

10.302
Fall 2004
Exam 2
Wednesday, November 10, 2004

1. (60 points) The product obtained from the bottom of a distillation column needs, for safety reasons, to be cooled before it is sent to storage. It is proposed that this be achieved by cooling with air in a crossflow exchanger (both fluids unmixed). The general situation is shown in Figure A.
- A. If the exchanger is infinitely large and if it were counter current (rather than crossflow), what is the minimum mass flow rate of air that would suffice to cool the 10 kg/s of product from 300°C to 50°C? You may take the air temperature to be 20°C.
- B. If the actual air flow rate exceeds the minimum found in Part A by 10%, but the exchanger configuration is crossflow, will operation be possible in an exchanger of reasonable size?
- C. The plan is to use tubes for which the OD is 1.0 inch and the ID is 0.8 inch. The tube length will be 10 ft. The material is carbon steel. The average linear velocity of the product within the tubes will be 1 m/s. That of the air outside the tube will be 4 m/s. The situation is sketched in Figure B.
- i) What is the value of the heat transfer coefficient at the inner surface of the tubes?
 - ii) What is the value of the heat transfer coefficient at the outer surface of the tubes? [You may ignore any flow effects due to the presence of other, nearby, tubes.]
 - iii) What is the value of the overall heat transfer coefficient? Base your answer on the inside area of the tubes. A value within 5% is adequate.
 - iv) If the total mass flow rate of air is 100 kg/s, what is the required exchanger area (based on tube ID)?
- D. If it were desired to increase the effective overall heat transfer coefficient, would you recommend that fins be placed on the tube interior or the tube exterior or both? Why?
- E. If square fins, each 3" on a side (see Figure C), were placed on the tube exterior, what would you predict for the average value of the heat transfer coefficient between the fins and the air? The distance between fins is 0.5 inches.

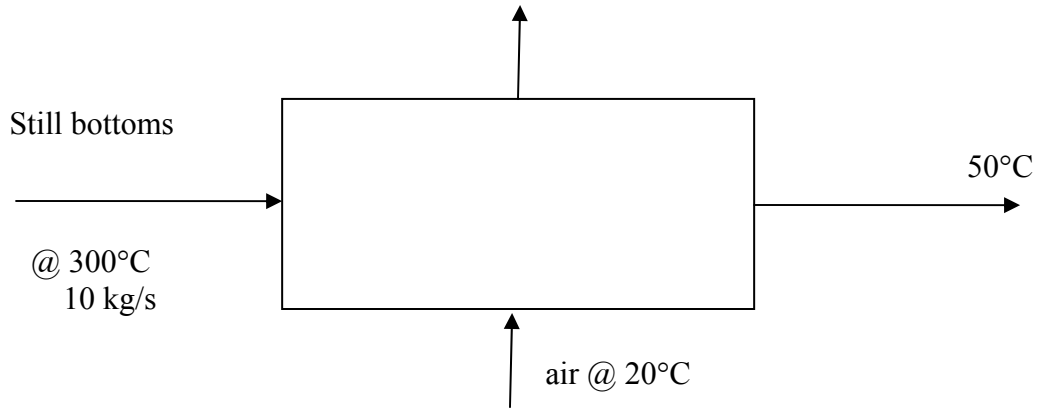


FIGURE A

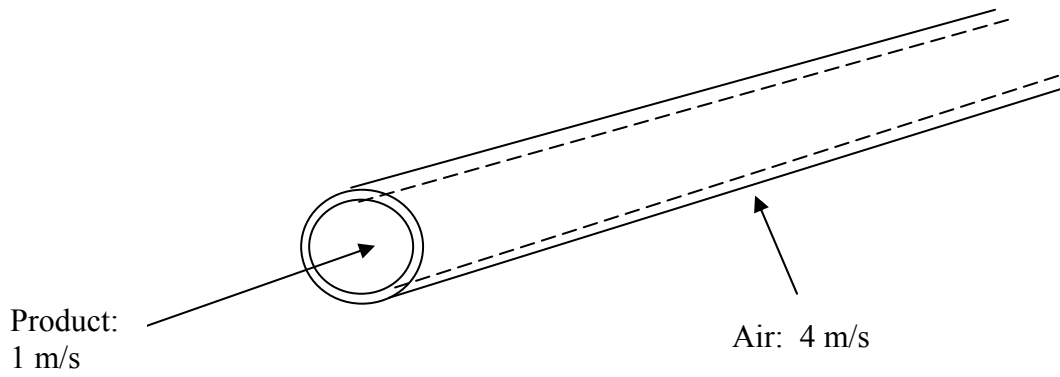
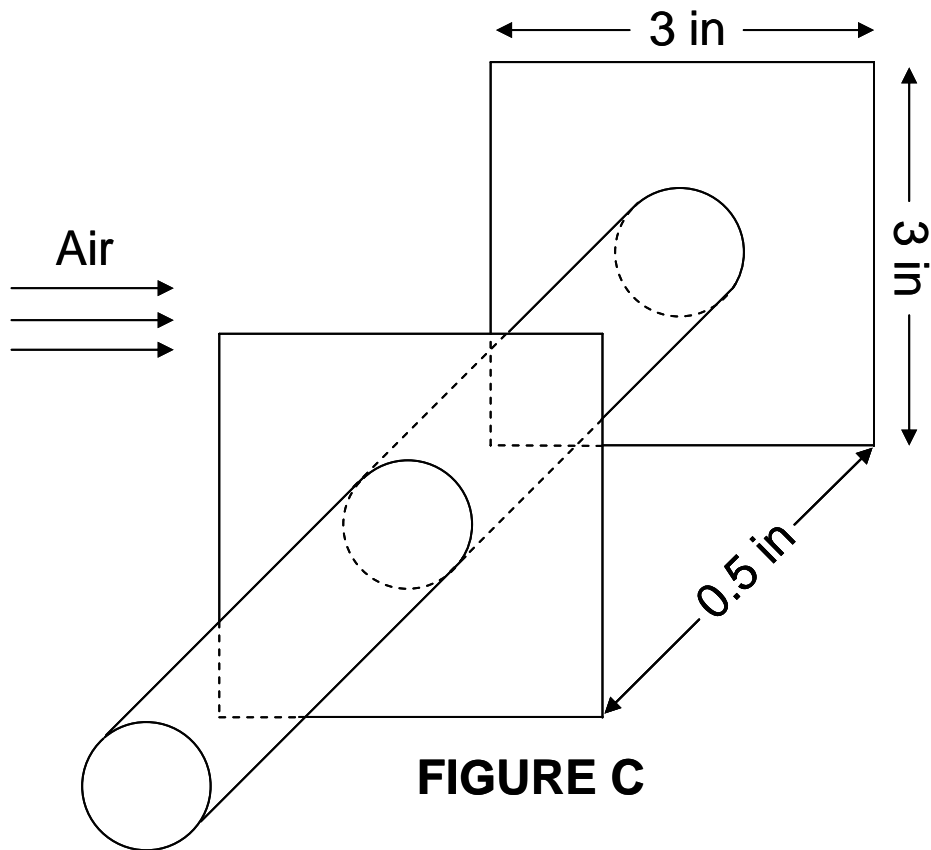


FIGURE B

**Properties**Product

ρ	=	1050 kg/m ³
c_p	=	2500 J/kg·K
ν	=	2×10^{-6} m ² /s
k	=	0.25 W/m·K
α	=	0.95×10^{-7} m ² /s
Pr	=	21

Air

ρ	=	1 kg/m ³
c_p	=	1000 J/kg·K
ν	=	21×10^{-6} m ² /s
k	=	0.030 W/m·K
α	=	30×10^{-6} m ² /s
Pr	=	0.7

Carbon Steel

ρ	=	7800 kg/m ³
c_p	=	400 J/kg·K
k	=	60 W/m·K

2. (40 points) You park your car outside overnight in the late fall. The sky is clear and the wind is calm. Just before daybreak, you note that the air temperature is 6°C but that the roof of your car is covered with a layer of frost. You may assume that the car roof has a full view of the night sky, which has an effective black body temperature of 230 K . The roof is also black and the inside surface of the roof is well insulated. The roof can be considered a flat plate of length 1.5 m from windshield to back window.

The properties of air are:

Thermal conductivity, k	$2.5 \times 10^{-2}\text{ W/mK}$
Density, ρ	1.1 kg/m^3
Heat capacity, c_p	1.0 kJ/kgK
Kinematic viscosity, ν	$1.5 \times 10^{-5}\text{ m}^2/\text{s}$
Prandtl Number, Pr	0.71

- A. Assume that the heat transfer coefficient by natural convection for the roof of the car is $5\text{ W/m}^2\text{K}$. Calculate the temperature of the car roof.
- B. How high must the local convective heat transfer coefficient be for the temperature of the roof to reach 0°C ?

You start your car and drive a short distance at 30 mph (13.4 m/s). The roof of the car continues to have a full view of the night sky. The roof may be assumed to be thermally non-conducting.

- C. At a position of 0.3 m from the windshield will the frost melt?
- D. At a position 1 m from the windshield will the frost melt?
- E. Roughly delineate the boundaries of the regions over which you expect frost to remain on the roof of the car and the regions that are frost-free?

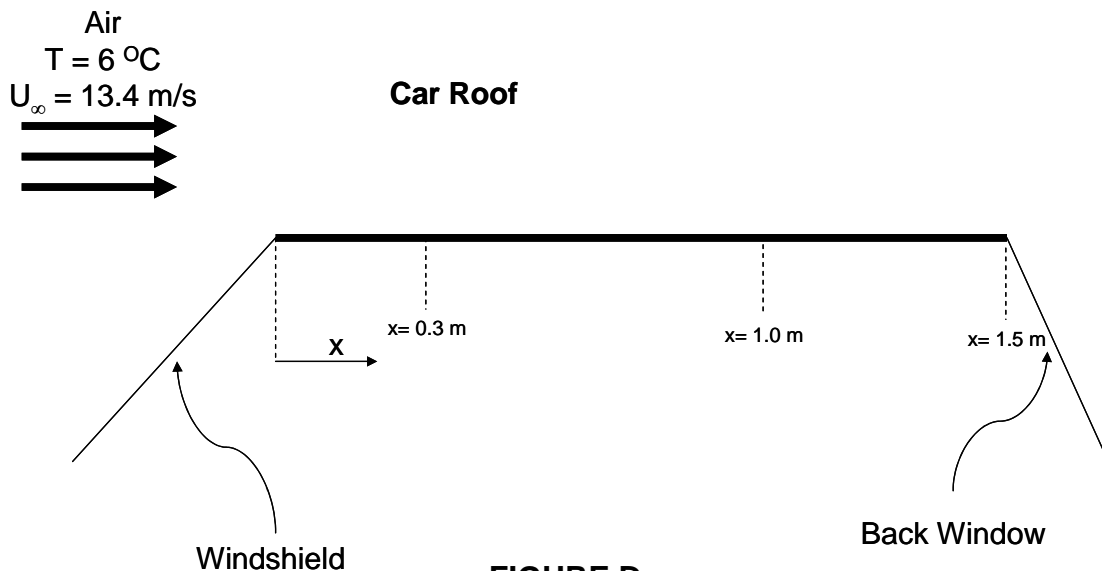


FIGURE D