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MET 440 Heat Transfer
Dr. Orlando Ayala
Fall 2019
Test 3

Take home – Due Tuesday November 05th 2019 before midnight.

READ FIRST

1. RELAX!!!! DO NOT OVERTHINK THE PROBLEMS!!!! There is nothing hidden. The test was designed for you to pass and get the maximum number of points, while learning at the same time. HINT: THINK BEFORE TRYING TO USE/FIND EQUATIONS (OR EVEN FIND SIMILAR PROBLEMS)

2. The total points on this test are one hundred (100). Ten (10) points are from your HW assignments, and ten (10) other points are based on the basis of technical writing. For the technical writing, I will follow the attached rubric. The other eighty (80) points will come from the problem solutions.

3. There are 2 problems to solve, each worth (80/2) points.

4. What you turn in should be only your own work. You cannot discuss the exam with anyone, except me. Call me, skype me, text me, email me, come to my office, if you have any question.

5. I do not read minds. You should be explicit and organized in your answers. Use drawings/figures. If you make a mistake, do not erase it. Rather use that opportunity to explain why you think it is a mistake and show the way to correct the problem.

6. You have to turn in your test ON TIME and ONLY through BLACKBOARD. You must submit only one file and it has to be a pdf file. For the ePortfolio you are also supposed to upload this artifact to your Google drive. When you are done solving the test, please go ahead and upload it now before you forget.

7. Do not start at the last minute so you can handle anything that could happen. Late tests will not be accepted. Test submitted through email will not be accepted either.

8. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University you have accepted the responsibility to abide by this code. This is an institutional policy approved by the Board of Visitors. It is important to remind you the following part of the Honor Code:

   IX. PROHIBITED CONDUCT
   A. Academic Integrity violations, including:
   1. *Cheating*: Using unauthorized assistance, materials, study aids, or other information in any academic exercise (Examples of cheating include, but are not limited to, the following: using unapproved resources or assistance to complete an assignment, paper, project, quiz or exam; collaborating in violation of a faculty member's instructions; and submitting the same, or substantially the same, paper to more than one course for academic credit without first obtaining the approval of faculty).

With that said, you are NOT authorized to use any online source of any type, unless is ODU related.

1. A plastic rod was initially heated to a uniform temperature of 70 ^{0}C, and allowed to be cooled in a fluid at a temperature of 25 ^{0}C and with a convective heat transfer coefficient of 20.42 W/m^2.K. After 1338 s of cooling, a thermocouple inserted in the center of the rod registers a temperature of 30 ^{0}C. Determine the plastic rod diameter for this to happen. At 1338 s, what is the temperature at the surface and at half the radius? The properties of the plastic are: ρ=1190 kg/m^3, c_p=1465 J/kg.K, and k=0.19 W/m.K.

2. Solve the 1st problem using COMSOL. Compare the analytical and the numerical results (convective heat transfer and temperatures) by computing the error.

   Present the results of the COMSOL problem following the attached rubric. You should print out the COMSOL full report and tailor it to the rubric structure.

PROBLEM 1

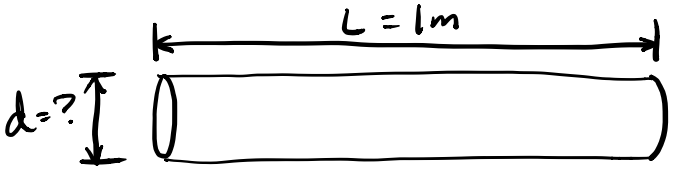
PURPOSE

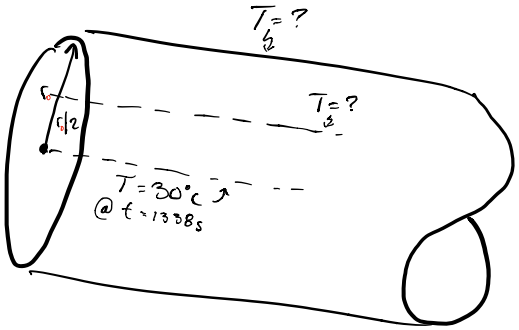
→ Determine the diameter of the plastic pipe must be such that the center of the pipe is 30°C at t = 1338s when initially at 70°C at t = 0s.

→ Also determine the temperatures at the pipe's surface as well as at half the radius.

DRAWINGS & DIAGRAMS

→ The diameter must be solved for (currently unknown) and the length of the cylinder is not given (assume 1 m)





SOURCES

→ Bayazitoglu, Y., Ozisik, N., "A Textbook for Heat Transfer Fundamentals," Begell House, Inc (2012)

DESIGN CONSIDERATIONS

→ Constant properties

→ Steady state

DATA & VARIABLES

→ See drawing and purpose

PROCEDURE

→ I will start by solving for alpha, since I have all the values needed. Once I have α, I can solve for the full radius, which satisfies the first requirement.

→ To solve for the temperatures at the rod's surface and half radius, I will need to calculate the Biot number at both instances. Once I have the Biot number, I can use the graph provided in Figure 6.6c on page 201 of the text to solve for the two temperatures.

CALCULATIONS

PART I

parameters

→ $k = 0.19\ W/m \cdot K$
→ $C_p = 1465\ J/kg \cdot K$
→ $\rho = 1190\ kg/m^3$
→ $t = 1338\ s$
→ $T_i = 70°C$
→ $T_\infty = 25°C$
→ $T_o = 30°C$
→ $h = 20.42\ W/m^2 \cdot K$

→ Calculate α

$$\alpha = k/\rho \cdot c_p$$

$$= \frac{0.19\ W/m^2 \cdot K}{(1190\ kg/m^3)(1465\ J/kg \cdot K)}$$

$$\alpha = 1.09 \times 10^{-7}\ m^2/s$$

→ calculate r_o = full radius of the rod

$$t = r_o^2/\alpha \quad \therefore \quad r_o = \sqrt{t \cdot \alpha} = \sqrt{(1338s)(1.09 \times 10^{-7} m^2/s)}$$

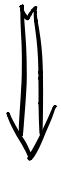
$$\therefore r_o = 0.0121m \quad \therefore d = 0.0242\ m$$ ANSWER 1

PART II

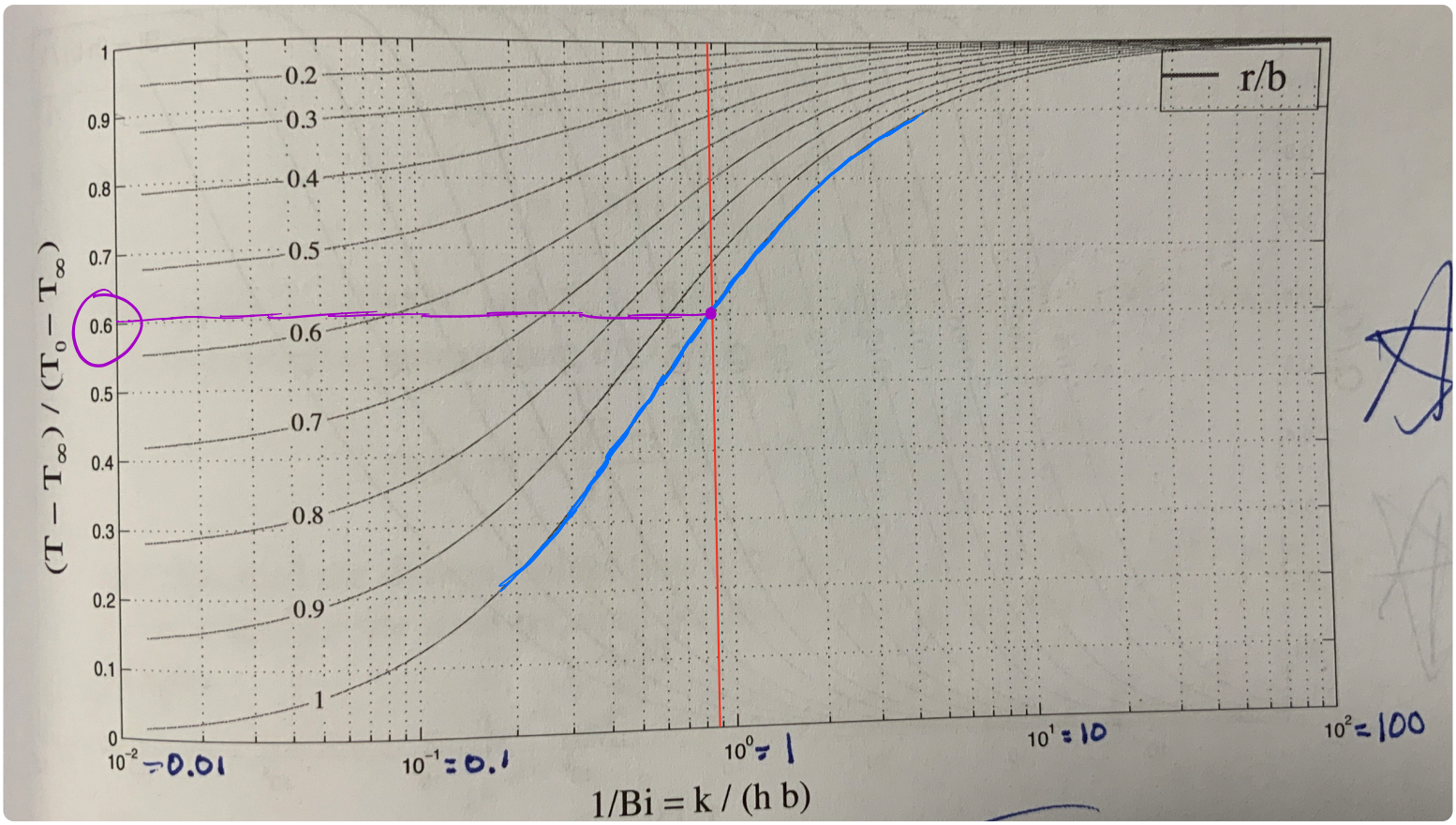
→ Calculate the Biot number at the surface of the rod:

$$Bi = h \cdot r_o/k = \frac{(20.42\ W/m^2 \cdot K)(0.0121m)}{0.19\ W/m \cdot K} = 1.3$$

→ For a long solid cylinder (as in this case) of radius r=b subjected to convection at the boundary surface, $\therefore r = b$, $\therefore r/b = 1$ in this case



→ Now I take the Biot number inverse ($1/Bi = 1/1.3 = 0.769$) and solve for the rod's surface temperature:



$$\frac{T - T_\infty}{T_o - T_\infty} = 0.6 \quad \therefore \quad T = (0.6)(T_o - T_\infty) + T_\infty = (0.6)(5^\circ C) + (25^\circ C)$$

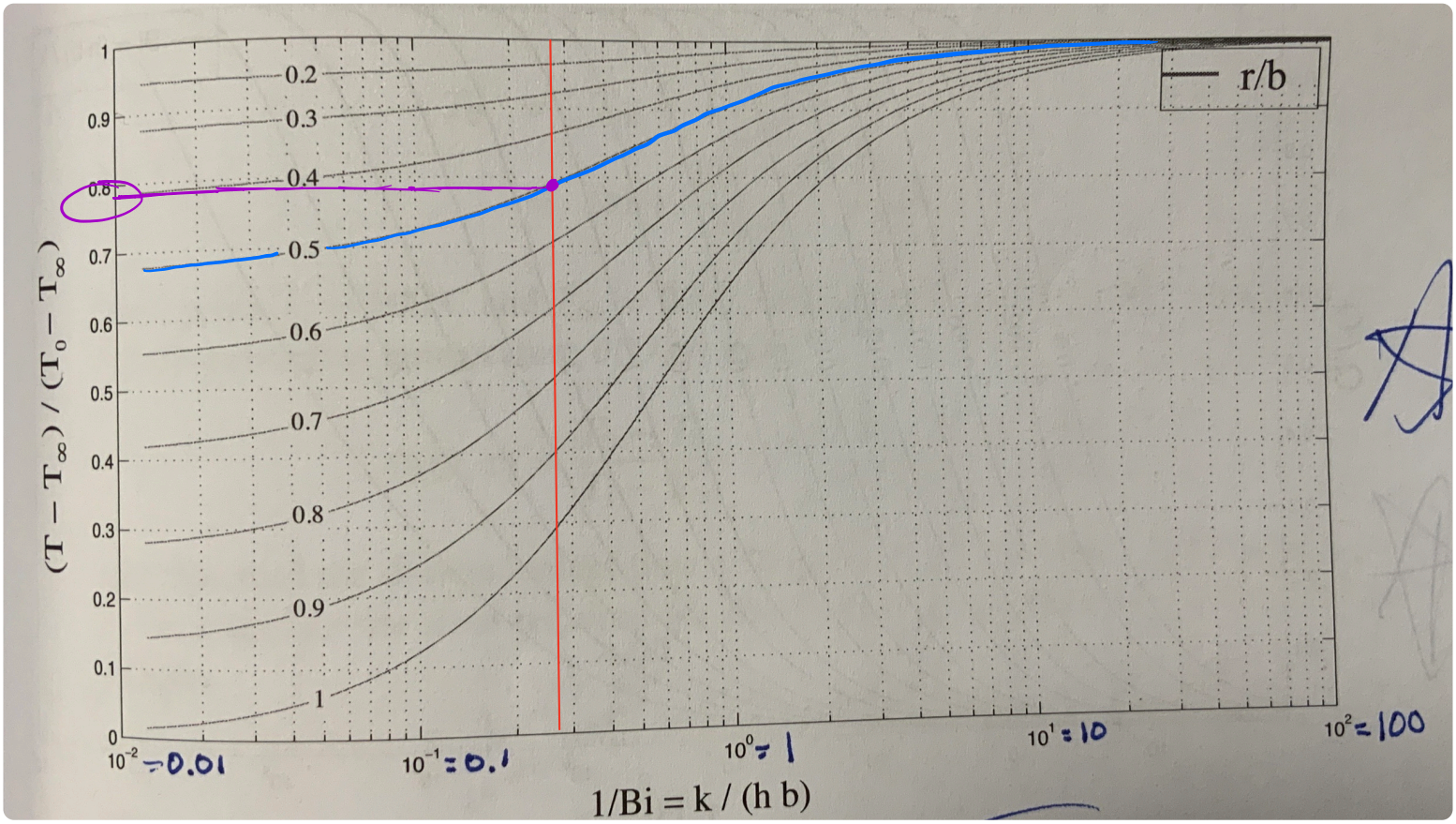
$$T_{surf} = 28^\circ C$$ ANSWER IIA

→ Calculate the Biot number at half the radius of the rod, then take the inverse:

$$Bi = h \cdot r_o / k = \frac{(20.42\ W/m^2 \cdot K)(0.00605\ m)}{0.19\ W/m \cdot K} = (0.65)^{-1} = \boxed{1.538}$$

$$10^{0.1} < 1.538 < 10^{0.2}$$
$$\parallel \qquad\qquad \parallel$$
$$1.25893 \qquad\qquad 1.58489$$

$$r/b = (r_o/2)/r_o \text{ (for this case)} = \frac{0.00605}{0.0121} = \boxed{0.5}$$



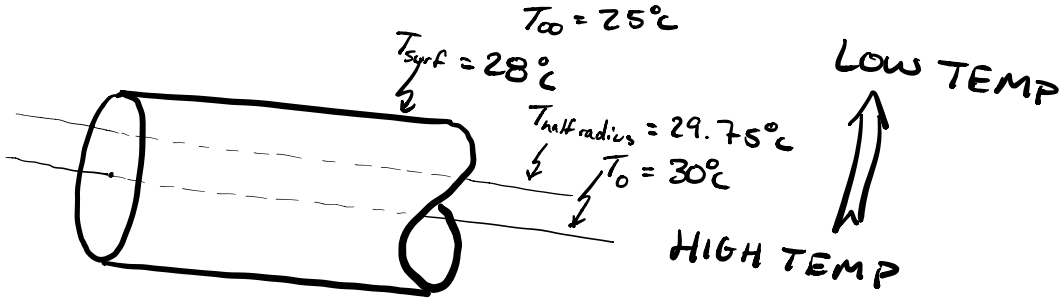
$$\therefore \quad \frac{T - T_\infty}{T_o - T_\infty} = 0.95 \implies T = (0.95)(T_o - T_\infty) + T_\infty = (0.95)(5°C) + 25°C$$

$T_{half\ radius} = 29.75°C$ ANSWER 11B

$D = 0.0242\ m$
$T_{surf} = 28°C$
$T_{half\ radius} = 29.75°C$

SUMMARY

→ The temperature gradient of the rod decreases with both distance and time as it extends from the shaft's center to its surface.



MATERIALS

→ The material is listed as a plastic with the following values

parameters

→ $K = 0.19 \, W/m \cdot K$
→ $Cp = 1465 \, J/kg \cdot K$
→ $\rho = 1190 \, kg/m^3$
→ $h = 20.42 \, W/m^2 \cdot K$

ANALYSIS

PART I → The values check out and the radius and diameter are good

PART II → The temperature gradient moves from high to low. If it had done anything different, I would have been concerned.

PROBLEM 2

1: PURPOSE

→ Use COMSOL to solve for the temperatures found at the rod's surface and halfway along the rod's radius.

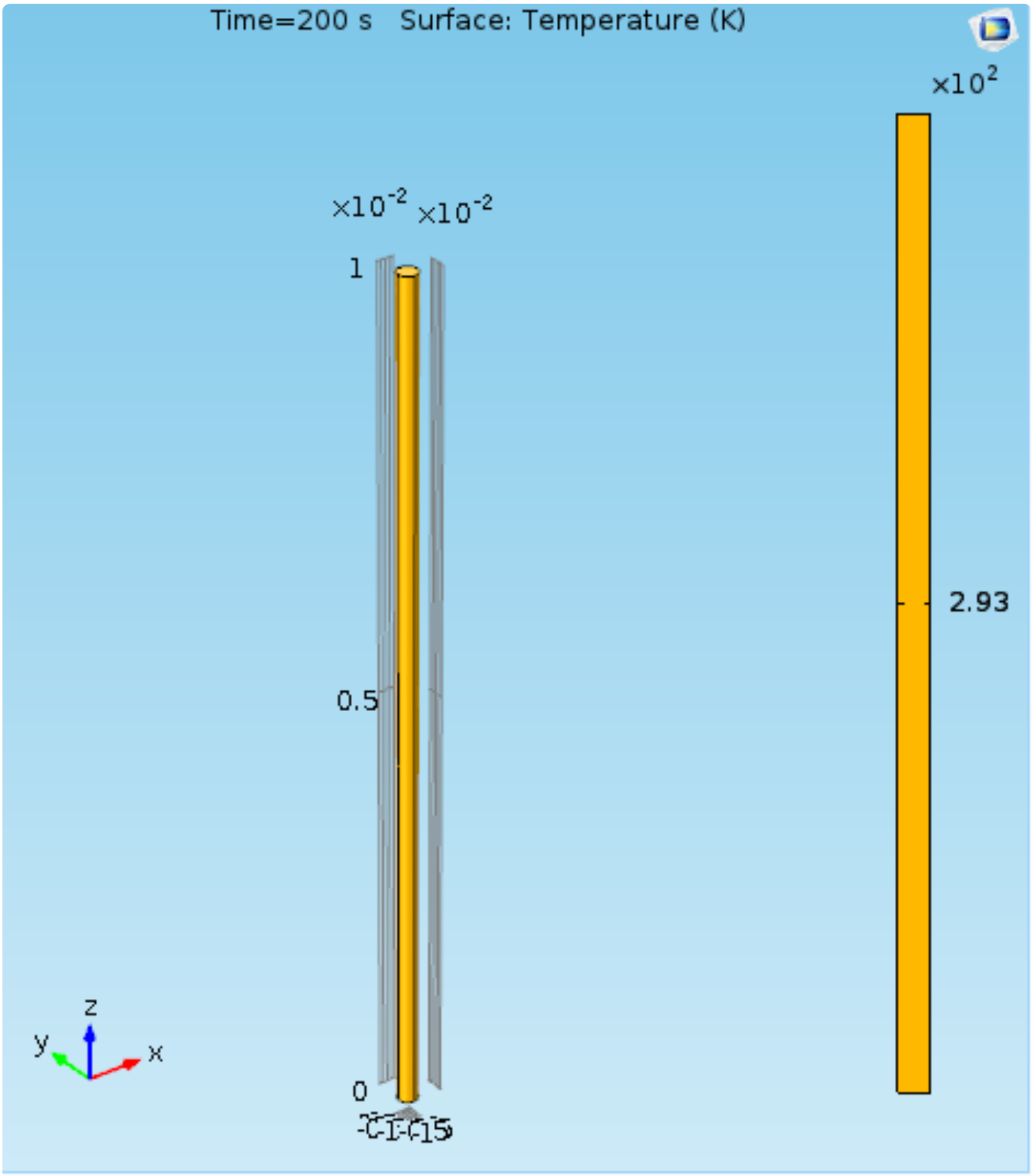
2: DATA & VARIABLES

2.1: PARAMETERS 1

Name	Expression	Value	Description
T_i	70[degC]	343.15 K	Initial Temperature
Tinf	25[degC]	298.15 K	Coolant Temperature
h_t	20.42[W/m^2/K]	20.42 W/(m²·K)	Heat Transfer Coefficient
k	0.19[W/m/K]	0.19 W/(m·K)	Thermal Conductivity
density	1190[kg/m^3]	1190 kg/m³	Density
C_p	1465[J/kg/K]	1465 J/(kg·K)	Specific Heat
Tcenter	30[degC]	303.15 K	Center Temperature
t	1338[s]	1338 s	Time

3: DRAWINGS & DIAGRAMS

3.1: GEOMETRY 1



4: MATERIALS

4.1 : Selection

4.2 :

Property	Name	Value	Unit	Property group
Thermal conductivity	k	k	W/(m·K)	Basic
Density	rho	density	kg/m³	Basic
Heat capacity at constant pres...	Cp	C_p	J/(kg·K)	Basic

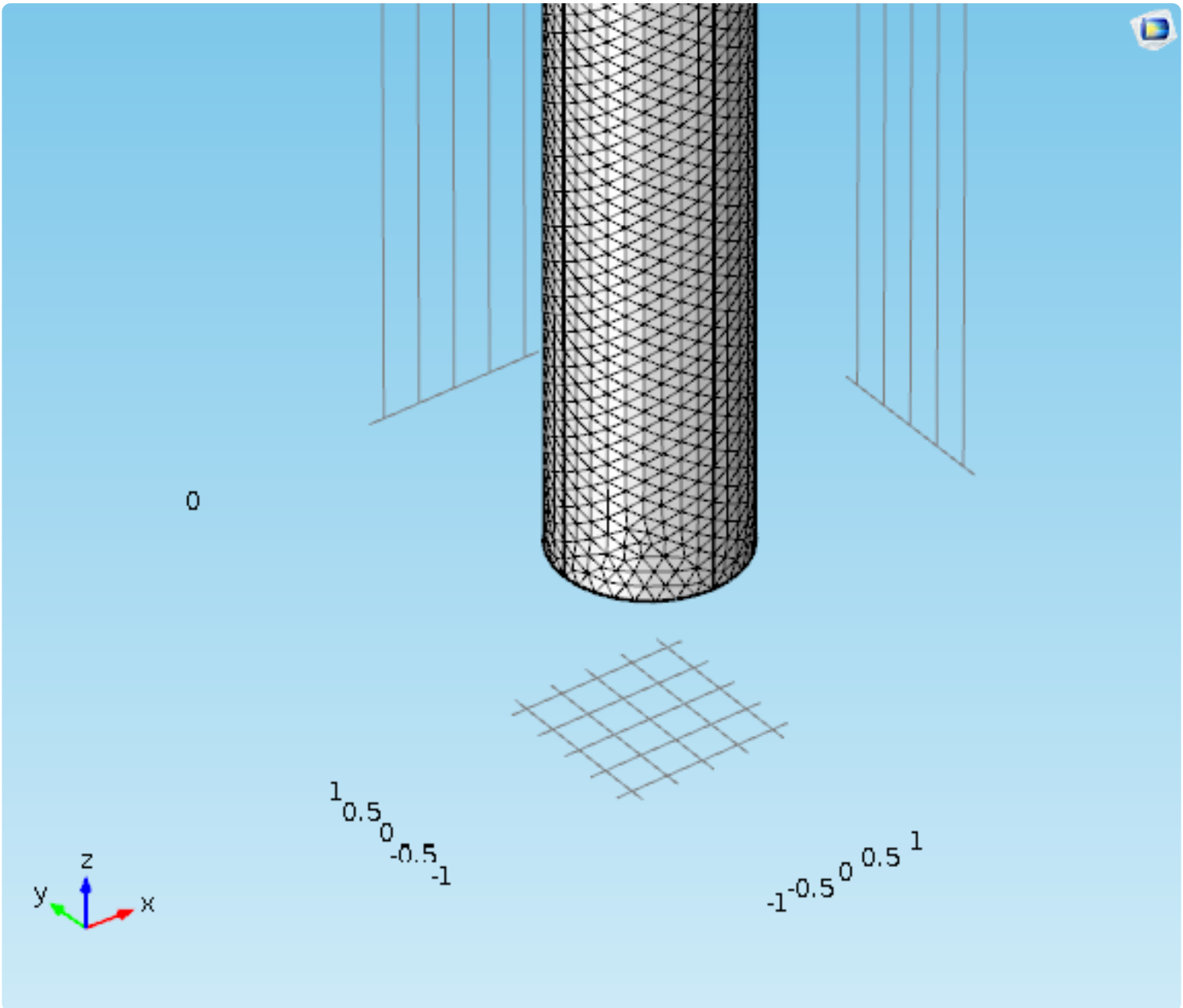
5: SOURCES

→ Bayazitoglu, Y., Ozisik, N., "A Textbook for Heat Transfer Fundamentals," Begell House, Inc (2012)

6: DESIGN CONSIDERATIONS

7: PROCEDURE

→ I have no mesh statistics



8: CALCULATIONS

9: SUMMARY

→ Using COMSOL to look at the temperature at the different distances along the rod's radius and compare the determined to the values calculated numerically.

10: ANALYSIS

→ In this portion of the exam, the comparison of solutions done by hand and with COMSOL is unsatisfactory. COMSOL is a powerful and helpful tool, but my lack of understanding of the software and my inability to see the simple answers has hindered me from solving this part of the test.

Problem solution rubric

	Exceeds Standard	Meets Standard	Approaches Standard	Needs Attention
	4	3	2	1
	10 points	7 points	4 points	0 points
1. Purpose 5%	The purpose of the section to be answered is clearly identified and stated.	The purpose of the section to be answered is identified, but is stated in a somewhat unclear manner.	The purpose of the section to be answered is partially identified, and is stated in a somewhat unclear manner.	The purpose of the section to be answered is erroneous or irrelevant.
2. Drawings & Diagrams 10%	Clear and accurate diagrams are included and make the section easier to understand. Diagrams are labeled neatly and accurately.	Diagrams are included and are labeled neatly and accurately.	Diagrams are included and are labeled.	Needed diagrams are missing OR are missing important labels.
3. Sources 5%	Several reputable background sources were used and cited correctly.	A few reputable background sources are used and cited correctly.	A few background sources are used and cited correctly, but some are not reputable sources.	Background sources are cited incorrectly.
4. Design considerations (assumptions, safety, cost, etc) 10%	Design is carried out with applicable assumptions and full attention to safety and cost, etc.	Design is generally carried out with assumptions and attention to safety, cost, etc.	Design is carried out with some assumptions and some attention to safety, cost, etc.	Assumptions, safety and cost were ignored in the design.
5. Data and variables 5%	All data and variables are clearly described with all relevant details.	All data and variables are clearly described with most relevant details.	Most data and variables are clearly described with most relevant details.	Data and variables are not described OR the majority lack sufficient detail.
6. Procedure 25%	Procedure is described in clear steps. The step description is in a complete and easy to understand short paragraph.	Procedure is described in clear steps but the step description is not in a complete short paragraph.	Procedure is described in clear steps. The step description is in a complete short paragraph but it is difficult to understand.	Procedure is not described in clear steps at all.
7. Calculations 20%	All calculations are shown and the results are correct and labeled appropriately. The units of all values are shown.	Some calculations are shown and the results are correct and labeled appropriately.	Some calculations are shown and the results labeled appropriately.	No calculations are shown OR results are inaccurate or mislabeled.
8. Summary 5%	Summary describes the design, the relevant information and some future implications.	Summary describes the design and some relevant information.	Summary describes the design.	No summary is written.
9. Materials 5%	All materials used in the design are clearly and accurately described.	Almost all materials used in the design are clearly and accurately described.	Most of the materials used in the design are clearly and accurately described.	Many materials are described inaccurately OR are not described at all.
10. Analysis 10%	The design is discussed and analyzed. Argumentative predictions are made about what might happen in case of change in the operation and how the design could be change.	The design is discussed and analyzed. Argumentative predictions are made about what might happen in case of change in the operation.	The design is discussed and analyzed. No argumentative predictions are made about what might happen in case of change in the operation and how the design could be change.	The design is not discussed and analyzed.