Review of Comparison of Heat Transfer and Pressure Drop between OTHSG and PCHE

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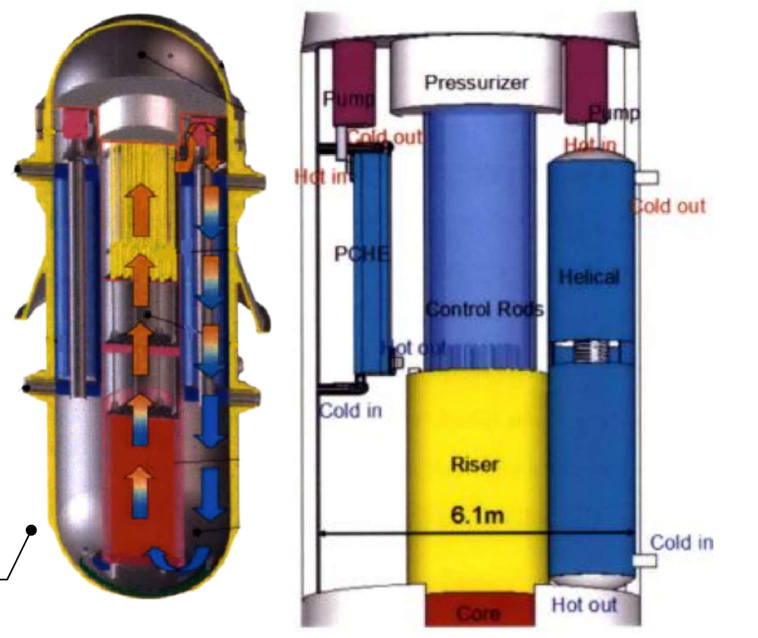
Introduction

- Small Modular Reactors (SMRs) integrate the core, pumps, and steam generators into a single vessel.
- This study compares two types of steam generators—OTHSG and PCHE—for such compact reactor systems, based on a thermal-hydraulic framework developed by MIT.

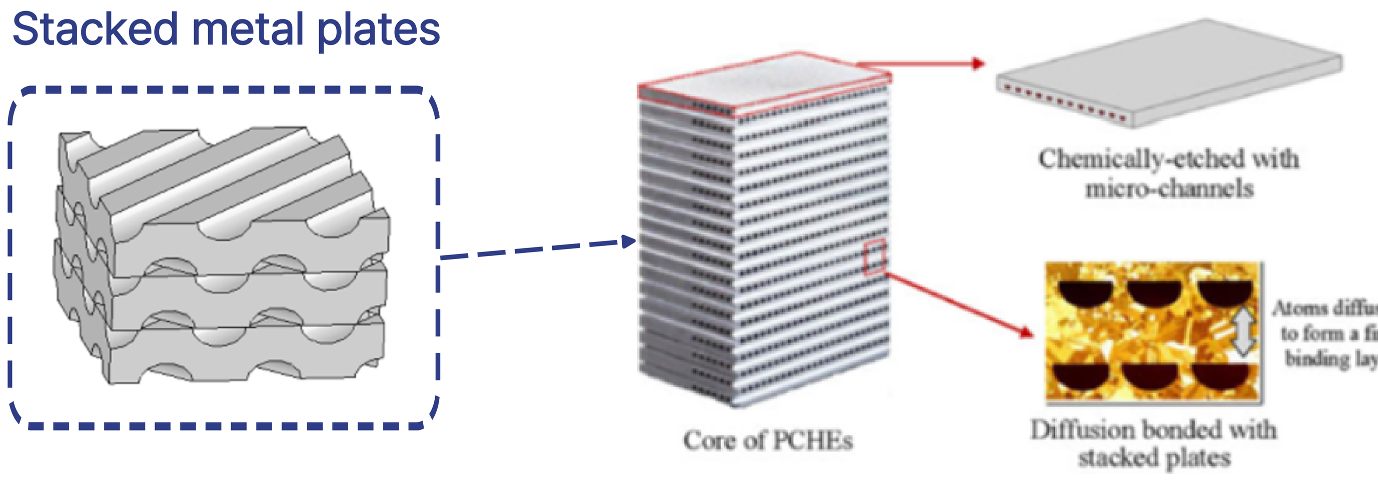


Integral SMR Configuration (IRIS)

Printed Circuit Heat Exchanger (PCHE)

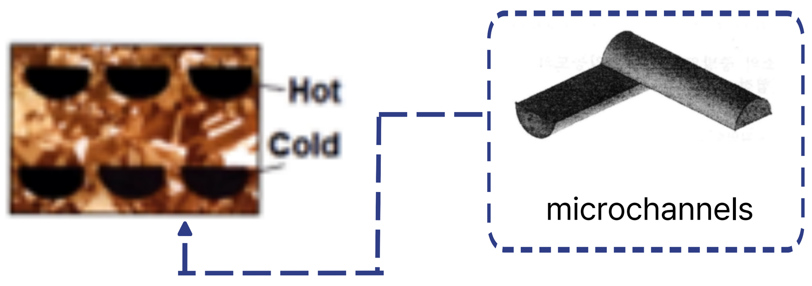
- A compact, microchannel-based heat exchanger designed for next-gen SMRs.

▶ Stacked metal plates



▶ Etched microchannels

- Chemically etched microchannels promote turbulence, boosting heat transfer.



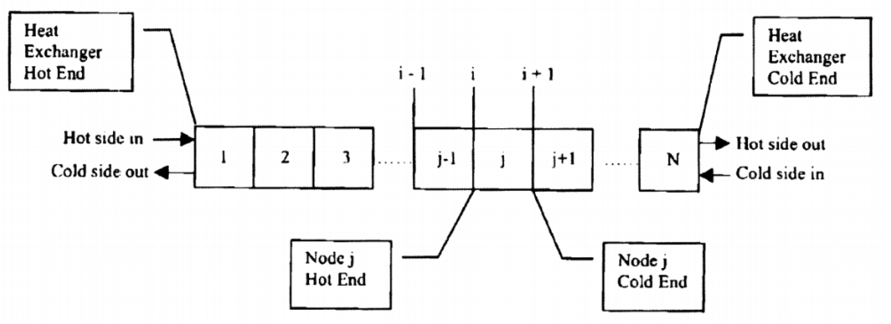
▶ Counterflow heat exchange

- Counterflow design maximizes temperature gradient, enhancing thermal efficiency.

Thermal Safety Margin Evaluation in PCHE

- PCHE Nodal Modeling Overview

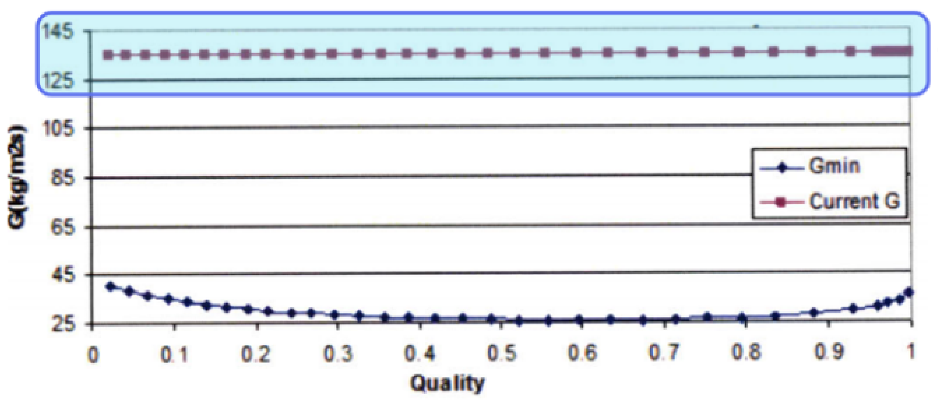
$$\dot{m}(H_{in} - H_{out}) = P_h \Delta z \cdot h_{tot}(\bar{T}_{hot} - \bar{T}_{cold})$$



→ The PCHE is divided into axial nodes to analyze heat transfer at discrete locations.

→ Energy is exchanged at each node between counterflowing hot and cold channels.

→ The flow directions are opposite for hot and cold fluids, as shown.



Mass Flux vs. Quality for PCHE Operation" or "Thermal Margin Analysis

✓ Current G > Gmin

→ Stable two-phase flow

→ provides sufficient thermal-hydraulic margin

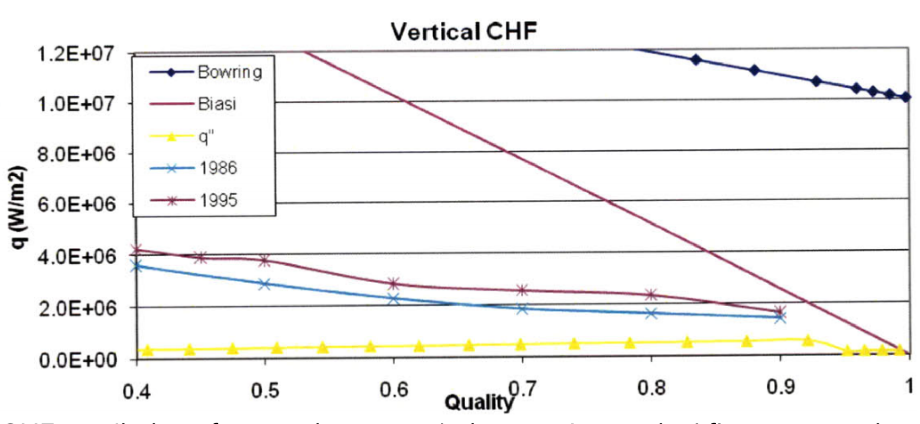
→ Safe operation

✓ Design Implications

→ Conservative CHF margin

→ Operating heat flux (q") is maintained below CHF limit

→ Multiple models = reliable design



CHF predictions from various correlations under vertical flow assumption

▶ Engineering Strengths

→ Exceptional heat transfer performance via microchannels

→ High surface area and power density per unit volume

→ Compact size enables easy integration in SMRs

→ Enables countercurrent flow, enhancing heat transfer efficiency

→ Operates under high-pressure and high-temperature conditions

▶ Design Considerations

→ Risk of fouling or clogging in microchannels

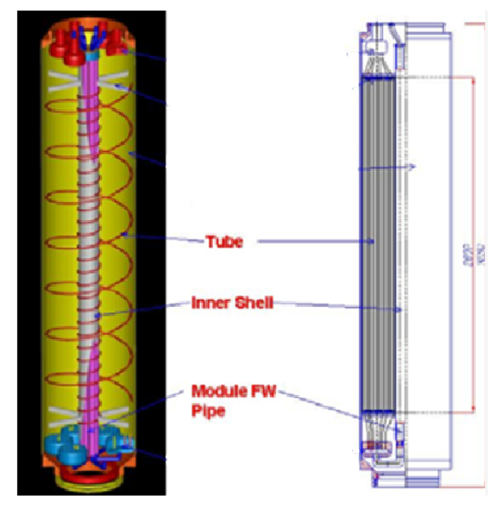
→ Difficult to inspect or clean internal flow paths

→ Requires advanced fabrication (e.g., diffusion bonding)

→ Limited long-term operational data in nuclear reactors

Once-Through Helically Coiled Steam Generator (OTHSG)

- OTHSG is a once-through steam generator composed of helically coiled tubes.
- It enables continuous phase change and compact integration within the reactor vessel, making it suitable for integral SMR designs like IRIS and SMART.



Internal Components of Helical Coil SG Module

▶ Technical Advantages

→ High heat transfer efficiency via helical coil geometry

→ Continuous phase change possible along tube length

→ Proven design with operating experience (e.g., IRIS, SMART)

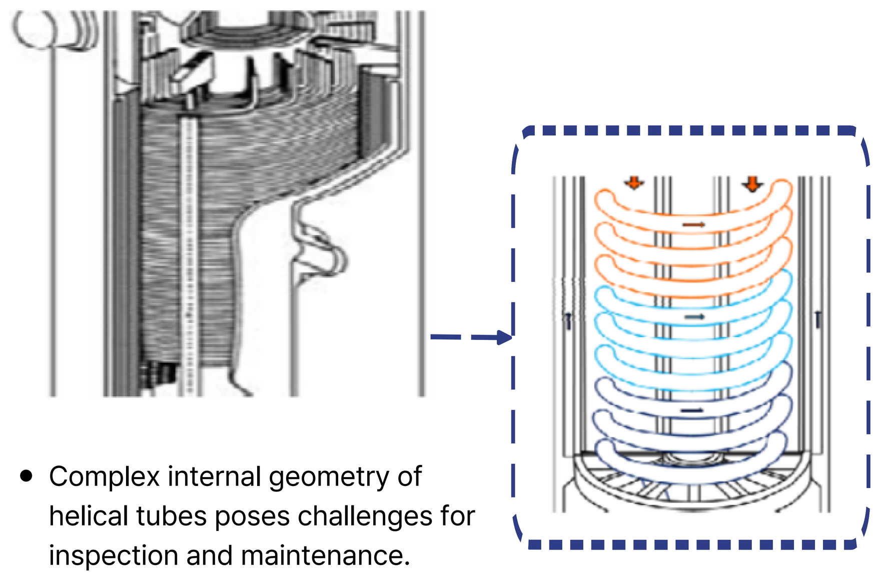
▶ Design Limitations

→ Larger volume compared to PCHE (less space-efficient)

→ Increased pressure drop due to curved flow path

→ Maintenance and inspection of helical tubes are difficult

→ Geometry complexity limits modularity and scaling



- Complex internal geometry of helical tubes poses challenges for inspection and maintenance.

Comparison of OTHSG and PCHE

Parameters	Helical	PCHE	
power	125	125	MW
Primary side:			
Mass Flow rate	589	589	Kg/s
Mass Flux	897	1276	Kg/m2s
Inlet Temperature	328.4	328.4	C
Outlet Temperature	292	291.9	C
Inlet Pressure	15.5	15.5	MPa
Pressure drop	72	64	kPa
H Transfer Coefficient	6,843	56,057	W/m2K
Secondary side			
Mass Flow rate	62.5	62.5	Kg/s
Mass Flux	693	135	Kg/m2s
Inlet Temperature	223.9	223.88	C
Outlet Temperature	317	319.95	C
Outlet Pressure	5.8	5.8	MPa
Pressure drop	296	77	MPa
H Transfer Coefficient	130,160	466,755	W/m2K
Geometry			
Diameter	variable	0.002	m
Width	-	0.6	m
Height	7.9	4.2	m
Length(core)	-	0.277	m
Volume (no headers)	65	0.7	m3
Volume w/headers	70	1.45	m3
Volume Ratio	48.28	0.02	-
Surface Area Density	44.5	1420	m2/m3
Power Density	1.92	178.57	MW/m3

✓ Lower Pressure Drop

→ Reduces pumping power
→ Improves thermal efficiency
→ Enhances flow stability

✓ High Heat Transfer Coefficient

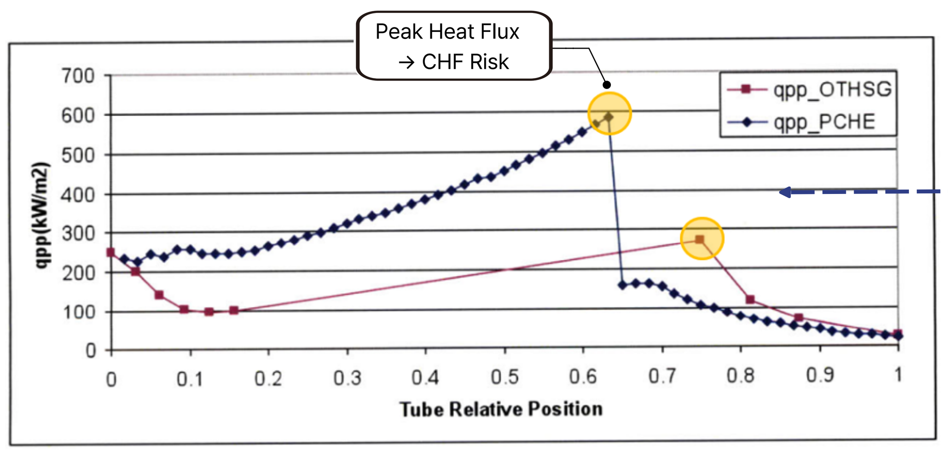
→ 3.6× higher than OTHSG
→ Enhances thermal margin
→ Supports compact reactor operation

✓ Large Surface Area Density

→ 32× greater surface area per volume
→ Enables efficient heat exchange in compact designs
→ Ideal for space-limited systems

✓ High Power Density

→ ~93× higher than OTHSG
→ Supports downsizing of SMR systems
→ Improves energy conversion efficiency



Heat Flux Distribution Comparison between PCHE and OTHSG

✓ Dry-out Region in PCHE

→ A steep rise in local heat flux is observed, indicating rapid vapor formation.

→ Sudden drop beyond the peak suggests approach to CHF (Critical Heat Flux).

→ Small hydraulic diameter and low mass flux intensify this behavior.

→ Flow optimization is essential to ensure thermal stability in this region.

→ Nevertheless, PCHE provides ~93× higher power density, enabling compact SMR design.

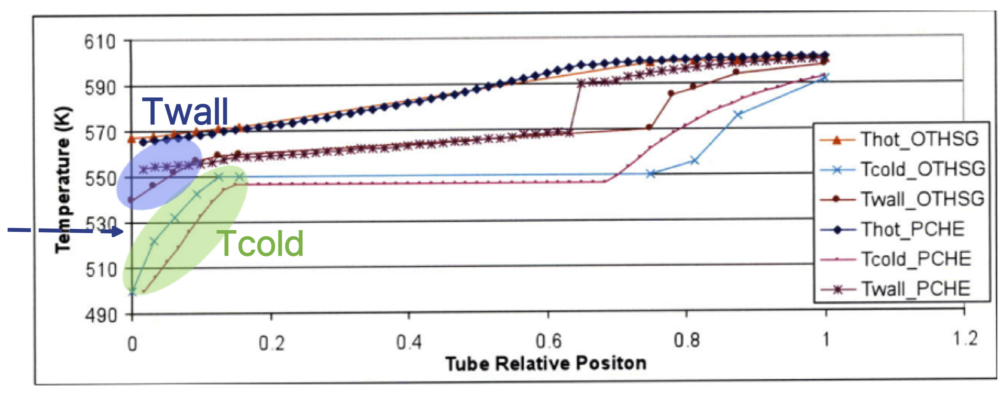
✓ Initial Heat Transfer Response: PCHE vs. OTHSG

→ PCHE shows a steep temperature rise in wall & cold fluid at inlet

→ Indicates quick thermal response and rapid heat transfer onset

→ Wall-to-cold temperature difference remains consistent

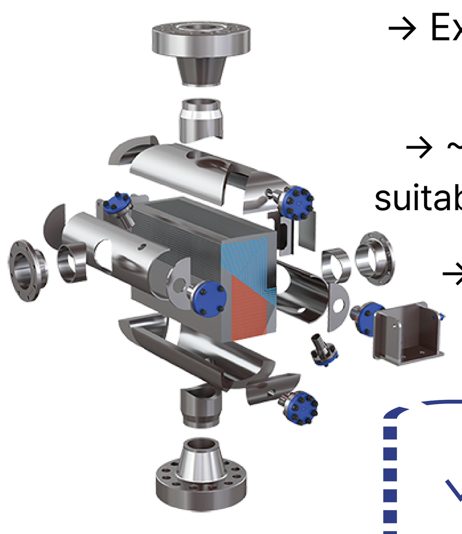
→ OTHSG exhibits slower increase, favoring thermal stability



Temperature Response of OTHSG and PCHE

Conclusion & Implications

▶ PCHE

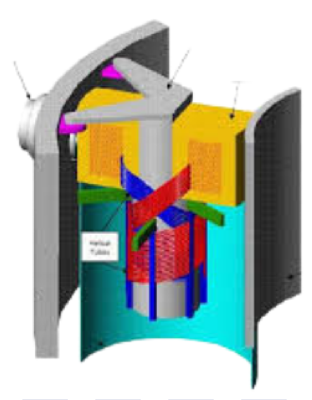


→ Excellent heat transfer performance

→ ~48× smaller volume, suitable for compact design

→ Low pressure drop

▶ OTHSG



→ Moderate but stable heat transfer performance

→ High compatibility with natural circulation

→ Larger volume and higher pressure drop

✓ With its excellent heat transfer capability and compact configuration, PCHE is a strong candidate for next-generation SMR applications.