NanoFluids in SMART Reactor Fuel Rod

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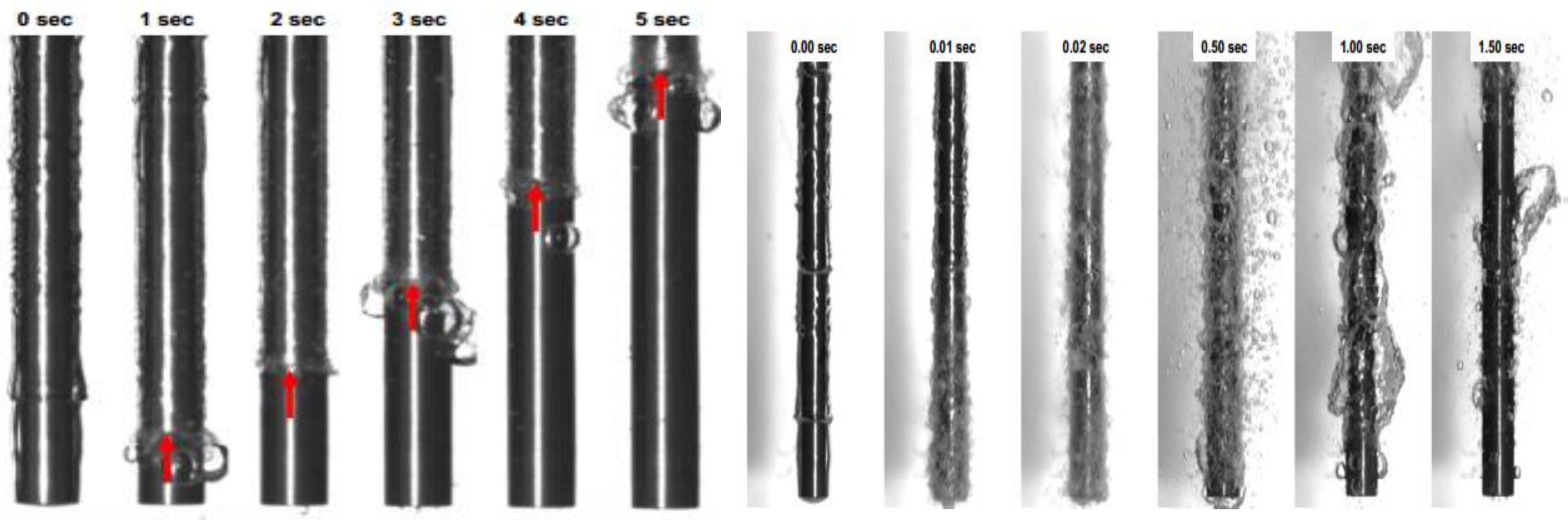
Abstract & Objectives

Cooling is one of the most important technical challenges facing many diverse industries, including microelectronics, transportation, solid-state lighting, and manufacturing. The use of solid particles as an additive suspended into the base fluid is technique for the heat transfer enhancement. Improving the thermal conductivity is the key idea to improve the heat transfer characteristics of conventional fluids. Since a solid metal has a larger thermal conductivity than a base fluid, suspending metallic solid fine particles into the base fluid is expected to improve the thermal conductivity of that fluid.

A Nanofluid is a fluid containing nanometer-sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil.

The figure below shows a quenching experiment made by inserting a hot rod into water, the figure to the left is water only and the figure to the right is water nanofluid.

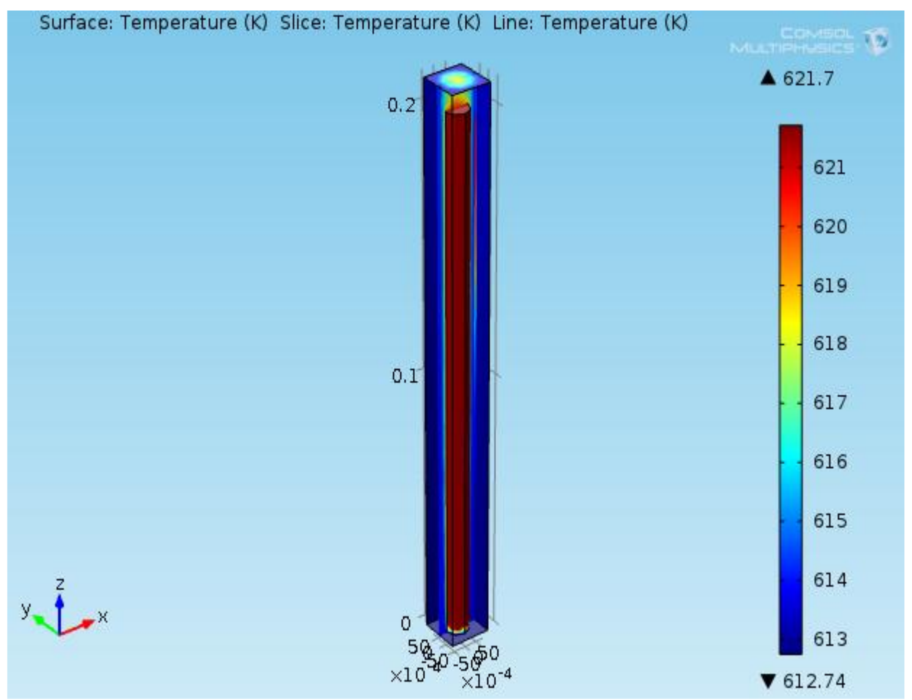


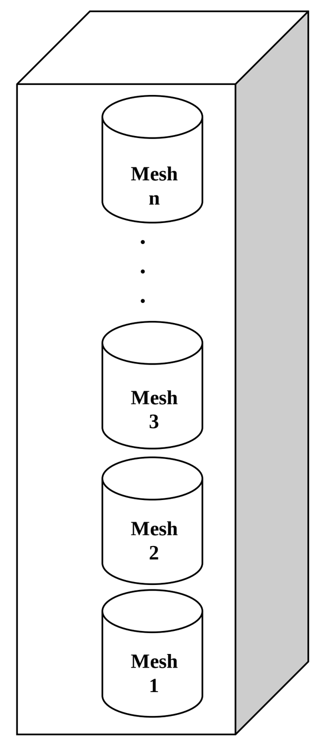
Undergoing research is investigating the potential use of nanofluids in Nuclear Reactors as they have proven to have a significant effect on the critical heat flux which would increase the efficiency of the heat removal process.

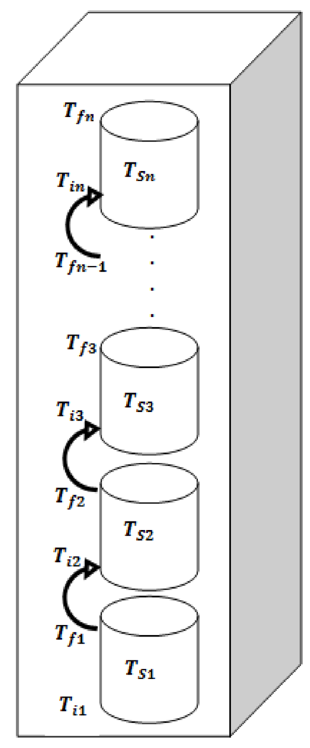
Observing the results of the above experiment, the goal of this project is to simulate a Nuclear Fuel Rod of a SMART Reactor inside a coolant channel, the coolant used is water and then a nanofluid made of water+ 3% Aluminum Oxide nanoparticles. The results of this experiment will be used to verify the benefit of using a nanofluid as a coolant and to obtain a quantitative estimate of this benefit.

Materials & Methods

The software package used is COMSOL Multiphysics. The modeling approach revolves around dividing the 2m long Nuclear Fuel Rod into 10 meshes 20 cm each. The output from the current mesh is used as input for the next mesh, as shown in the figures below. The process is then repeated for the mentioned nanocoolant and then temperature of the coolant is noted and recorded.

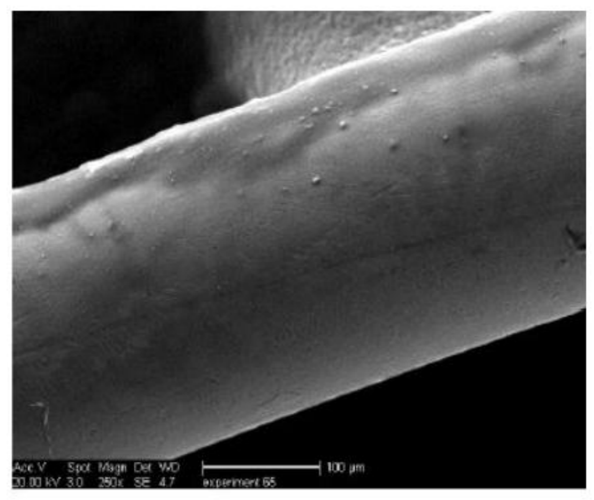


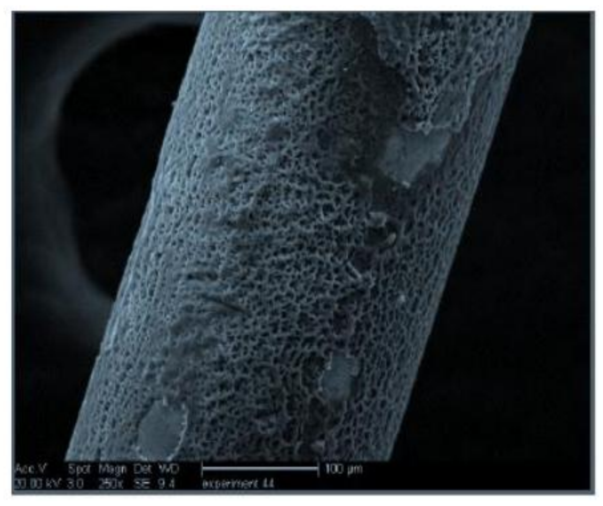




The Physics interfaces used in simulating this fuel rod are the Conjugate Heat & Mass the Transfer ,to model the heat transfer from the fuel rod to the flowing coolant, and Laminar Two Phase ,to model to model the nanoparticles as metallic spherical bubbles with high thermal conductivity as they are made of Aluminum Oxide in this study. The design parameters are of the SMART Reactor design.

The figure below shows how bubbles form near a fuel rod in pure water (left) and how nanoparticles agglomerate around a fuel rod, and thus drastically increasing thermal conductivity and critical heat flux.



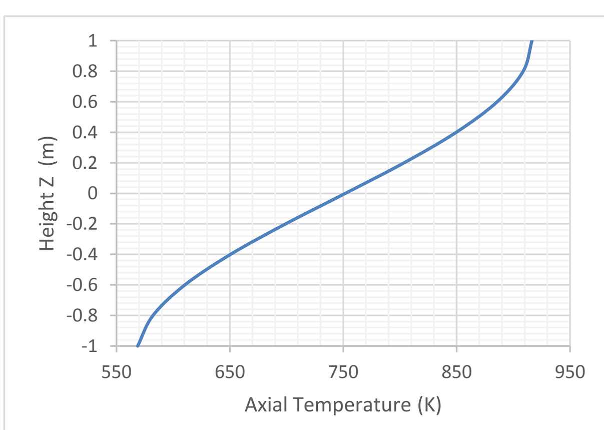


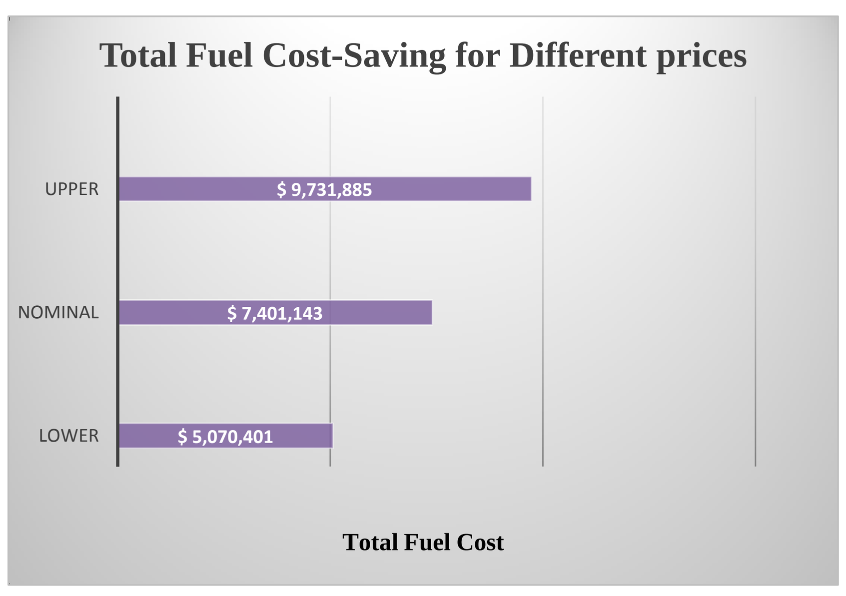
IMAN1

Results

Mesh #	Theor. Model Surface Temp. K	Theor. Model Surface Temp. °C		Comsol Model Nano fluid coolant Temp. K	Comsol Model Nano fluid coolant Temp. °C	Comsol Model Ligh water Temp. K	Comsol Model Ligh water Temp. °C	Theor. Model Ligh water Temp. K	Theor. Model Ligh water Temp. °C
10.0	916.4	643.4	outlet	626.5	353.5	601.6	328.6	599.2	326.2
			inlet	621.2	348.2	596.4	323.4		
9.0	908.7	635.7	outlet	621.2	348.2	596.4	323.4	593.6	320.6
			inlet	612.8	339.8	591.9	318.9		
8.0	885.8	612.8	outlet	612.8	339.8	591.9	318.9	588.2	315.2
			inlet	600.7	327.7	587.8	314.8		
7.0	849.7	576.7	outlet	605.4	332.4	587.8	314.8	583.2	310.2
			inlet	595.9	322.9	583.9	310.9		
6.0	803.6	530.6	outlet	597.9	324.9	583.9	310.9	578.8	305.8
			inlet	591.3	318.3	578.6	305.6		
5.0	699.2	426.2	outlet	591.1	318.1	578.6	305.6	572.4	299.4
			inlet	586.9	313.9	572.5	299.5		
4.0	650.5	377.5	outlet	582.1	309.1	572.5	299.5	570.5	297.5
			inlet	575.4	302.4	571.0	298.0		
3.0	610.3	337.3	outlet	575.4	302.4	571.0	298.0	569.4	296.4
			inlet	571.6	298.6	570.0	297.0		
2.0	582.2	309.2	outlet	571.6	298.6	570.0	297.0	568.8	295.8
			inlet	569.5	296.5	568.9	295.9		
1.0	568.7	295.7	outlet	569.5	296.5	568.9	295.9	568.7	295.7
			inlet	568.7	295.7	568.7	295.7		

Tempreture Difference	347.7		57.8	32.9	30.5





Fuel Mass Saving and Power Enhancement Calculations Results

	Normal Reactor		Nano-Reactor	
	water		*Nano-Fluid*	
Coolant Pressure/ MPa	15	*Specific Enthaply*	15	*Specific Enthaply*
Core Inlet Temp./ °C	295.7	1320.88	295.70	1320.88
Core Outlet Temp./ °C	323	1480.70	340.70	1680.43
Δ H		159.82		359.55
Energy (Mega Watt)	334.02		751.46	
Energy Per Year/ Joule	1.05E+13		2.37E+13	
Energy Per Year/ Mev	6.58E+28		1.48E+29	
# of Fissions Per Year	3.29E+26		7.41E+26	
# of U-235 Particles	3.29E+26		7.41E+26	
Avogadro's #	6.02E+23		6.02E+23	
Number of Moles	546.62		1229.77	
Mass of U-235 utilized/g	128456.39		288995.13	
Mass of U-235 utilized/Kg	128.46		289.00	

Power Increasing	224.98%

Mass of U-235 Gained/Kg	160.5387403
Mass of U 4.8% Gained/Kg	3344.557091

Conclusion

The use of nanofluids has proven to have significant effect on increasing the amount of heat extracted from the nuclear fuel rod as evident by the temperature difference across the coolant channel. The difference across the SMART reactor channel is estimated to be around 30 °C using water as a coolant and 57.8 °C when the coolant is nanofluid (water+Al2O3 3%), such increase in temperature difference at a pressure of 15 MPa amounts to a large amount of heat extracted from the fuel rods. The amount of heat extracted from the rod can be determined by calculating the enthalpy of the coolants. The results show a 224% increase in the heat extracted, which is almost equal to obtaining another reactor by just using nanofluids!

This additional amount of heat extracted after converting it to energy and fissions per year will help us determine the mass of uranium saved by using nanofluids, and thus how the increased thermal efficiency of nanofluids has impacted economy of the reactor. This is shown by the paragraph and is based on the low, nominal, and high prices of uranium.

Why IMAN1 ???

The introduction of supercomputing will have numerous advantages, some of which:

1- The ability to increase meshing complexity and thus increasing overall accuracy and reliability of results.
2- Drastic decrease in computational time, which implies that more room will be allowed for development, the model that ran for hours on our personal computers now completes in few minutes on IMAN1's high performance resources.
3- The ability to increase diversity and complexity of model, by simulating different nanofluids at different concentrations.

References

1. S. J. Kim, I. C. Bang, J. Buongiorn, The Enhancement of the Critical Heat Flux in Water-Based Nanofluids for Applications in Nuclear Systems, Massachusetts Institute of Technology.
2. Status report 77 - System-Integrated Modular Advanced Reactor (SMART).