Engineering Ethics Cases with Numerical Problems

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Mechanical Engineering Case 1

Nuclear Plant Heat Exchanger Problems

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Suggested Courses:

Thermodynamics & Heat Transfer

Level:

Junior & Senior

Based on "To Dissent or Not to Dissent"*

I. Narrative

Alison Turner is a department manager at a commercial nuclear generating plant. She is also a member of the Plant Nuclear Safety Review Committee (PNSRC). The committee's responsibilities include reviewing and approving design changes, and submittals to the Nuclear Regulatory Commission (NRC).

Today Alison finds herself in a difficult situation. PNSRC is meeting to decide what to do about a heat exchanger problem. Routine testing on the previous morning revealed degraded cooling water flow and high differential pressure in both heat exchangers in the safety system. The most likely cause of the problem is sand accumulation in the filter at the cooling water inlet to the heat exchangers. The two heat exchangers are in parallel, and when operating at full heat transfer capacity, each one individually provides sufficient cooling to safely operate the plant. Two heat exchangers are used in case one of them fails.

After extensive analysis by engineers in the mechanical engineering and nuclear safety and licensing departments, they have concluded that the cooling water flow falls 30 percent below the minimum requirement set by the technical specifications under which the plant is licensed. To allow for continued plant operation at the current cooling water flow rate, nuclear safety and licensing has prepared a Justification for Continued Operation (JCO), based on mechanical engineering's analysis, for submission to NRC. PNSRC is now meeting to decide whether to approve the JCO and forward it to NRC. If the JCO is not approved, the plant must be shut down for expensive repairs.

Seven members of the PNSRC are present, enough for a quorum. Alison is the least senior member present. From the outset of the meeting, committee chair Rich Robinson has made it clear that it is important to act quickly, since any shutdown will cost the company, and ultimately the rate payers, a lot of money in additional fuel costs. He says that "the JCO seems fine," and calls for an open vote.

Alison has reviewed the JCO and is uncomfortable with an assumption made in the analysis. The assumption made is that the degraded flow through the cooling water side of the heat exchanger (~30% less than nominal) has a negligible effect on the overall heat transfer coefficient (U). Single failure criteria requires the plant to assume the loss of one heat exchanger in accident situations. Alison is concerned that if one heat exchanger fails, the combined loss of heat transfer capacity and lower coolant flow rate would result in a dangerous operating condition. The JCO does not discuss what might happen under that contingency.

Alison is considering requesting a delay in the PNSRC vote so that a more complete analysis can be conducted. She is concerned, however, that Rich may oppose the delay from fear that a negative result may require the plant to be shut down to make repairs.

II. Numerical Problems

Given:

Volumetric Flow Rate - Hot Side = 2000 gpm

Volumetric Flow Rate - Cold Side - initial = 4000 gpm

T_{hi} (Temperature - Hot Side - Inlet)= 300 F

T_{ci} (Temperature - Cold Side - Inlet)= 85 F

$T_{ho\ nominal}$ (Temperature - Hot Side - Exit - Initial Case) = 125 F

$T_{ho\ maximum}$ (Temperature - Hot Side - Maximum Limit) = 140 F

$h_{c\ initial}$ (Heat Transfer Coefficient - Cold Side - Initial) = 634 BTU/ft^2-hr-F

h_h (Heat Transfer Coefficient - Hot Side) = 634 BTU/ft^2-hr-F

A (Area for Heat Transfer) = 10,000 ft^2

k (Thermal Conductivity)= 36 BTU/hr-ft-F

L (Tube Thickness) = 0.5"

c_p (Specific Heat Capacity) = 1 BTU/lbm-F

EQUATIONS:

$$\dot{Q} = \dot{m}_h c_p (T_{hi} - T_{ho})$$

$$\dot{Q} = \dot{m}_c c_p (T_{co} - T_{ci})$$

$$\dot{Q} = UA\Delta T_{lm}$$

$$\Delta T_{lm} = \frac{(T_{ho} - T_{ci}) - (T_{hi} - T_{co})}{\ln \frac{(T_{ho} - T_{ci})}{(T_{hi} - T_{co})}}$$

$$\frac{1}{U} = \frac{1}{h_c} + \frac{1}{h_h} + \frac{L}{k}$$

1) FIND THE NOMINAL HEAT TRANSFER RATE

$$\dot{Q} = \dot{m}_h c_p (T_{hi} - T_{ho})$$

Q = $1*10^6$ lbm/hr * 1 BTU/lbm-F * (300 F - 125 F) = $1.75 * 10^8$ BTU/hr

2) FIND THE NOMINAL T_{co}

$$\dot{Q} = \dot{m}_c c_p (T_{co} - T_{ci}) \Rightarrow T_{co} = \frac{\dot{Q}}{\dot{m}_c c_p} + T_{ci}$$

$$T_{co} = \frac{1.75 * 10^8 \frac{BTU}{hr}}{2 * 10^6 \frac{lbm}{hr} * 1 \frac{BTU}{lbm - F}} = 172.5°F$$

3) DETERMINE T_{lm}

$$\Delta T_{lm} = \frac{(T_{ho} - T_{ci}) - (T_{hi} - T_{co})}{\ln \frac{(T_{ho} - T_{ci})}{(T_{hi} - T_{co})}}$$

$$\Delta T_{lm} = \frac{(125°F - 85°F) - (300°F - 172.5°F)}{\ln \frac{(125°F - 85°F)}{(300°F - 172.5°F)}} = 75.5°F$$

4) CALCULATE NOMINAL U

$$\dot{Q} = UA\Delta T_{lm} \Rightarrow U = \frac{\dot{Q}}{A\Delta T_{lm}}$$

$$U = \frac{1.75 * 10^8 \frac{BTU}{hr}}{10{,}000 ft^2 * 75.5°F} = 232 \frac{BTU}{hr - ft^2 - F}$$

OR

$$\frac{1}{U} = \frac{1}{h_c} + \frac{1}{h_h} + \frac{L}{k}$$

$$\frac{1}{U} = \frac{1}{634 \frac{BTU}{ft^2 - hr - F}} + \frac{1}{634 \frac{BTU}{ft^2 - hr - F}} + \frac{0.5in * \frac{ft}{12in}}{36 \frac{BTU}{hr - ft - F}} = 4.31 * 10^{-3} \frac{hr - ft^2 - F}{BTU} \therefore U = 232 \frac{BTU}{hr - ft^2 - F}$$

5) SOLVE FOR DEGRADED CONDITIONS - ASSUME U STAYS CONSTANT

3 equations, 3 unknowns

Solving numerically - T_{ho} (Temperature - Hot Side - Exit)= 135 F

6) SOLVE FOR DEGRADED CONDITIONS ACCOUNTING FOR FLOW EFFECTS ON U

h_c(Heat Transfer Coefficient) $\propto \vec{V}^{0.8}$(Fluid Velocity)

Therefore $\frac{h_{ci}(\text{Heat Transfer Coefficient - Initial})}{\vec{V}_{ci}^{0.8}(\text{Initial Cold Fluid Velocity})} = \frac{h_{cf}(\text{Heat Transfer Coefficient - Final})}{\vec{V}_{cf}^{0.8}(\text{Final Cold Fluid Velocity})}$

Therefore

$$h_{cf} = h_{ci} * \frac{\vec{V}_{cf}^{0.8}}{\vec{V}_{ci}^{0.8}} = h_{ci}\left(\frac{\vec{V}_{cf}}{\vec{V}_{ci}}\right)^{0.8} = 634\frac{\text{BTU}}{\text{ft}^2 - \text{hr} - \text{F}} * 0.7^{0.8} = 477\frac{\text{BTU}}{\text{ft}^2 - \text{hr} - \text{F}}$$

Solving numerically - T_{ho} = 141 F

III. Questions Regarding Ethics and Professionalism

1. Should Alison express her reservations about the JCO and request a delay of the PNSRC vote? Explain.

2. Brad Louks states that the heat exchanger system in question is "an accident mitigation system, and it's never had to be used here - or in any other commercial nuclear plant that we know of, for that matter. In fact lots of plants don't even have this safety system." Should this ease Alison's concerns or change her intent to request a vote delay? What part does Brad's seniority over Alison play?

3. Though not a committee requirement, the PNSRC has always acted unanimously. In this case, all committee members except Alison have indicated that they will vote to approve the JCO. How might this affect Alison's decision?

4. Construct a case where Alison clearly should request a delay and further investigation (case 1) and a case where she clearly should not (case 2). Is the actual case closer to case 1 or case 2? Point out similarities and differences between the actual case and case 1 and case 2 in order o justify your position.

IV. Solutions to Ethical Questions

1. Alison should express her dissenting opinion in the open vote. It is likely that other members may vote the way she does as well. Even though she is the least senior member present, her opinion is still valuable, and in order to have a clear conscience, she should speak her mind. After all, the engineering codes ask that the safety and welfare of the public be placed paramount. This means above all else (even higher utility rates).

1. Brad's seniority over Alison puts her in a weaker position. Alison needs to be careful here and be tactful in the manner in which she presents her dissenting opinion. She should "stick to her guns" and cite the NSPE code if she feels it necessary.

1. This may incline Alison to feel that she must act in unison with the other members of the board. Since there has been a strong tradition of unanimity, this opens up the possibility that Alison may feel the need to "think like the group," and this is clearly wrong. She may feel it necessary to abstain from voting if she feels she

should not cast a negative vote.

1. This calls for two paradigmatic examples. The first example-she should request a delay: public safety is clearly at risk (this is not a back-up system), the effects of a malfunction will be relatively widespread, the harms to the public will be immediate, & the harm to the public will be death within 20 miles. The second example-she should not request a delay: public safety is not at high risk (this is a tertiary back-up system), the effects of a malfunction will be confined to a few individuals, the harms to the public will be long in coming, & the harm to the public will not be serious (e.g. slightly polluted ground water that tastes bad, but causes no ill side effects). Now, you must chose which example the case is closer to. In the author's opinion, the Alison's case lies closest to the example that she should request a delay.