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MET 440 Heat Transfer
Dr. Orlando Ayala
Fall 2018
Test 1

Take home – Due Sunday September 23rd 2018 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. The other eighty (80) points will come from the problem solutions. For the technical writing I will follow the attached rubric.

3. There are 3 problems. Each problem is worth (80/3) 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 (which is optional) you are supposed to upload this artifact to your Google drive. I will provide more instructions later.

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.

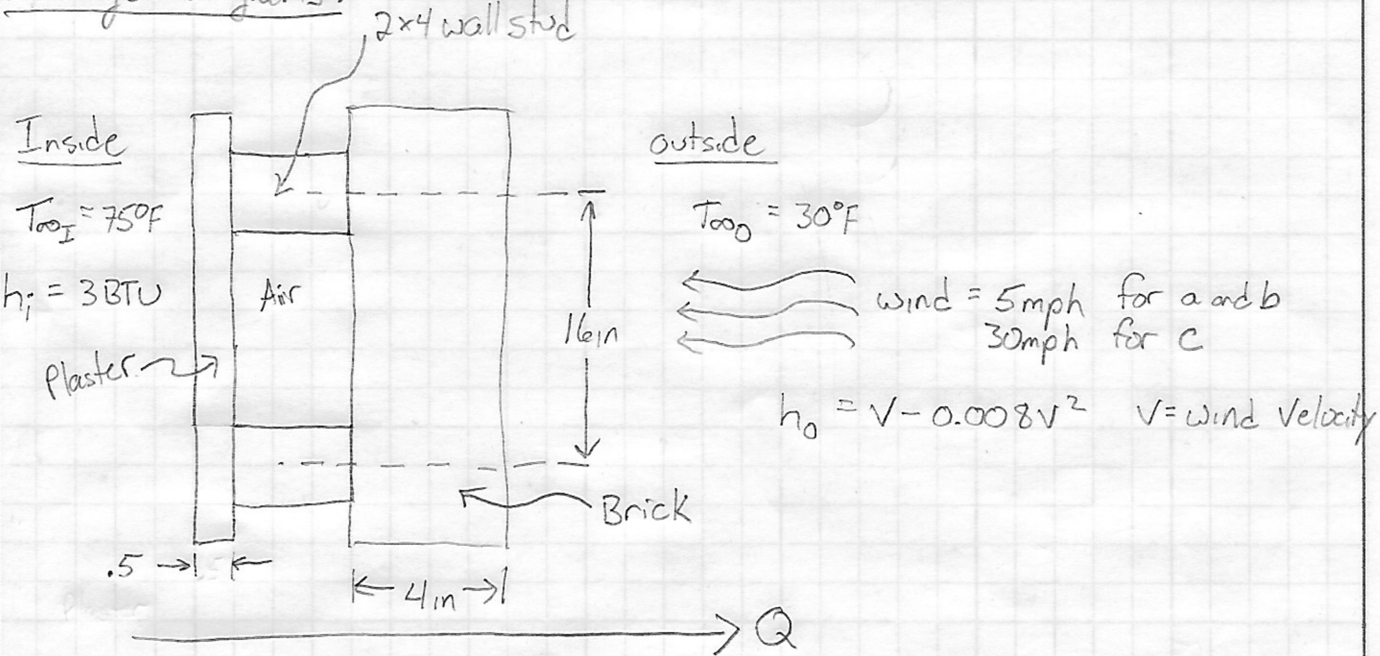
8. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University you have accepted the responsibility 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) Purpose: Determine the heat transfer and Temperature at the inside surface of a composite wall for multiple scenarios. Those scenarios include wind traveling at 5 MPH across the outside of the wall with motionless air inside the wall, wind traveling at 5mph across the outside of the wall with moving air inside the wall and wind blowing at 30mph across the outside of the wall with air moving inside the wall.

Drawings + Diagrams:



Sources:

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

- Ayala, O., MET 440 Heat Transfer. Old Dominion University online. 2018. web. Sept 2018.

Design Considerations:

- Steady state
- constant properties
- No heat generation
- 1D heat transfer

Data + Variables:

Refer to Drawings + Diagrams

Per Table B6:

$K_{Brick} = .69\ W/m \cdot °C \times .5779\ BTU/h \cdot ft \cdot °F = .3987\ BTU/h \cdot ft \cdot °F$

$K_{plaster} = .48\ W/m \cdot °C \times .5779\ BTU/h \cdot ft \cdot °F = .2774\ BTU/h \cdot ft \cdot °F$

$K_{maple} = .166\ W/m \cdot °C \times .5779\ BTU/h \cdot ft \cdot °F = .0959\ BTU/h \cdot ft \cdot °F$

$K_{stagnant\ Air} = .025\ W/m \cdot °C \times .5779\ BTU/h \cdot ft \cdot °F = .0144\ BTU/h \cdot ft \cdot °F$

1 (cont.)

Procedure:

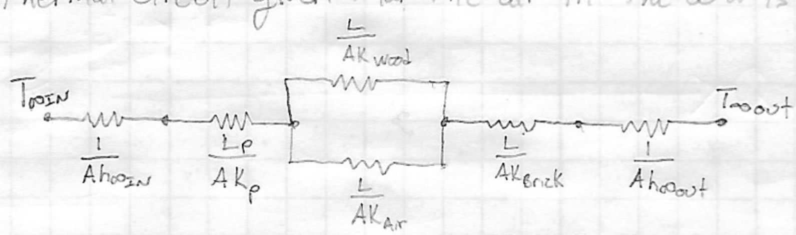
- The convective heat transfer coefficient (h) for the outside air must be calculated using the given formula $h = V - 0.0008V^2$.
- Thermal circuits for each scenario must be constructed
- Once the circuits have been constructed and the resistances have been determined we can use $Q = \frac{\Delta T}{R_{eq}}$ to determine the heat transfer through the wall.
- Once Q has been determined we can use it to find the temperature of the inside wall and the temperature of the moving air in the wall for part c

Calculations:

a) h of outside air given that the wind is blowing 5mph:

$$h = V - 0.008V^2$$
$$h = 5 - 0.008(5)^2$$
$$h = 5 - .2$$
$$h = 4.8\ BTU/hr \cdot ft^2 \, {}^\circ R$$

Thermal circuit given that the air in the wall is stagnant:



$$R_{\infty In} = \frac{1}{Ah_{\infty IN}} = \frac{1}{(1.33ft^2)(3\ BTU/hr\ ft^2\,{}^\circ R)} = .2506\ \frac{hr\,R}{BTU}$$

$$R_{plaster} = \frac{L_P}{AK_P} = \frac{.0417\ ft}{(1.33ft^2)(.2774\ BTU/hr\ ft\,R)} = .1130\ \frac{hr \cdot ft\,{}^\circ F}{BTU}$$

$$R_{wood+Air} = \left[\frac{AK}{L} + \frac{AK}{L}\right]^{-1} = \left[\frac{(.167ft)(.0959)}{.333ft} + \frac{(1.167ft)(.0144)}{.333ft}\right]^{-1} = 10.146\ \frac{hr\ ft\,{}^\circ F}{BTU}$$

$$R_{Brick} = \frac{L_B}{AK_B} = \frac{.333ft}{(1.33ft^2)(.3987)} = .6280\ \frac{hr\ ft\,{}^\circ F}{BTU}$$

$$R_{\infty out} = \frac{1}{Ah_{\infty out}} = \frac{1}{(1.33ft^2)(4.8\ BTU/hr\ ft^2\,{}^\circ R)} = .1566\ \frac{hr\,{}^\circ R}{BTU}$$

$$Q = \frac{\Delta T}{R_{eq}}$$

$$Q = \frac{45^\circ}{11.2942\ \frac{ft\ hr}{BTU}} = \boxed{3.984\ BTU/ft \cdot h}$$

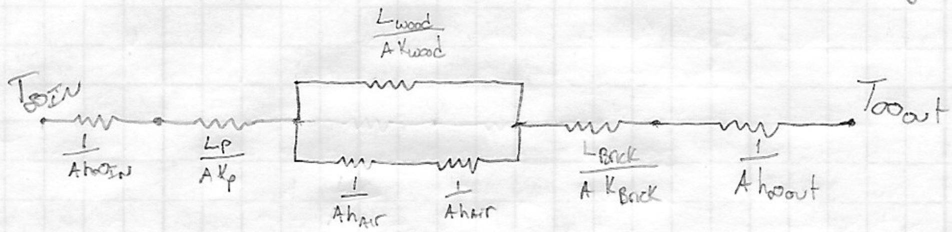
Inside wall Temperature: T_∞ —conv— T_1

$$Q = \frac{T_\infty - T_1}{R} = T_1 = T_{\infty IN} - QR \quad T_1 = 75^\circ F - \left(3.984\frac{BTU}{ft \cdot h}\right)\left(.2506\ \frac{h \cdot ft\,{}^\circ F}{BTU}\right)$$

$$\boxed{T_1 = 74^\circ F}$$

1 cont

b) Thermal circuit given that the air in the wall is moving:



$$R_{\infty IN} = \frac{1}{A h_{\infty IN}} = \frac{1}{(1.33ft^2)(3\,BTU/hr\,ft^2\,R)} = .2506 \frac{hr\,°R}{BTU}$$

$$R_{Plaster} = \frac{L_P}{A K_P} = \frac{.0417\,ft}{(1.33ft^2)(.2774\,BTU/hr\cdot ft\cdot °F)} = .1130 \frac{hr\cdot ft\cdot °F}{BTU}$$

$$R_{wood} = \frac{L_{wood}}{A K_{wood}} = \frac{.333\,ft}{(.167ft^2)(.0959\,BTU/hr\cdot ft\cdot °F)} = 20.793 \frac{hr\cdot ft\cdot °F}{BTU}$$

$$R_{Air} = \frac{1}{A h_{Air}} = \frac{1}{(1.167ft^2)(3\,BTU/hr\,ft^2\cdot R)} = .2856 \frac{hr\,°R}{BTU} \times 2 = .5713 \frac{hr\,°R}{BTU}$$

$$R_{wood+Air} = \left[\frac{1}{R_{Air}} + \frac{1}{R_{wood}}\right]^{-1} = \left[\frac{1}{20.793} + \frac{1}{.5713}\right]^{-1} = .5560 \frac{hr\cdot ft\cdot °F}{BTU}$$

$$R_{Brick} = \frac{L_{Brick}}{A K_{Brick}} = \frac{.333\,ft}{(1.33ft^2)(.3987\,BTU/h\cdot ft\cdot °F)} = .6280 \frac{h\cdot ft\cdot °F}{BTU}$$

$$R_{\infty out} = \frac{1}{A h_{\infty out}} = \frac{1}{(1.33ft^2)(4.8\,BTU/hr\,ft^2\cdot R)} = .1566 \frac{hr\,°R}{BTU}$$

$$Q = \frac{\Delta T}{R_{eq}} = \frac{45°}{1.7042}$$

$$\boxed{Q = 26.405\,BTU/ft\cdot h}$$

Inside wall Temperature: T_∞ —conv— T_1

$$Q = \frac{T_\infty - T_1}{R}$$

$$T_1 = T_\infty - QR$$

$$T_1 = 75°F - \left(26.405 \frac{BTU}{ft\,h}\right)\left(.2506 \frac{hr\,°F}{BTU}\right)$$

$$\boxed{T_1 = 68.38°F}$$

1 cont

c) Given 30 mph wind and equation for h_{out} as $h = V - .008V^2$; Calculate new h_{out} and new heat transfer.

$$h_{out} = 30\text{mph} - .008(30\text{mph})^2$$

$$h_{out} = 22.8 \frac{BTU}{hr \cdot ft^2 \, ^\circ F}$$

New convective resistance:

$$R_{\infty out} = \frac{1}{Ah_{\infty}}$$

$$R_{\infty out} = \frac{1}{(1.33ft)(22.8 \frac{BTU}{hr \cdot ft^2 \cdot ^\circ F})}$$

$$R_{\infty out} = .0330 \frac{hr \cdot ^\circ F}{BTU}$$

Since the $h_{\infty out}$ is the only resistance to change, we use resistances calculated in part b.

$$Q = \frac{\Delta T}{R_{eq}}$$

$$Q = \frac{45^\circ}{1.5806}$$

$$\boxed{Q = 28.47 \frac{BTU}{ft \cdot hr}}$$

Temp of air inside wall

$\frac{1}{Ah} \rightarrow \frac{1}{(1.33ft^2)(3 \frac{BTU}{hr ft^2 \, ^\circ F})} \rightarrow .2506 \frac{hr \, ^\circ F}{BTU}$

$\frac{L}{AK} \rightarrow \frac{.0417ft}{(1.33ft^2)(.2774)} \rightarrow .1130 \frac{hr \, ft \, ^\circ F}{BTU}$

$\frac{1}{Ah} \rightarrow \frac{1}{(1.167ft^2)(3 \frac{BTU}{hr ft^2 \, ^\circ F})} \rightarrow .2856 \frac{hr \, ^\circ F}{BTU}$

$$Q = \frac{T_{\infty IN} - T_{\infty wall}}{R_{eq}}$$

$$T_{\infty wall} = T_{\infty IN} - QR$$

$$T_{\infty wall} = 75^\circ F - (28.47 \frac{BTU}{ft \cdot hr})(.6492)$$

$$\boxed{T_{\infty wall} = 56.52^\circ F}$$

1 cont

Summary:

For the scenario with 5mph wind and stagnant air inside the wall a heat transfer of 3.984 BTU/ft·h was calculated with an inside wall Temperature of 74°F, a loss of only 1°F from the inside ambiant.

For the scenario with 5mph wind and moving air inside the wall there is a 26.405 BTU/ft·h heat transfer with an inside wall temp. of 68.38°F, a drop of 6.62 °F from the ambiant room temp.

There is a significant difference between whether or not the air inside the wall is moving. It is more difficult for the heat to move through the wall when the air is stagnant, creating a higher resistance and less of a temperature drop. When the molecules are moving around it is easier for them to transfer heat thus, a lower resistance and more of a temperature drop.

This is further affirmed when the wind outside was moving at 30mph instead of 5mph. The overall resistance was lower leading to an increased heat transfer and much lower temperatures as you move through the wall,

Materials:

- Plaster
- wood
- Brick
- Air

Analysis:

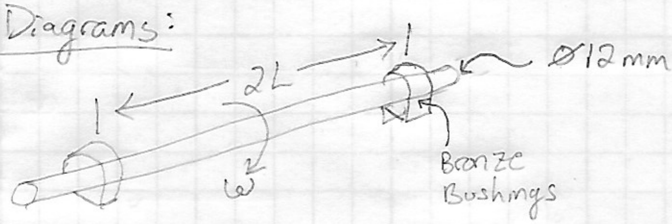
As air molecules move it creates less resistance and increased heat transfer and the faster the air moves the less resistance it offers. This is why insulation is required to keep temperatures more consistent. Insulation offers an increase in resistance.
As seen here stagnant air in the spaces of your home also offer increased resistance.
The harder the wind is blowing, the harder your air conditioning unit will have to work to keep a consistent temperature inside your home.

(2)

Purpose:

Determine how to describe the scenario given and which Temperature profile formula to use.
Determine the length of the shaft that would result in a maximum temperature of 100°C at the middle of the shaft, where a pulley is to be placed.

Drawings + Diagrams:



Sources:

- Bayazitoglu, Y., Ozisik, N., "A Text book for Heat Transfer Fundamentals." Begel House (2012)
- Ayala, O., MET 440 Heat Transfer. Old Dominion University online. 2018. web. Sept 2018

Design Consideration:

- Steady State
- 1D heat Transfer
- No heat generation
- will perform calculations using half of shaft
- Temp at bushings is max.
- $x = L$

Data + Variables:

Refer to drawings + diagrams.

- Temp of shaft at bushings = 175°C
- $T_{\infty room} = 35°C$
- Midpoint of shaft ≤ 100°C
- Shaft is 1.5% carbon steel → $K = 36\ W/m\cdot°C$ per Table B-4
- $h_{shaft \to Air} = 5\ W/m^2\cdot°K$

Procedure:

Analyze half of shaft assembly to find L, then double
Choose temperature profile equation based on given scenario.
Once all variables are known, plug into temperature profile equation and solve for L
L will equal half of the required shaft length so it will need to be doubled.

Calculations:

a) The shaft in this configuration acts as a fin because it helps dissipate the heat generated by the friction at the bushings. The heat travels through the shaft while being transferred to the surrounding air via convection. Due to the fact that there are 2 bushings, one at each end, producing heat, the center of the shaft's span will be the coolest point on the shaft.

b) The temperature at the middle of the shaft will be lower than at the bushings because as the heat travels through the shaft it is transferred to the cooler ambient air via convection.

c) I think that the prescribed temperature profile equation best fits the given scenario.
we are not analyzing a shaft or fin with an end open to ambiant and there is still heat at the point of analysis. In addition a temperature at the point of analysis is known

I have chosen to use the prescribed temperature equation. Right or not I don't have a clue.
The equation is

$$\frac{\theta}{\theta_b} = \frac{\theta_L/\theta_b \sinh mx + \sinh m(L-x)}{\sinh mL} \qquad \text{where } m = \sqrt{\frac{hP}{kA_c}}$$

$$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{(5\,W/m^2K)(.0377\,m)}{(36\,W/m\cdot°C)(.0001131\,m^2)}} = 6.804$$

$$\frac{50°C - 35°C}{175°C - 35°C} = \frac{\frac{175°C - 50°C}{175°C - 35°C}\sinh(6.804L) + \sinh(6.804(L-L))}{\sinh(6.804L)}$$

$$\frac{15°C}{140°C} = \frac{.8929\ \sinh(6.804L) + 0}{\sinh(6.804L)}$$

* Summary:
I do not know where to go from here. Perhaps I chose the wrong equation but it seems to me to be the one that fits.
I am assuming that since the shaft assembly is symmetrical and after you reach the half way point on the shaft that the temperature will start to rise as you make your way toward the bushing on the opposite side.
If we analyze just one side of the assembly $L = x$ and that makes zero's in the equations.
I am sure that once I see your solution it will be clear (maybe even obvious) what I should have done.
The equations you showed us in the lecture do not appear to be in our book and I am confused on the rules of when to use which and how. I did not feel that was the case until now.

2 cont

Materials:

- Carbon steel
- Bronze bushings

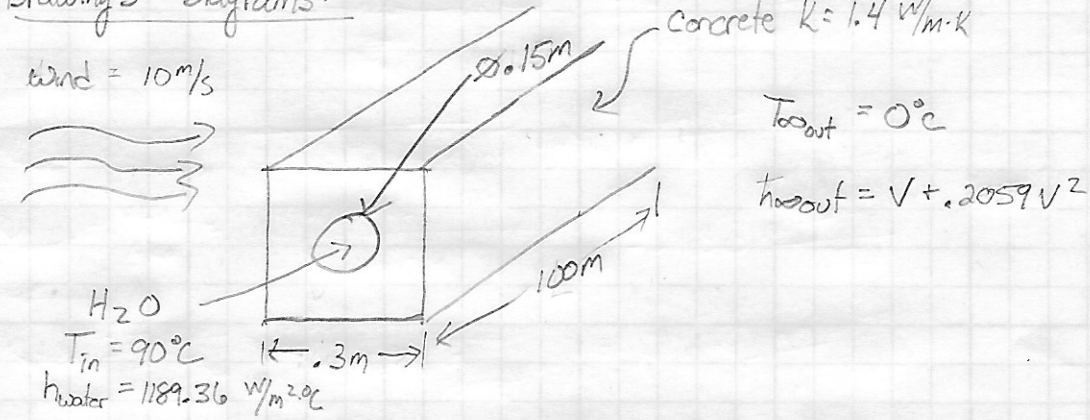
Analysis:

The longer the shaft is the more heat will be lost. both by conduction and convection to the ambiant air. It is common sense that the farther away you get from the source of the heat the cooler it will be.

(3)

Purpose: Determine the heat loss from the water flowing in the steel pipes through the concrete and into the outside air.
In addition, determine the mass flow rate of the water through the pipes.

Drawings + Diagrams:



Sources:

- Bayazitoglu, Y., Ozisik, N., "A Textbook for Heat Transfer Fundamentals." Begel House, Inc (2012)
- Ayala, O., MET440, Heat Transfer. Old Dominion University, online. 2018. web. Sept 2018.

Design Considerations:

- Steady state
- No heat Generation
- 2D Heat Transfer

Data + Variables:

Refer to drawings + Diagrams

Procedure:

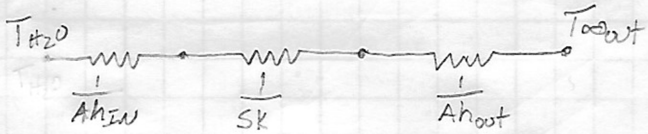
- Determine h_∞ using given equation and wind velocity
- Determine S for given configuration using scenario 11 from Table 4.2 on p127
- Calculate R_{conv} and R_{cond} using given data
- Build Thermal circuit for pipe in Concrete.
- Calculate Heat loss using $Q = \frac{\Delta T}{R_{eq}}$

3 cont

Calculations:

$h_{\infty out} = V + .2059V^2$
$h_{\infty out} = 10 m/s + .2059(10 m/s)^2$
$h_{\infty out} = 30.59 \, W/m \cdot °C$

Thermal circuit of Scenario given:



$R_{IN} = \frac{1}{Ah_{IN}} = \frac{1}{(1m^2)(1189.36 \, W/m^2 \cdot °C)} = .000841 \, W/°C$

$R_{cond} = \frac{1}{SK} = \frac{1}{\left(\frac{2\pi \cdot 1m}{\ln(.54 \cdot 3m / .075m)}\right)(1.4 \, W/mK)} = .08755 \, W/°C$

$R_{out} = \frac{1}{Ah_{out}} = \frac{1}{(1m)(30.59 \, W/m°C)} = .03269 \, W/°C$

$Q = \frac{\Delta T}{R_{eq}} = \frac{90°C - 0°C}{.121081} = \boxed{743.30 \, W/m}$

The heat transfer from the water to the outside air is 743.30 W/m or 74,330 W for the entire length of the pipe.

For determining mass flow rate we need C_p of H_2O at 90°C Table B-2 does not have it listed for 90°C so we must interpolate.

$\frac{100 - 80}{90 - 80} = \frac{4.2161 - 4.1964}{C_p - 4.1964}$

$\frac{20}{10} = \frac{0.0197}{C_p - 4.1964}$

$C_p = \frac{(0.0197)(10)}{20} + 4.1964$

$C_p = 4.206 \, kJ/kg \cdot °C$

Determine mass flow rate using Q, C_p and T

$\frac{74330 \, J/s}{(4206 \, J/kg \cdot °C)(5°C)} = \boxed{3.534 \, kg/s}$

3cont.

Summary:

With the given scenario the heat transfer rate from the water flowing in each pipe, through the concrete and into the outside air is 743.30 W/m or 74.3 KW for the entire length of the assembly. The mass flow rate of the water through the pipe is 3.534 kg/s.

Materials:

- Steel pipe
- Concrete slab
- water
- Air/wind

Analysis:

If a greater Flow rate was desired the change in temperature would need to be decreased. That could be accomplished by adding an insulated layer to the outside of the concrete or possibly by using smaller diameter pipe.