1^{st} Project

Computer-Aided Project of 2019 Numerical Heat Transfe

Xi'an Jiaotong University

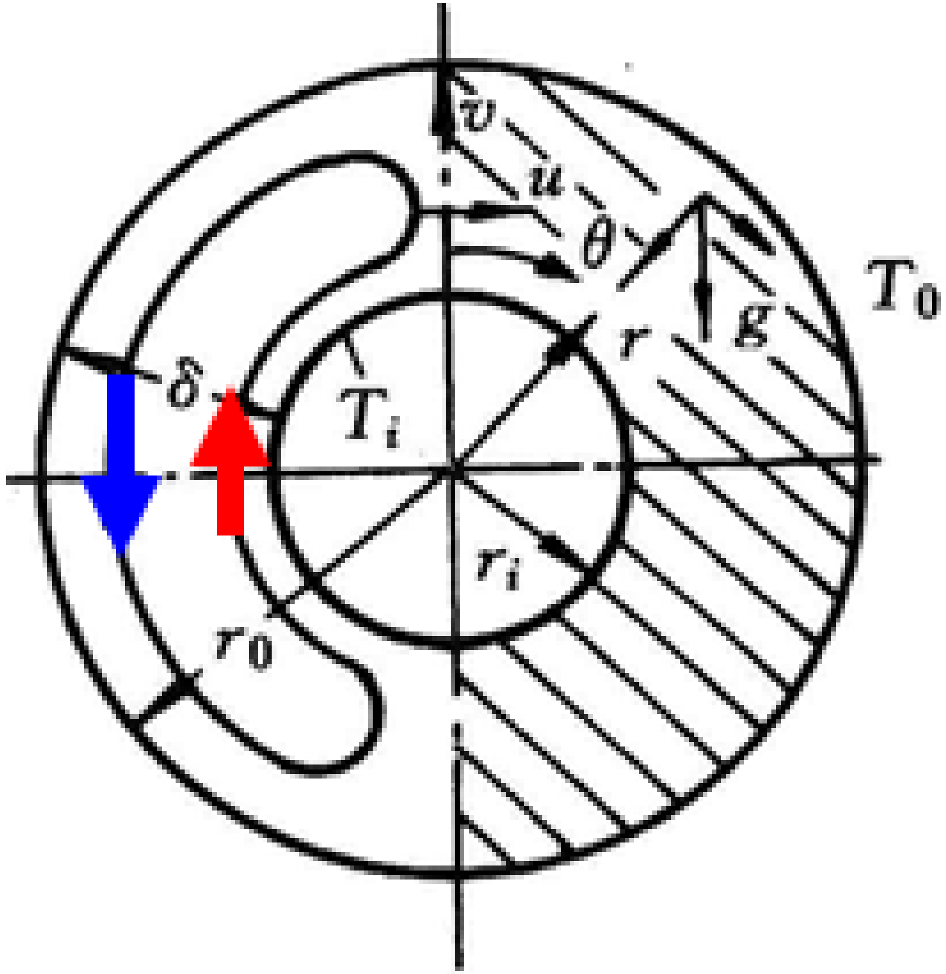
We present three computer-aided projects: one is to be solved by our teaching code (Project 1）, the 2nd and 3rd ones are to be solved by FLUENT (Fundamental , Project 2, Intermediate Project 3) . Every student can choose one project according to your interest and condition.

For the first project the self-developed computer code should attached in your final report.

For the second and third project Class F and Class I will have different projects. The instructors will assign the project at the end of the lecture.

Computer-Aided Project (1) of NHT-2019, Xi'an Jiaotong University

（Laminar natural convection in annular space）



$(T_i > T_0)$

1. Project formulation

For air natural convection within an annular space as shown in Fig. 1 , following conditions are given: $\delta / r_o = 0.4$, flow is laminar and the average air temperature is $50^\circ C$

For $\mathrm{Ra} = g\beta\Delta T\delta^3 \nu / a^2 = 10^2, 10^3, 10^4, 10^5$, determine the relative thermal conductivity: $\lambda_{\mathrm{eq}} / \lambda_{air}$ .The temperature difference between inner wall and outer wall is not large, so the Boussinesq assumption can be adopted. By using Tecplot or other software, display the isotherms and streamlines and the variation of $\lambda_{\mathrm{eq}} / \lambda_{air}$ vs. Ra. Natural convection heat transfer rate between the inner and outer surface is expressed by an effective thermal conductivity λ_{eq} as follows:

$$\phi = \frac{2\pi L \lambda_{eq} \Delta T}{\ln(d_2 / d_1)}$$

λ_{eq} is the equivalent thermal conductivity of the entire annular space.

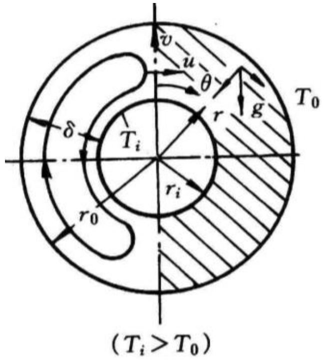
2. Suggestions and Requirements

1) Considering the symmetry of the geometry, only half of the structure should be simulated.
2) The solution should be grid-independent.
3) The project report should be written in the format of the Journal of Xi’an Jiaotong University. Both Chinese and English can be accepted.
4) Examples 9-4 (Mode=3) and 9-6（Natural convection） may be consulted.
5) Please submit in the USER part developed by yourself for solving the problem.

The project report should be due in before April 30, 2020 to room 204 of East 3rd Building of Xingqing campus. If you need the course score earlier, please submit your report ealier too and inform me.

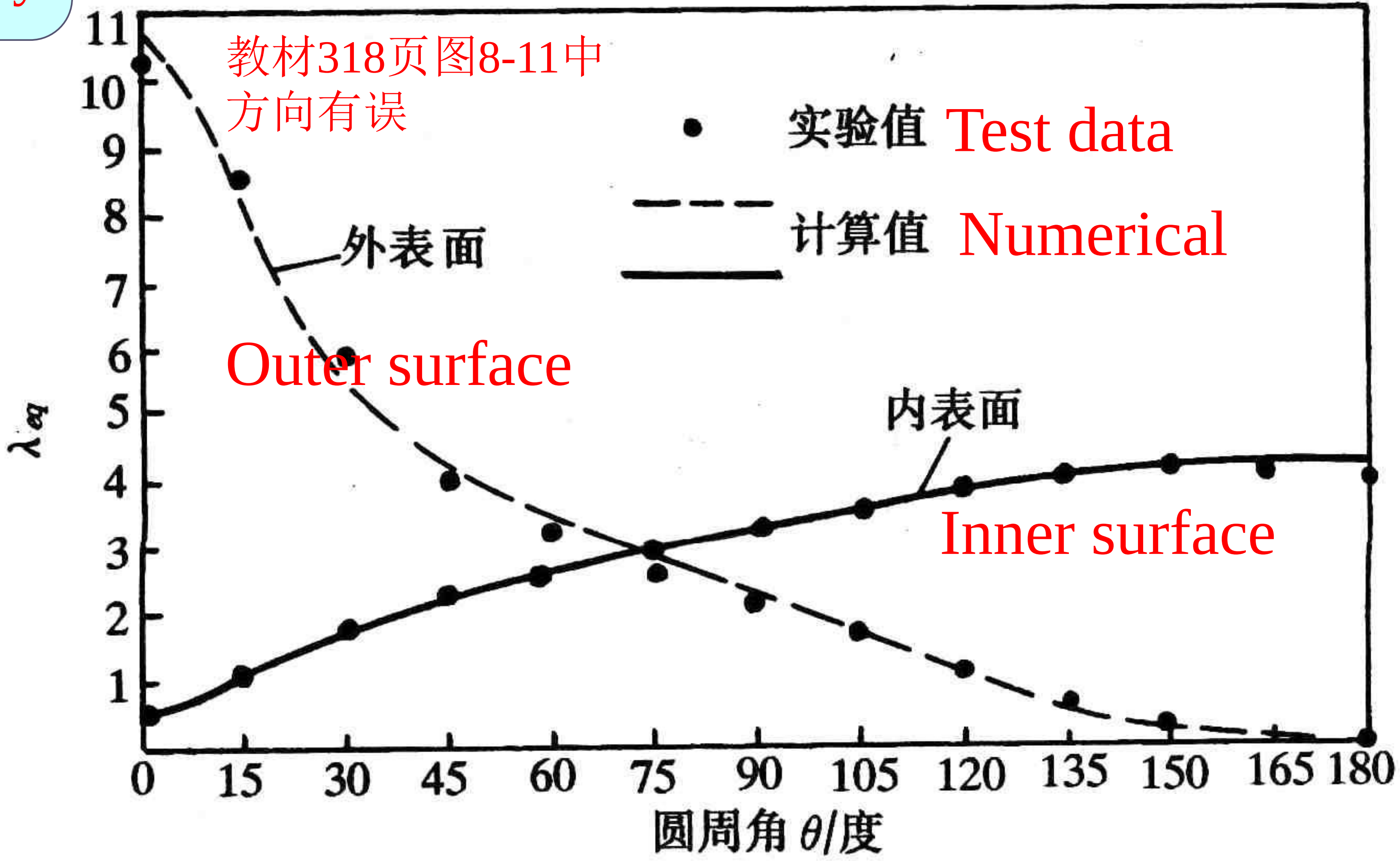
Local dimensionless thermal onductivity

Kuehn T H, Goldstein R J. An experimental and theoretical study of natural convection in the annulus between horizontal concentric cylinders. J Fluid Mech, 1971, 74:605-719



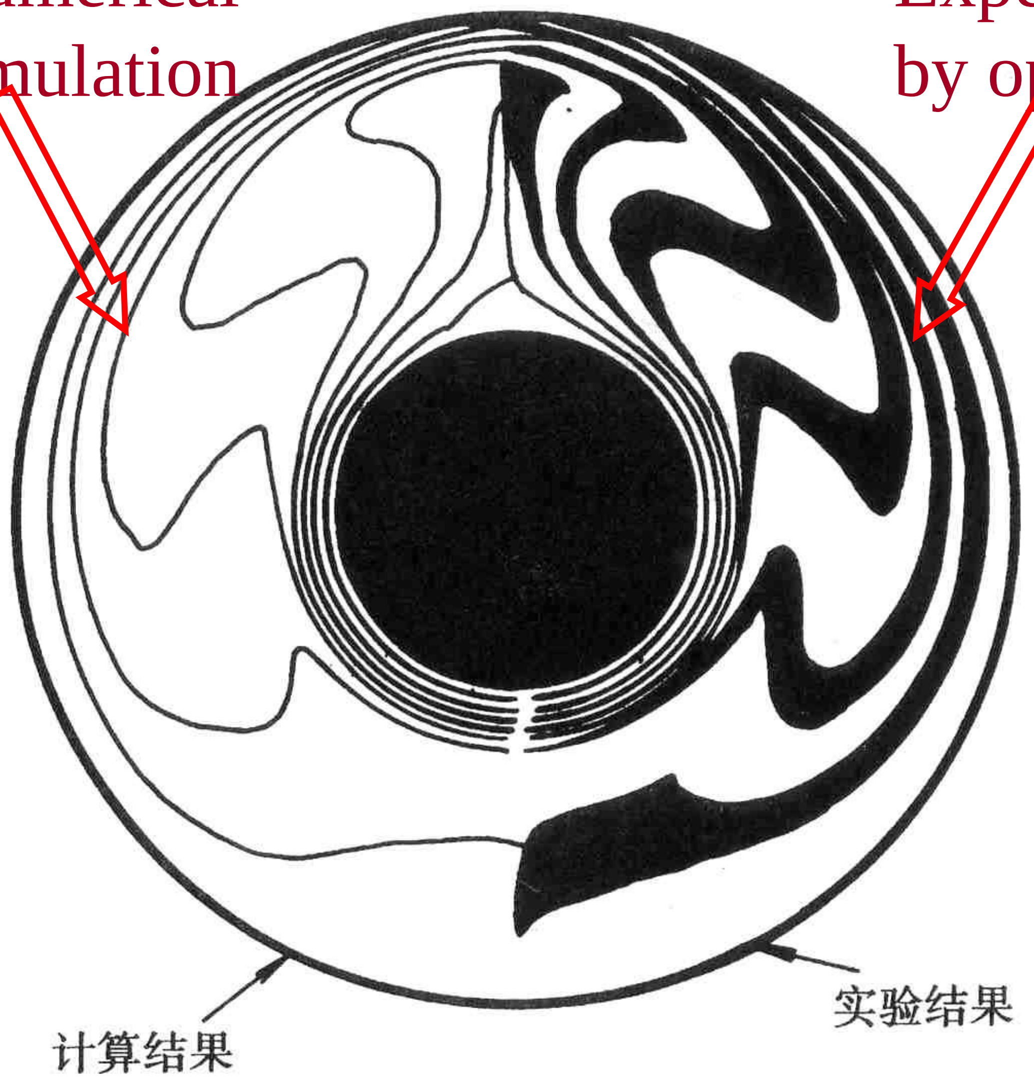
Local relative thermal conductivity

$$\overline{\lambda_{eq}} = \left(\frac{q_{convection}}{q_{conduction}}\right)_\theta$$



Numerical simulation

Experiment by optical method



实验与计算条件

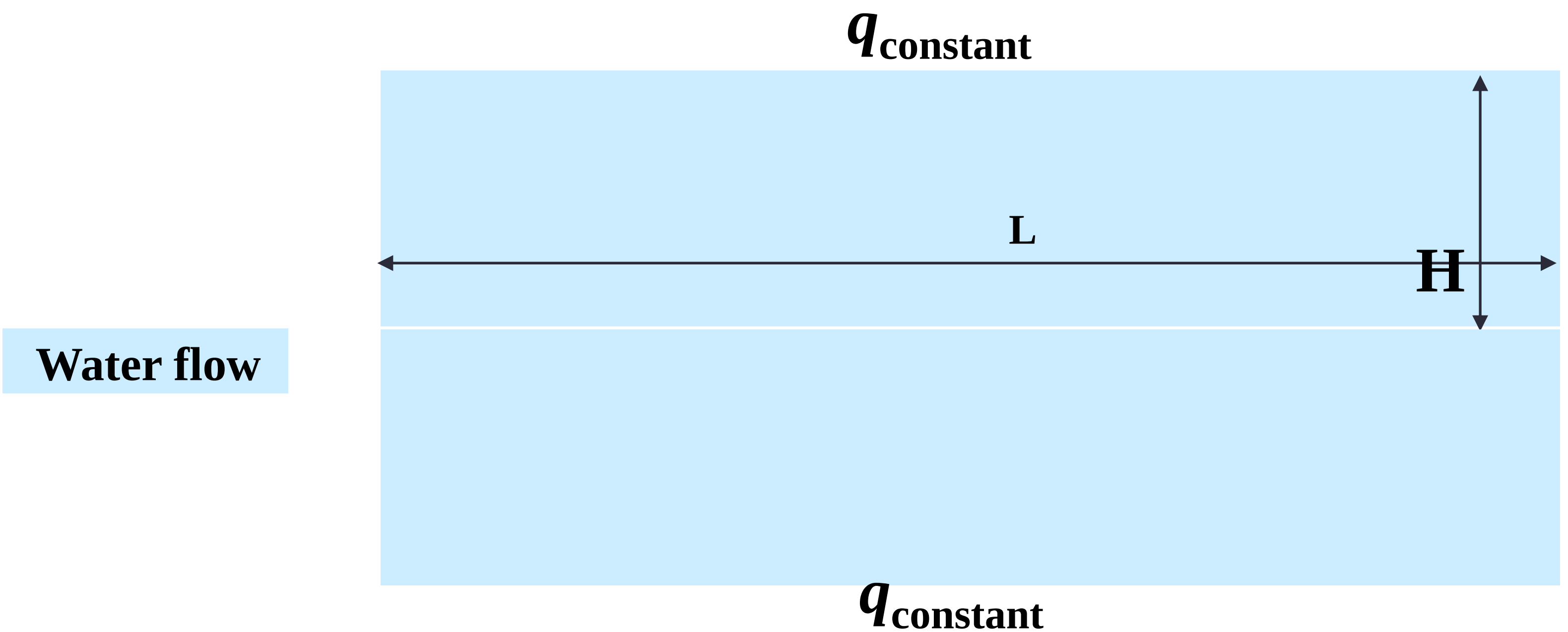
	实验	计算
Ra_δ	4.7×10^4	5×10^4
Pr	0.706	0.7
δ/Di	0.8	0.8

Comparison of isotherms (等温线)

2^{nd} Project

Computer-aided project (3) of NHT-2019, XJTU

Known: There are two kinds of solid particles A and B. The diameter of A and B are different. A and/or B will be packed into a microchannel to form porous zone to enhance heat transfer. Half of the microchannel will be occupied by the porous zone.



Computational domain

Parameter	H	L	ρ_{water}	η_{water}	$c_{p\ water}$	λ_{water}	ε
Value (Unit)	0.2 (cm)	2 (cm)	1000.0 ($kg{\cdot}m^{-3}$)	998×10^{-6} ($kg{\cdot}m^{-1}{\cdot}s^{-1}$)	4182 ($J{\cdot}kg^{-1}{\cdot}K^{-1}$)	0.59 ($W{\cdot}m^{-1}{\cdot}K^{-1}$)	0.5
Parameter	d_A	d_B	*Re*				
Value (Unit)	100 (μm)	50 (μm)	0.1-50				

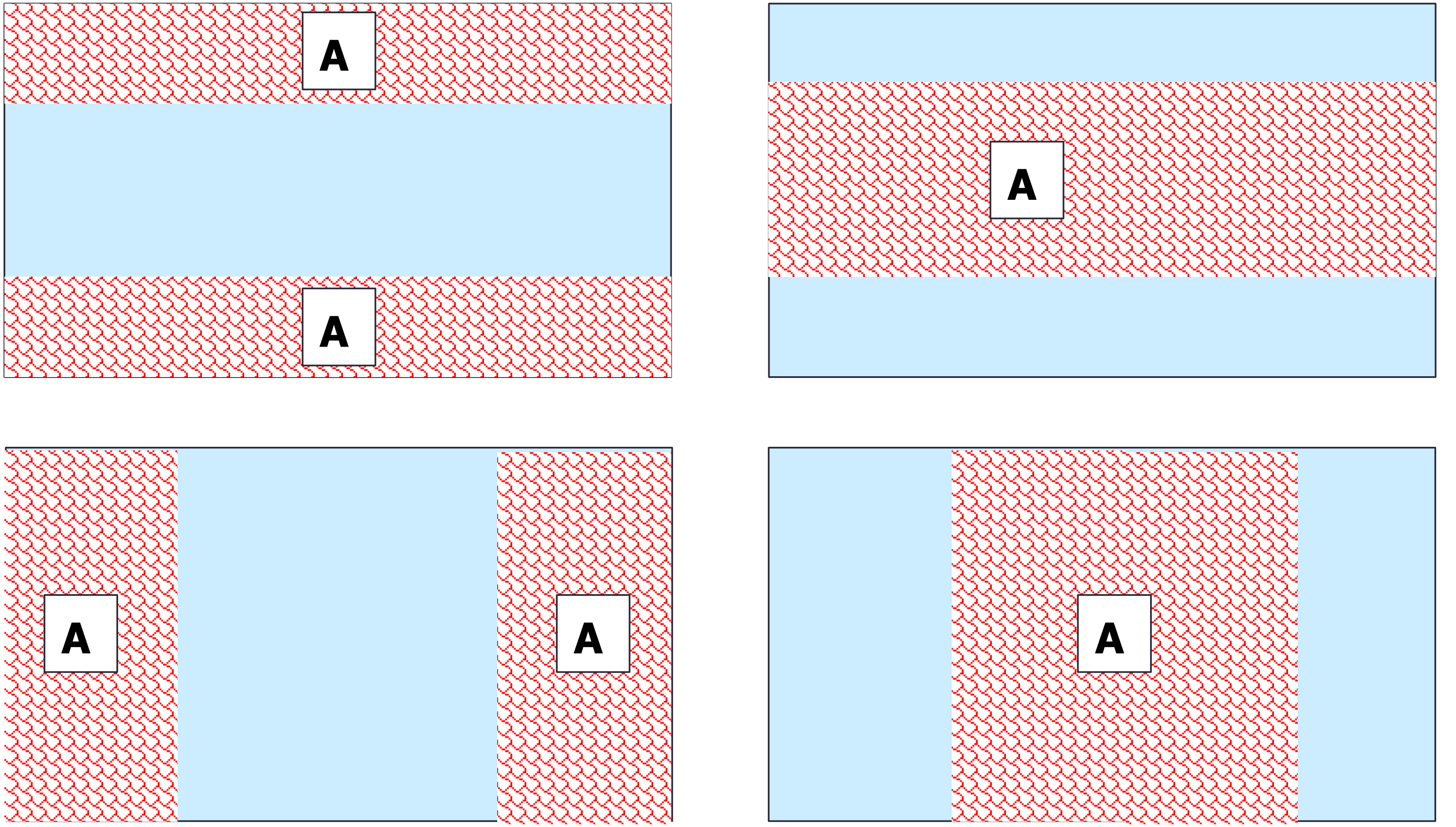
Assumptions:

constant physical properties, steady, laminar flow

Boundary conditions

Boundary	Condition
x=0	$v_x=U_{in}$, T=300 K
x=L	p=0 Pa , $T_{backflow}$=300 K
y=H	$v_x=v_y=0$ $\quad q=500\mathrm{Wm}^{-2}$
Porous region	Thermal-equilibrium model

Possible position of porous zone



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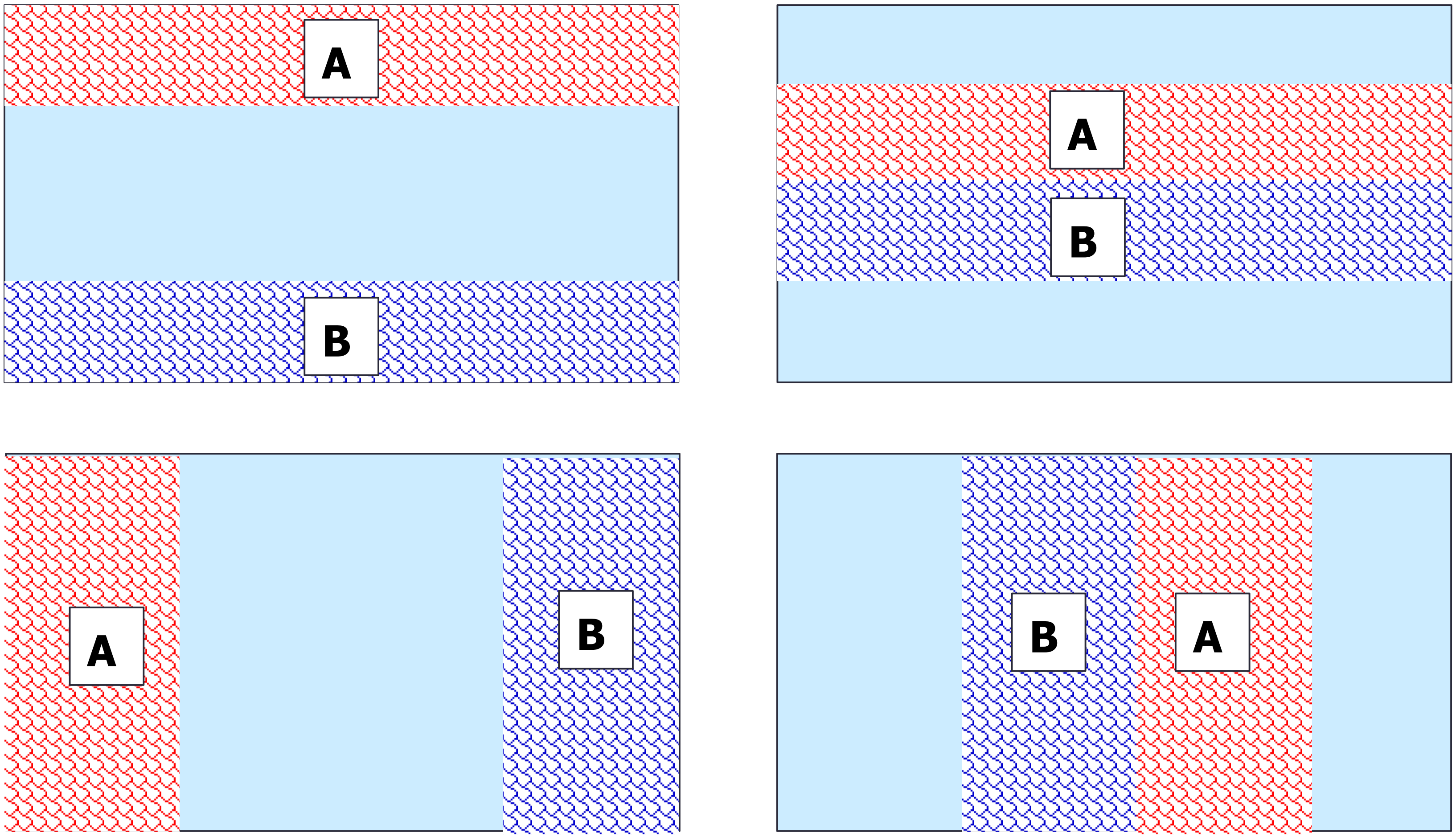
Possible position of porous zone



More patterns should be considered…

Solve:

$$PN = \frac{Nu / Nu_{\text{base case}}}{\Delta p / \Delta p_{\text{base case}}}$$

Simulate the heat transfer and laminar flow based on above conditions, and try to find the desirable structures of porous media to obtain high *PN*. Analyze the *Nu*, pressure drop (ΔP) and PN at different *Re* and permeability. Thermal-equilibrium model is adopted for porous medium region. KC equation is adopted to calculate the permeability.

$$Re = \frac{\rho u_{\text{inlet}} \mathrm{H}}{\mu} \qquad k = \frac{D_{\mathrm{p}}^{\,2} \varepsilon^3}{150(1-\varepsilon)^2}$$

3rd roject

Project of Numerical Heat Transfer

In modern industrial applications, effective cooling technology is indispensable for manufacturing solid state devices in order to simultaneously guarantee their quality and economic cost.

In this project, to manufacture a solid state device with cross section area of 1600 mm×800 mm and thickness d mm, a cooling mold with symmetric (up and down) configurations is applied as shown in Fig. 1. As an effective cooling methodology, water cooling technique is used in this work so that the water flow channel in mold is required. **Please design the water flow channel in mold and find the appropriate water flow rate in purpose of satisfying the following requirements:**

(1) The temperature T of contact surface between solid state device and mold could be cooled down from its initial temperature 700°C to 350°C within time t (s).

(2) The non-uniformity range of entire contact surface temperature is within ΔT (K)

The initial temperature of solid state device (including the contact surface with mold) $T_s = 700$°C. The initial temperature of mold is $T_m = 300$°C.

Thermophysical properties of solid state device：

Density：$\rho = 2.5 \times 10^3 \text{ kg/m}^3$

Specific heat：$C = 3\times10^{-7}T^3 - 9\times10^{-4}T^2 + 1.3T + 454.2$ J/(kg·K)(Temperature unit：K)

Thermal conductivity：$\lambda = 0.973$ W/(m·K)

Mold material is stainless steel with following thermophysical properties:

Density：$\rho = 8 \times 10^3 \text{ kg/m}^3$

Specific heat：$C = 3\times10^{-5}T^2 + 0.1275T + 467.81$ J/(kg·K) (Temperature unit：K)

Thermal conductivity：$\lambda = -2\times10^{-6}T^2 + 0.0167T + 10.515$ W/(m·K)

(Temperature unit: K)

The default liquid water in Ansys Fluent is used.

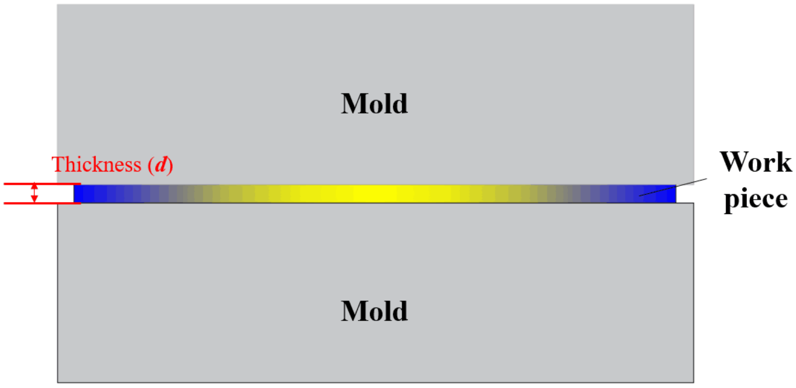


Fig. 1 Schematic diagram of solid state device with cooling mold

Group Assignment：

Last number of student ID	Device thickness d/mm	Required cooling time t/s	Non-uniformity temperature range ΔT/K
0,5	1.5	4	7
1,6	2	5	8
2,7	2.5	6	9
3,8	4	8	10
4,9	5	10	11