Research on the Thermo-Hydraulic Analysis of DEMO Blanket

C.L. Liu
JAEA

Special thanks:
S.Nishio, A. Saito, K.Tobita

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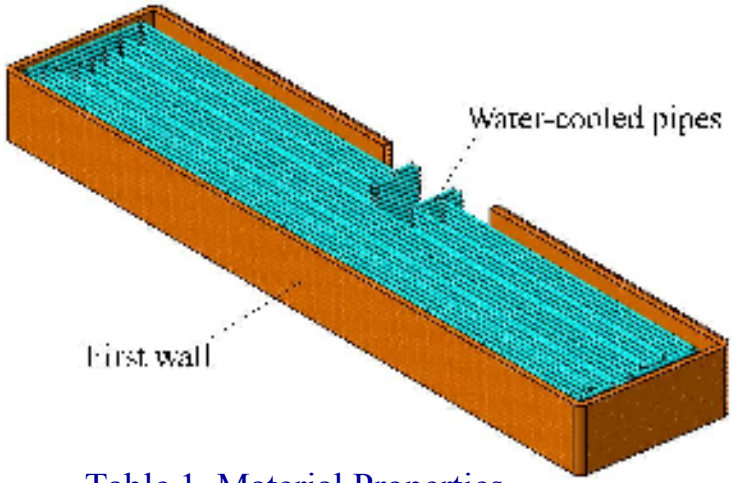
● The blanket thermal transportation research

§ Blanket model introduction

Demo blanket mainly includes the first wall, the pipes and the coolants. One blanket module has multi-layer pipes with coolants. In the first wall, there is a channel for water-cooled cycle.

§ Boundary conditions water density: 1000Kg/m3; Φ(Coolant)=9mm;Vin=3m/s; Tin=290℃. Pin=22MP



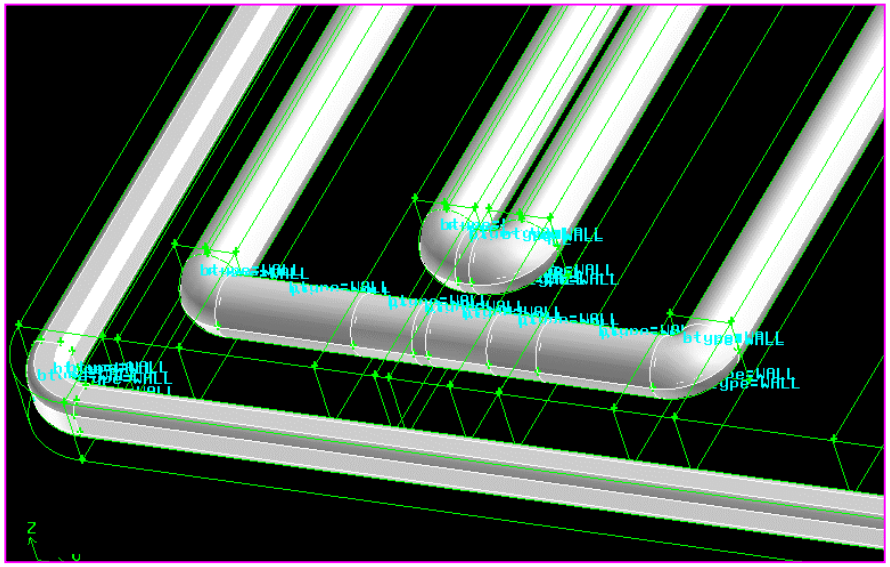


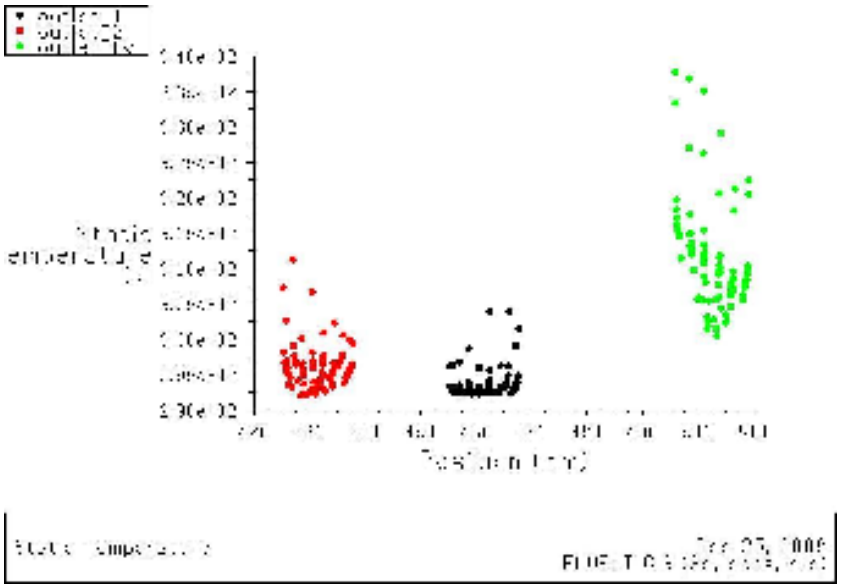
Table 1 Material Properties

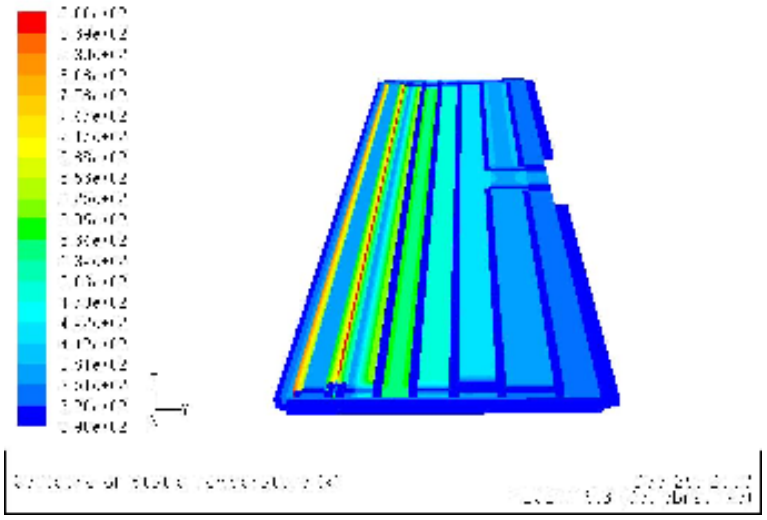
Properties / Materials	Density (Kg/m3)	Thermal conductivity (W/m-K)
Li2TiO3 Pebble	1895	1.2
Li4SiO4 Pebble	2000	1.5
Li/BePebble	1339	6
Be Pebble	1200	7.3
Be Plate	1848	35
F82H	7610	33

※ The whole model of one layer

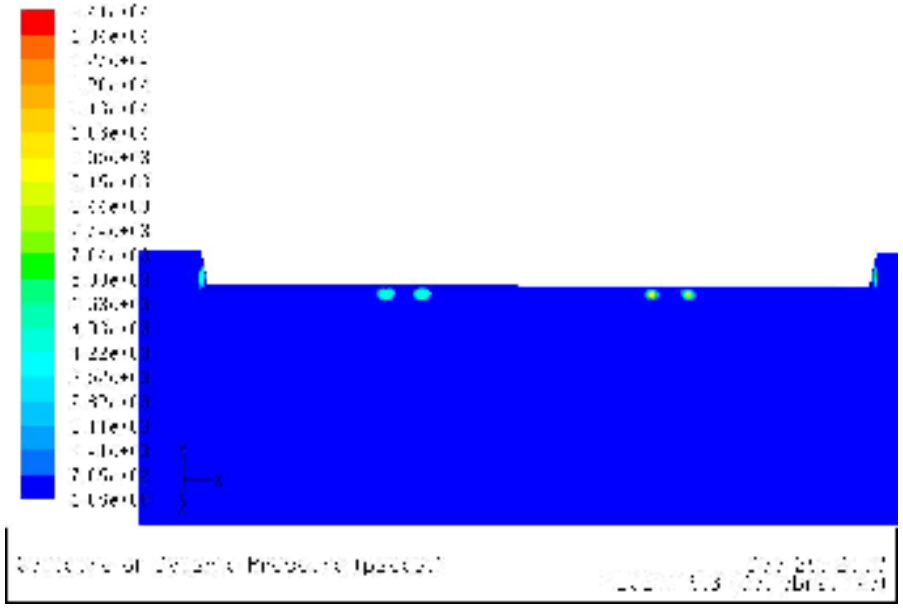
＊ Peak temperature appeared in the center of the Li2TiO3 pebble region due to the high neutron load in this region. The breeder material like Li2TiO3 has the lower thermal conductivity which influence the thermal transportation so much.

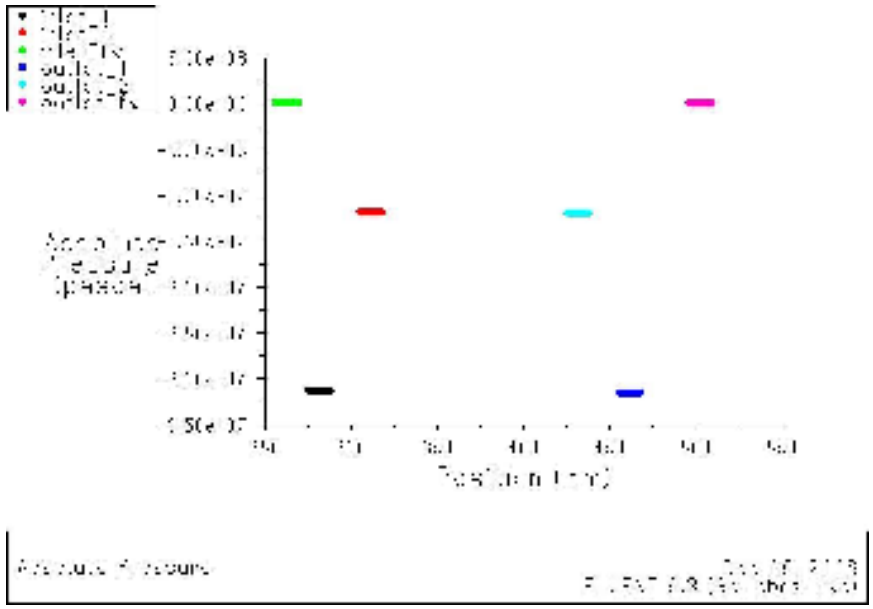
＊The temperature of outlets appeared the cases: the outlet1's is higher than the outlet2's due to the high neutron load in pipe1 region, but the outlet of first wall channel appeared the maximum value.





* The maximum dynamic pressure of the coolants reach 0.014MPa，
* Pressure loss: inlet1/outlet1l(0.2MPa)＞inlet2/outlet2 (0.15MPa)＞ first wall channel(0.04MPa).
* The longer length of the coolant circuit, the more pressure loss of the flow circuit, this will be confirmed in the later calculation.





※ The first wall /pipe with coolants

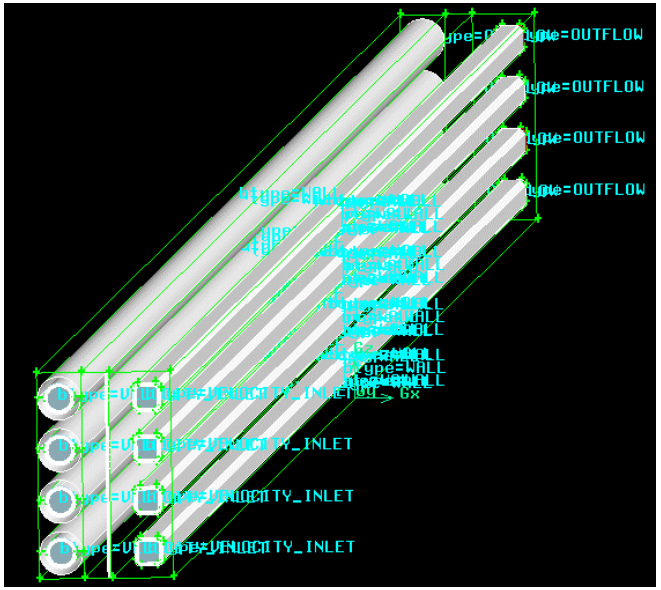
＊Model 3 : 4 layers , (2 m long) and with FW, breeders : Li (pebble), Be(plate) ;Model 4 : 1 layer, (2 m long) and with FW, breeders : Li (pebble), Be(plate/pebble) .

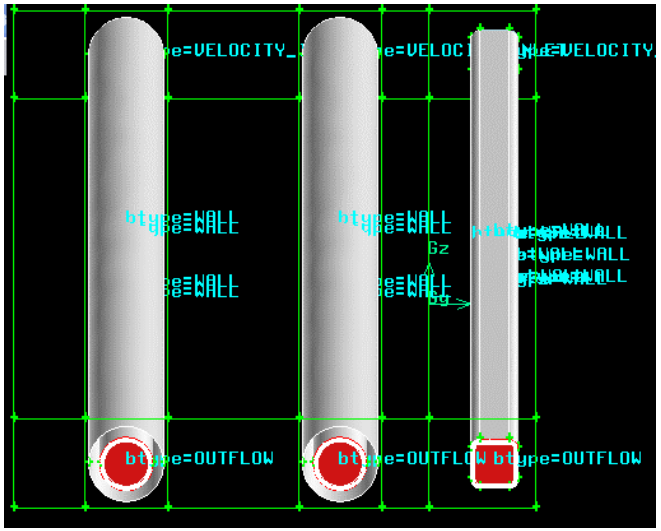
＊ High temperature appeared in the Li2TiO3 region, it is found the Be region has high inner energy due to its higher CP.

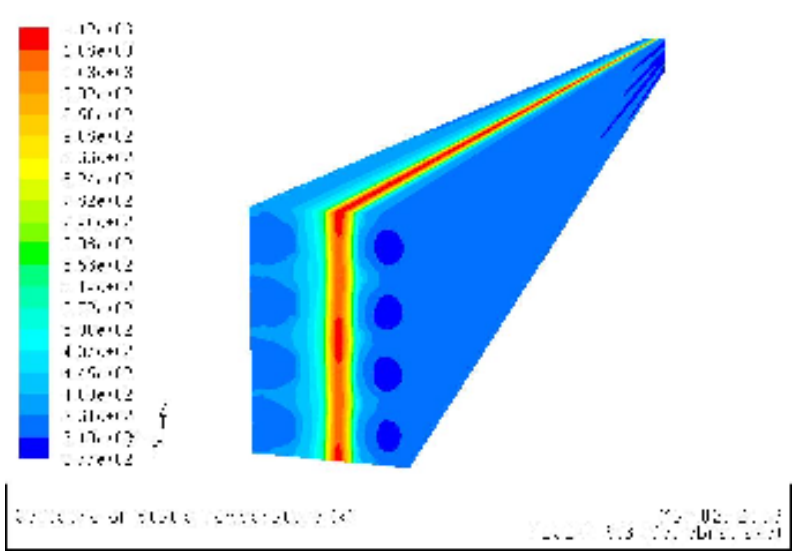
＊ The outlet temperature of channels is higher than the pipe coolants' .

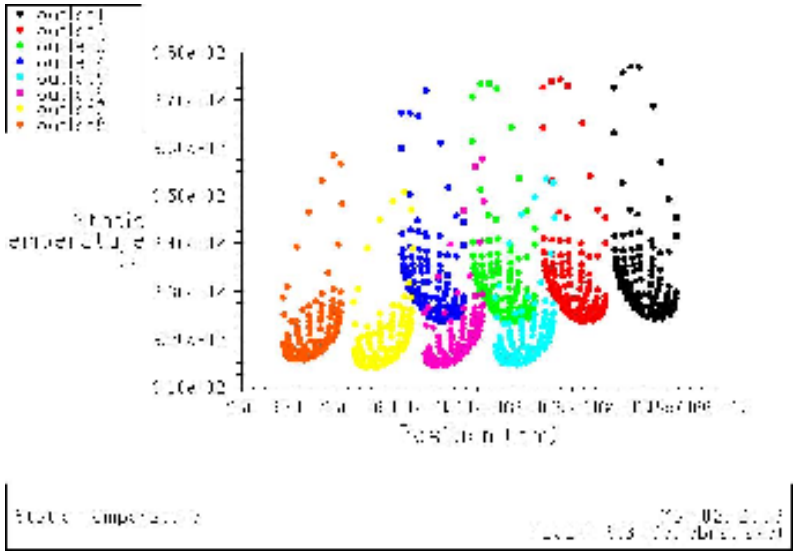
＊ If the be plate change to be pebble, the temp. of the outlets will be increased due to the lower thermal conductivity .

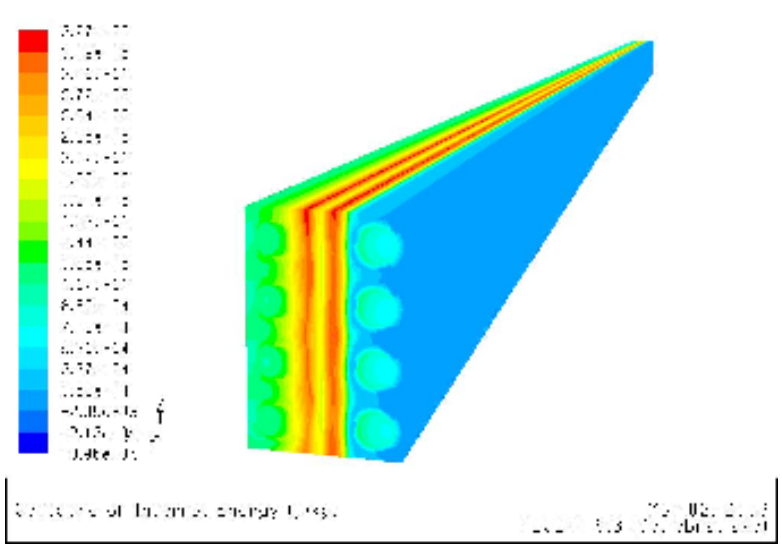
＊ The pressure loss:FW/pipe(15KPa/10 KPa), the equivalent diameter(9.2 mm/9mm), the pressure loss will be increased along with the diameter of the coolant increased.

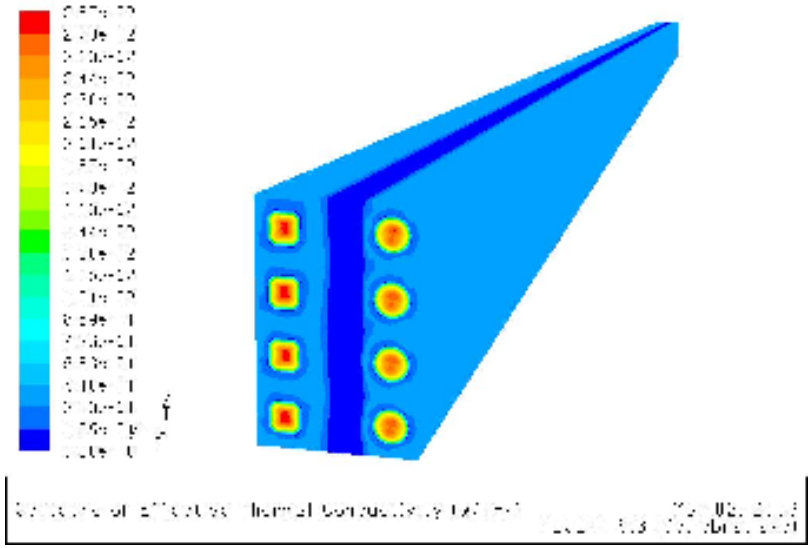


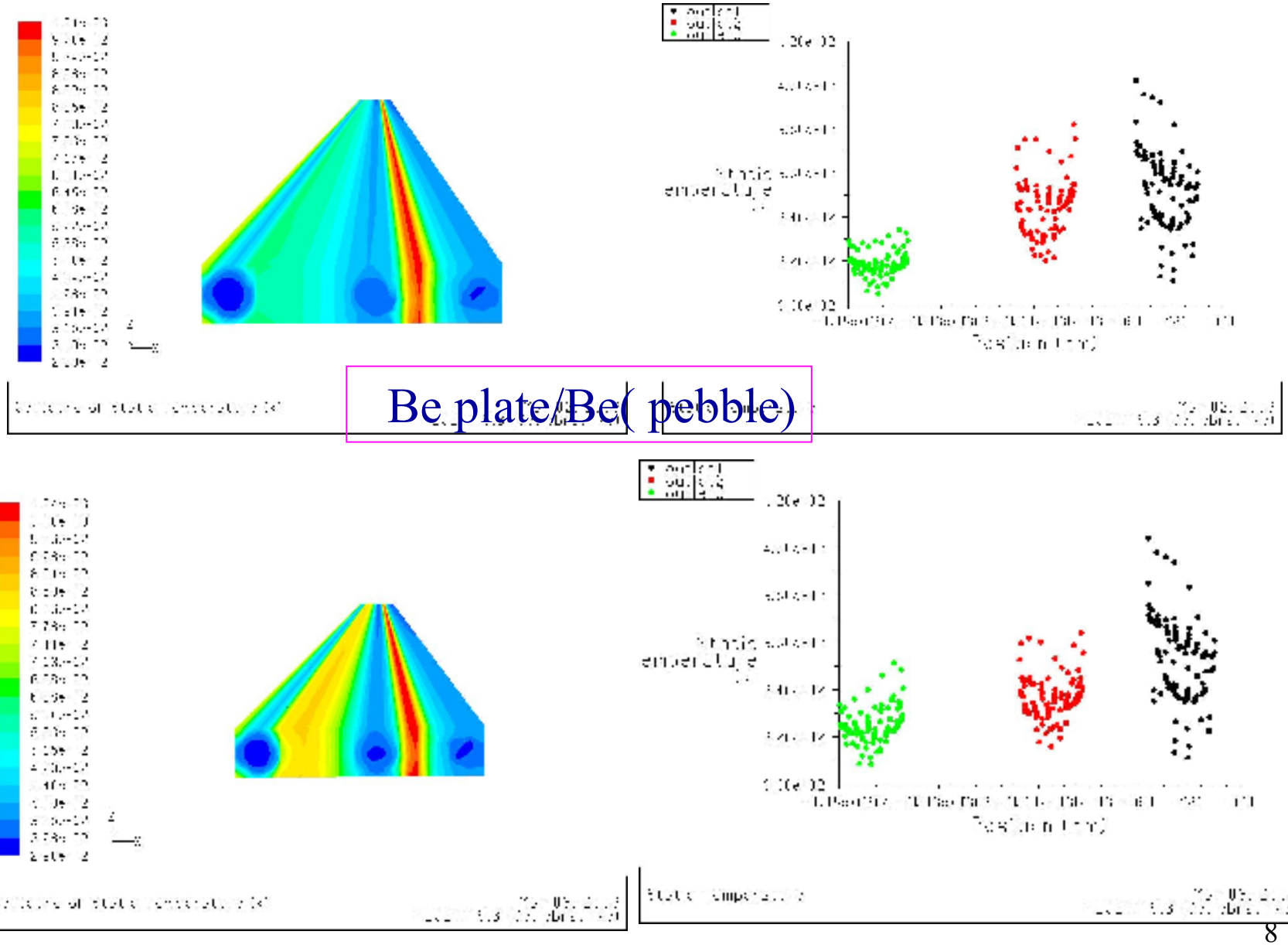












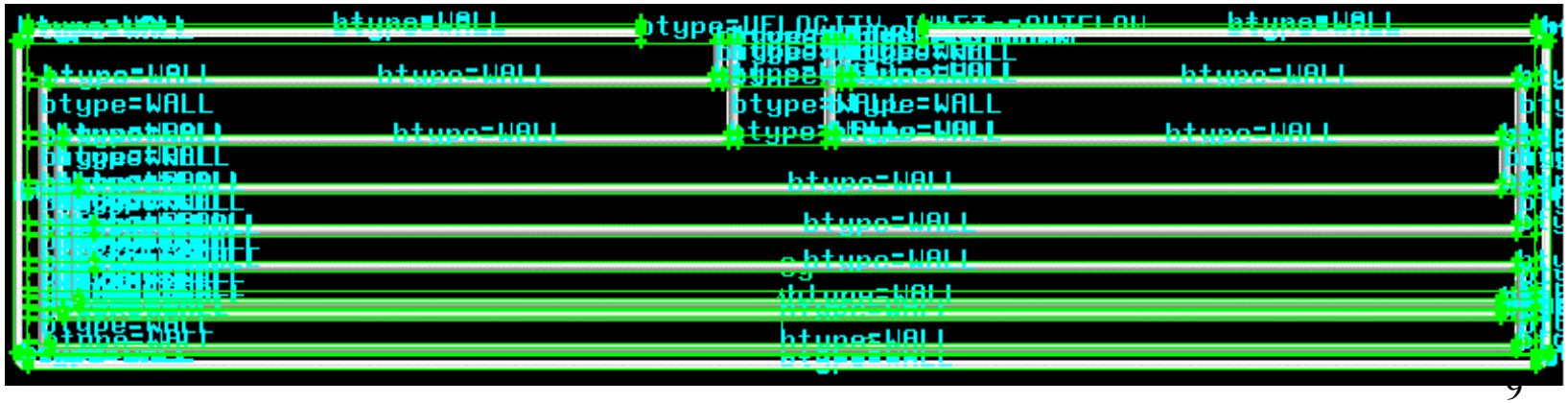
Be plate/Be(pebble)

● The hydraulic analysis of the piping system

§ Two sets of the coolant pipes (pipe1:8127mm/pipe2:8003mm) are modeled to detail the pressure loss and the outlet temperature changes . Coolant diameter:4,6,9mm. CFD models included Inlets/outlets, fluid zones, solid zones.

§ **Inlet coolant** Pin=22MPa.Coolant density=0.6g/mm3, Tin=300℃.

* case1: inlet velocity based
* case2: inlet mass flow rate (MFR) based



● case1: inlet velocity based/pressure loss

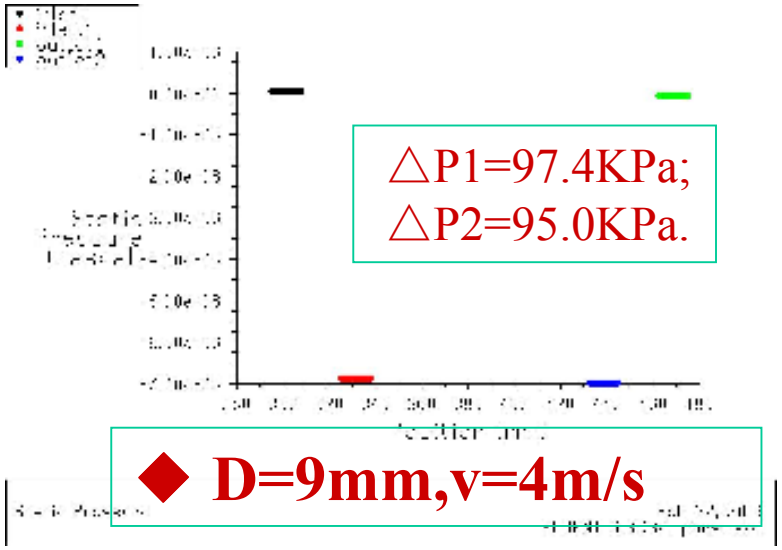
＊ The less diameter, the higher pressure loss.

＊ If the velocity will become higher, the pressure loss will be increased.

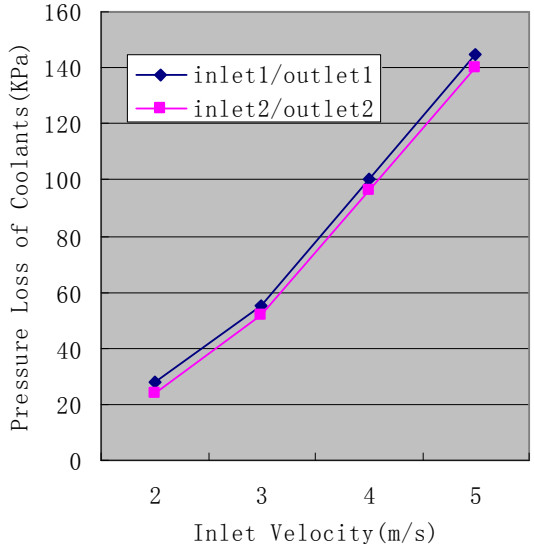
＊ If coolant density become higher, the pressure loss will be increased.

＊ The longer of the coolant pipe, the more pressure loss it has.

＊ The pressure loss is also related to coolant viscosity (kg/m-s), if the coolant viscosity drop down, the pressure loss will reduce.

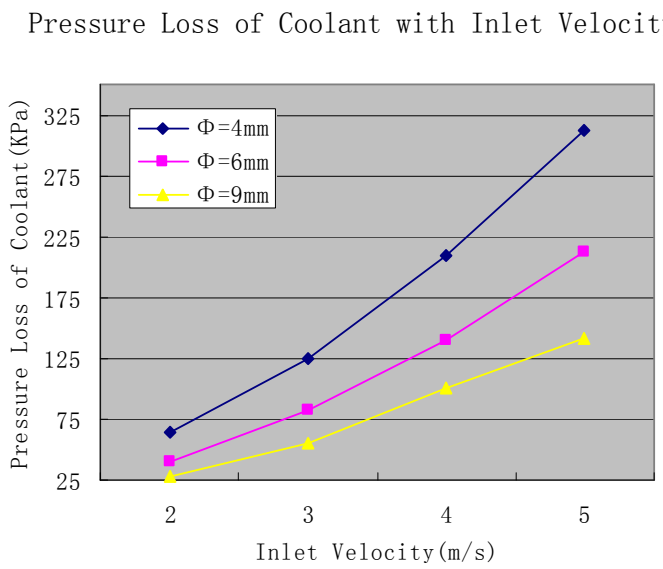


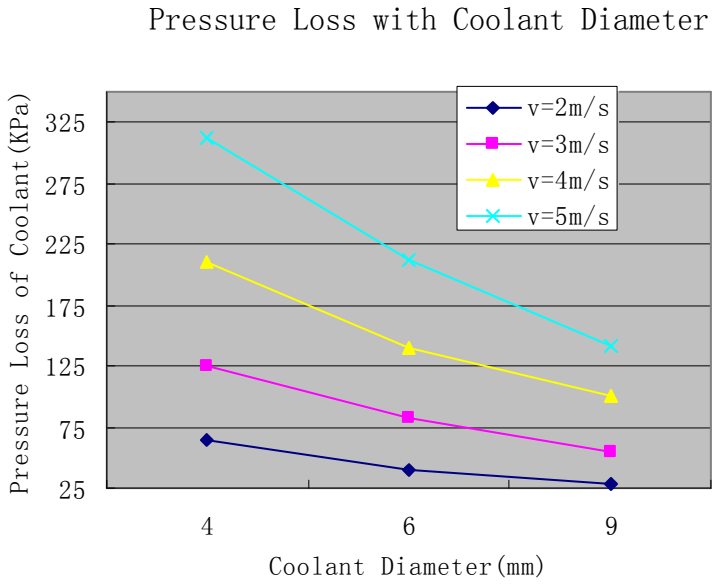
◆ **D=9mm,v=4m/s**



◆ **D=9mm**

◆D=4,6,9mm;v=2,3,4,5m/s





◆ D=9mm,v=3m/s

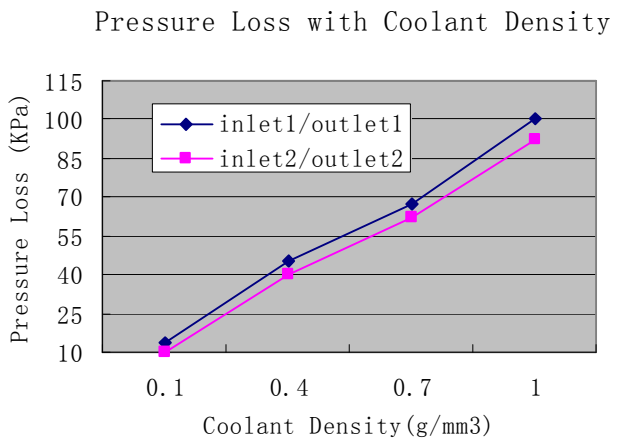


Table 2 Pressure Loss (KPa) Based on Inlet Velocity

Diameter (mm) \ Velocity (m/s)	2	3	4	5
4	60	125	210	305
6	38.5	83	140	210
9	28	59	97.5	150

● case1: inlet velocity based/temp. changes

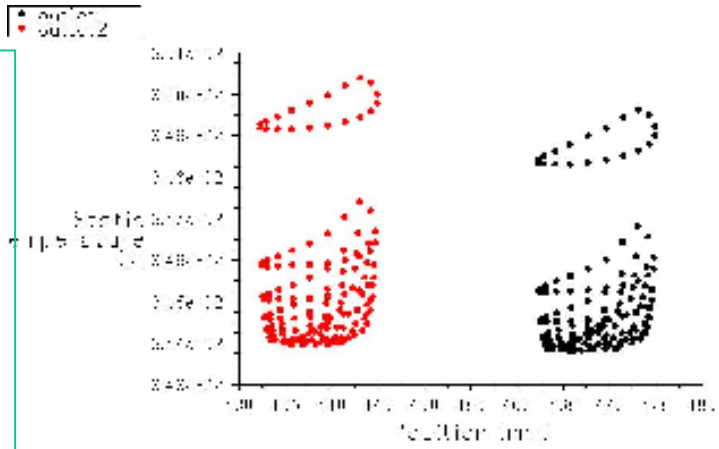
＊ The outlet temperature has two typical region, one is peak temp.(about 16%) , the other is majority temp. (about 84%) .

＊ The temperature of outlet will reduce along with the inlet velocity increased.

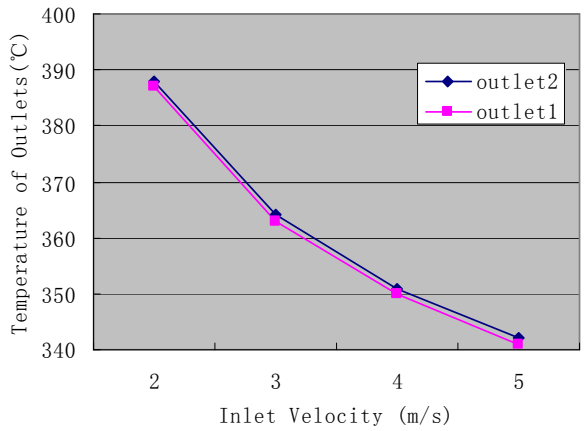
＊ For the two sets coolant pipe, the outlet2 is higher about 1℃ than the outlet1 due to the different length of the coolant pipe.

＊ If the diameter of the coolant become bigger, the temp. of the outlet will be drop down, because more coolant could remove more heat.

＊ If the diameter of the coolant is given, when pressure loss is increased, the temp. of outlet will be drop down correspondingly.

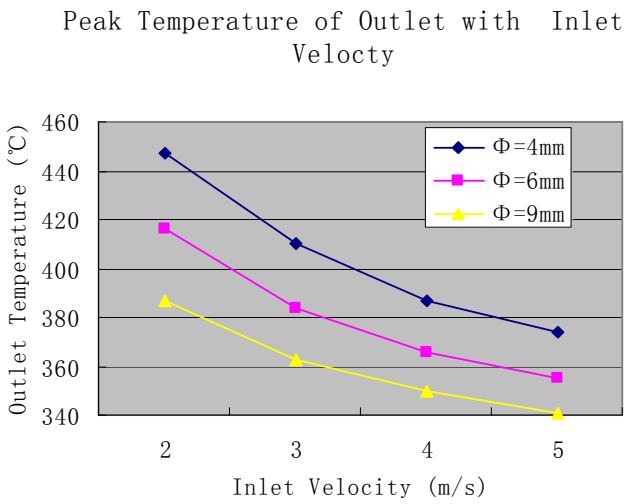


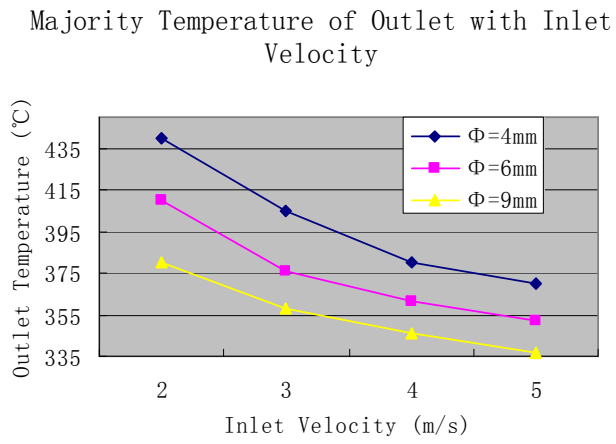
Peak Temperaure Comparison of Outlets with Inlet Velocity

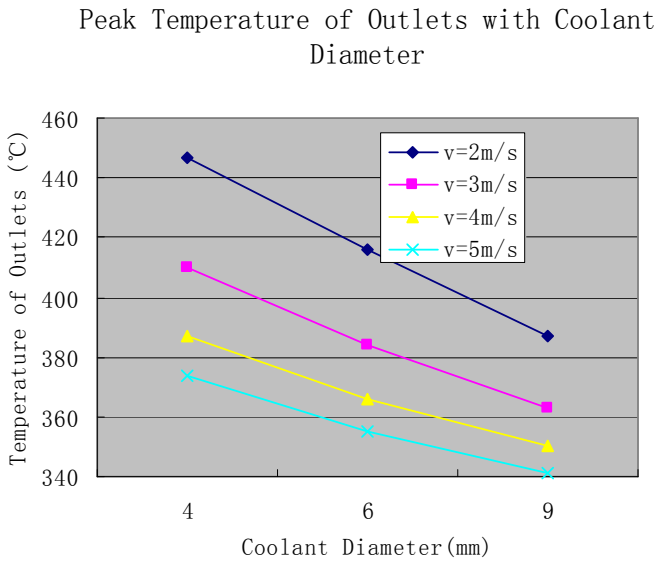


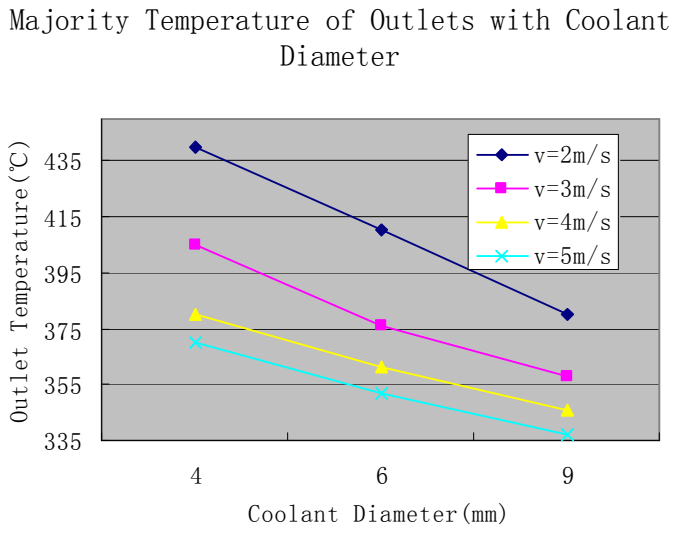
◆ D=9mm,v=4m/s

◆D=4,6,9mm;v=2,3,4,5m/s



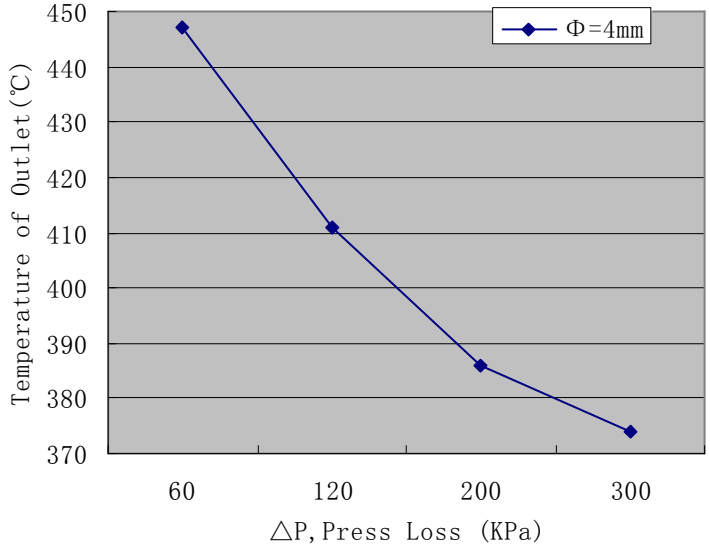




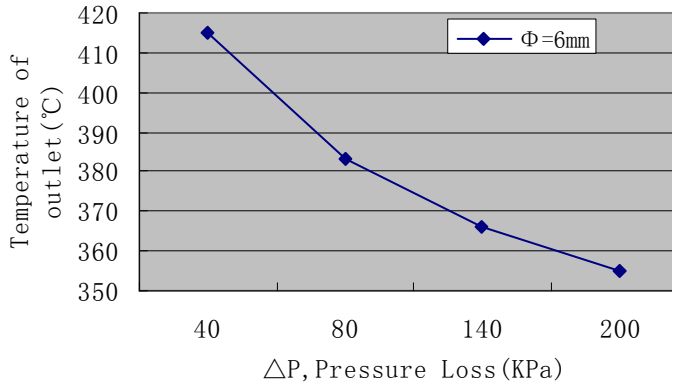


* If the diameter of the coolant is given, when pressure loss is increased, the temp. of outlet will be drop down correspondingly.

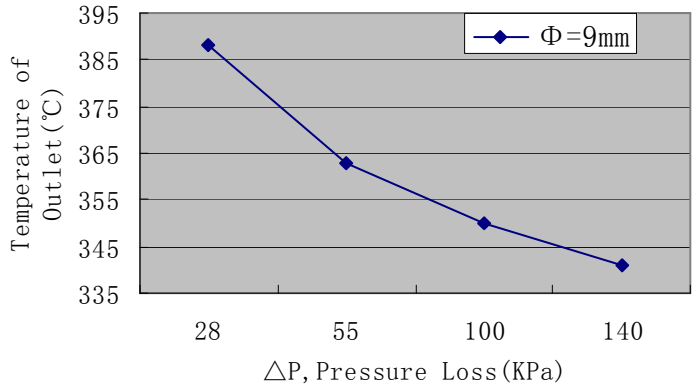
Peak Temperature of Outlet with Press Loss



Peak Temperature of Outlet with Pressure Loss



Peak Temperature of Outlet with Pressure Loss



● case2: MFR based

＊ For the same MFR, each coolant has its own inlet velocity, namely, the velocity will be increased along with coolant diameter drop.

＊ The pressure loss of the inlet1/outlet1 will be a little bit more than the inlet2/outlet2's, generally, 2-5KPa.

＊The pressure loss will be increased with the coolant diameter reduced.

＊ For the temperature of outlet2 is higher than the oulet1's, generally,

1-2℃, but the gap will be reduced along with the MFR increased.

＊The temperature of the outlet will be drop down with the MFR increased.

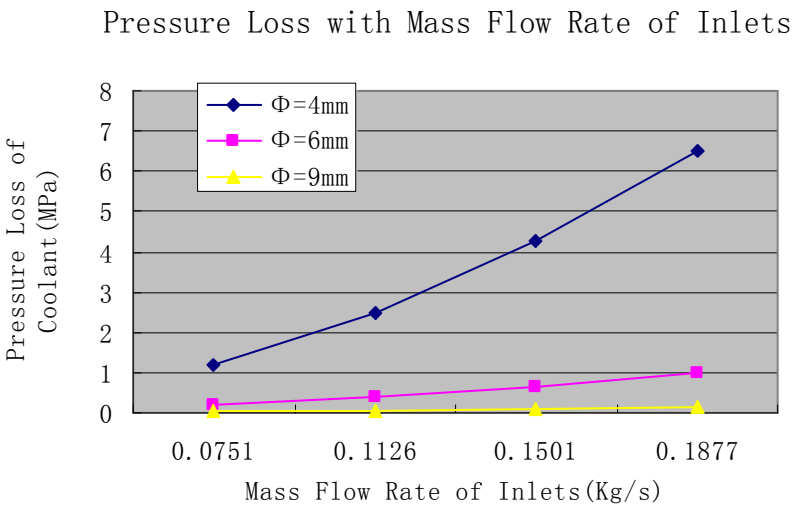
＊The temperature of the outlet will be increased along with the coolant diameter increased.

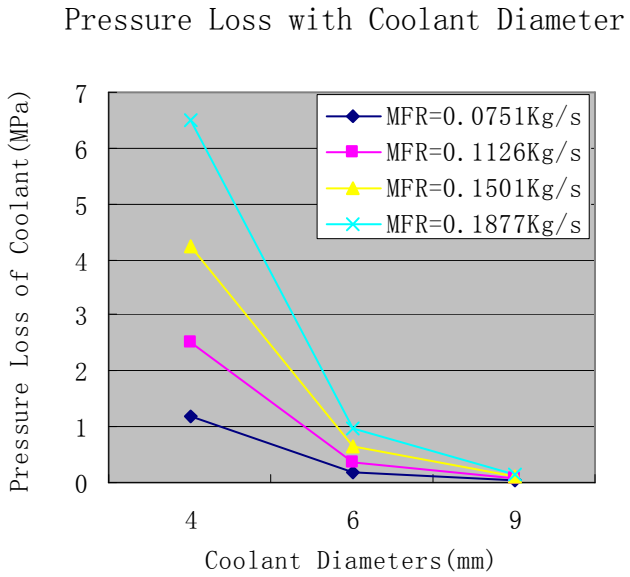
Table 3 Inlet Velocity (m/s) Based on the MFR

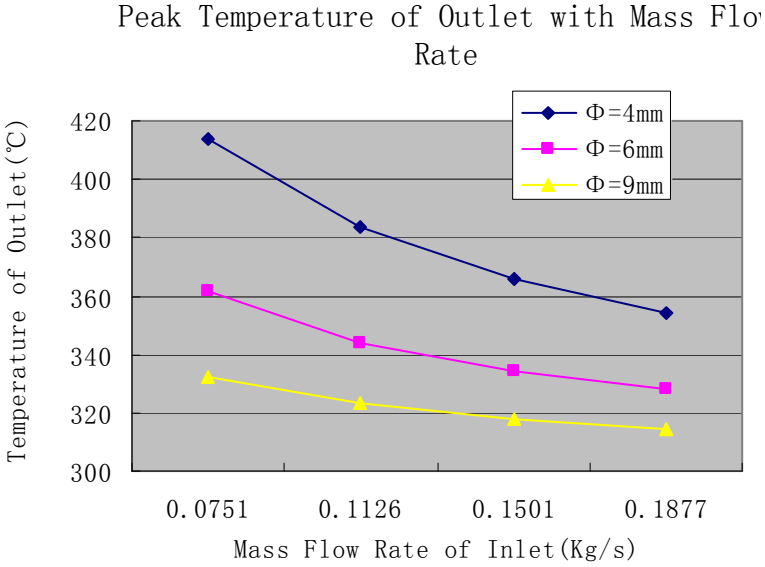
MFR(Kg/s) / Φ(mm)	0.0751	0.1126	0.1501	0.1877
4	10.4	15.6	20.8	26.0
6	4.5	6.8	9.0	11.3
9	2	3	4	5

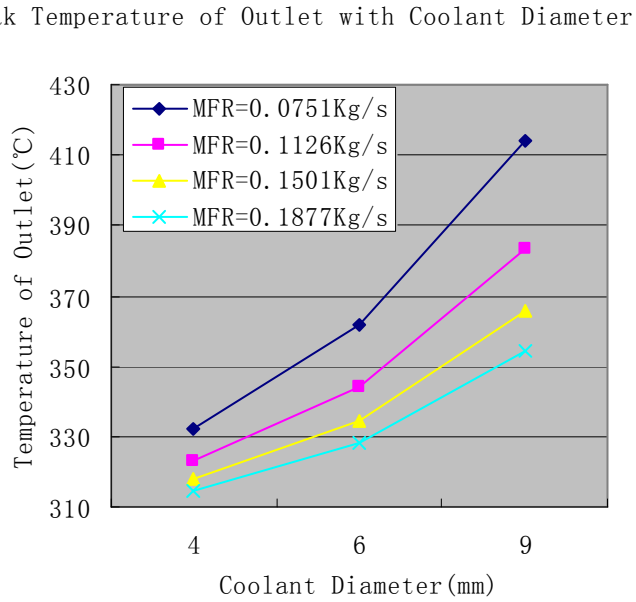
Table 4 Pressure Loss (MPa) Based on MFR

MFR (Kg/s) / Diameter (mm)	0.0751	0.1126	0.1501	0.1877
4	1.20	2.50	4.25	6.60
6	0.180	0.375	0.635	0.970
9	0.028	0.059	0.0975	0.150


Pressure Loss with Mass Flow Rate of Inlets
Pressure Loss of Coolant(MPa)
8
7
6
5
4
3
2
1
0
Φ=4mm
Φ=6mm
Φ=9mm
0.0751
0.1126
0.1501
0.1877
Mass Flow Rate of Inlets(Kg/s)


Pressure Loss with Coolant Diameter
Pressure Loss of Coolant(MPa)
7
6
5
4
3
2
1
0
MFR=0.0751Kg/s
MFR=0.1126Kg/s
MFR=0.1501Kg/s
MFR=0.1877Kg/s
4
6
9
Coolant Diameters(mm)


Peak Temperature of Outlet with Mass Flo
Rate
Temperature of Outlet(℃)
420
400
380
360
340
320
300
Φ=4mm
Φ=6mm
Φ=9mm
0.0751
0.1126
0.1501
0.1877
Mass Flow Rate of Inlet(Kg/s)


Peak Temperature of Outlet with Coolant Diameter
Temperature of Outlet(℃)
430
410
390
370
350
330
310
MFR=0.0751Kg/s
MFR=0.1126Kg/s
MFR=0.1501Kg/s
MFR=0.1877Kg/s
4
6
9
Coolant Diameter(mm)

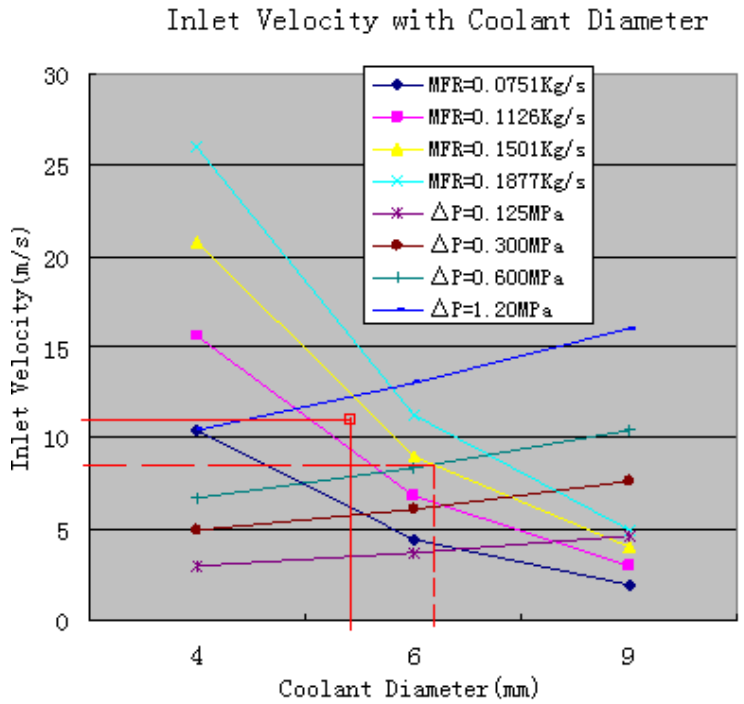
＊ Pipe bore decision: if keep the MFR=0.1501Kg/s, and require the pressure loss is 0.6MPa, so the coolant diameter could be 6.25mm and the inlet velocity is about 8 m/s;

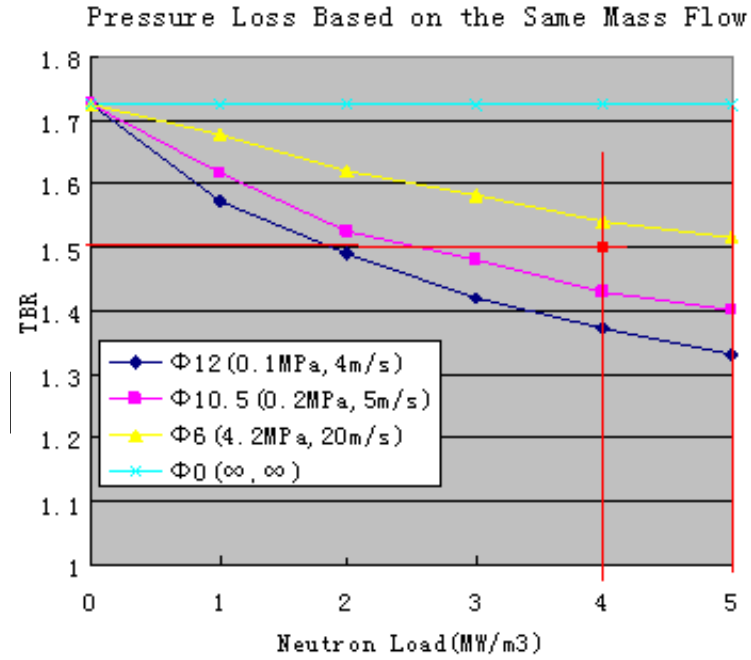
＊ Pressure loss estimation: if the inlet velocity is given, as 10.2m/s, and the pipe bore is 5.4mm, the pressure loss maybe between the 1.2MPa and 0.6MPa, and the MFR is under 0.1501Kg/s and more than 0.1126Kg/s.

＊ Parameters choice based on the TBR :

1) the MFR keep same, When neutron load is increased, the pipe diameter will be reduced, because small diameter require high velocity, and could remove much more heat.($Q=V * \triangle T * S * \rho$)

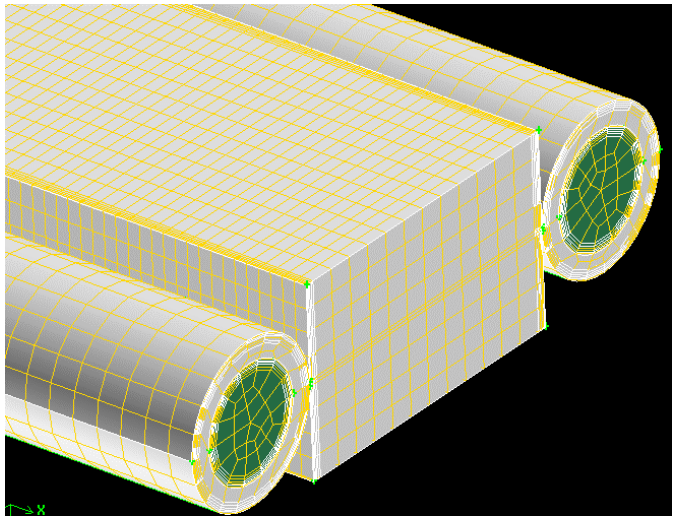
2) If TBR drop, the pipe diameter could be increased.

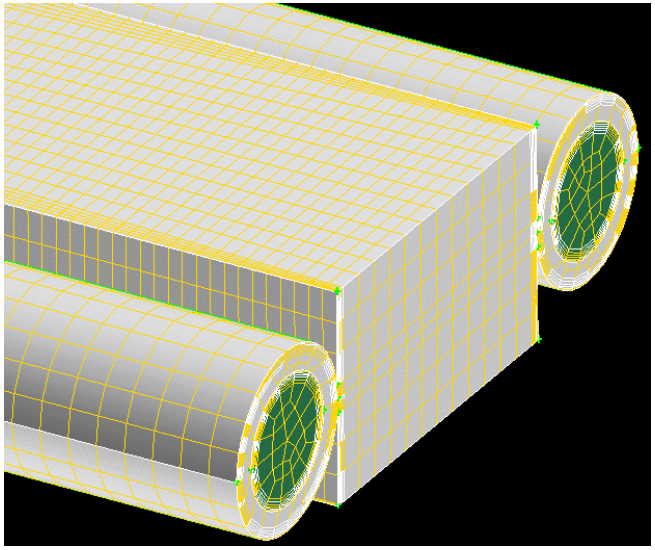




● Heat remove capability research

Inlet coolant
Pin=25MP,Tin=290℃,Vin=3m/s,water density:1000Kg/m3



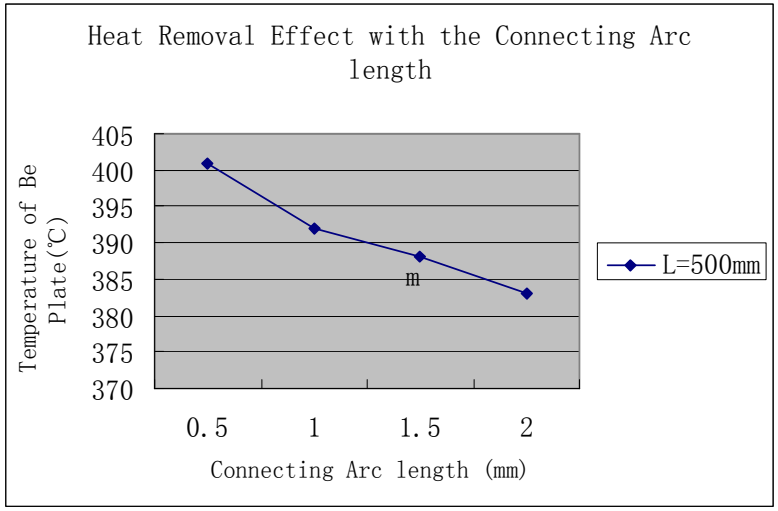


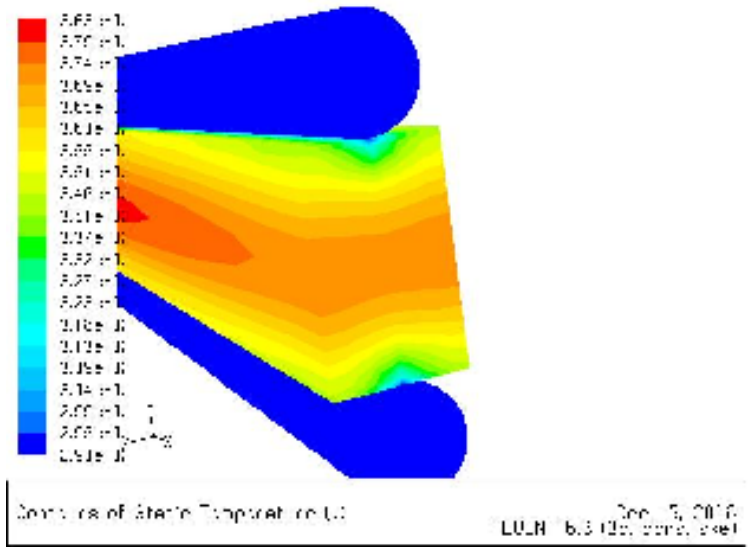
※ The connection area analysis

＊ 4 models were made to go further the heat removal capability of the structure.

＊ The length of the connecting arc were chose as 0.5,1,1.5,2mm respectively, and the length of the model pipe is 500mm.

* Along with the connecting surface area increased, temperature distribution is dropped down;
* More little length of the connecting arc was not recommended .

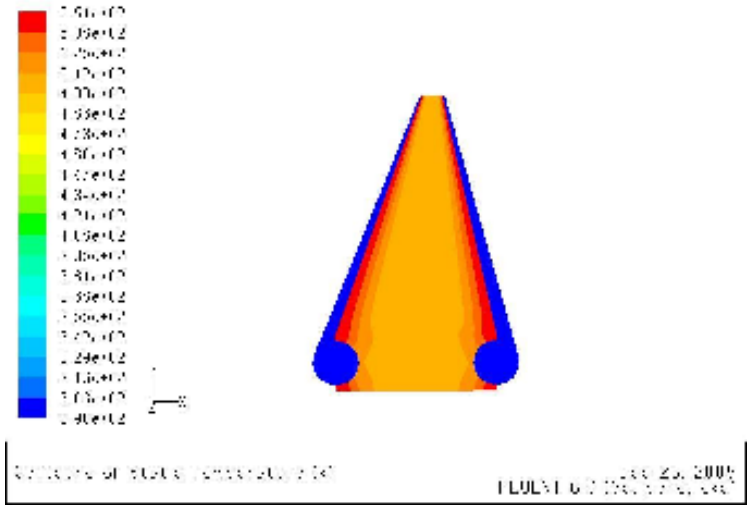


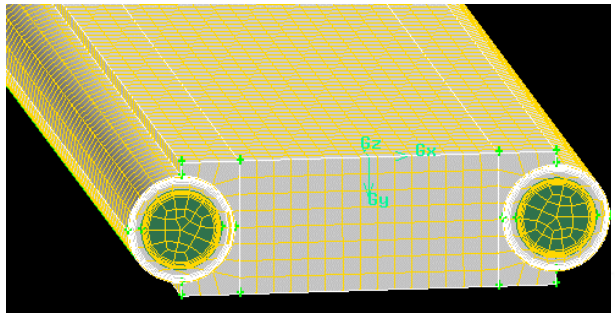


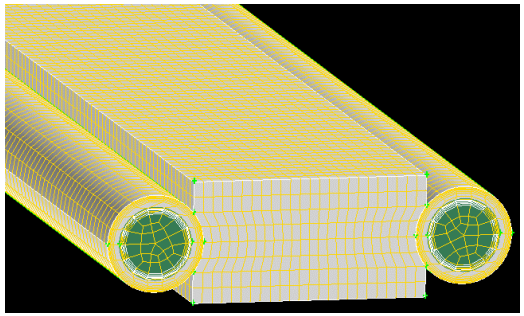
※ The comparison between Be pebble and the Be plate

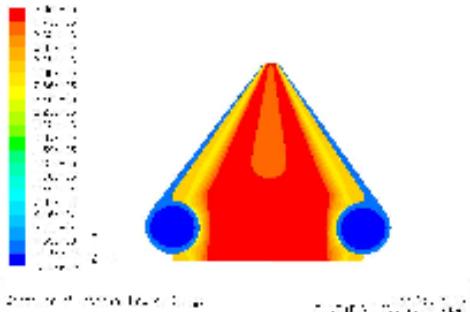
＊For model 6, be temperature is 551 ℃ and the model 7 is 419 ℃.

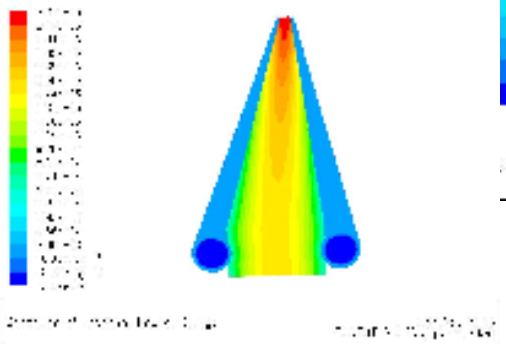
＊The inner energy (J/Kg) of model 6 is 395000 compare to the case 220000of model 7, as shows in the following figures.

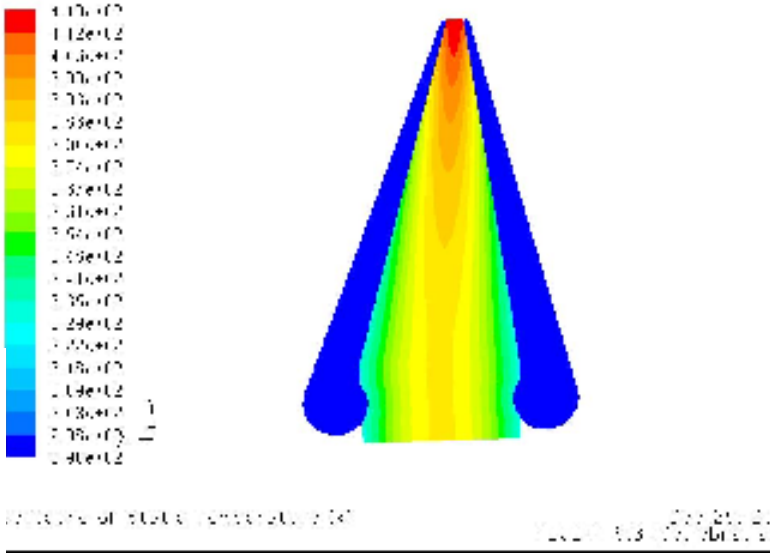












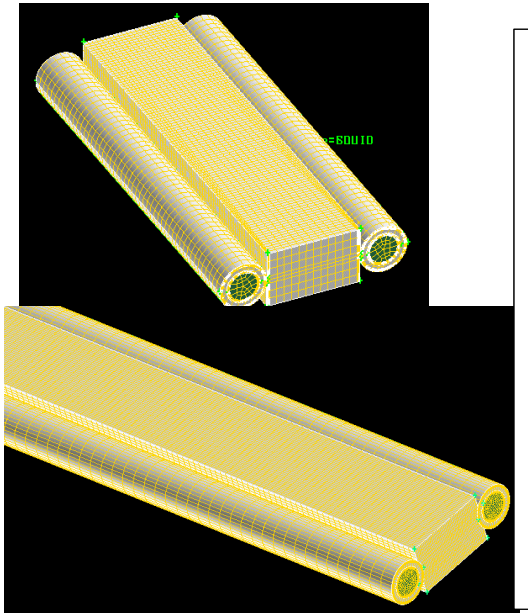
※ The heat remove efficiency based on the thermal conductivity

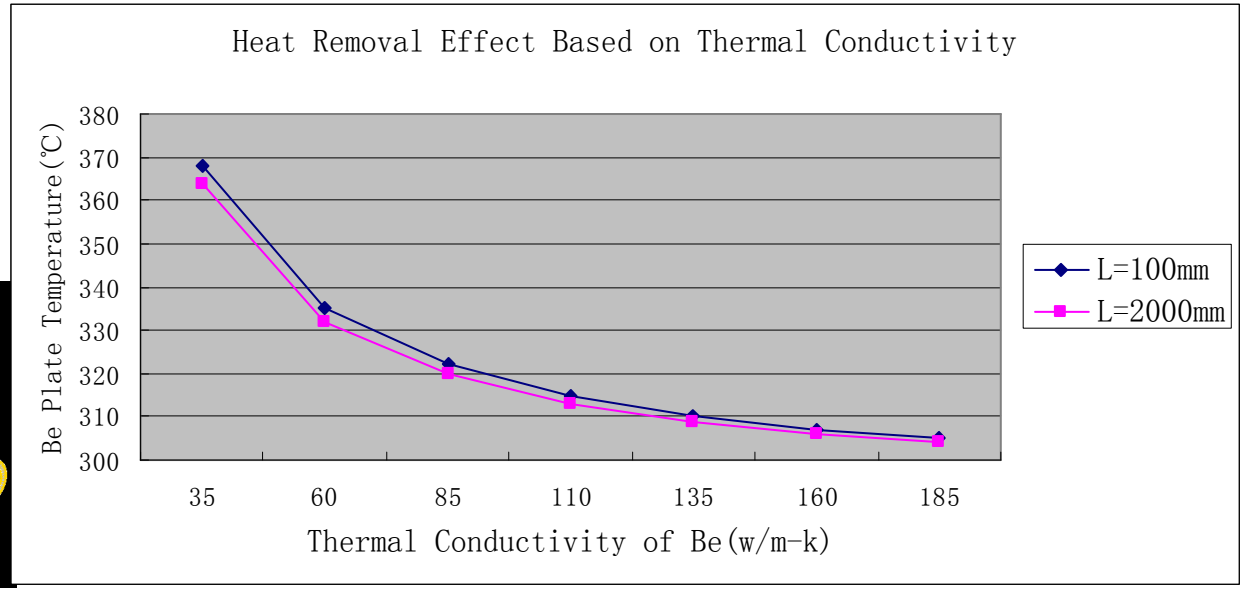
＊Based on the two models, although the pipe length is different, almost obtained the similar results, namely, the thermal conducting trend is the same.

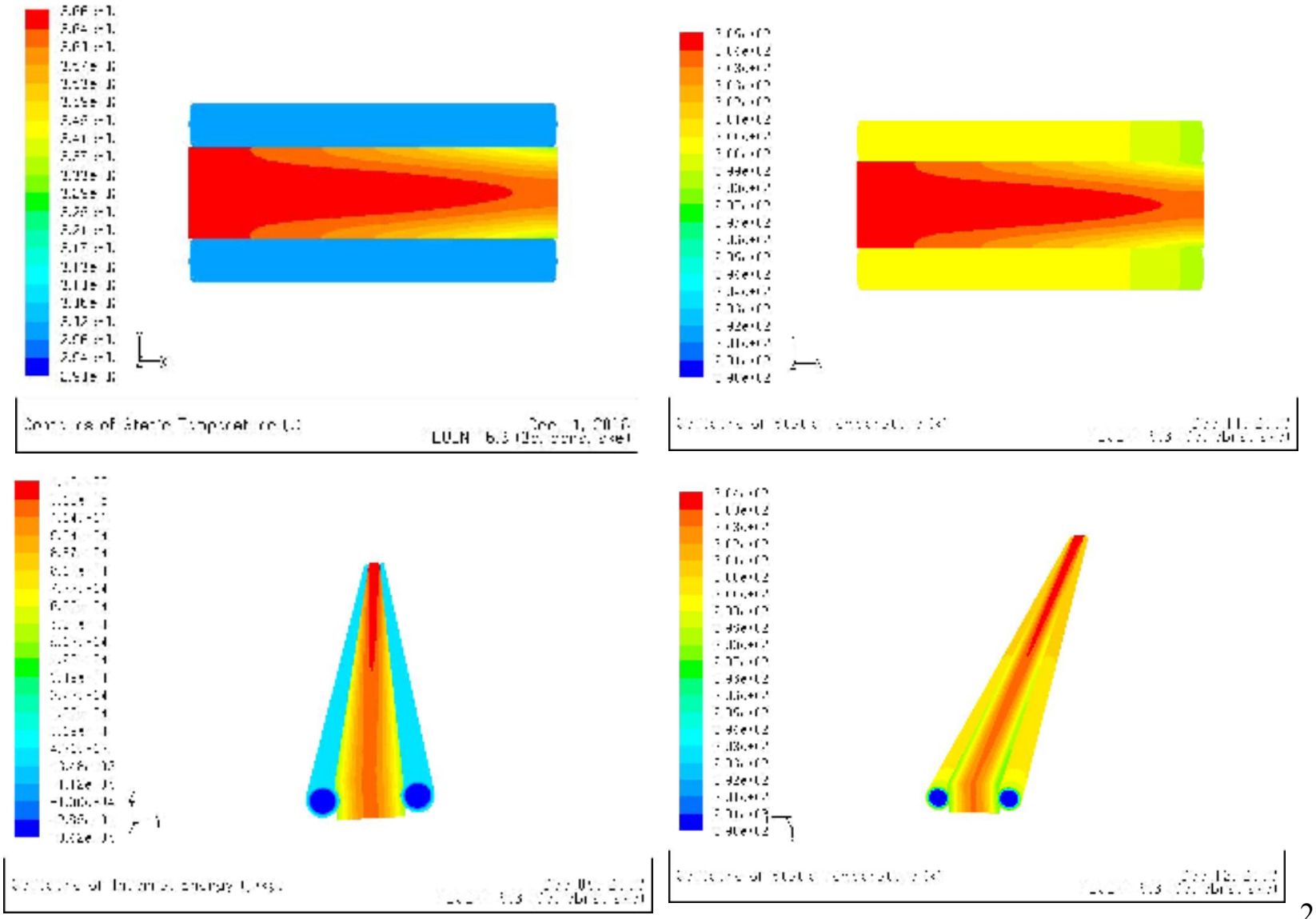
＊ Along with the value of be thermal conductivity increasing, the heat removal capability is improved.

＊ when the thermal conductivity reach a certain value(160 w/m-k) ,the heat removal effect was improved slowly.

＊ The fluid flow would influence the thermal conducting activities a little, if the pipes are longer ones, and surely the coolants would bring out much more heat.







● Summary

※ The peak temperature would appear in the Li2TiO3 pebbles regions due to the neutron heat distribution at a high level in these region, it influence the hydraulic transportation so much due to the lower thermal conductivity.

※ The outlet temperature of will be mainly depended on the heat distribution.

※ The pressure loss will be depended on many factors, as the inlet velocity, MFR, the density and the viscosity of the coolant and also including some structure factors.

※ Pebble touching has the lower efficiency than the plate touching for the solid breeders thermal transportation.

※ 30-60 w/k-m is the sufficient value for thermal conductivity of the solid breeder materials.

※ The touching area is the significant for the thermal conduction almost with a linear distribution of the heat removal capability. Very short length for touching arc under the 1mm would not be recommended.

Thanks!