Natur, Technik, Systeme NTSY1

Semesterend-Prüfung, Januar 2017

Erstes Semester Wirtschaftsingenieurwesen, ZHAW, WI16 (a-b), WI15t

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Allgemeine Bemerkungen

Dauer der Prüfung: 150 Minuten.

Antworten müssen begründet und nachvollziehbar sein.

Erlaubte Hilfsmittel: **Persönlich verfasste Zusammenfassung von 6 Seiten; Buch: The Dynamics of Heat**. Rechen- und Schreibzeugs.

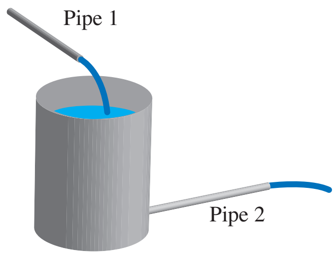
Lösen Sie **jede Aufgabe auf einem separaten Blatt**.

Schreiben Sie jedes Blatt an (Name, Datum, Prüfung, Nummer der Aufgabe).

Geben Sie die Aufgabenblätter mit Ihren Lösungen ab. Schreiben Sie die Aufgabenblätter mit Ihrem Namen an.

Punkteverteilung:
Aufgabe 1: 12
Aufgabe 2: 14
Aufgabe 3: 14

1. Wasser fliesst aus einem gradwandigen Tank durch ein horizontales Rohr am Boden des Tanks. Der Abfluss ist anfangs gleich Null, wird also zuerst angefahren. Zudem fliesst von oben Wasser mit einem konstanten Strom zu.



Daten:

Anfängliche Füllhöhe im Tank: 0.25 m

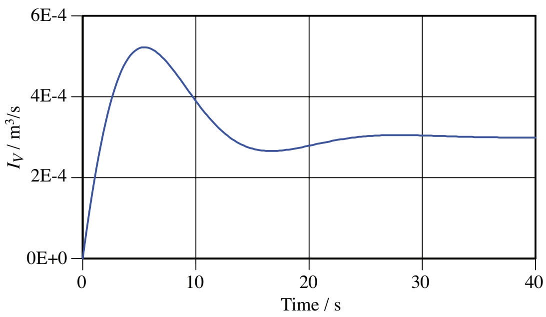
Radius des Tanks: 0.050 m

Widerstandswert der Strömung aus dem Tank: $4.0 \cdot 10^6$ Pa·s/m^3

Dichte des Wassers: 1000 kg/m^3

Stärke des Schwerefeldes: 10 N/kg

Beobachtung: Messung des Abflusses als Funktion der Zeit (Vergrösserung auf Rückseite.)



a. Formulieren Sie die momentane Volumenbilanz für das Wasser im Tank. [2 P]

b. Bestimmen Sie die hydraulische Kapazität des Tanks. [1 P]

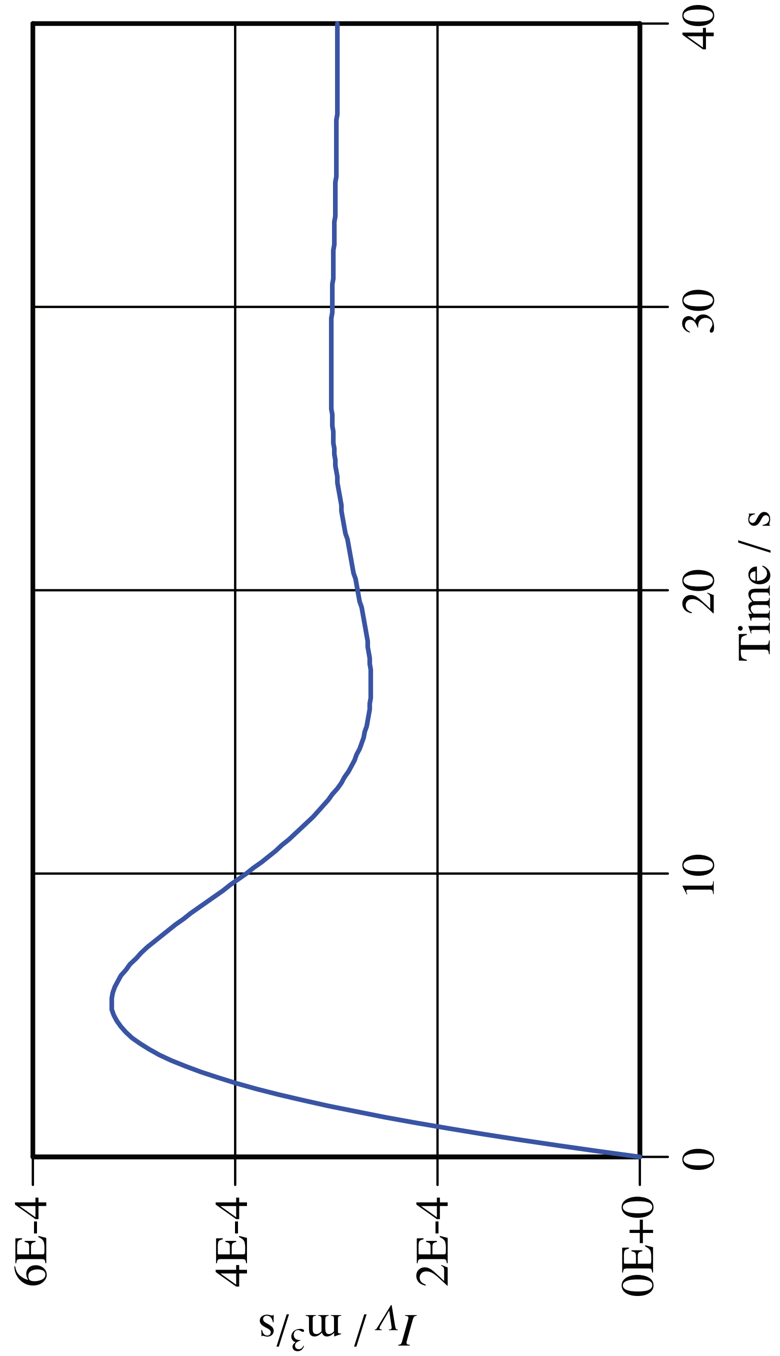
c. Wie gross ist der konstante Zustrom von Wasser zum Tank? Wieso? [2 P]

d. Wie hoch wird das Wasser im Tank im stationären Zustand stehen? Wieso? [2 P]

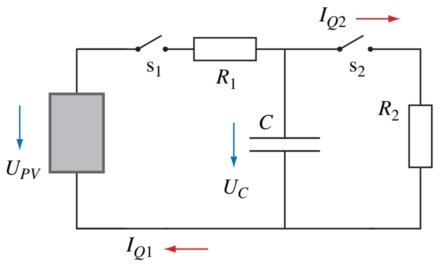
e. Wie gross ist die Induktivität des Wassers im Ausflussrohr? Erklären Sie Ihr Vorgehen. [2 P]

f. Bestimmen Sie so genau wie möglich die Füllhöhe des Wassers im Tank als Funktion der Zeit. Zeichnen Sie dazu ein Füllhöhe-Zeit Diagramm mit Zahlen (und Einheiten) auf den Achsen. Maxima und Minima sollten deutlich erkennbar sein. Erklären Sie Ihr Vorgehen. [3 P]

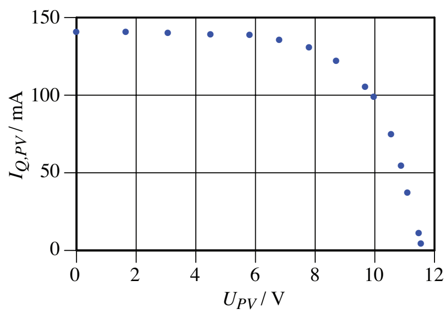
Aufgabe 1.



2. Eine kleine Labor-Solaranlage besteht aus drei Teilen: (1) einem PV Panel, (2) einem Kondensator (mit Kapazität C) als Speicher plus Vorwiderstandselement mit konstantem Widerstandswert R_1 und (3) einem ohmschen Lastwiderstand mit konstantem Widerstandswert R_2. Zwischen den drei Teilen hat es zwei Schalter (S1 und S2). Siehe Schaltungsdiagramm.



Das charakteristische Diagramm des PV Panels ist für eine bestimmte Lichtstärke der verwendeten Lampe gemessen worden und im nebenstehenden Diagramm dargestellt.



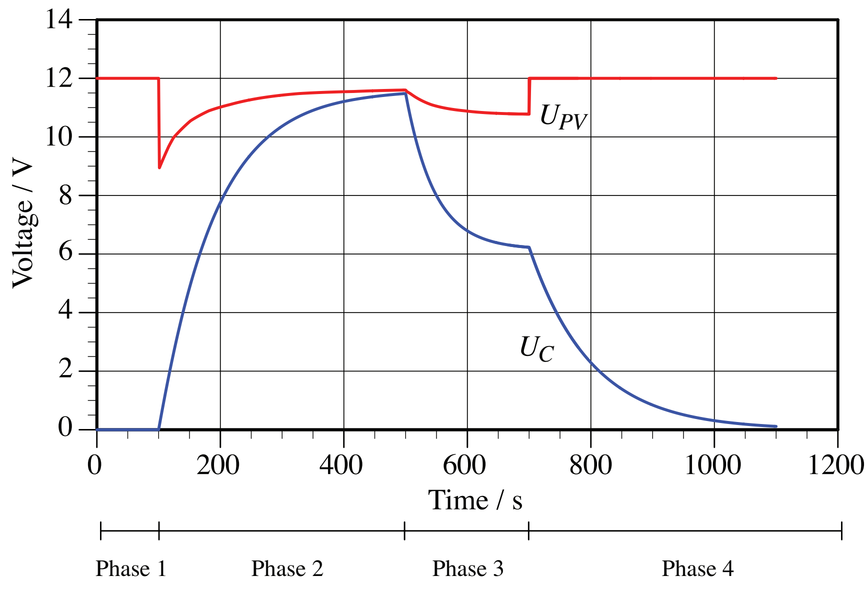
a. Bestimmen Sie die maximale Leistung des PV-Panels (maximum power point, MPP) graphisch aus den Daten. Beschreiben Sie kurz, wie Sie dabei vorgehen. [1 P]

Bei derselben Lichtintensität wird jetzt mit Hilfe des PV-Panels der Kondensator in der obigen Schaltung geladen. Die Intensität des auf das PV-Panel einfallenden Lichts und die Temperatur bleiben während des ganzen Experiments konstant.

b. Bestimmen Sie den Wert für R_1, damit Sie das PV-Panel direkt nach dem Schliessen von Schalter S1 (S2 ist noch offen) am MPP betreiben können. Der Kondensator ist ungeladen. [1 P]

c. Bestimmen graphisch Sie die Stromstärke in der ersten Masche und die Spannung über dem PV-Panel direkt nach dem Schliessen von Schalter S1 (S2 ist noch offen), wenn sie den Widerstandswert R_1 gegenüber dem Wert in b verdoppeln. Der Kondensator ist ungeladen. [2 P]

Für alle weitere Aufgaben gilt jetzt $R_1 = 75\ \Omega$. Die Spannung über dem PV-Panel (U_{PV}) und dem Kondensator (U_C) werden gemessen. Die Resultate dieser Messung sind in der folgenden Graphik gezeigt.



d. Betrachten Sie die gemessenen Daten für U_{PV} und U_C, und bestimmen Sie die Schalterstellungen für S1 und S2 für die vier Phasen des Experiments. Erklären Sie kurz, was in der jeweiligen Phase passiert. [2 P]

e. Bestimmen Sie die Leistung des PV-Panels zum Zeitpunkt $t = 150$ s aus der Graphik. [1 P]

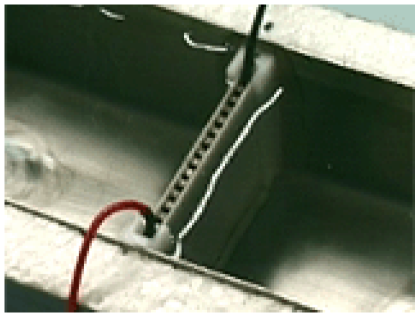
f. Bestimmen Sie den Energiestrom in den Kondensator zum Zeitpunkt $t = 150$ s. [1 P]

g. Vergleichen Sie Ihre Resultate aus e und f. Erklären Sie die Differenz der beiden Resultate. [1 P]

h. Der Lastwiderstand beträgt $R_2 = 100\ \Omega$. Bestimmen Sie aus den gemessenen Daten die Kapazität des Kondensators. Erklären Sie, wie Sie dabei vorgehen. [2 P]

i. Bestimmen Sie die Änderungsrate der Energie des Kondensators am Anfang und am Ende der Phase 3. [3P]

3. Ein Peltierelement (PE) befindet sich als Trennwand zwischen zwei Kammern, die aus dünnem Blech gemacht sind. Aussen um das Gefäss ist eine Schicht Styropor angebracht.

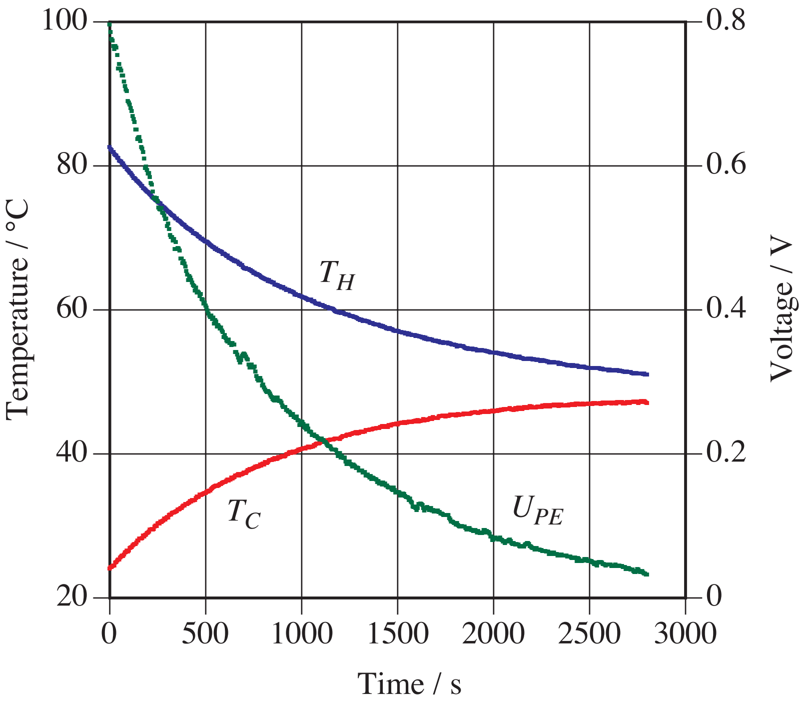


In die linke Kammer wird heisses Wasser eingefüllt, rechts kaltes (je 0.50 kg). Beide Wassermengen werden mechanisch umgerührt. Die spezifische Entropiekapazität von Wasser wird wie folgt bestimmt:

$$\kappa_S = \frac{c}{T} \quad , \quad c = 4200 \frac{\text{J}}{\text{K} \cdot \text{kg}}$$

Ein Widerstandselement (1.30 Ω) wird an die Kabel des Peltierelements angeschlossen. (Die Schaltung besteht nur aus dem Peltierlement und dem Widerstandselement.)

Der Deckel wird geschlossen. Die Temperaturen der beiden Wassermengen und die elektrische Spannung über dem Peltier Element werden gemessen.



a. Formulieren Sie die momentane Form der Entropiebilanz für das heisse Wasser. Begründung. [1 P]

b. Bestimmen Sie die Änderungsraten der Temperaturen gerade am Anfang (aus den Daten). [1 P]

c. Schätzen Sie den Entropiestrom durch das Peltierelement am Anfang ab ($t = 0$ s). Sie müssen dazu als Vereinfachung annehmen, dass das Rühren und der Wärmeverlust an die Umwelt keinen Einfluss haben. (Sie sollten etwa 0.20 W/K erhalten.) [2 P]

d. Bestimmen Sie für 6 Punkte (500 s, 750 s, …, 1750 s) die Temperaturdifferenz zwischen den Wassermengen links und rechts und die elektrische Leistung des Peltierelements. Stellen Sie die Leistung in einer Grafik als Funktion des Quadrates der Temperaturdifferenz dar. [2 P]

e. Erklären Sie, warum man das Ergebnis in Aufgabe d erwarten sollte (d.h., interpretieren und erklären Sie, was man da erhalten hat). [2 P]

f. Wie gross ist die elektrische Leistung im Vergleich zur thermischen Leistung, die sich aufgrund der Temperaturdifferenz (und dem Entropiestrom) zwischen dem Wasser links und rechts ergibt? ($t = 0$ s.) [2 P]

g. Der elektrische Innenwiderstand des PE beträgt ziemlich genau 1.0 Ω. Wie hoch ist demnach die thermoelektrische Spannung des PE gerade bei $t = 0$ s? Der Seebeck-Koeffizient des PE beträgt 0.053 V/K. Wie gross ist demnach die Temperaturdifferenz zwichen der heissen und der kalten Seite des PE bei $t = 0$ s? Welcher Bruchteil der Temperaturdifferenz zwischen den Wassermengen ist das? [2 P]

h. Sie haben auf der heissen und der kalten Seite des PE je einen konvektiven Wärmeübergang zwischen Wasser und PE-Oberfläche. Zeichnen Sie ein Prozessdiagramm mit PE und den beiden Wärmeübergängen je als Wärmewiderstand (Prozessdiagramm mit Entropieströmen, Entropieproduktionsraten, Temperaturniveaus und Energieströmen und Leistungen). [2 P]

Natural and Technical Systems NTSY1

Final Exam, January 2017

First Semester Wirtschaftsingenieurwesen, ZHAW, WI16 (a-b), WI15t

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General Remarks

Duration of the exam: 150 minutes.

Answers must be explained and must be documented.

Allowed tools: **Personally written summary of up to 6 pages**. **Book: The Dynamics of Heat.** Calculators and writing materials.

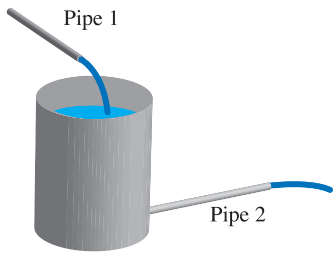
Please solve **each problem on a separate sheet**.

Write your name, date, exam, and number of problem on **every sheet**.

Hand in the problem statements with your solutions. Write your name on the problem statements!

Points:
Problem 1: 12
Problem 2: 14
Problem 3: 14

1. Water flows out of a straight-walled tank having a horizontal pipe at the bottom. Initially, the outflow equals zero meaning that it has to be started first. There is water flowing in from the top at constant rate.



Data:

Initial level of water in tank: 0.25 m

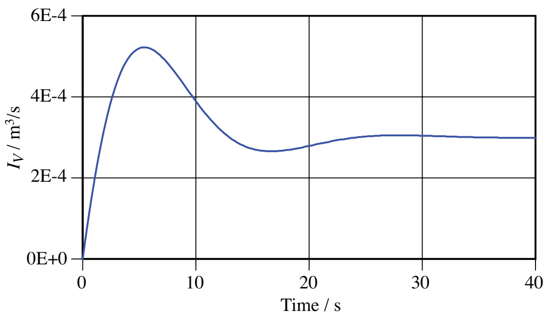
Radius of tank: 0.050 m

Resistance of flow out of tank: $4.0 \cdot 10^6$ Pa·s/m^3

Density of water: 1000 kg/m^3

Gravitational field strength: 10 N/kg

Observation: Measurement of outflow as a function of time (see the enlargement on the back if this page).



a. Formulate the instantaneous form of the law of balance of water in the tank. [2 P]

b. Determine the hydraulic capacitance of the tank. [1 P]

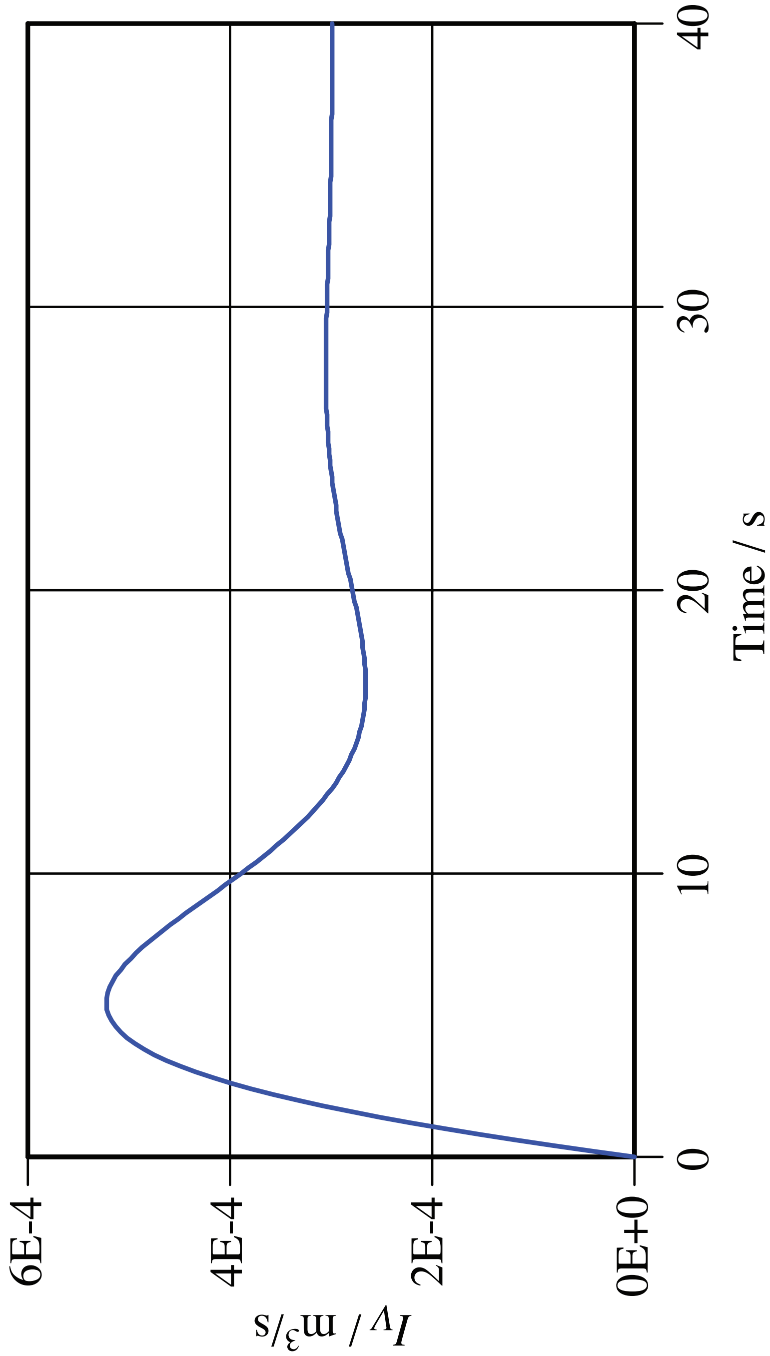
c. What is the magnitude of the constant inflow of water? Explain how you obtain your result. [2 P]

d. What will be the level of water for steady-state? Explain your result. [2 P]

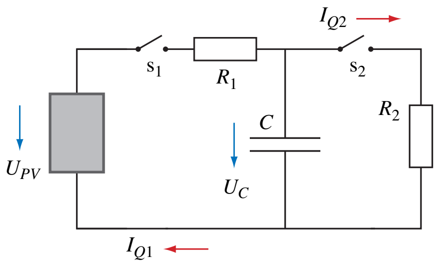
e. What is the inductance of water in the outlet pipe? Explain how you obtain your solution. [2 P]

f. Determine as carefully as possible the level of water in the tank as a function of time. Draw a level-time diagram having values (and units) on the axes. Maxima and minima should be clearly visible. Explain your procedure. [3 P]

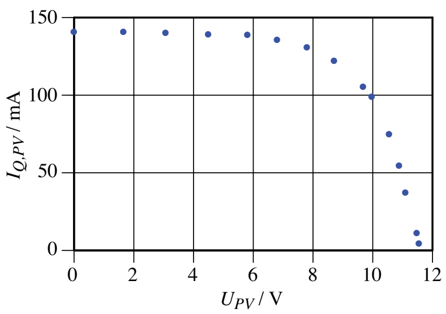
Problem 1.



2. A small laboratory PV system consists of three parts: (1) a PV panel, (2) a capacitor (having capacitance C) serving as a storage element and a resistor having constant resistance R_1 and (3) an ohmic resistor as a load having constant resistance R_2. There are two switches (S1 and S2) between the three parts. Check the circuit diagram below.



The characteristic diagram of the PV panel (below) has been measured for a certain intensity of light of the lamps used in the experiment.

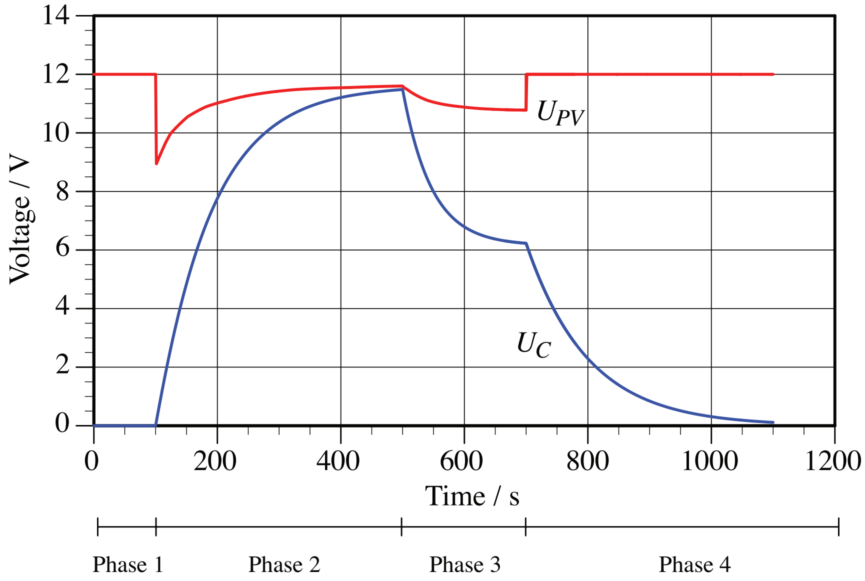


a. Determine the maximum power (Maximum Power Point, MPP) of the panel using the characteristic diagram. Explain how you obtain your result. [1 P]

Using the same intensity of light as before, the capacitor in our circuit is charged. The intensity of light and the temperature of the panel are assumed to be constant.

b. Determine the value of R_1 so that the panel is operated at maximum power (MPP) right after closing switch S1 (S2 is kept open). Initially, the capacitor is uncharged. [1 P]
c. Use graphical means to determine the current in the first loop of the circuit right after closing switch S1 (S2 is open) *if you double* the value of R_1 compared to what you obtained in problem b. Initially, the capacitor is uncharged. [2 P]

For all subsequent questions, we have used $R_1 = 75\ \Omega$. The voltages across the panel (U_{PV}) and the capacitor (U_C) have been measured; they are displayed as functions of time in the following diagram.



d. Consider the measured functions (U_{PV} and U_C) and determine the position of the switches S1 and S2 for the four phases identified during the experiment. Briefly explain what is happening during those phases. [2 P]

e. Determine the electric power of the panel at $t = 150$ s using graphical data. [1 P]

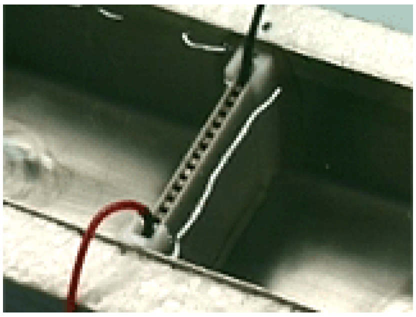
f. Determine the energy current entering the capacitor at $t = 150$ s. [1 P]

g. Compare your results obtained in e and f. Explain the difference between the results. [1 P]

h. The resistance of the load resistor equals $R_2 = 100\ \Omega$. Use graphical data to determine the capacitance of the capacitor. Explain your procedure. [2 P]

i. Determine the rate of change of energy of the capacitor at the start *and* end of Phase 3. [3P]

3. A Peltier device (PD) serves as a wall between two bodies of water inside a container made of thin metal. On the outside, the container is insulated to some degree using styrophoam.

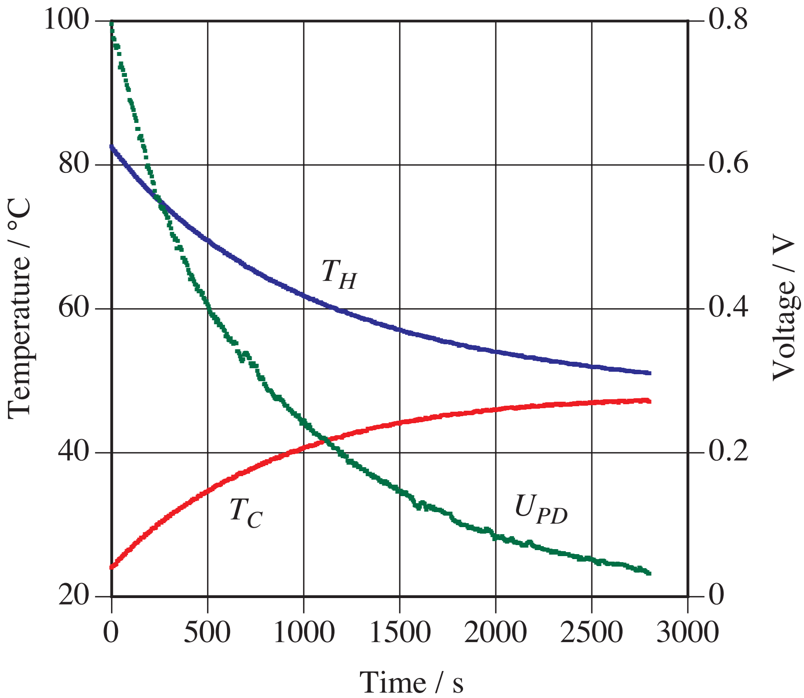


The left chamber is filled with hot water, the one on the right contains cold water (0.50 kg each). In both chambers, the water is stirred mechanically. The specific entropy capacitance of water is determined as follows:

$$\kappa_S = \frac{c}{T} \quad , \quad c = 4200\,\frac{\text{J}}{\text{K}\cdot\text{kg}}$$

A resistor (1.30 Ω) is connected to the PD meaning that the electric circuit contains the PD and the resistor only.

The lid of the container is closed. Temperatures of the two bodies of water and voltage across the PD are measured.



a. Formulate the instantaneous form of the law of balance of entropy for the body of hot water. Explain. [1 P]

b. Determine the rates of change of temperatures (T_H and T_C) right at the start from the graphical data. [1 P]

c. Estimate the current of entropy through the Peltier device (t = 0 s). In order to achieve this, you should neglect mechanical stirring and heat loss to the environment. (You should obtain a result close to 0.20 W/K) [2 P]

d. For 6 points (500 s, 750 s, …, 1750 s), determine the temperature difference between the two bodies of water and the electric power of the PD at those moments. Plot the power of the PD as a function of the square of the temperature difference. [2 P]

e. Interpret the result obtained in Problem d, i.e., explain why we should see such a result. [2 P]

f. For $t = 0$ s, what is the ratio of electric power to thermal power we should expect on the basis of the temperature difference (and the entropy current) between the bodies of water? [2 P]

g. The electric (internal) resistance of the PD equals 1.0 Ω. How high is the thermoelectric voltage of the PE at $t = 0$ s? The Seebeck coefficient of the PD equals 0.053 V/K. What is the temperature difference between the hot and the cold sides of the PD at $t = 0$ s? What fraction of the temperature difference between the bodies of water is this? [2 P]

h. On the hot and cold sides of the PD, we each have a convective heat transfer layer between water and surface of the PD. Interpret these layers as thermal resistors. Now draw a process diagram for the system consisting of two thermal resistors and the PD. The process diagram contains flows of entropy, entropy production rates, temperature levels, energy currents and power(s). [2 P]

ANSWERS

1. Hydraulic system

a. Formulate the instantaneous form of the law of balance of water in the tank: [2 P]

$$\dot{V} = I_{V,in} - I_{V,out}$$

b. Determine the hydraulic capacitance of the tank. [1 P]

$$C_V := \frac{\Delta V}{\Delta p_C} = \frac{A\Delta h}{\rho g \Delta h} = \frac{\pi r^2}{\rho g} = 7.85 \cdot 10^{-7} \frac{\text{m}^3}{\text{Pa}}$$

c. What is the magnitude of the constant inflow of water? Explain how you obtain your result. [2 P]

Use the condition of steady-state:

$$\dot{V}(\infty) = 0 \quad \Rightarrow \quad I_{V,in}(\infty) = I_{V,out}(\infty)$$

From the graph:

$$I_{V,out}(\infty) = 3.0 \cdot 10^{-4} \frac{\text{m}^3}{\text{s}} \quad \Rightarrow \quad I_{V,in}(\infty) = 3.0 \cdot 10^{-4} \frac{\text{m}^3}{\text{s}}$$

d. What will be the level of water for steady-state? Explain your result. [2 P]

Again use the condition of steady-state:

$$\Delta p_R(\infty) = R_V I_{V,out}(\infty)$$
$$\Delta p_L(\infty) = 0 \quad \Rightarrow \quad \Delta p_C(\infty) = \Delta p_R(\infty)$$
$$h(\infty) = \frac{\Delta p_C(\infty)}{\rho g} = \frac{\Delta p_R(\infty)}{\rho g} = \frac{R_V I_{V,out}(\infty)}{\rho g} = 0.12\text{m}$$

e. What is the inductance of water in the outlet pipe? Explain how you obtain your solution. [2 P]

Use the conditions at $t = 0$:

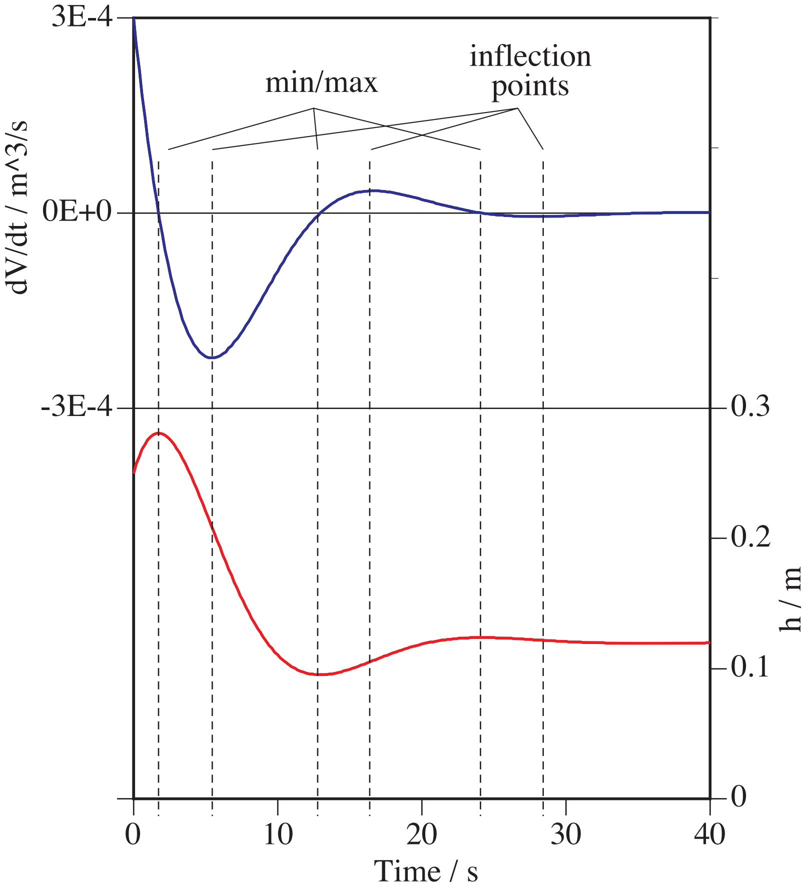
$$\frac{d}{dt} I_{V,out} = \frac{1}{L_V} \Delta p_L$$
$$\Delta p_L(0) = \Delta p_C(0) \quad , \quad \Delta p_C(0) = \rho g h(0)$$
$$\left.\frac{d}{dt} I_{V,out}\right|_{t=0} \approx 2.1 \cdot 10^{-4} \frac{\text{m}^3}{\text{s}^2} \quad \text{(from the graph)}$$
$$L_V \approx 1.2 \cdot 10^7 \frac{\text{Pa} \cdot \text{s}^2}{\text{m}^3}$$

f. Determine as carefully as possible the level of water in the tank as a function of time. Draw a level-time diagram having values (and units) on the axes. Maxima and minima should be clearly visible. Explain your procedure. [3 P]

Determine rate of change of volume:

$$\dot{V} = I_{V,in} - I_{V,out}$$

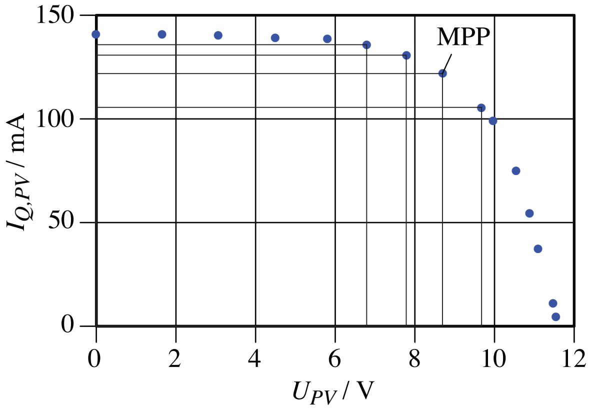
Then integrate this function using the initial value to obtain V(t), divide by the area of the tank to obtain h(t).



2. PV circuit

a. Determine the maximum power (Maximum Power Point, MPP) of the panel using the characteristic diagram. Explain how you obtain your result. [1 P]

Determine the area of IQPV-UPV rectangles and find the maximum: UPV(MPP) = 8.7 V, IQPV(MPP) = 0.12 A.



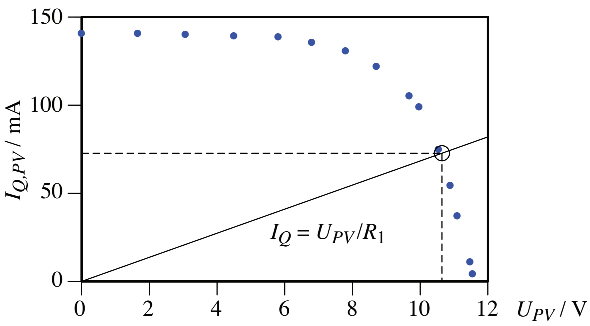
b. Determine the value of R_1 so that the panel is operated at maximum power (MPP) right after closing switch S1 (S2 is kept open). Initially, the capacitor is uncharged. [1 P]

$$U_{R1} = U_{PV} \quad (U_C = 0)$$
$$U_{R1} = R_1 I_Q$$
$$R_1 = \frac{U_{R1}}{I_Q} = \frac{8.7}{0.12}\Omega = 72.5\Omega$$

c. Use graphical means to determine the current in the first loop of the circuit right after closing switch S1 (S2 is open) *if you double* the value of R_1 compared to what you obtained in problem b. The capacitor is uncharged. [2 P]

1. R1 = 145 Ω. Use the data points in the characteristic diagram to calculate some resistances. Find the UPV-IQPV pair that is closest: UPV = 10.55 V, IQPV = 75 mA.

2. Draw resistive characteristic curve for R1 in the characte-ristic diagram. Find intersection (UPV = UR1, IQ1 is equal for both elements).



d. Consider the measured functions (U_{PV} and U_C) and determine the position of the switches S1 and S2 for the four phases identified during the experiment. Briefly explain what is happening during those phases. [2 P]

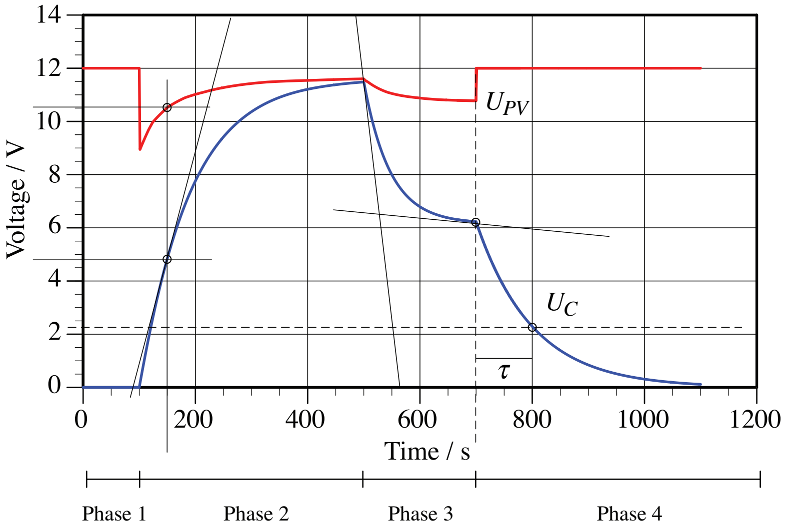
Phase 1: S1 open, S2 open: UPV at open circuit value.

Phase 2: S1 closed, S2 open: Charge flows, capacitor is charged, UPV drops because of flow of charge.

Phase 3: S1 closed, S2 closed: Capacitor is charged and discharged; new steady-state is reached.

Phase 4: S1 open, S2 closed: Capacitor is discharged; UPV back at open circtuit value.

e. Determine the electric power of the panel at $t = 150$ s using graphical data. [1 P]



UPV(150) = 10.5 V, UC(150) = 4.75 V, therefore UR1 = 5.75 V. R1 = 75 Ω, therefore IQPV = 0.077 A. P_PV = UPV·IQPV = 0.81 W. (Second pssibility: With UPV = 10.V, use characteristic diagram to find IQPV:)

f. Determine the energy current entering the capacitor at $t =$ 150 s. [1 P]

$$I_{E,C} = \mathcal{P}_{PV} - \mathcal{P}_{diss,R1}$$

$$\mathcal{P}_{diss,R1} = U_C I_{Q,PV}$$

$$I_{E,C} = \mathcal{P}_{PV} - U_C I_{Q,PV} = 0.81\text{W} - 5.75 \cdot 0.077\text{W} = 0.36\text{W}$$

or

$$I_{E,C} = U_C I_{Q,PV} = 4.75 \cdot 0.077\text{W} = 0.37\text{W}$$

or

$$I_{E,C} = dE_C / dt = d\left(CU_C^2 / 2\right) / dt = CU_C dU_C / dt =$$
$$= 1.0 \cdot 4.75 \cdot 0.08\text{W} = 0.38\text{W}$$

The capacitance will be determined in h (it is 1.0 F).

g. Compare your results obtained in e and f. Explain the difference between the results. [1 P]

The difference is the rate at which energy is dissipated in resistor R1.

h. The resistance of the load resistor equals $R_2 = 100\ \Omega$. Use graphical data to determine the capacitance of the capacitor. Explain your procedure. [2 P]

Use discharging in Phase 4. The time constant is 100 s, therefore, C = 1.0 F. (See the U-t diagram above with graphical determinations…)

i. Determine the rate of change of energy of the capacitor at the start *and* end of Phase 3. [3P]

$$dE_C / dt = d\left(CU_C^2 / 2\right) / dt = CU_C dU_C / dt =$$
$$= 1.0 \cdot 11.5 \cdot (-0.175)\mathrm{W} = -2.0\mathrm{W}$$
$$dE_C / dt = d\left(CU_C^2 / 2\right) / dt = CU_C dU_C / dt =$$
$$= 1.0 \cdot 6.2 \cdot (-0.002)\mathrm{W} = -0.012\mathrm{W}$$

or…

$$dE_C / dt = I_{E,in} - I_{E,out} = U_C I_{Q1} - U_C I_{Q2}$$

3. Peltier device

a. Formulate the instantaneous form of the law of balance of entropy for the body of hot water. Explain. [1 P]

Entropy transfer through Peltier device to cold water, entropy loss to environment, entropy production due to mechanical stirring:

$$\dot{S}_H = -I_{S,Peltier} - I_{S,loss} + \Pi_S$$

b. Determine the rates of change of temperatures (T_H and T_C) right at the start from the graphical data. [1 P]

Use the diagram, draw tangents to TH(t) and TC(t) at t = 0. Results: dTH/dt (0) = – 0.033 K/s, dTC/dt (0) = 0.029 K/s.

c. Estimate the current of entropy through the Peltier device (t = 0 s). In order to achieve this, you should neglect mechanical stirring and heat loss to the environment. (You should obtain a result close to 0.20 W/K) [2 P]

Set IS,loss and Pi_S equal to zero:

$$\dot{S}_H = -I_{S,Peltier}$$

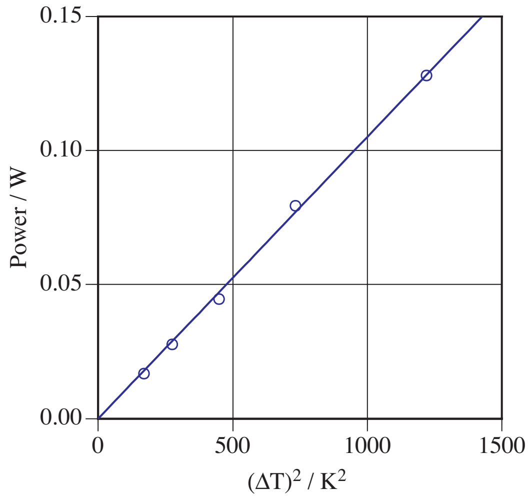
Entropy-temperature relation:

$$\dot{S}_H = K_S \dot{T}_H$$

Therefore

$$I_{S,Peltier} = -\frac{mc}{T_H}\dot{T}_H = 0.195\frac{\text{W}}{\text{K}}$$

d. For 6 points (500 s, 750 s, …, 1750 s), determine the temperature difference between the two bodies of water and the electric power of the PD at those moments. Plot the power of the PD as a function of the square of the temperature difference. [2 P]



e. Interpret the result obtained in Problem d, i.e., explain why we should see such a result. [2 P]

We should expect the electric power to be proportional to (a fraction of) the thermal power which is

$$\mathcal{P}_{th} = \Delta T\, I_S$$

The entropy current through the device should be proportional to the temperature difference

$$I_S = G_S \Delta T$$

which leads to

$$\mathcal{P}_{el} \sim (\Delta T)^2$$

f. For $t = 0$ s, what is the ratio of electric power to thermal power we should expect on the basis of the temperature difference (and the entropy current) between the bodies of water? [2 P]

$$\mathcal{P}_{th} = \Delta T\, I_S = 59\,\text{K} \cdot 0.20\,\text{W}/\text{K} = 12\,\text{W}/\text{K}$$

$$\mathcal{P}_{el} = U I_Q = U_R^2 / R = 0.50\,\text{W}$$

$$\eta := \frac{\mathcal{P}_{el}}{\mathcal{P}_{th}} = 0.042$$

g. The electric (internal) resistance of the PD equals 1.0 Ω. How high is the thermoelectric voltage of the PE at $t = 0$ s? The Seebeck coefficient of the PD equals 0.053 V/K. What is the temperature difference between the hot and the cold sides of the PD at $t = 0$ s? What fraction of the temperature difference between the bodies of water is this? [2 P]

$$U_{TE} = U_{PD} - U_{Ri} = U_{PD} - R_i I_Q$$

$$I_Q = \frac{U_{R,ext}}{R_{ext}}$$

$$U_{TE} = U_{PD} - R_i \frac{U_{R,ext}}{R_{ext}} = -0.79\text{V} - \frac{1.0}{1.3} \cdot 0.79\text{V} = -1.4\text{V}$$

Temperature difference across PD:

$$U_{TE} = \varepsilon \Delta T_{PD}$$

$$\Delta T_{PD} = \frac{U_{TE}}{\varepsilon} = \frac{1.4}{0.053}\text{K} = 26\text{K}$$

$$\frac{\Delta T_{PD}}{T_H - T_C} = \frac{26}{82 - 24} = 0.46$$

h. On the hot and cold sides of the PD, we each have a convective heat transfer layer between water and surface of the PD. Interpret these layers as thermal resistors. Now draw a process diagram for the system consisting of two thermal resistors and the PD. The process diagram contains flows of entropy, entropy production rates, temperature levels, energy currents and power(s). [2 P]