Flow and Thermal Effects of Blockages in a Nano-fluid Cooled Nuclear Fuel Subassembly

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FLOW AND THERMAL EFFECTS OF BLOCKAGES IN A NANOFLUID COOLED NUCLEAR FUEL SUBASSEMBLY

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Abstract

Nanofluids have great impact on heat transfer characteristics due to increased thermal conductivity and heat transfer coefficient. In this study, Titanium nanoparticles mixed in liquid sodium has been chosen for analyzing the effect of nanofluid in a Nuclear Fuel Sub-assembly. This study is conducted to observe the effect of nanoparticles on the heat transfer characteristics such as heat transfer coefficient, clad temperature, coolant temperature etc. The effects of varying nano-particle concentration and blockage size on the bundle has also been studied. To achieve this, 7-pin fuel bundle with and without blockage has been modeled and analyzed using computational fluid dynamics (CFD) simulation codes.

Problem Definition

- To analyze the effects of nanofluids in a nuclear fuel sub-assembly with flow blockage.
- The blockage and high reactivity of sodium with oxygen posses a great operational threat.
- A reduction in chemical reactivity is observed by dispersing Titanium nanoparticles in liquid sodium (Park et al., 2015)

Objectives and Methodology

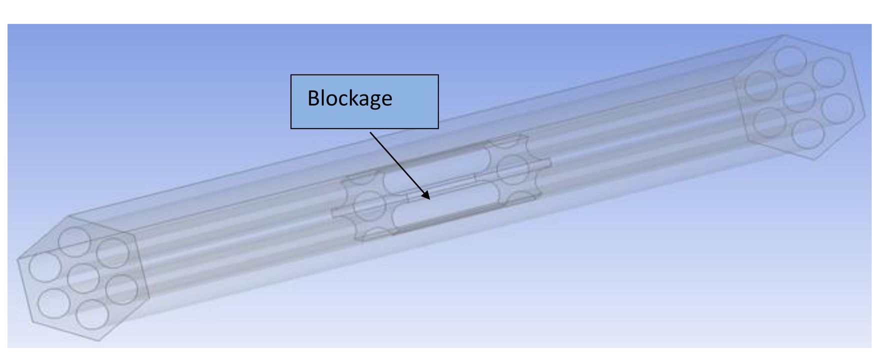
Objectives:

1. To analyse the thermal effects of nanofluids in different flow blockage conditions.
2. To study the effect of nanoparticle concentration in reactor core with flow blockage.

Methodology:

1. Define the governing equations used in CFD analysis.
2. Define the equations used to predict the thermo-physical properties of nanofluids.
3. Model the geometry and analyze it for different parameters considered in the study.

Computational Work



CFD model of geometry with blockage

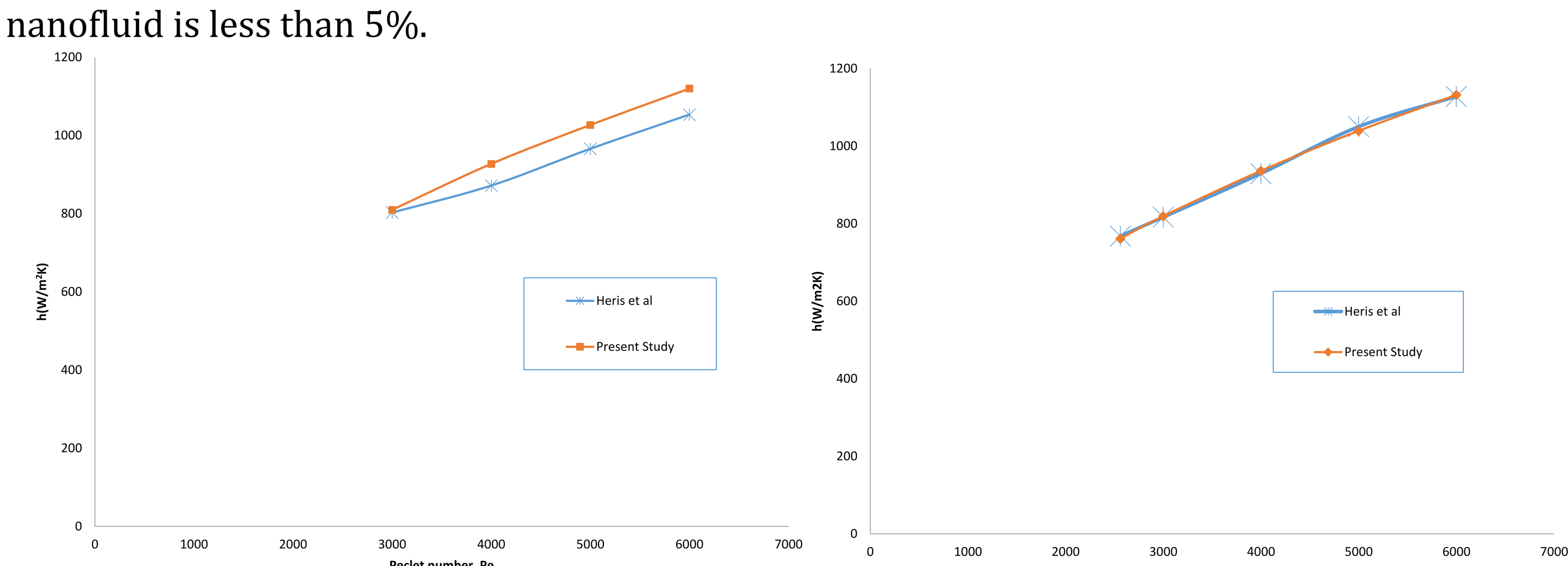
- The blockage is positioned such that the centroids of sub-assembly and blockage coincide.
- The fuel pins have a diameter of 6.6 mm and a length of 1000 mm.
- The blockage blocks 30% of the nominal flow area.

Blockages considered in this study

TYPE	DIAMETER (mm)	LENGTH (mm)	SURFACE AREA BLOCKED(%)
B1	16	200	30
B2	20	200	40.5
B3	20	500	40.5

VALIDATION STUDY

The equations used for calculating the thermo-physical properties of nanofluids are validated against the experimental results by Heris et al., 2007. The experimental setup has been modelled in ANSYS and the analysis is carried out using same nanofluid and boundary conditions. The maximum deviation observed for 2% and 2.5% volume concentration of nanofluid is less than 5%.



Variation of heat transfer coefficient at nanoparticle concentration of (a) 2 % (b) 2.5%

Results & Discussion

1. Effect of nanofluid in blockage:

From Fig. 1 it is observed that with inclusion of nanoparticles in the liquid sodium coolant, the temperature of coolant increases. This demonstrates an increase in the heat transfer from the pins thus reducing the thermal stress on the fuel pins. Similarly trend is observed for the other two blockages as shown in Fig. 2. Here ϕ represents nanoparticle concentration.

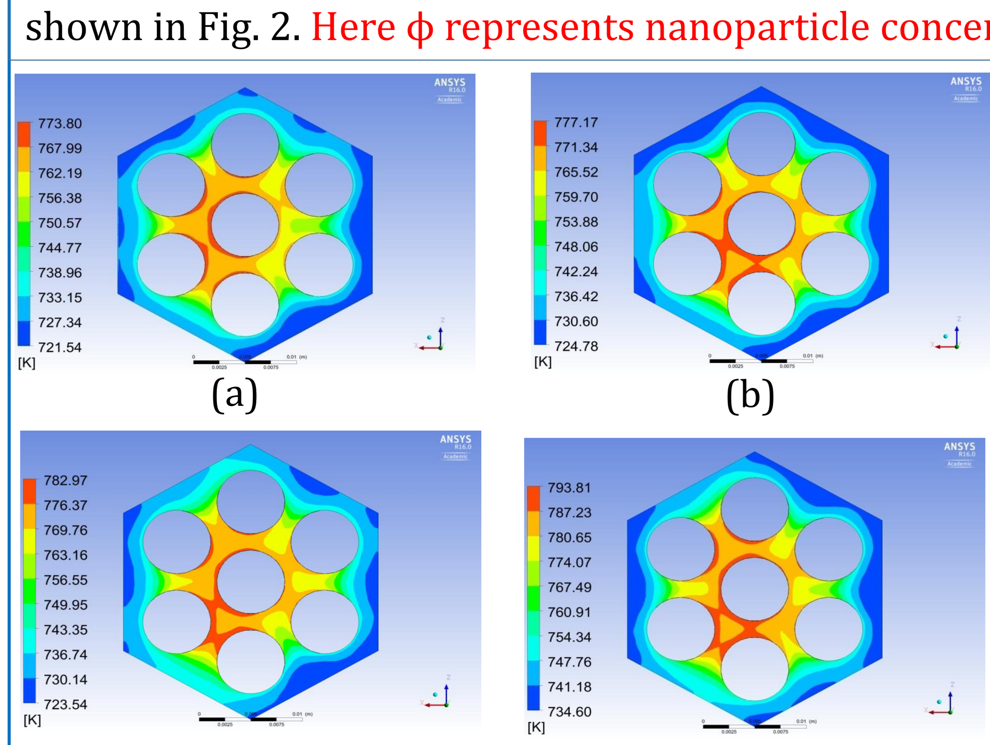


Fig. 1 Temperature for B2 bundle at outlet for:
(a) without nanofluid (b) φ=2%
(c) φ=2.5% (d) φ=3%

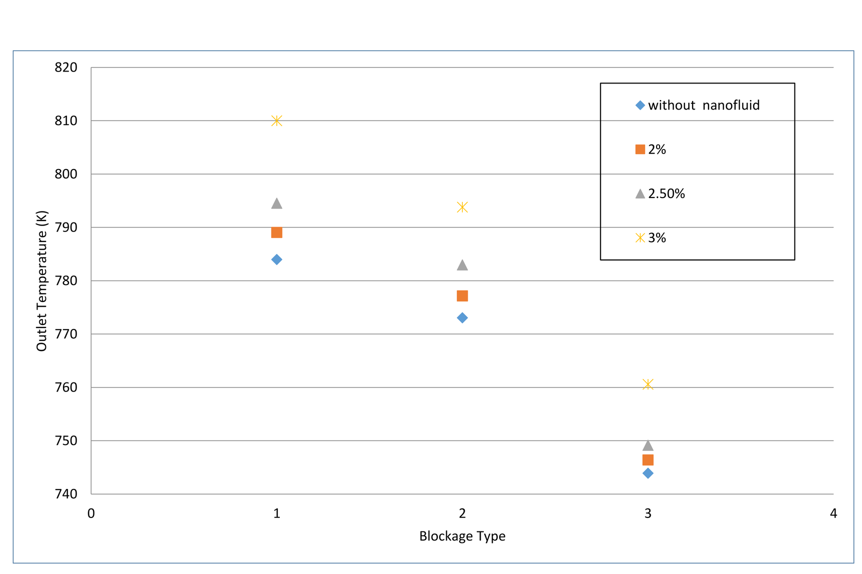


Fig. 2 Bundle outlet temperature for different Nanofluid concentrations

2. Effect of Blockage Size:

The comparison of the three blockage types is carried out by using coolant as liquid sodium with 2 % volume fraction of titanium nanoparticles. In the Fig. 3 both (a) and (b) sections show a decrement in the coolant temperature as one move from blockage B1 to B3. The decrease in temperature accounts for the increased fuel pin temperature. The decrease in coolant temperature in B2 can be accounted for the increased blockage area which reduces the coolant volume in contact with the fuel pins. The similar line of reasoning can be assumed for B3 in which not only the radial extent but the axial extent of blockage has increased which reduces the volume of coolant in contact even more thereby reducing the heat transferred.

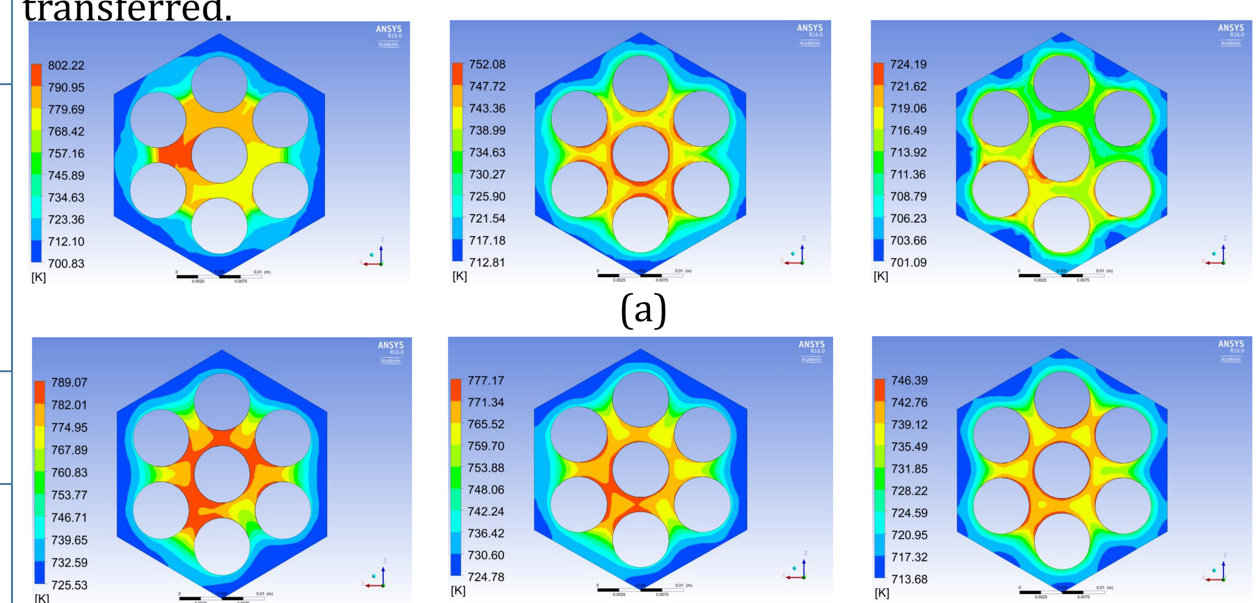


Fig. 3 Temperature profiles of the three blockage types at (a) near the upper boundary of blockage (b) At the outlet of subassembly

3. Effect of Nanoparticle Concentration:

From the Fig. 4 we observe a gradual increase in the heat transfer coefficient by increasing the nanoparticles concentration. Such variation can be seen for all the 3 blockages. The Fig. 5 depicts the reduction in wall temperature at the outer boundary of blockage B1 with increasing nanoparticle concentration. The analyses of wall adjacent temperature for the pin-1 in B1 blockages yields a satisfactory result in proving the heat transfer effects of nanofluid. A similar trend is observed for the other 2 blockages as well.

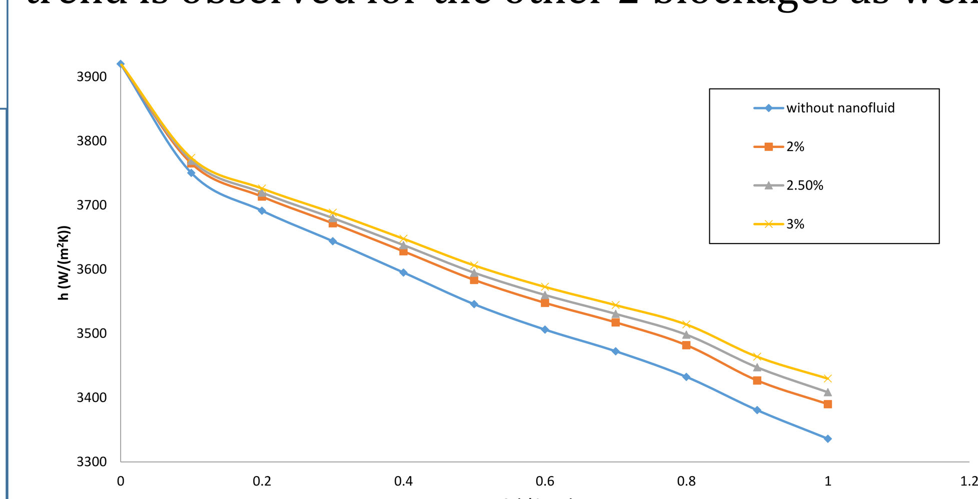


Fig. 4 Variation of heat transfer coefficient along the axial length of a pin for different nanofluid in B3 bundle

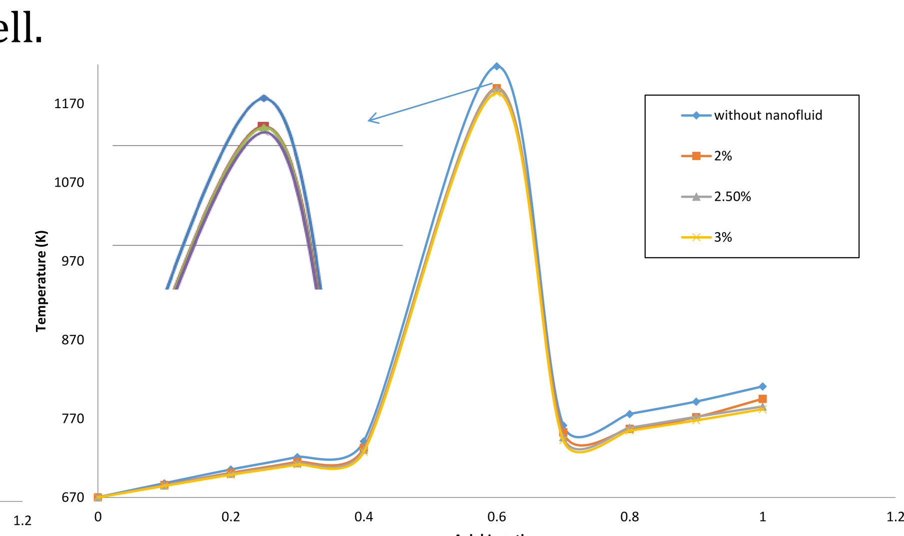


Fig. 5 Wall Adjacent Temperature of central pin for different nanofluids in B2 bundle

4. Non-dimensional Study:

The change in the thermo-physical properties of coolant due to nanoparticle inclusion can be accounted by performing a non-dimensional study. So by keeping same Reynolds number we obtain different velocities for different volume fraction of nanoparticles. Fig. 6 depicts the value of heat transfer coefficient along the axial length of a pin in B1 blockage for the 3 different coolant conditions. It is observed that the same velocity case also increases the heat transfer characteristics for the blocked condition without having to increase the pump power.

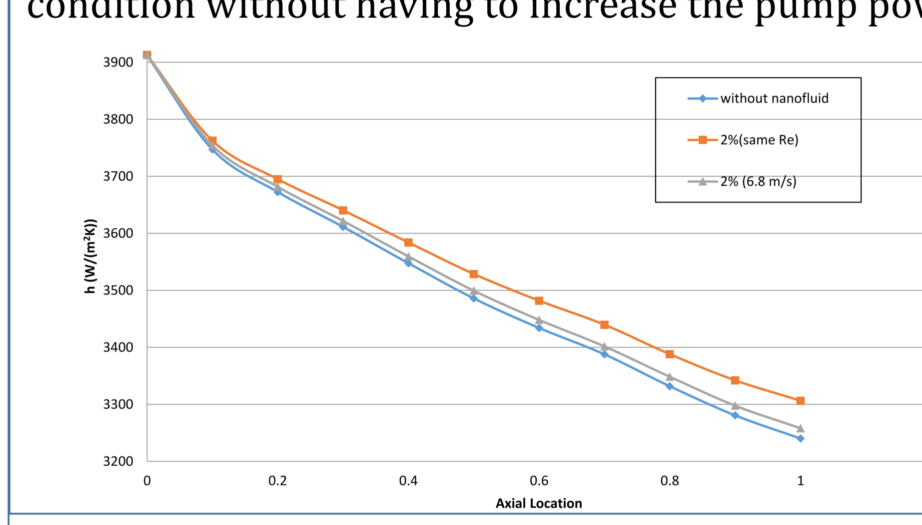


Fig. 6 Variation of heat transfer coefficient along the axis for a pin

Conclusions

1. A substantial enhancement in the heat transfer characteristics is observed by employing nanofluids in the blocked bundle. This can be accounted by the increase in thermal conductivity of nanofluids.
2. The surface heat transfer coefficient increases with nanoparticle concentration in outer pin as well as the central pin.
3. The wall adjacent temperature of the central pin reduces with increase in nanoparticle concentration. This is due to enhanced heat transfer coefficient.
4. The temperature of the coolant increases with nanofluid concentration which depicts an improvement in the heat transfer from fuel pin to coolant. This increase in coolant temperature reciprocates the decrease in fuel pin temperature.

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