Development of Heat Pipe Code for Extended Safety Analysis of Heat Pipe Reactor

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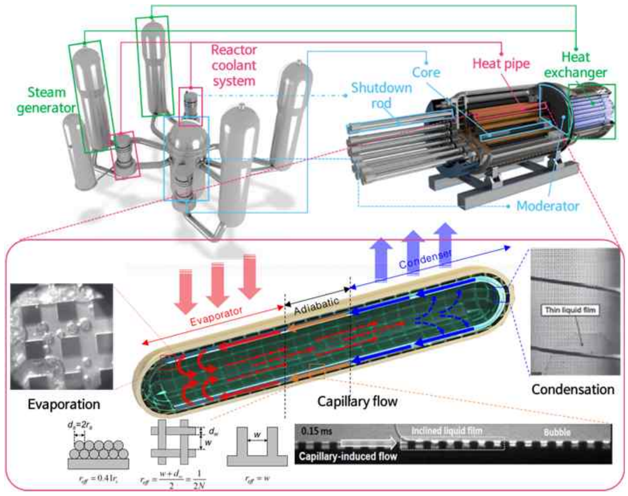
1. Introduction

- **Heat Pipe Microreactor (HPR)**, which replaces the reactor coolant systems of the conventional reactors by heat pipe, can be operated with or without gravity and be miniaturized.
- In order to develop a domestic heat pipe reactor, it is necessary to prove the safety of the reactor by performing safety analysis through the development of **computational analysis technology** for the heat transfer performance of the heat pipe corresponding to **the reactor coolant system (RCS)** of light water reactors.
- While the existing heat pipe codes have predictive performance for **priming conditions**, **the actual heat pipe design** and **operating conditions** may differ depending on the reactor and environment, thus this should be considered on the simulation.



2. Existing Code

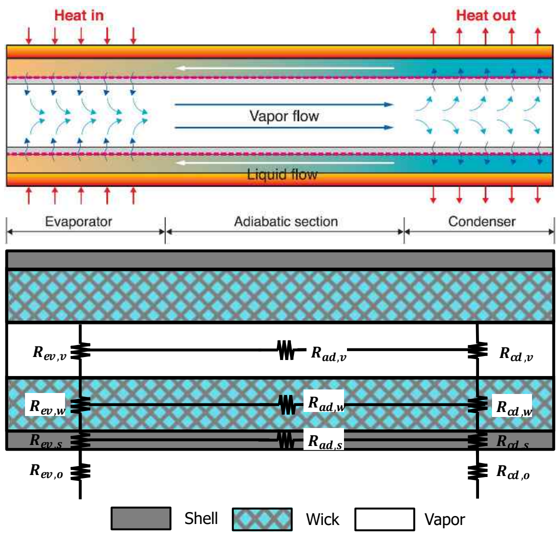


Fig. 2. Heat Pipe Heat Resistance Computer Modeling Structure

- Lumped Parameter Method, One-dimensional thermal resistance network based on thermal resistance circuits, performs heat transfer performance analysis.
- Parameters: boundary conditions, design geometry, and working fluid properties
- It calculates **Operational Limits** & **wall/fluid temperatures** (capillary limit, entrainment limit, sonic limit, viscous limit, boiling limit).

3. Improvement - Fill Ratio

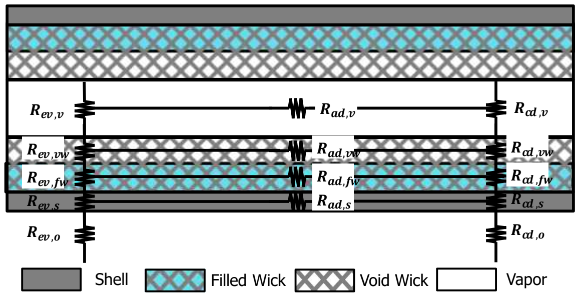


Fig. 3. Improved Heat Pipe Heat Resistance Computer Modeling Structure

Location	Heat Transfer (q)	Thermal Resistance (R)	Thermal Resistance(R) of **Existing Code**
Outside – Shell	$q_{o,s} = \frac{T_\infty - T_s}{R_1}$	$\frac{1}{2\pi r_0 L_e}\left[\frac{1}{h_e} + \frac{\Delta r_s}{2k_s}\right]$	$\frac{1}{2\pi r_0 L_e}\left[\frac{1}{h_e} + \frac{\Delta r_s}{2k_s}\right]$
Shell – Filled Wick	$q_{s,fw} = \frac{T_s - T_{fw}}{R_1}$	$\frac{1}{2\pi r_i L_e}\left[\frac{\Delta r_s}{2k_s} + \frac{\Delta r_l}{2k_l}\right]$	$\frac{1}{2\pi r_i L_e}\left[\frac{\Delta r_s}{2k_s} + \frac{\Delta r_l}{2k_l}\right]$
Filled Wick – Void Wick	$q_{fw,vw} = \frac{T_{fw} - T_{vw}}{R_1}$	$\frac{1}{2\pi r_{fw} L_e}\left[\frac{\Delta r_l}{2k_l} + \frac{\Delta r_v}{2k_v}\right]$	$\frac{1}{2\pi r_w L_e}\left[\frac{\Delta r_l}{2k_l}\right]$
Void Wick - Vapor	$q_{vw,v} = \frac{T_{vw} - T_v}{R_1}$	$\frac{1}{2\pi r_{vw} L_e}\left[\frac{\Delta r_v}{2k_v}\right]$	
Vapor	$q_v = \dot{m} h_{fg}$	Ignore	Ignore

Table. 1. Heat Transfer and Heat Resistance of Improved Computer Model

- The existing code only considered when the wick is fully saturated with liquid.
- The '**Fill Ratio**' was additionally considered on computer modeling.
- Additional **heat resistance layers for the void wick** was added.
- The heat transfer and heat resistance expression of wick was splitted. (Wick -> Filled Wick + Void Wick)

4. Results and Discussion

Length(evaporator)	0.25 m
Length(adiabatic)	0.5 ~ 5.0 m
Length(condenser)	0.25 m
Tube diameter	0.0191 m
Tube thickness	0.0012 m
Tube thermal conductivity	16.2W/m-K
Initial operating temperature	1023K
Heating power	500W
Coolant bulk temperature	703K
Effective heat transfer coefficient	$100W/m^2$-K
Tube angle	0 radian
Gravity	$9.8\ m/s^2$

Table. 2. Simulation Condition Setting

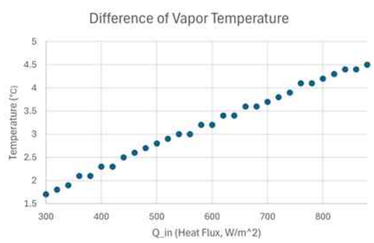


Fig. 4. Difference of vapor temperature

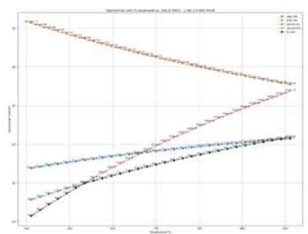


Fig. 5. Operational Limits when 10.1% filled

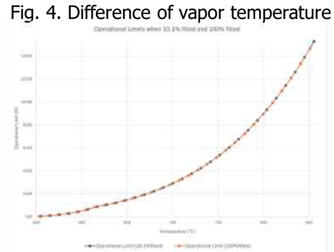


Fig. 6. Operational Limits

- The operational Limits were not changed at the same temperature(Fig. 6).
- As the fill ratio was reduced by 0.1 times, the **temperature increased** from approximately 1.7 degrees to 4.5 degrees with increasing heat flux.
- By considering the fill ratio, a **more accurate temperature value** can be obtained under the same q''_{in} environment, thereby enabling a more precise operational limit to be determined.

5. Conclusion

The heat pipe performance analysis code was improved by considering the fill ratio. When the liquid fill ratio of wick was reduced by 10.1%, the temperature increased from approximately 1.7 degrees to 4.5 degrees with increasing heat flux. As the wick thickness increases, this difference will become more pronounced, thus this improvement is considered significant. For future work, hydraulic calculations for the vapor flow passage will be added in the future to further enhance the accuracy.

References

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