Heat Removal System Group

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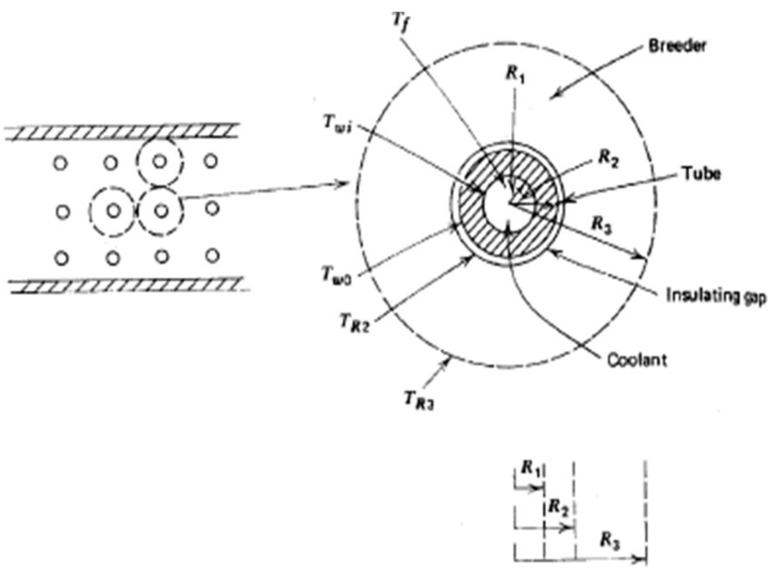
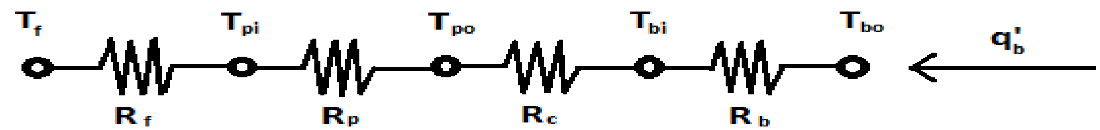
Summarization of Results

- Using stainless steel pipes and water coolant, the temperature of the blanket can be maintained between $429\ ^\circ\mathrm{C}$ and $790\ ^\circ\mathrm{C}$, which is within the design specification of $397\ ^\circ\mathrm{C}$ and $795\ ^\circ\mathrm{C}$.
- A beryllium-coated first wall can successfully remove half the heat from the plasma using water as a coolant.
- A tungsten divertor can successfully remove half of the plasma heat using water as a coolant.
- The overall cycle efficiency is 35%.

Blanket Coolant Tube Array, Unit Cell, and Resistive Circuit



Blanket Tube Array and Unit Cell



Resistive Circuit Model of Heat Flow

T_f = *temperature of the fluid*

T_{pi} = *temperature of the inner pipe surface*

T_{po} = *temperature of the outer pipe surface*

T_{bi} = *temperature of the inner blanket surface*

T_{bo} = *temperature of the outer blanket surface*

q'_b = *linear heat flux*

$$R_f = \frac{1}{2\,\pi\,r_{pi}\,h_f} = \text{fluid convective resistance}$$

$$R_p = \frac{ln\,\frac{r_{po}}{r_{pi}}}{2\,\pi\,k_p} = \text{pipe thermal resistance}$$

$$R_c = \frac{1}{2\,\pi\,r_{bi}\,h_c} = \text{pipe} - \text{blanket contact resistance}$$

$$R_b = \frac{r_{bo}^2}{4\,\pi\,k_b(r_{bo}^2 - r_{bi}^2)}\left(\frac{r_{bi}^2}{r_{bo}^2} - 1 - 2\,ln\frac{r_{bi}}{r_{bo}}\right) = \text{blanket thermal resistance}$$

Model Geometry, Parameters, and Unit Cell Thermal Profile

$q_s''' = 0 \text{ and } q_w''' = 0$

19 pipe rows in the blanket width

Stainless Steel 316 Pipes

Pipe thickness = 3 mm

Inner pipe diameter = 10 mm

$T_c^{in} = 286\ ℃$

$T_c^{out} = 324\ ℃$

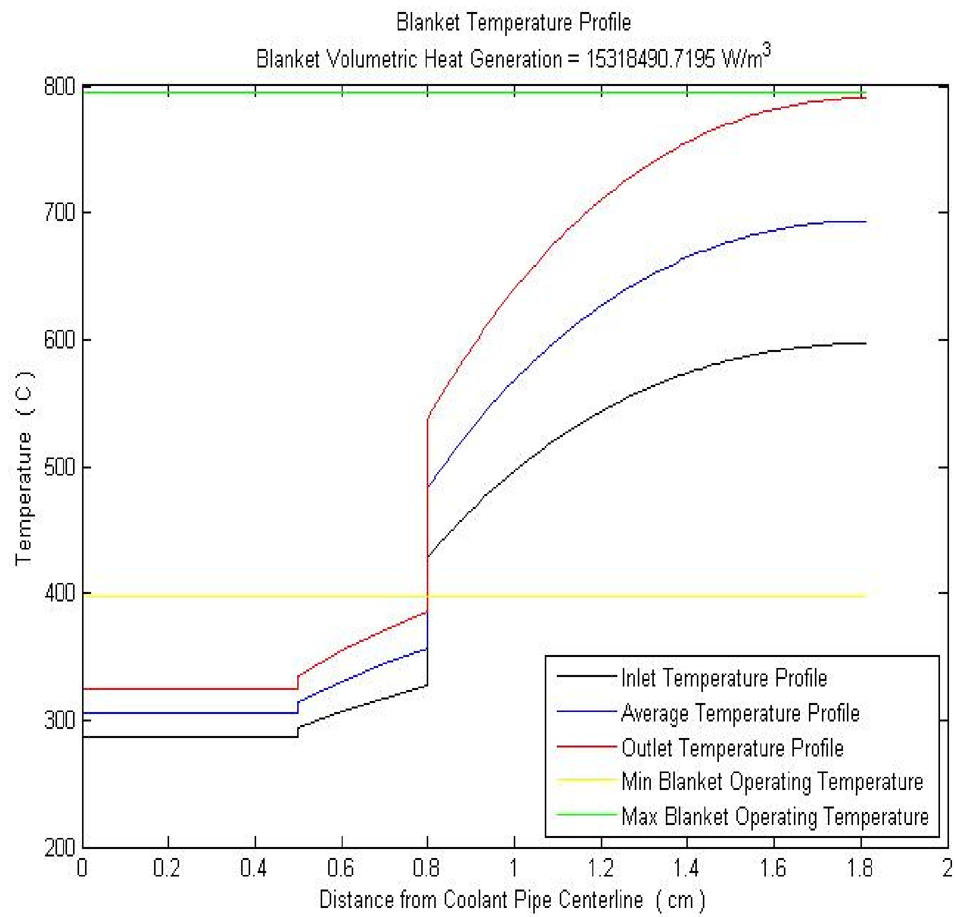
Water pressure = 15.5 MPa

Gap contact resistance = 2000 $\frac{W}{m^2 K}$

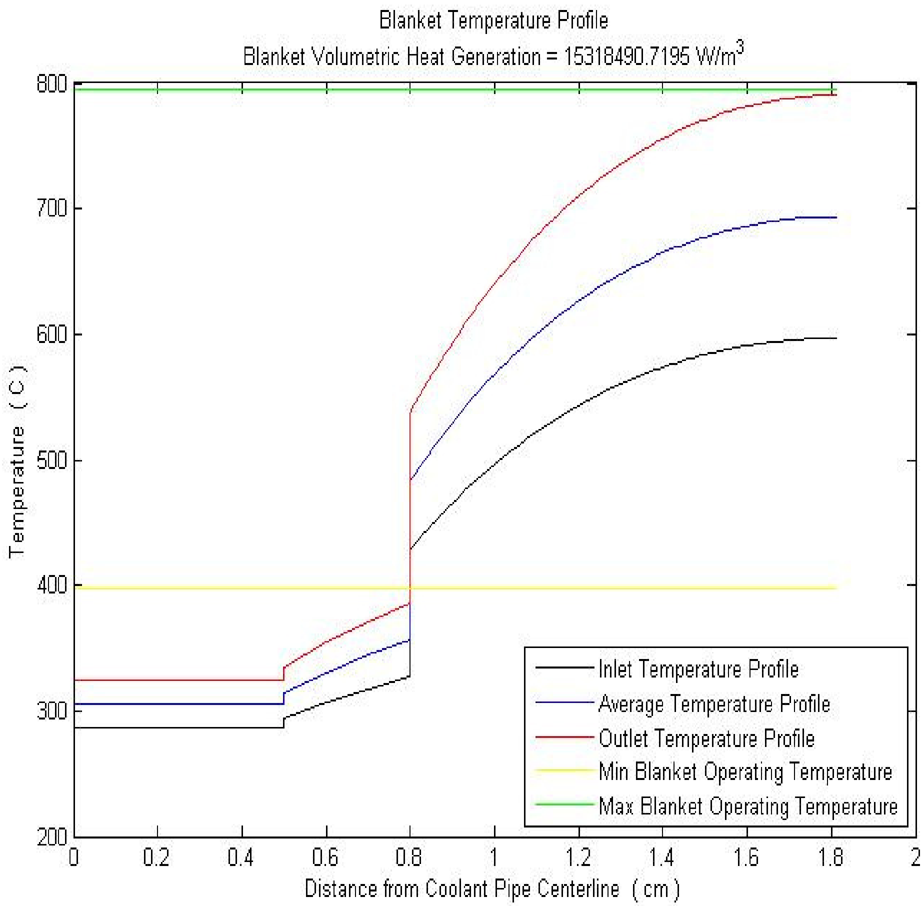
Pipe roughness = 4.5e-3

Pipe Ultimate Yield Stress = 580 MPa

Pipe Yield Stress = 290 Mpa



Unit Cell Thermal Profile and Results



Number of pipes = 39,710

Pipe spacing = 3.63 cm

$\frac{Volume\ Li_2O}{Total\ Volume} = 0.632$

Pumping power required = 4.26 MW

$S_m = 193\ MPa$

Pipe Hoop Stress = 25.8 MPa

Pipe Thermal Stress = 126 MPa

$w_c^* = 16{,}139\ \frac{kg}{s}$

$T_b^{min} = 429\ ℃$

$T_b^{max} = 790\ ℃$

Inlet Temperature Profile uses $q'_{min} = 0.8\ q'_{ave}$

Outlet Temperature Profile uses $q'_{max} = 1.2\ q'_{ave}$

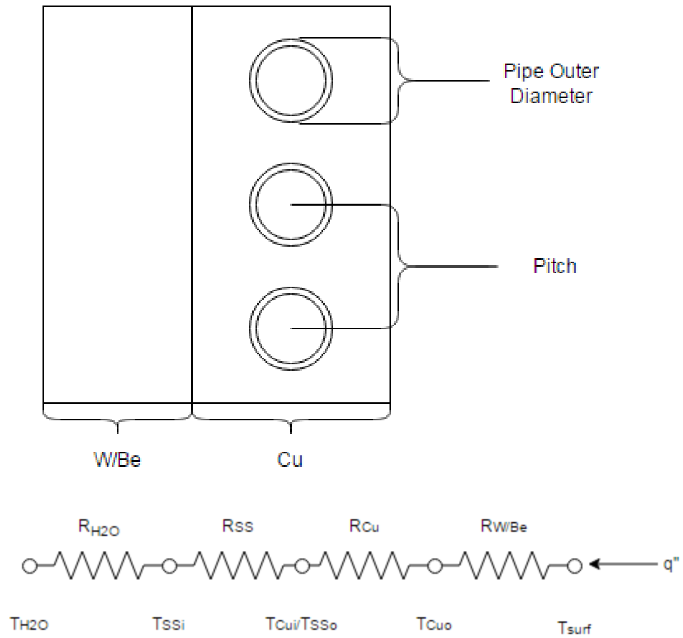
First Wall and Divertor

Used resistor model in slab geometry

Assumed f_{div}=.5 and A_{div}=0.1A_{wall}

Constraints:

- Melting
- Hoop stress in pipe
- Thermal stress in pipe
- Brittle fracture in Cu
- Limit friction power loss in pipe



First Wall Design

q''w=0.864 MW/m^2

395 Pipes

Pipe thickness = 1 mm

Inner pipe diameter = 10 mm

Pitch = 22 mm

Beryllium Thickness = 25 mm

Copper Thickness = 20 mm

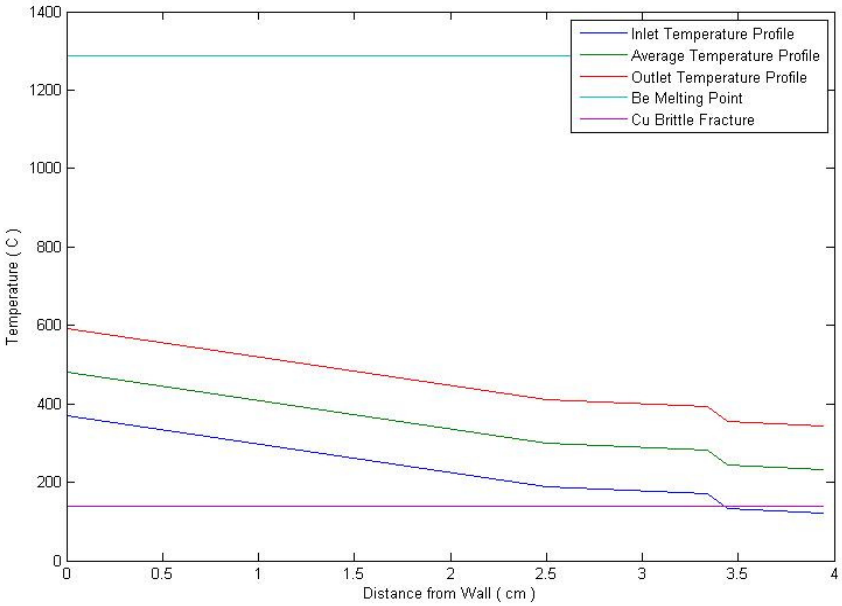
Pumping Power = 0.19 MW

Coolant Mass flow = 286 kg/s

$T_c^{in} = 140\ ℃$

$T_c^{out} = 340\ ℃$

Coolant Pressure = 15.5 MPa



Divertor Design

q''_{div}=8.644 MW/m^2

2175 Pipes

Pipe thickness = 0.2 mm

Inner pipe diameter = 2 mm

Pitch = 4 mm

Tungsten Thickness = 25 mm

Copper Thickness = 6 mm

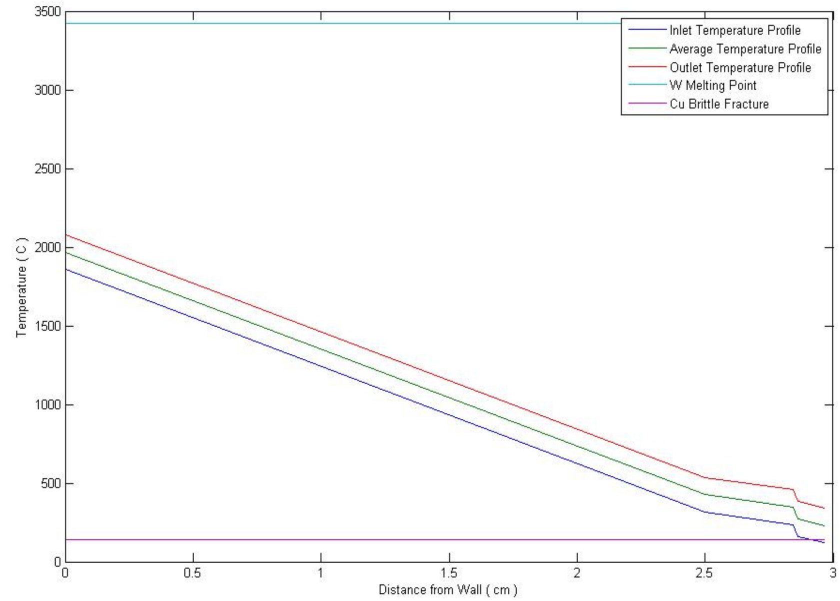
Pumping Power = 6.54 MW

Coolant Mass flow = 286 kg/s

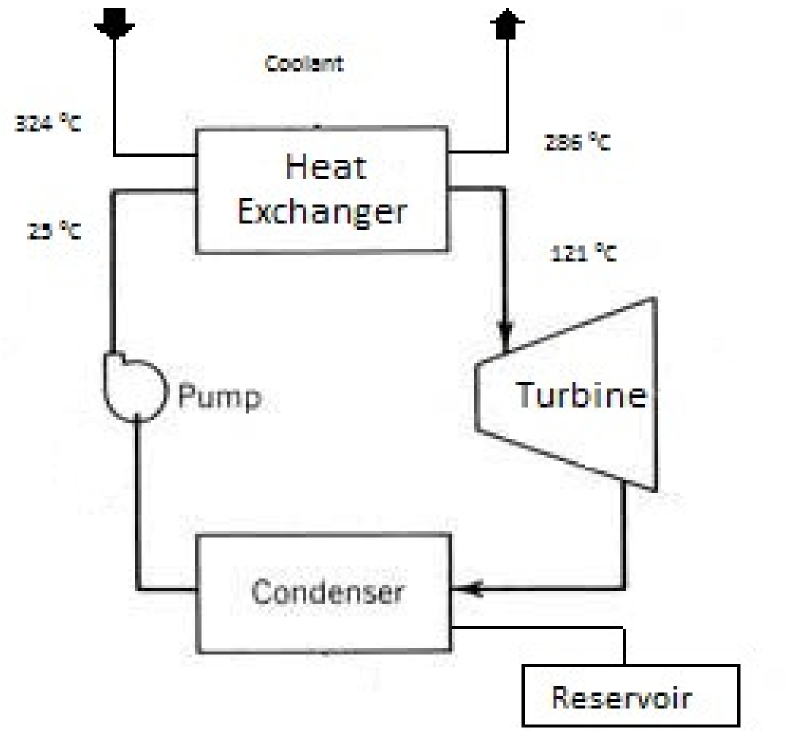
$T_c^{in} = 140\ ℃$

$T_c^{out} = 340\ ℃$

Coolant Pressure = 15.5 MPa



Two Loop Rankine Cycle



<u>Main line connects all piping systems</u>

Assumed negligible loss in heat exchanger and condenser

Total Pump Power Required: 10.99 MW

Blanket Coolant = 15328 kg/s

Divertor Coolant = 286 kg/s

First wall Coolant = 286 kg/s

Total coolant flow rate: 15900 kg/s

Estimated reservoir flow rate: 5000 kg/s

$P_{el, in}$ = 1000 MW

$\eta_{th,el}$ = 34.7% ≈ 35% (Target = 35-40%)

P_{output} ≈ 350 MW

References

- Stacey, W. M., (2010). *Fusion: An Introduction to the Physics and Technology of Magnetic Confinement Fusion,* 2nd Ed. Wiley-VCH
- Todreas, N. E., Kazimi, M. S., (2011). *Nuclear Systems Volume 1: Thermal Hydraulic Fundamentals,* 2nd ed. CRC Press
- Bergman, T. L., Lavine, A. S., Incropera, F. P., Dewitt, D. P., (2011). *Fundamentals of Heat and Mass Transfer,* 7th ed., John Wiley & Sons
- Moran, M. J., Shapiro, H. N., Boettner, D. D., Bailey, M. B., (2010). *Fundamentals of Engineering Thermodynamics,* 7th ed., John Wiley & Sons
- ASM Aerospace Specification Metals Inc., Type 316 Stainless Steel, Retrieved from http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MQ316A