UNIVERSITY OF ILLINOIS
DEPARTMENT OF NUCLEAR, PLASMA AND RADIOLOGICAL ENGINEERING
NPRE 449 – Nuclear Systems Engineering and Design

Computer Project

In this project the temperatures and pressure in the hot channel of a PWR and a BWR are calculated. In both cases the linear heat generation rate changes in z as:

$$q'(z) = q'_0 \cos(\pi z/H_e), \quad -H/2 \le z \le H/2$$

where H is the fuel height and H_e is the extrapolated height.

Assumptions:

- Steady-state
- No internal heat generation in the fluid
- Axial conduction is negligible
- Single phase properties are constant (based on inlet pressure and temperature)
- Saturation temperature, liquid saturation enthalpy, and vapor saturation enthalpy are functions of pressure. All other saturation properties are constant (based on inlet pressure)
- Changes in fuel and clad properties with temperature are negligible

PWR

Geometry:

- H = 4 m
- H_e = 4.3 m
- D_{rod} = 0.95 cm
- Pitch = 1.26 cm
- D_{Fuel} = 0.82 cm
- Gap thickness = 0.006 cm
- k_{gap}=0.25 W/m^{o}C
- k_fuel=3.6 W/m^{o}C;
- k_cladding=21.5 W/m^{o}C

Conditions:

- G = 4000 kg/m^{2}s
- q'_0 = 380 W/cm
- P (z=-H/2) = 15 MPa
- T_f (z=-H/2) = 277^{o}C

BWR

Geometry:

- H = 4.1 m
- H_e = 4.4 m
- D_{rod} = 1.227 cm
- Pitch = 1.62 cm
- D_{Fuel} = 1.04 cm
- Gap thickness = 0.010 cm
- k_{gap}=0.25 W/m^{o}C
- k_fuel=3.6 W/m^{o}C;
- k_cladding=21.5 W/m^{o}C

Conditions:

- G = 2350 kg/m^{2}s
- q'_0 = 605 W/cm
- P (z=-H/2) = 7.5 MPa
- T_f (z=-H/2) = 272^{o}C

Write a comprehensive professional report detailing the assignment and findings. The report should be a standalone document (contain everything necessary to understand & reproduce the results). Equations should be professionally typed.

Strongly suggested report outline:

- **Cover page (Name, date, title, etc.)**
- **Table of Contents**
- **Table of Figures**
- **Table of Tables**

I. Introduction
  - **a. importance of problem**
  - **b. objectives and scope of report**

II. Problem Statement
  - **a. describe the problem being analyzed (redescribe pg.1 with own figure, table(s), and narrative)**

III. Methods
  - **a. Modeling (Derive and describe equations utilized)**
    - **i. Fluid flow (HEM)**
    - **ii. Heat transfer at clad/fluid boundary (single phase, two-phase, CHF)**
    - **iii. Heat transfer in fuel pin (Heat diffusion Equation)**
  - **b. Numerical methods**
    - **i. how are final equations from III.a given in numerical form**

IV. Results and Analysis
  - **a. Describe the results of the code with figures and in narrative form (see below)**
  - **b. Provide analysis with figures and in narrative form (see below)**

V. Conclusions
  - **a. Briefly summarize the work in the report**
  - **b. highlight the major observations of the analysis**
  - **c. comment on the completeness or lack of completeness of the analysis**

VI. References

VII. Appendix (Code)

At a minimum, the results and discussion should cover the following content:

Part A: Hot channel of a PWR

1. Show mesh convergence.
2. Plot the following as function of z (z on y-axis):
   Coolant temperature
   Clad outer surface temperature
   Clad inner surface temperature
   Fuel surface temperature
   Fuel centerline temperature
   Pressure
   Departure From Nucleate Boiling Ratio (DNBR)

   Compare the maximum temperatures for each (coolant, clad, fuel)

2. Determine the location of maximum fuel centerline temperature, $z_{Max,CL}$. On the same figure, plot the radial temperature profile in the fuel and cladding. Provide one figure for each of the axial locations: z=H/4, z=H/2, and $z=z_{Max,CL}$(z location of max Center Line temperature).

3. Based on the calculated MDNBR, does this PWR meet the thermal design criteria?

4. Describe the sensitivity of the maximum centerline temperature to changes in boundary conditions (q'_0, G, T_{fin}, P_{in}).

Part B: Hot channel of a BWR

1. Show mesh convergence.
2. Plot the following as function of z (z on y-axis):
   Coolant temperature
   Clad outer surface temperature
   Clad inner surface temperature
   Fuel surface temperature
   Fuel centerline temperature
   Pressure
   Density
   Quality and critical quality
   Void fraction
   DNBR

   Determine the location of ONB and saturated boiling. Mark these locations on the coolant and clad outer temperature plots.
   Compare the maximum temperatures for each (coolant, clad, fuel)

3. Determine the location of maximum fuel centerline temperature, $z_{Max,CL}$. On the same figure, plot the radial temperature profile in the fuel and cladding. Provide one figure for each of the axial locations: z=H/4, z=H/2, and $z=z_{Max,CL}$(z location of max Center Line temperature).

4. Determine the MDNBR and CPR (critical power ratio). Does this BWR meet the thermal design criteria?

5. Describe the sensitivity of the maximum centerline temperature to changes in boundary conditions (q'_0, G, T_{fin}, P_{in}).

In the final report be sure to show all derivations and correlations for the expressions used.

Please submit your final report through gradescope

Please submit your code through email to Prof. Brooks and Mr. Malik as a single document that can be directly run (only change for BWR/PWR through a single variable as discussed in class).

Computer project report checklist

General

1. Show differential equations you are solving
2. Show analytic solution of the differential equations
3. Show complete derivation of numerical solution
4. Computer written only, comprehensive, self-contained report.
5. Submit on Gradescope: report itself, **as appendices** to the report add computer program.

Content

6. Report should be self-contained explaining all necessary elements of the problem, do not repeat assignment text verbatim, do not copy/paste the assignment itself.
7. Do not submit results as raw "column of numbers" data.
8. Add references, if relevant.

Formatting

9. Cover page with your name, assignment title/number, course number, date.
10. Include page numbers, except on the title/cover page.
11. Report body has to start on page 1.
12. Use portrait orientation.
    - Landscape for a single page with large table/figure is OK.
13. The report can be submitted in B&W or color, but plots, figures and its labels must be formatted to be visible, readable, and differentiable on the printout.
14. Use only one font type and size for the main body of the report.
15. Use monospaced font (e.g. Courier, Consolas) for computer programs, functions, scripts, etc.
16. Do not use monospaced font for the report body.
17. Italicize variables, do not italicize units

Equations

18. Number each equation in a consistent way.
19. Equations should be numbered to the right of the equation.
20. Use notation consistent with the class lectures.
21. Typeset equations properly (e.g. Equation Editor, LaTeX, MathType, etc.), do not type them as text (e.g. as in text editor).

Tables and Figures

22. Number and label each table and figure in a consistent way.
23. Use proper labels for plots, figures, tables – title, axis, legend, units, etc.
24. Table title should be above the table, figure title should be below the figure.
25. Titles, legends, labels must be of sufficient size and quality to be easily readable.
26. Make units (e.g. time) on plots/figures understandable to humans, for example:
    - if scale exceeds 100s of sec, change to min
    - if scale exceeds 100s of min, change to hours
    - if scale exceeds 100s of hours, change to days, etc…

27. Use sufficiently high quality figures such that they look smooth and sharp.
    - Screen shots are probably too low quality.
    - JPEG and other lossy compression is probably too low quality.
    - High resolution and lossless compression is recommended.

Programming

28. Test your programs/functions thoroughly, after you finished testing, test it some more!
29. Python does not have to be used for programming, but instructor believes this is one of the easiest and most useful tools to use.
30. Python does not have to be used for plotting, but instructor believes this is one of the easiest and most useful tools to use.

Other

31. The purpose of the assignment is a comprehensive, self-contained, consistently formatted report, not the programming itself. If you are not sure about what and how much to include, imagine that you have to grade it – make it concise and easy to follow.
32. I'm being picky because I want you to write good reports. The content and formatting rules are [almost] universal.