# Thermal Hydraulic Study For HLM Flows using COMSOL Multi-physics

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# Contents

# Introduction

- Liquid Metals are the effective coolants in nuclear reactors
- LBE, Flibe, Molten Sodium and LLE
- High Thermal Conductivity
- Heat Transfer differs from common fluids
- Estimation of HTC's is vital

# Thermal hydraulics of HLM’s

- Studies have to be carried out to predict the performance of systems.
- TALL facility, to study the thermal hydraulic behaviour of LBE
- LBE experiments related to ADS have been carried out in Karlsruhe, Germany to validate computer codes
- Test loop HANS, BARC to validate LE-BANC code
- Missing experiments in LLE

- In experimental design, it is necessary to carry out a detailed CFD analysis to test the performance of HLM's.
- Reliable physical models related to Heat Transfer at turbulent conditions are missing !!
- Very few studies are available on the effect of Nusselt number with turbulent Prandtl number using HLM's.

# Present Work

- LBE is selected for study
- Preliminary review and assessment of LBE turbulent flows
- Applicability of heat transfer correlations in turbulent regimes is studied in circular tubes.
- Nusselt number is computed by COMSOL  tool and compared with various HTC's and experimental results available
- Analysis useful in designing heat transfer experiment's using HLM's

# Liquid metal Heat Transfer

- Low prandtl number ($Pr<0.4$)
- Molecular conduction is significant in fully developed turbulent flows
- Generally for Conventional fluids,

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \quad \text{(for heating )}$$

$$Nu = 0.023 Re^{0.8} Pr^{0.3} \quad \text{(for cooling)}$$

## For liquid metals

- **Lyon**-Nusselt number for a fully developed single phase flow in a tube with constant flux

  $Nu = 7.0 + 0.025Pe^{0.8}$ $300 < Pe < 10^4$ (3)

- **R. A. Seban and T.T. Shimazaki** , for turbulent tube flow with constant wall temperatures.

  $Nu = 5.0 + 0.025Pe^{0.8}$ $Pe < 4*10^3$ (4)

- **Lubarsky and Kaufman** using 3 and 4 they corrected the equation to

  $Nu = 0.625Pe^{0.4}$ (5)

- **Sleicher et al (1973)** investigated the local heat transfer coefficient's in NaK flows [1]

  $Nu = 6.3 + 0.0167Pe^{0.88} Pr^{0.08}$ (6)

- **Kirillov and Ushakov ,** recommended following correlation for LBE flows

  $Nu = 4.5 + 0.018Pe^{0.8}$ (7)

- **Stromquist,** considered the effect of wetting of liquid metals and recommended

  $Nu = 3.6 + 0.018 Pe^{0.8}$ $88 < Pe < 4000$ (8)

# Thermo-physical Properties

- Density ($kg/m^3$), $\rho$= 11096- 1.3236T
- Dynamic Viscosity(Pa.s), $\eta$=$4.94x10^{-4}$ x exp(754.1/T)
- Specific heat (J/Kg K), $C_p$= 159 - $2.72x10^{-2}$T + $7.12x10^{-6}T^2$
- Thermal conductivity (W/m K), K= 3.61 + $1.517x10^{-2}$T – $1.741x10^{-6}T^2$

# Model Test Section

The heat transfer phenomenon of LBE is studied in a test section which is a vertical circular tube with inner and outer radius 20.93 and 26.67 mm respectively.

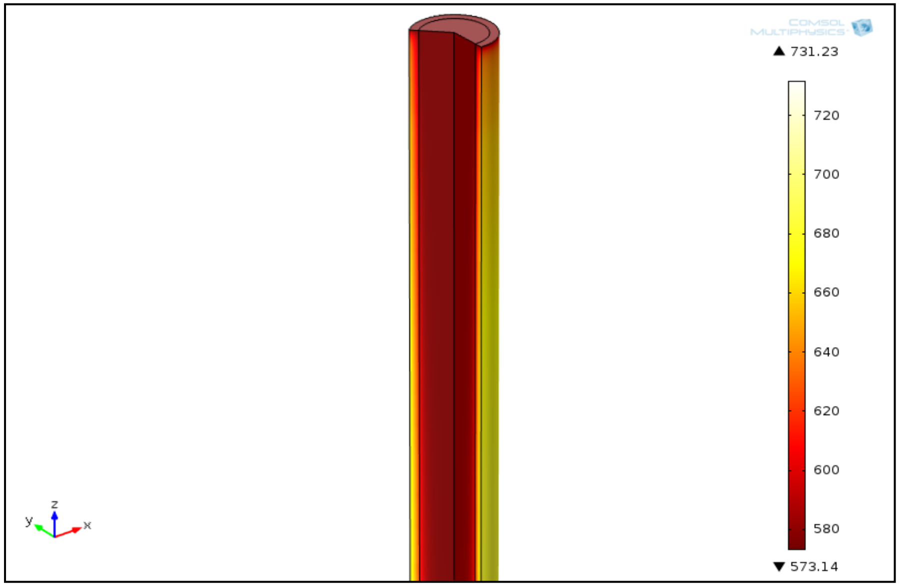
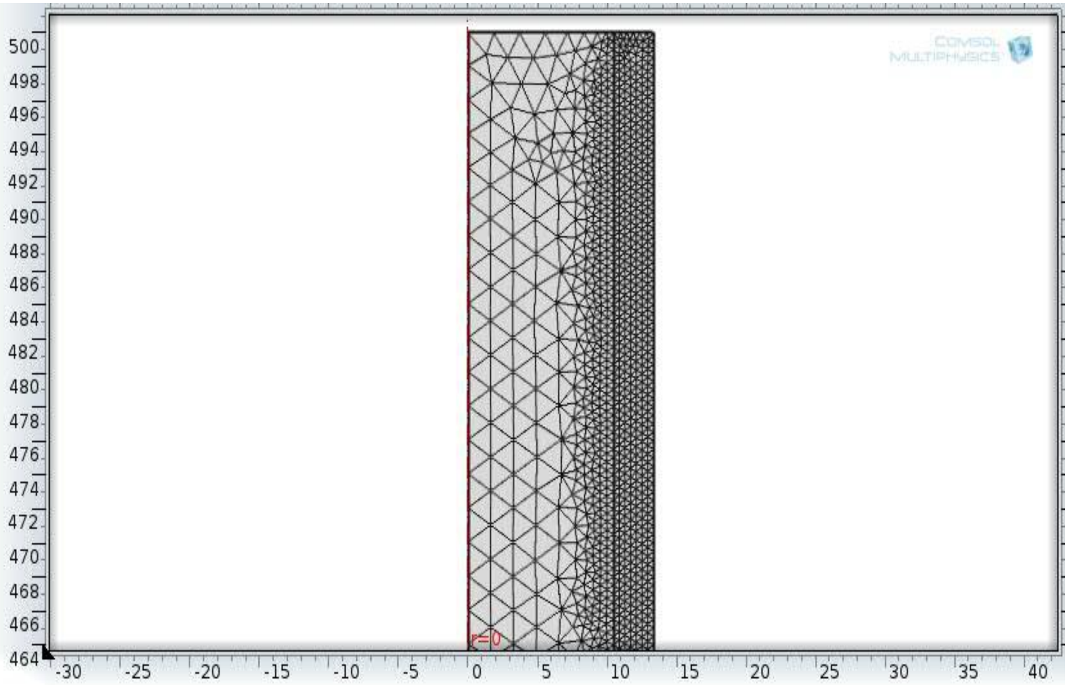



**Figure1- Model of LBE Test section in COMSOL.**

**Table1.** The list of the parameters used in the simulation

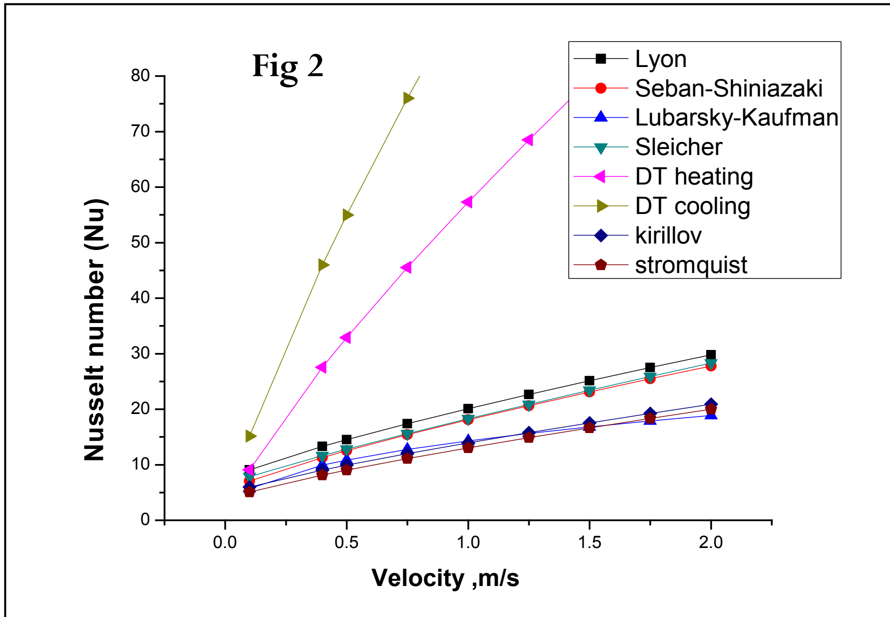
| Parameter | Value range |
|---|---|
| **Inlet temperature** | 300 °c |
| **Heat flux from the wall** | 24.509 KW |
| **Velocity** | 0.5-2.0 m/s |
| **Mass flow rate** | 2-3 kg/s |
| **Total length** | 1.5495 |
| **Reynolds number** | 60000-100000 |
| **Prandtl number** | 0.01-0.02 |
| **Peclet number** | 600-2000 |
| **Turbulent prandtl number** | 0.9-3.0 |
| **Turbulence model** | k-ε model |

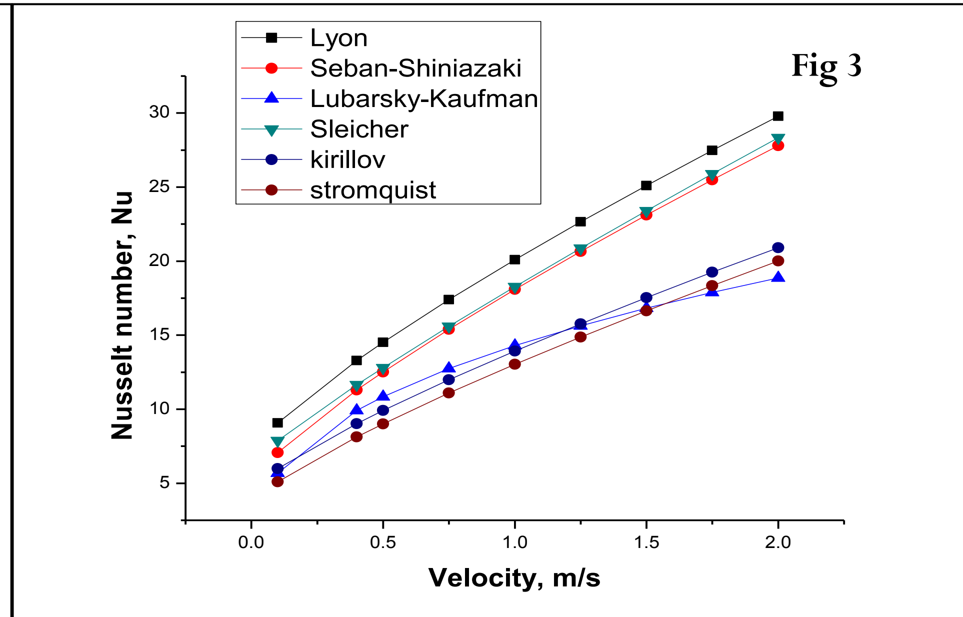
# COMSOL approach

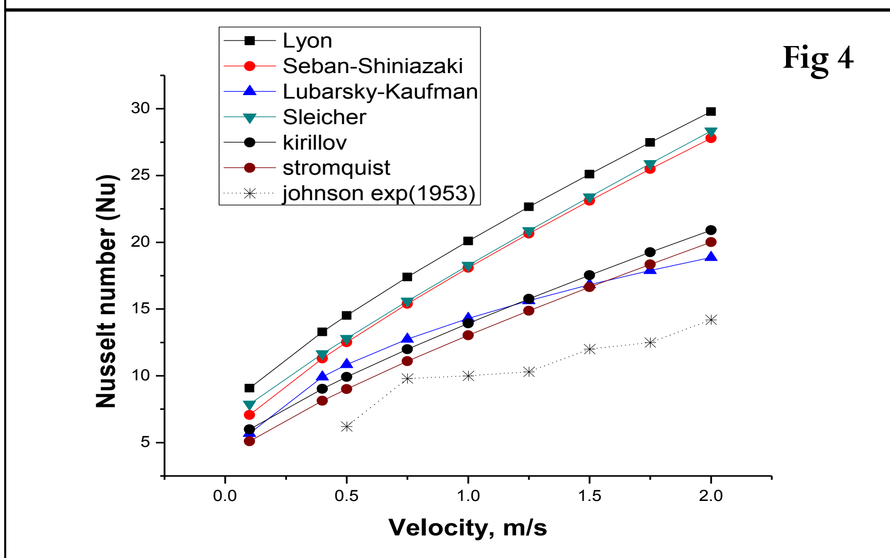
- Conjugate heat transfer/CFD module is chosen.
- Description of TKE, Eddy Length Scale, turbulent intensity in HLM simulations are important to accurately predict flows,
- 


- Maximum and minimum mesh size at the wall is 0.5 mm and 0.3 mm respectively
- At the liquid metal it is 2 mm and 0.3 mm.

# Results and Discussions



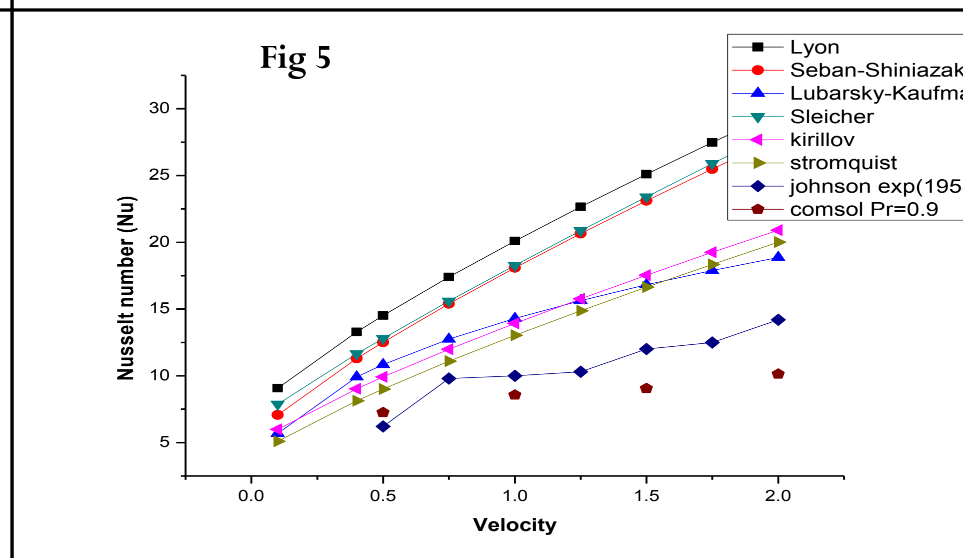




Fig 2- HTC's WITH DT equations Fig 3- Liquid metal HTC's Fig 4- with Experimental data Fig 5- with COMSOL

## Effect of turbulent prandtl number ($Pr_t$) on Nusselt number

- Ratio between momentum eddy diffusivity / heat transfer eddy diffusivity
- Both the experimental and theoretical studies in the open literature shows that the Nusselt number decreases with the increase of turbulent number
- Default value in COMSOL is $Pr_t = 0.9$

- T he Nusselt number has been calculated for turbulent prandtl number of 0.9, 2.0 and 3.0 for LBE test section

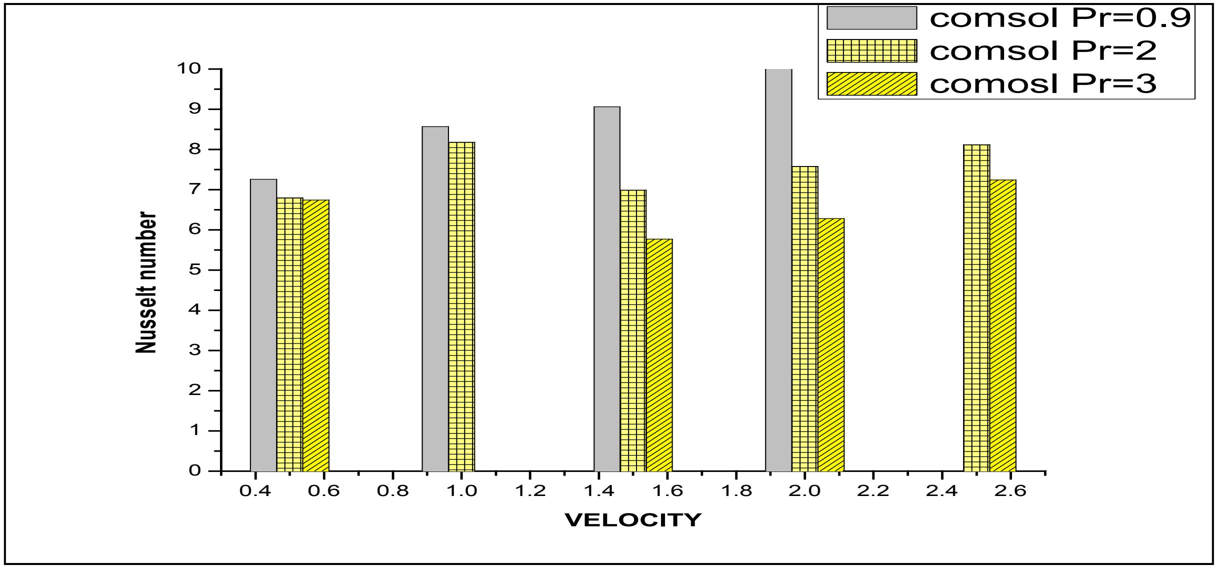



**Fig 6 - Nusselt Number Vs. Velocity at various $Pr_t$**

# Conclusions

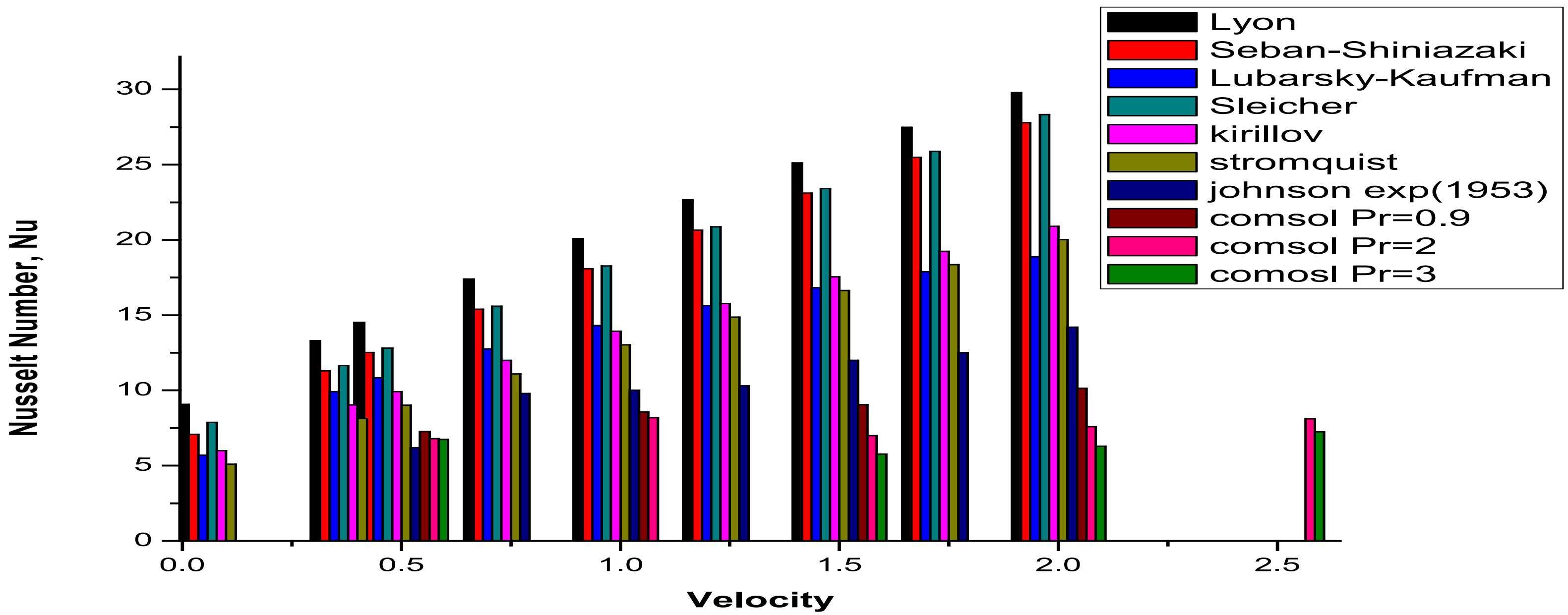


**Figure 9. Shows the range of data points for various correlations and obtained Nu from comsol simulations**

- The Nusselt number values of the test section simulated in COMSOL lies closer to the lower range of HTC's proposed by Kirillov and Stromquist (equations 7& 8 respectively) which may be taken as the input to thermal hydraulics codes involving LBE and in experimental design involving circular pipes.
- Possible discrepancy's may be due to the source of LBE properties
- Nusselt number decreases with the increase in Turbulent Prandtl Number.
- Detail study of test section and mesh sensitivity has to be carried out.
- Finally similar process can be applied to check the applicability of HTC involving LLE in fusion applications and determine the heat transfer.

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# Thank You