Due date: 11:59 PM September 11, 2020

Instructions: *Open book. Group study is encouraged, but the solutions submitted MUST BE YOUR OWN WORK. Please show your work steps. State your assumptions and justify your equations. Partial credit will be awarded on careful and clear arguments. Wrong unsupported numerical answers can only receive zero credit. Please upload your solutions in the designated Assignment 1 folder in myCourses.*

Problem 0: Assignment Prep

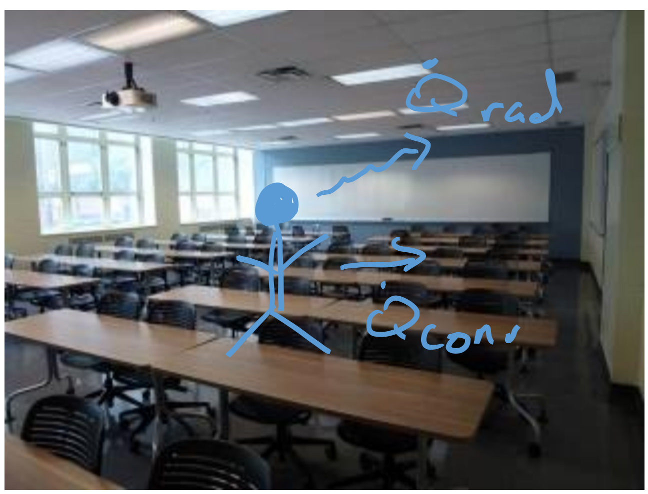
- *Lecture pre-recordings: R0, R1, R2*
- *Zoom live recordings: L1, L2*
- *Supplementary reading: Textbook Chapter 1 - you are only responsible for the sections we covered in the lectures.*

Problem 1: Warmup

Please list five (5) examples of heat transfer in everyday life. Use specific examples. For example, if you say "cooking", explain what aspect of cooking you think can be explained with concepts of heat transfer.

Problem 2: Comparing the relative importance of different modes of heat transfer

Suppose you are standing in the center of a large auditorium. Your skin's temperature is 33°C and the temperature of the walls and surrounding air is 21°C. Evaluate the fraction of heat transfer from your skin's surface contributing to the total heat transfer due to (i) radiation and (ii) natural convection. Assume both your skin and the walls to behave as blackbodies, and the heat transfer coefficient to be 2.5 $\frac{W}{m^2K}$. For part (i) use both the linearized approximation and non-linearized expression for the radiant heat transfer between two surfaces.

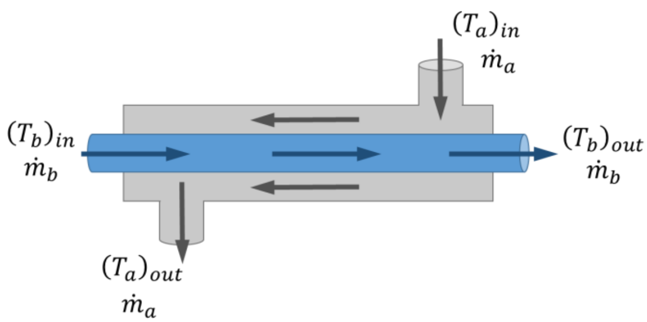


McConnell Engineering

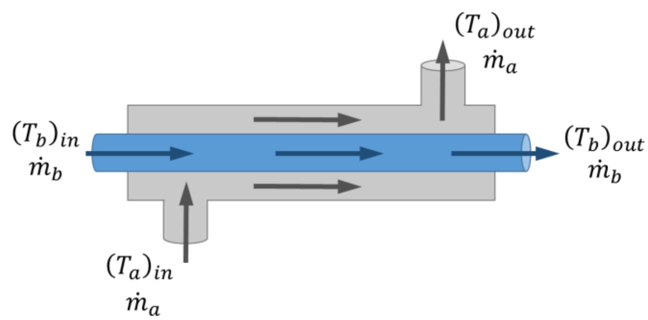
Problem 3: Thermodynamics Review - Heat Exchanger Design

The adiabatic heat exchanger shown in the figure below on the left operates in steady flow with fixed conditions for stream a and an unspecified flow rate for stream b. The counter-flowing streams a and b are incompressible fluids with $c_a = 4\ \frac{kJ}{kg-K}$ and $c_b = 2\ \frac{kJ}{kg-K}$. The mass flow rate of stream a is $\dot{m}_a = 1\ kg/s$. The temperatures from stream a are: $(T_a)_{in} = 400\ K$, $(T_a)_{out} = 300\ K$. The inlet temperature for stream b is $(T_b)_{in} = 300\ K$, but the outlet temperature is unspecified. The pressure drops in the flow are zero. For the conditions specified

a) **(5 points)** Express $(T_b)_{out}$ as a function of $\dot{m}_b$.
b) **(5 points)** Taking the entire heat exchanger as the control volume, express the rate of entropy generation $\dot{S}_{gen}$ as a function of $\dot{m}_b$.
c) **(3 points)** Generate a plot using your favorite software (e.g. Excel, Matlab, etc.) with the rate of entropy generation $\dot{S}_{gen}$ on the y-axis and the mass flow rate for stream b $\dot{m}_b$ on the x-axis *(*see note below).*
d) **(3 points)** For what value(s) of $\dot{m}_b$ is the heat exchanger reversible?
e) **(3 points)** What value(s) of $\dot{m}_b$ will violate the second law of thermodynamics?
f) **(3 points)** Calculate $(T_b)_{out}$ for the reversible heat exchanger.
g) **(6 points)** For the heat exchanger to be reversible, do you think it is possible for the streams to flow in a parallel-flow arrangement as shown in the figure below on the right? Explain your answer using thermodynamic arguments we have learned in class.



Heat exchanger in counter-flow arrangement (parts a-f)



Heat exchanger in parallel-flow arrangement (part g)

**<u>NOTE</u>: If you do not know how to merge a figure to your final exam submission in a single file, you can sketch the plot by hand in your exam without any penalty.*

Problem 4: Heat loss from a cabin

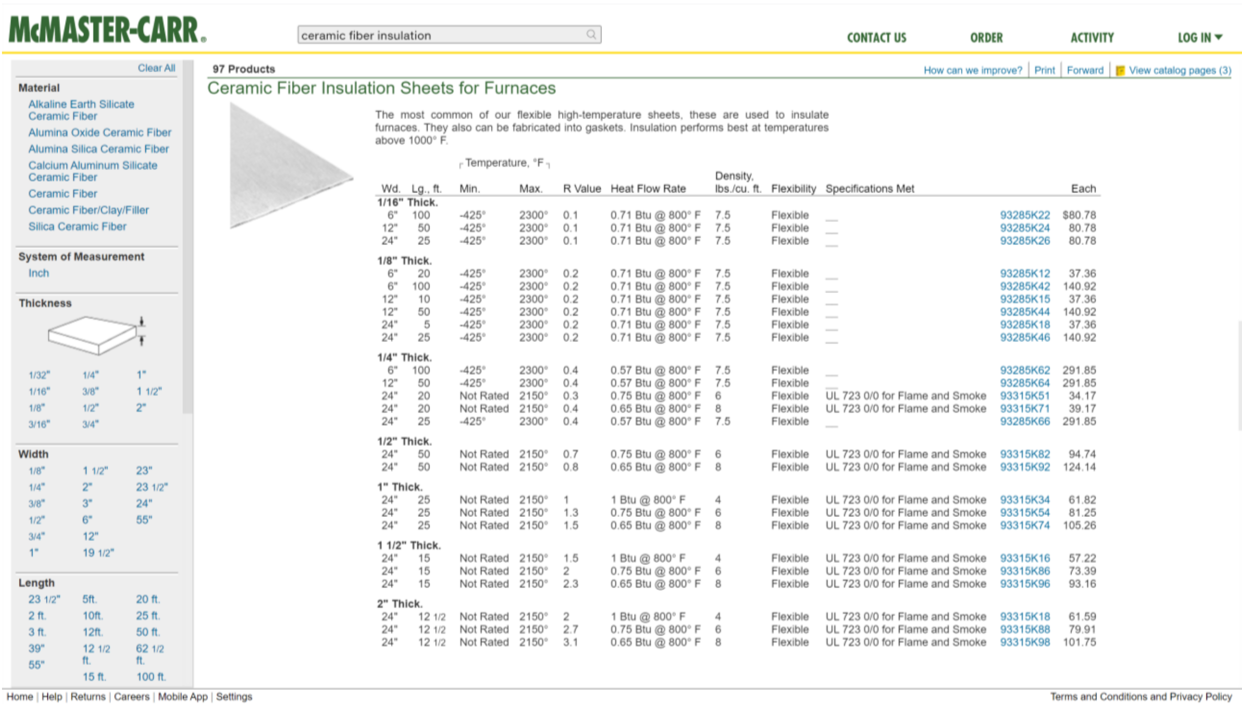
The walls of an empty single-room cabin somewhere far north in the boreal forest consist of two 3 cm-thick layers of pine wood sandwiching 6 cm of fiberglass insulation. The temperature inside the cabin is held at 20°C when the air outside the cabin is -3°C. The exterior surface of the cabin is painted with white acrylic paint. If the interior and exterior convective heat transfer coefficients are $h_{c,i}$=3 and $h_{c,o}$=6 W/m^2 K, respectively, estimate the heat flux through the wall.

Source: Unsplash

Problem 5: R values for thermal insulation

In the United States, insulations are often specified in terms of their resistance in [Btu/hr ft^2 °F], called the "R" value. You can see typical R values from the McMaster-Carr product page shown below.

i. What is the R value of a 10 cm-thick layer of fiberglass insulation?
ii. How thick a leyr of cork is required to give an R value of 18?
iii. What is the R value of a 2 cm-thick board of white pine?



McMASTER-CARR. ceramic fiber insulation CONTACT US ORDER ACTIVITY LOG IN

Clear All

Material
Alkaline Earth Silicate Ceramic Fiber
Alumina Oxide Ceramic Fiber
Alumina Silica Ceramic Fiber
Calcium Aluminum Silicate Ceramic Fiber
Ceramic Fiber
Ceramic Fiber/Clay/Filler
Silica Ceramic Fiber

System of Measurement
Inch

Thickness
1/32" 1/4" 1"
1/16" 3/8" 1 1/2"
1/8" 1/2" 2"
3/16" 3/4"

Width
1/8" 1 1/2" 23"
1/4" 2" 23 1/2"
3/8" 3" 24"
1/2" 6" 55"
3/4" 12"
1" 19 1/2"

Length
23 1/2" 5ft. 20 ft.
2 ft. 10ft. 25 ft.
3 ft. 12ft. 50 ft.
39" 12 1/2 ft. 62 1/2 ft.
55" 15 ft. 100 ft.

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Ceramic Fiber Insulation Sheets for Furnaces

The most common of our flexible high-temperature sheets, these are used to insulate furnaces. They also can be fabricated into gaskets. Insulation performs best at temperatures above 1000° F.

		Temperature, °F								
Wd.	Lg., ft.	Min.	Max.	R Value	Heat Flow Rate	Density, lbs./cu. ft.	Flexibility	Specifications Met		Each
1/16" Thick.										
6"	100	-425°	2300°	0.1	0.71 Btu @ 800° F	7.5	Flexible	—	93285K22	$80.78
12"	50	-425°	2300°	0.1	0.71 Btu @ 800° F	7.5	Flexible	—	93285K24	80.78
24"	25	-425°	2300°	0.1	0.71 Btu @ 800° F	7.5	Flexible	—	93285K26	80.78
1/8" Thick.										
6"	20	-425°	2300°	0.2	0.71 Btu @ 800° F	7.5	Flexible	—	93285K12	37.36
6"	100	-425°	2300°	0.2	0.71 Btu @ 800° F	7.5	Flexible	—	93285K42	140.92
12"	10	-425°	2300°	0.2	0.71 Btu @ 800° F	7.5	Flexible	—	93285K15	37.36
12"	50	-425°	2300°	0.2	0.71 Btu @ 800° F	7.5	Flexible	—	93285K44	140.92
24"	5	-425°	2300°	0.2	0.71 Btu @ 800° F	7.5	Flexible	—	93285K18	37.36
24"	25	-425°	2300°	0.2	0.71 Btu @ 800° F	7.5	Flexible	—	93285K46	140.92
1/4" Thick.										
6"	100	-425°	2300°	0.4	0.57 Btu @ 800° F	7.5	Flexible	—	93285K62	291.85
12"	50	-425°	2300°	0.4	0.57 Btu @ 800° F	7.5	Flexible	—	93285K64	291.85
24"	20	Not Rated	2150°	0.3	0.75 Btu @ 800° F	6	Flexible	UL 723 0/0 for Flame and Smoke	93315K51	34.17
24"	20	Not Rated	2150°	0.4	0.65 Btu @ 800° F	8	Flexible	UL 723 0/0 for Flame and Smoke	93315K71	39.17
24"	25	-425°	2300°	0.4	0.57 Btu @ 800° F	7.5	Flexible	—	93285K66	291.85
1/2" Thick.										
24"	50	Not Rated	2150°	0.7	0.75 Btu @ 800° F	6	Flexible	UL 723 0/0 for Flame and Smoke	93315K82	94.74
24"	50	Not Rated	2150°	0.8	0.65 Btu @ 800° F	8	Flexible	UL 723 0/0 for Flame and Smoke	93315K92	124.14
1" Thick.										
24"	25	Not Rated	2150°	1	1 Btu @ 800° F	4	Flexible	UL 723 0/0 for Flame and Smoke	93315K34	61.82
24"	25	Not Rated	2150°	1.3	0.75 Btu @ 800° F	6	Flexible	UL 723 0/0 for Flame and Smoke	93315K54	81.25
24"	25	Not Rated	2150°	1.5	0.65 Btu @ 800° F	8	Flexible	UL 723 0/0 for Flame and Smoke	93315K74	105.26
1 1/2" Thick.										
24"	15	Not Rated	2150°	1.5	1 Btu @ 800° F	4	Flexible	UL 723 0/0 for Flame and Smoke	93315K16	57.22
24"	15	Not Rated	2150°	2	0.75 Btu @ 800° F	6	Flexible	UL 723 0/0 for Flame and Smoke	93315K86	73.39
24"	15	Not Rated	2150°	2.3	0.65 Btu @ 800° F	8	Flexible	UL 723 0/0 for Flame and Smoke	93315K96	93.16
2" Thick.										
24"	12 1/2	Not Rated	2150°	2	1 Btu @ 800° F	4	Flexible	UL 723 0/0 for Flame and Smoke	93315K18	61.59
24"	12 1/2	Not Rated	2150°	2.7	0.75 Btu @ 800° F	6	Flexible	UL 723 0/0 for Flame and Smoke	93315K88	79.91
24"	12 1/2	Not Rated	2150°	3.1	0.65 Btu @ 800° F	8	Flexible	UL 723 0/0 for Flame and Smoke	93315K98	101.75

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