

b) p = constant

***Opl:***

voor T nemen we gem v 25 en 300 => 162.5°C => 435.65 K

a) Voor cv gebruiken we tabel A2 en lineaire interpolatie:

kJ/kg.K

cv = ΔU/ΔT => ΔU = cv avg. ΔT = 189 kJ voor 1 kg O2

(want voor isochore processen geeft ΔU de warmtetransfer)

OF 

b) Voor cp gebruiken we tabel A2 en lineaire interpolatie:

kJ/kg.K

Cp = ΔH/ΔT => ΔH = cp avg. ΔT = 260 kJ voor 1 kg O2

(want voor isobare processen geeft ΔH de warmtetransfer)

OF

## Oefening 4.84

50,5 sec

## Oefening 4.100

4 repen per uur

## Oefening 4.121

***Assumptions*** The process is quasi-equilibrium.

***Analysis***(*a*)Initially the system is a saturated mixture at 125 kPa pressure, and thus the initial temperature is



The total initial volume is

H2O

5 kg



Then the total and specific volumes at the final state are



2

1

3

*P*

*v*

Thus,



(*b*) When the piston first starts moving, *P*2 = 300 kPa and *V*2 = *V*1 = 4.127 m3. The specific volume at this state is



which is greater than *vg* = 0.60582 m3/kg at 300 kPa. Thus **no liquid** is left in the cylinder when the piston starts moving.

(*c*) No work is done during process 1-2 since *V*1 = *V*2. The pressure remains constant during process 2-3 and the work done during this process is



## Oefening 4.125

**a)** v1= 0.005106 m3

**b)** wout = 2,97 kJ

**c)** Qin= 30,9 kJ

## Oefening 4.130

a) tabel A4: (volume verandert niet)

22°C: uf = 92.281 kJ/kg (met lin. Interpolatie)

80°C: uf = 334.97 kJ/kg

(cv = ΔU/ΔT volume verandert niet)

Δu = 334.97 kJ/kg - 92.281 kJ/kg = 242,739 kJ/kg

ΔU = Δu.m = 242,739 kJ/kg . 20L . 50 = 242 739 kJ

15 kW = 15 kJ/s = 54 000 kJ/h

Tijd nodig = = 4,76 h

b) Tijd nodig = = 9,26 h

## Oefening 4.135

ΔT = 0,6 °C

## Oefening 4.136

***Assumptions* 1** Thermal properties of the ice and water are constant. **2** Heat transfer to the glass is negligible. **3** There is no stirring by hand or a mechanical device (it will add energy).

***Properties*** The density of water is 1 kg/L, and the specific heat of water at room temperature is *c* = 4.18 kJ/kg·°C (Table A-3). The specific heat of ice at about 0°C is *c* = 2.11 kJ/kg·°C (Table A-3). The melting temperature and the heat of fusion of ice at 1 atm are 0°C and 333.7 kJ/kg,.

***Analysis*** (*a*) The mass of the water is



Water

20°C

0.2 L

Ice cubes

0°C

We take the ice and the water as our system, and disregard any heat and mass transfer. This is a reasonable assumption since the time period of the process is very short. Then the energy balance can be written as





Noting that *T*1, ice = 0°C and *T*2 = 5°C and substituting gives

*m*[0 + 333.7 kJ/kg + (4.18 kJ/kg·°C)(5-0)°C] + (0.2 kg)(4.18 kJ/kg·°C)(5-20)°C = 0

*m* = 0.0364 kg = **36.4 g**

(*b*) When *T*1, ice = -8°C instead of 0°C, substituting gives

*m*[(2.11 kJ/kg·°C)[0-(-8)]°C + 333.7 kJ/kg + (4.18 kJ/kg·°C)(5-0)°C]

+ (0.2 kg)(4.18 kJ/kg·°C)(5-20)°C = 0

*m* = 0.0347 kg = **34.7 g**

Cooling with cold water can be handled the same way. All we need to do is replace the terms for ice by a term for cold water at 0°C:



Substituting,

[*m*cold water (4.18 kJ/kg·°C)(5 - 0)°C] + (0.2 kg)(4.18 kJ/kg·°C)(5-20)°C = 0

It gives

*m* = 0.6 kg = **600 g**

## Oefening 4.149

***Properties*** The specific heat ratio for air at room temperature is *k* = 1.4.

***Analysis*** The explosive energy per unit volume is given as



For an ideal gas,

*u*1 - *u*2 = *cv*(*T*1 - *T*2)



and thus



Substituting,



which is the desired result.

Using the relation above, the total explosive energy of 20 m³ of air at 5 MPa and 100°C when the surroundings are at 20°C is determined to be



# Hoofdstuk 5

## Oefening 5.22

***Properties*** The properties of air are *R* = 0.287 kJ/kg.K and *cp* = 1.008 kJ/kg.K (at 350 K from Table A-2b)

***Analysis*** (*a*) The diameter is determined as follows:





300 kPa

77°C

Air

25 m/s

18 kg/min



(*b*) The rate of flow energy is determined from



(*c*) The rate of energy transport by mass is



(*d*) If we neglect kinetic energy in the calculation of energy transport by mass



Therefore, the error involved if neglect the kinetic energy is only **0.09%**.

**Oefening 5.32**

***Assumptions*** **1** This is a steady-flow process since there is no change with time. **2** Air is an ideal gas with constant specific heats. **3** Potential energy changes are negligible. **4** There are no work interactions. **5** The diffuser is adiabatic.

***Properties*** The specific heat of air at the average temperature of (20+90)/2=55°C =328 K is *cp* = 1.007 kJ/kg⋅K (Table A-2*b*).

***Analysis*** There is only one inlet and one exit, and thus . We take diffuser 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



AIR

100 kPa

20°C

500 m/s

200 kPa

90°C



Solving for exit velocity,



## Oefening 5.55

*T*2 = 267,3°C

## Oefening 5.65

x=0,422

## Oefening 5.84

***Assumptions*** **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible.  **4** Fluid properties are constant.

***Properties*** The specific heats of cold and hot water are given to be 4.18 and 4.19 kJ/kg.°C, respectively.

***Analysis*** We take the cold water tubes as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

Hot water

100°C

3 kg/s

Cold Water

15°C

0.60 kg/s



Then the rate of heat transfer to the cold water in this heat exchanger becomes



Noting that heat gain by the cold water is equal to the heat loss by the hot water, the outlet temperature of the hot water is determined to be



## Oefening 5.117

406 K

## Oefening 5.130

***Assumptions*** **1** This is an unsteady process since the conditions within the device are changing during the process, but it can be analyzed as a uniform-flow process by using constant average properties for the steam leaving the tank.  **2** Kinetic and potential energies are negligible. **3** There are no work interactions involved. **4** The direction of heat transfer is to the tank (will be verified).

***Properties*** The properties of water are (Tables A-4 through A-6)

STEAM

2 MPa

*Q*



***Analysis*** We take the tank as the system, which is a control volume since mass crosses the boundary. Noting that the microscopic energies of flowing and nonflowing fluids are represented by enthalpy *h* and internal energy *u*, respectively, the mass and energy balances for this uniform-flow system can be expressed as

*Mass balance*:



*Energy balance*:



The state and thus the enthalpy of the steam leaving the tank is changing during this process. But for simplicity, we assume constant properties for the exiting steam at the average values. Thus,



The initial and the final masses in the tank are



Then from the mass and energy balance relations,





## Oefening 5.141

The rate of accumulation of water in a pool and the rate of discharge are given. The rate supply of water to the pool is to be determined.

***Assumptions* 1** Water is supplied and discharged steadily. **2** The rate of evaporation of water is negligible. **3** No water is supplied or removed through other means.

***Analysis*** The conservation of mass principle applied to the pool requires that the rate of increase in the amount of water in the pool be equal to the difference between the rate of supply of water and the rate of discharge. That is,



since the density of water is constant and thus the conservation of mass is equivalent to conservation of volume. The rate of discharge of water is



The rate of accumulation of water in the pool is equal to the cross-section of the pool times the rate at which the water level rises,



Substituting, the rate at which water is supplied to the pool is determined to be



## Oefening 4.143

2,46 kg/m3

## Oefening 5.148





## Oefening 5.151

***Assumptions*** **1** The process in the mixing chamber is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** There are no work interactions. **4** The device is adiabatic and thus heat transfer is negligible.

20°C

*T*mix

Tank

*T*1 = 80°C

*T*2 = 60°C

20°C

0.06 kg/s

Mixing chamber



***Properties*** The specific heat and density of water are taken to be *cp* = 4.18 kJ/kg.K, ρ = 100 kg/m3 (Table A-3).

***Analysis*** We take the mixing chamber 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

Energy balance:



or  (1)

Similarly, an energy balance may be written on the water tank as

 (2)

where 

and 

Substituting into Eq. (2),



Substituting into Eq. (1),



# Hoofdstuk 6

## Oefening 6.23

Q’H=W’net / nth = 350 kW/0,04 = 8750 kJ/s

* \* 3600 (omzetten naar kJ/h) = 31,5 . 106 kJ/h

## Oefening 6.25

Situatieschets: organisatie A wil een nieuwe ‘power plant’ om 150 000 MW elektriciteit op te wekken. Er zijn twee mogelijkheden: ofwel bouwen ze een power plant die $1300 per kW en welke een efficiëntie heeft van 34 % ; de andere mogelijkheid is een ander soort cylcle die $ 1500 per kW en een efficiëntie heeft van 45 %. De gemiddelde verbrandingswarmte van de brandstof is 28 000 000 kJ per ton. Wat is de prijs van de brandstof als we weten dat het verschil in totale kostprijs van de cycles na 5 jaar is weggewerkt.

Als eerste berekenen we de standaardkost van de machines voor het produceren van 150 000 MW

150 000X 103 kW X 1300 $ / kW = 1,95 x 1011 $

150 000X 103 kW X 1500 $ / kW = 2,25 X 1011 $

De eerste machiene is dus duidelijk goedkoper maar deze heeft een lagere efficiëntie waardoor ze meer brandstof moet verbruiken om diezelfde150 000 MW te produceren. Na 5 jaar wordt dit verschil dus weggewerkt.

We berekenen voor de twee systemen de warmte die erin gestoken moet worden gedurende de 5 jaar.

ᵑ = hieruit volgt dat Q in( per s ) =

ᵑ = hieruit volgt dat Q in( per s ) =

Voor deze warmtes berekenen we hoeveel brandstof we ervoor nodig hebben.

Volgens het gegeven moet na 5 jaar de totale kost hetzelfde zijn dus geldt er :

(Prijs/ ton) x + 1,95 x 10 ^ 11 = (prijs / ton) X + 2,25 X 1011

hieruit vinden we deprijs per ton brandstof welke gelijk is aan 50 $

## Oefening 6.49

Een huis wordt verwarmd door een elektrisch toestel welke 1200 kWh verbruikt tijdens een wintermaand. Stel dat men in plaats hiervan een warmte pomp gebruikt met een COP van 2,4 hoeveel geld zou men dan besparen wanneer men een prijs van 8,5 e/ kWh hanteert. (e is een Dolar cent ofzo )

De prijs om 1200 kWh te produceren is :

8,5 e/ kWh X 1200 kWh = 10200 e

Dit dus de prijs die je betaald als er met het elektrisch toestel wordt verwarmd.

Vermist het elektrisch toestel alle elektriciteit (arbeid) omgezet in warmte geldt er:

Wnet, in = QH = 1200 kWh

Met de warmtepomp wordt de W net, in :

COP= = 500 kWh

(! QH is hetzelfde als bij de elektrische motor want uiteindelijk moet er evenveel warmte aan het huis worden toegevoegd om het onder zelfde omstandigheden even warm te krijgen)

De prijs om 500 kWh te produceren is :

8,5 e/ kWh X 500 kWh = 4250 e

Het prijsverschil is dus 10200 e - 4250 e = 5950 e en dus ongeveer 59 dollar

## Oefening 6.51

1,75 kW

## Oefening 6.85

- nth,maximum=1-QL/QH = 1 – TL/TH = 1 – (433K/298K) = 0,312

- table A-6 (gebruik hf): 25°C: hf=104 , 83 kJ/kg  
 160°C: hf=675,47 kJ/kg  
 Verschil = 570,64 kJ/kg 🡪 \*440kg/s = 251 081,6 kJ/s

nth= W’net / Q’h = (22 MJ/s)/(251,0816 MJ/s) = 0,087

Q’in = 251 081,6 kJ/s – 22MJ /s = 229,0816 MJ/s

## Oefening 6.137

***Properties*** The enthalpy of vaporization of R-134a at -8°C is *hfg* = 204.52 kJ/kg (Table A-12).

***Analysis*** The coefficient of performance of the cycle is

*T*

*v*

20°C

4

3

1

2

*QH*

*QL*

-8°C

and 

Then the amount of refrigerant that vaporizes during heat absorption is



since the enthalpy of vaporization *hfg* at a given *T* or *P* represents the amount of heat transfer per unit mass as a substance is converted from saturated liquid to saturated vapor at that *T* or *P*. Therefore, the fraction of mass that vaporized during heat addition process is



The pressure at the end of the heat rejection process is



## Oefening 6.144

Q’in = m’ (h22°C – h8°C) + 45 kW = …  
 m’ = 0,4 L/h \* 20 = 8L/h = 8kg/h

Tabel A-4: lineaire interpolatie doen (y=(y2-y1)/(x2-x1) \* (x-x1) + y1  
 y = h (kJ/kg) en x = T (°C)

8°C 🡺 tss 5°C en 10°C: y = 4,2004\*x + 0,018 🡪 y=h8°C= 33,2 kJ/kg  
 22°C 🡺 tss 20°C en 25°C: y = 4,183\*x + 0,255 🡪 y=h8°C= 92,281 kJ/kg

Q’in = m’ (h22°C – h8°C) + 45 kW = (8/3600) kg/s \* (92.281-33.2) kJ/kg + 45.10-3 kW  
 = 0,176 kW

W’net = Q’in / COP = 0,176 kW / 2,9 = 0,061 kW

## Oefening 6.145

A washing machine uses $33/year worth of hot water heated by a gas water heater. The amount of hot water an average family uses per week is to be determined. 🡪 192 L/week

# Hoofdstuk 7

## Oefening 7.28

***Assumptions***  The heat pump operates steadily.

***Analysis*** Since the heat pump is completely reversible, the combination of the coefficient of performance expression, first Law, and thermodynamic temperature scale gives

10°C

21°C

HP

100 kW







The power required to drive this heat pump, according to the coefficient of performance, is then



According to the first law, the rate at which heat is removed from the low-temperature energy reservoir is



The rate at which the entropy of the high temperature reservoir changes, according to the definition of the entropy, is



and that of the low-temperature reservoir is



The net rate of entropy change of everything in this system is



as it must be since the heat pump is completely reversible.

## Oefening 7.33

According to the conservation of mass principle,



An entropy balance adapted to this system becomes



When this is combined with the mass balance, it becomes



Multiplying by *dt* and integrating the result yields



Since all the entropies are same, this reduces to



Hence, the entropy of the surroundings can only increase or remain fixed.

## Oefening 7.49

***Assumptions*** **1** The system is stationary and thus the kinetic and potential energy changes are zero. **2** There are no work interactions involved other than the boundary work. **3** The thermal energy stored in the cylinder itself is negligible. **4** The compression or expansion process is quasi-equilibrium.

***Analysis*** The energy balance for this system can be expressed as



The initial state properties are



*T*

*s*

2

1

Since the entropy is constant during this process,



Substituting,



## Oefening 7.52

The total heat transfer for the process 1-2 shown in the figure is to be determined.

***Analysis*** For a reversible process, the area under the process line in *T*-*s* diagram is equal to the heat transfer during that process. Then,



*T* (°C)

*S* (kJ/K)

2

1

500

100

0.2 1.0

## Oefening 7.55

***Assumptions*** **1** This is a steady-flow process since there is no change with time. **2** The process is isentropic (i.e., reversible-adiabatic).

***Analysis*** There is only one inlet and one exit, and thus . We take the turbine 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



Turbine

2 MPa

360°C

100 kPa



*T*

*s*

2

1

2 MPa

100 kPa

The inlet state properties are



For this isentropic process, the final state properties are (Table A-5)



Substituting,



## Oefening 7.64

***Assumptions*** **1** The system is stationary and thus the kinetic and potential energy changes are zero. **2** There are no work interactions involved. **3** There is no heat transfer between the system and the surroundings.

***Analysis*** (a) The energy balance for this system can be expressed as



The heat released by the chips is



The mass of the refrigerant vaporized during this heat exchange process is



Only a small fraction of R-134a is vaporized during the process. Therefore, the temperature of R-134a remains constant during the process. The change in the entropy of the R-134a is (at -40°F from Table A-11)



(b) The entropy change of the chips is



(c) The total entropy change is



The positive result for the total entropy change (i.e., entropy generation) indicates that this process is possible.

## Oefening 7.69

*a*) Using the entropy data from the compressed liquid water table: wp=15,10 kJ/kg

*b*) Using inlet specific volume and pressure values: wp=15,14 kJ/kg; Error = 0,3%

c) Using average specific volume and pressure values: wp=15,10 kJ/kg; Error = 0%

## Oefening 7.78

***Assumptions*** Helium and nitrogen are ideal gases with constant specific heats.

***Properties*** The properties of helium are *cp* = 5.1926 kJ/kg⋅K, *R* = 2.0769 kJ/kg⋅K (Table A-2a). The specific heat of nitrogen at the average temperature of (427+27)/2=227°C=500 K is *cp* = 1.056 kJ/kg⋅K (Table A-2b). The gas constant of nitrogen is *R* = 0.2968 kJ/kg⋅K (Table A-2a).

***Analysis*** From the entropy change relation of an ideal gas,





Hence, helium undergoes the largest change in entropy.

## Oefening 7.99

***Assumptions*** **1** Kinetic and potential energy changes are negligible. **2** Air is an ideal gas with constant specific heats. **3** The room is well-sealed and there is no heat transfer from the room to the surroundings. **4** Sea level atmospheric pressure is assumed. *P* = 101.3 kPa.

***Properties*** The properties of air at room temperature are *R* = 0.287 kPa.m3/kg.K, *cp* = 1.005 kJ/kg.K, *cv* = 0.718 kJ/kg.K. The specific heat of water at room temperature is *cw* = 4.18 kJ/kg.K (Tables A-2, A-3).

***Analysis*** (*a*) The mass of the air in the room is



Water

45 kg

95°C

Room

90 m3

12°C

An energy balance on the system that consists of the water in the container and the air in the room gives the final equilibrium temperature



(*b*) The heat transfer to the air is



(*c*) The entropy generation associated with this heat transfer process may be obtained by calculating total entropy change, which is the sum of the entropy changes of water and the air.





 

# Hoofdstuk 9

## Oefening 9.19

The three processes of an air-standard cycle are described. The cycle is to be shown on *P-v* and *T-s* diagrams, and the net work per cycle and the thermal efficiency are 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 variable specific heats.

***Properties*** The properties of air are given in Table A-17.

*v*

*v*

*P*

3

2

1

*q*in

*q*out

***Analysis*** (*b*) The properties of air at various states are



*s*

*T*

1

3

2

*q*in

*q*out

(c) 

## Oefening 9.21

A Carnot cycle with the specified temperature limits is considered. The net work output per cycle is to be determined.

***Assumptions*** Air is an ideal gas with constant specific heats.

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

***Analysis*** The minimum pressure in the cycle is *P*3 and the maximum pressure is *P*1. Then,

*s*

*T*

3

2

*q*in

*q*out

4

1

900

300

or 

The heat input is determined from

Then, 

## Oefening 9.24

*De thermische energie reservoirs van een ideaal gas Carnot cyclus zijn op 670°C en 4°C. Het toestel dat de cyclus uitvoert, voert elke keer dat de cyclus doorlopen wordt 100 kJ warmte af.  
Gevraagd:*

* *QH = totale hoeveelheid warmte aangevoerd*
* *Wnet = totale arbeid geproduceerd door de cyclus, elke keer deze doorlopen wordt*

We hebben volgende gegevens:

* TH = 943 K en TL = 277 K
* QL = 100 kJ

Voor de thermische efficiëntie hebben we enkele formules, waaronder 1 voor een reversibele cyclus, en 1 voor een gewone. Door beiden te gebruiken, kunnen we QH bepalen.

Verder geldt ook volgende formule, waaruit we de netto geleverde arbeid kunnen halen.

## Oefening 9.33

An ideal Otto cycle is considered. The thermal efficiency and the rate of heat input are 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 *cp* = 1.005 kJ/kg.K, *cv* = 0.718 kJ/kg·K, and *k* = 1.4 (Table A-2a).

***Analysis*** The definition of cycle thermal efficiency reduces to

*v*

*v*

*P*

4

1

3

2

*q*in

*q*out



The rate of heat addition is then



## Oefening 9.39

***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 850 K are *cp* = 1.110 kJ/kg·K, *cv* = 0.823 kJ/kg·K, *R* = 0.287 kJ/kg·K, and *k* = 1.349 (Table A-2b).

***Analysis*** (*a*) Process 1-2: polytropic compression



1

*Q*in

2

3

4

### *P*

##### V

*Q*out



Process 2-3: constant volume heat addition





Process 3-4: polytropic expansion.







Process 4-1: constant volume heat rejection.

(*b*) The net work output and the thermal efficiency are





(*c*) The mean effective pressure is determined as follows



(*d*) The clearance volume and the total volume of the engine at the beginning of compression process (state 1) are





The total mass contained in the cylinder is



The engine speed for a net power output of 70 kW is



Note that there are two revolutions in one cycle in four-stroke engines.

(*e*) The mass of fuel burned during one cycle is



Finally, the specific fuel consumption is



## Oefening 9.40

216 kPa

## Oefening 9.52

***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 *R* = 0.287 kPa·m3/kg⋅K,  *cp* = 1.005 kJ/kg·K, *cv* = 0.718 kJ/kg·K, and *k* = 1.4 (Table A-2a).

***Analysis*** We begin by using the process types to fix the temperatures of the states.

*v*

*v*

*P*

4

1

2

3

*q*in

*q*out





Combining the first law as applied to the various processes with the process equations gives



According to the definition of the thermal efficiency,



## Oefening 9.60

*Een 4-cylinder 2-takt dieselmotor van 2,4 L, die opereert op een ideale Dieselcyclus, heeft een compression ratio van 17 en een cutoff ratio van 2,2. Aan het begin van het compressieproces heeft de lucht een temperatuur van 55°C en een druk van 97 kPa.  
Gevraagd:  
  
Bepaal, gebruik makend van de cold-air standard assumptions, hoeveel vermogen de motor zal leveren aan 1500 toeren per minuut. (revolutions per minute)*

***Assumptions*** **1** The air-standard assumptions are applicable with nitrogen as the working fluid. **2** Kinetic and potential energy changes are negligible. **3** Nitrogen is an ideal gas with constant specific heats.

***Properties*** The properties of nitrogen at room temperature are *cp* = 1.039 kJ/kg·K, *cv* = 0.743 kJ/kg·K, *R* = 0.2968 kJ/kg·K, and *k* = 1.4 (Table A-2).

***Analysis*** Process 1-2: isentropic compression.

*v*

*P*

4

1

2

3

*Q*in

*Q*out



Process 2-3: *P* = constant heat addition.



Process 3-4: isentropic expansion.



***Discussion*** Note that for 2-stroke engines, 1 thermodynamic cycle is equivalent to 1 mechanical cycle (and thus revolutions).

## Oefening 9.64

***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 *R* = 0.2870 kJ/kgK (Table A-1); *cp* = 1,005 kJ/kgK ; *cv* = 0,718 kJ/kgK and *k* = 1.4 (Table A-2).

***Analysis*** Working around the cycle, the germane properties at the various states are



*v*

*v*

*P*

4

1

2

3

*q*out

*x*

*q*in



 where *rp*= pressure ratio (= 1,1)







Applying the first law to each of the processes gives











The net work of the cycle is



and the net heat addition is



Hence, the thermal efficiency is



## Oefening 9.73

An ideal Stirling engine with air as the working fluid operates between the specified temperature and pressure limits. The net work produced per cycle and the thermal efficiency of the cycle are to be determined.

***Assumptions*** Air is an ideal gas with constant specific heats.

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

***Analysis*** Since the specific volume is constant during process 2-3,

*s*

*T*

3

2

*q*in

*q*out

4

1

800 K

300 K



Heat is only added to the system during reversible process 1-2. Then,



The thermal efficiency of this totally reversible cycle is determined from



Then,



## Oefening 9.75

*s*

*T*

3

2

*q*in

*q*out

4

1

560 R

***Assumptions*** Air is an ideal gas with constant specific heats.

***Properties*** The properties of air at room temperature are   
*R* = 0.3704 psia·ft3/lbm.R = 0.06855 Btu/lbm·R,  *cp* = 0.240 Btu/lbm·R,   
*cv* = 0.171 Btu/lbm·R, and *k* = 1.4 (Table A-2Ea).

***Analysis*** Applying the ideal gas equation to the isothermal process 3-4 gives 

Since process 4-1 is a constant volume process,



According to first law and work integral,

 

The net work is then



## Oefening 9.78

750 kW