Karlsruhe Institute of Technology

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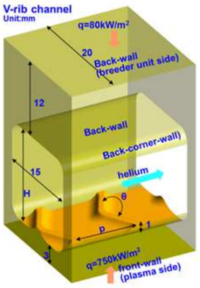
Optimization of Channel for Helium Cooled DEMO First Wall by Application of One-sided V-shape Ribs

The plasma facing first wall (FW) of a fusion power reactor has to absorb high heat fluxes from the plasma. Helium gas as a coolant offers several advantages in terms of safety. However the use of standard smooth cooling channel surfaces are limited regarding the cooling of high heat flux components in fusion power reactors. Based on our previous assessments, a round-edged, one-side-ribbed rectangular channel was chosen as the baseline geometry, with the ribbed-side facing the plasma-facing wall. Optimizations were done on a V-shaped one-side-ribbed channel by means of CFD simulation, focusing on the rib pitch, rib angle and channel height.

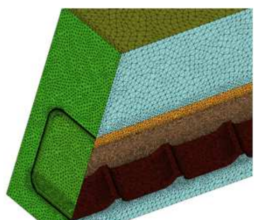
Geometry:
- Channel width: 15mm;
- Channel height: 7.5~15mm;
- V-Rib angle: 20~120°;
- Rib pitch: 4.5~10mm.

Boundary Conditions:
- Helium inlet pressure 8MPa, 340°C; mass flux ~ 222 kg/s/m²;
- Constant wall heat flux of 750kW/m² on the plasma side (front-wall) and 80kW/m² on the Breeder Unit side (back-wall).

CFD Tool:
- Ansys CFX V14.0
- Using the Reynolds Stress Model (RSM), k-ω SST model (SST) and the Scale-Adaptive Simulation (SAS).

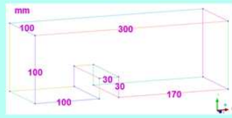


mesh

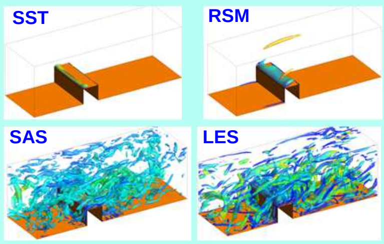


Test Case: iso-thermal flow in a transversal-ribbed channel*.

Fluid: air 1 atm, 25°C
Re: 40000
U_{bulk}: 6.18m/s



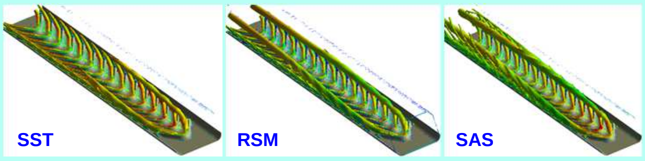
*Casarsa, L.: 2003, 'Aerodynamic performance investigation of a fixed ribroughened internal cooling passage'. Ph.D. thesis, Von Karman Institute for Fluid Dynamics.



Comparison of iso-surfaces of Q-criterion

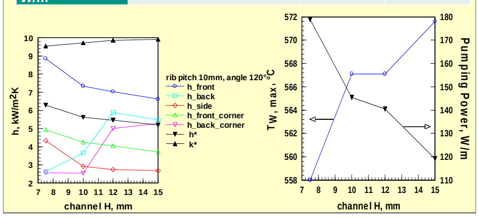
Comparison of Turbulence Models

model	RSM	SST	SAS
$T_{w,max}$, °C	552.4	545.2	551.9
$T_{w,ave}$, °C	428.6	424.8	428.1
h_{front}, kW/m²K	7.25	7.93	7.61
h_{back}, kW/m²K	3.17	3.35	3.23
h_{side}, kW/m²K	3.36	3.69	3.76
$h_{front-corner}$, kW/m²K	4.44	4.91	4.63
$h_{back-corner}$, kW/m²K	2.32	2.09	1.99



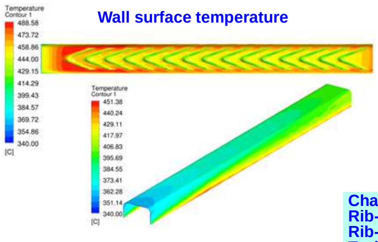
Effect of Channel Height

Height	7.5	10	12	15
A_{cross}, mm²	109.07	146.57	176.57	221.57
G, kg/s	0.0245	0.0327	0.0392	0.0490
D_h, mm	10.50	12.59	13.97	15.67
Re	72122	86163	95500	106976
$T_{w,max}$, °C	558.0	567.1	567.1	571.6
H_{front}, kW/m²K	8.85	7.34	7.03	6.62
h*, kW/m²K	6.29	5.62	5.47	5.20
k*, kW/m²K	9.54	9.72	9.86	9.91
f_D	0.1120	0.0843	0.0764	0.0591
Pumping Power, W/m	178.9	145.4	140.5	119.2

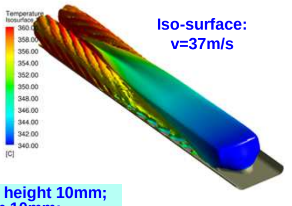


Flow & Temperature Fields

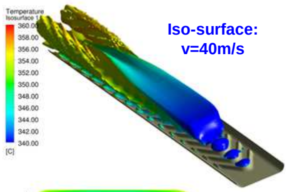
Wall surface temperature

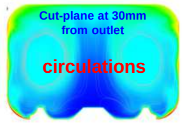


Iso-surface: v=37m/s



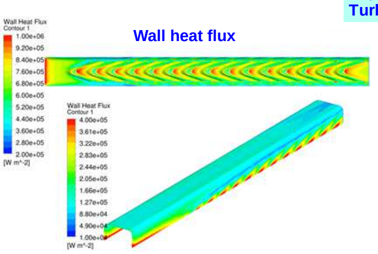
Iso-surface: v=40m/s



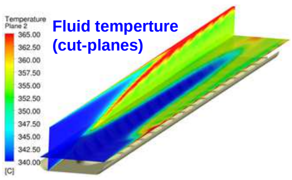


Channel height 10mm;
Rib-pitch 10mm;
Rib-angle 40°;
Turb. Model: SAS

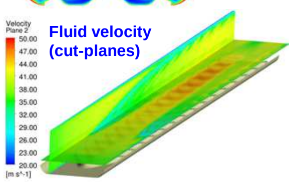
Wall heat flux



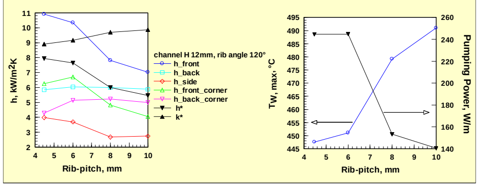
Fluid temperture (cut-planes)



Fluid velocity (cut-planes)



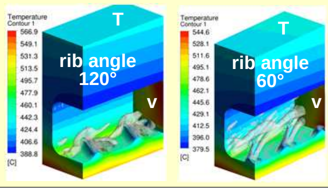
Effect of Rib Pitch

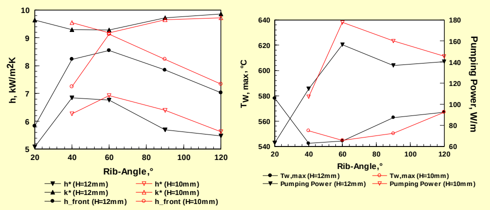


Effect of Rib Angle

Near-wall flow structure and temperature, velocity fields.

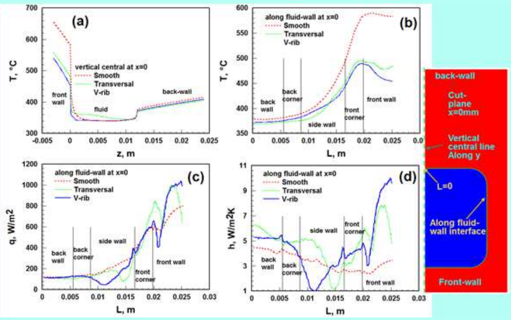
Channel H = 12mm, Rib-pitch 10mm





Comparison of smooth, transversal ribbed and V-ribbed channels

	smooth	Transversal-rib	V-rib
A/A_0 (front)	1.00	1.22	1.13
$T_{w,max}$, °C	659.1	578.9	567.1
h_{front}, kW/m²K	2.87	5.48	7.03
h_{back}, kW/m²K	4.77	6.52	5.88
h_{side}, kW/m²K	3.09	3.21	2.74
$h_{front-corner}$, kW/m²K	2.63	4.18	4.05
$h_{back-corner}$, kW/m²K	4.42	5.67	5.00
h*, W/m²/K	3.14	5.01	5.47
k*, W/m²/K	11.28	10.01	9.86
f_D	0.0276	0.0708	0.0764
Pumping Power, W/m	50.6	130.3	140.5



- The effect of the channel height on the maximum wall temperature is relatively small; the decrease of rib pitch leads to decreasing of maximum wall temperature, while also leads to a relatively large increase of pumping power.
- The modification of rib angle can be made to reduce the wall temperature without significantly increasing the pumping power.
- Overall, the V-ribbed channel with a channel height of 10mm, rib pitch of 10mm and rib angle of 40° is one of the favorable configurations, which can achieve a heat transfer enhancement by a factor of 2.8 compared to the smooth channel and reduces the maximum wall temperature by about 100°C.
- A major mechanism of heat transfer enhancement for the V-ribbed channels (with the "V" pointing upstreams) is the two large scale circulations induced by the two legs of the V-ribs. Therefore, it is believed that for a given coolant flow rate there is an optimal rib angle.
- The SAS model can be used for predicting the flow in ribbed channels. The RSM and SST models are unable to reveal the turbulent structures; while the RSM model can provide similar predictions of temperature and heat transfer coefficient as the SAS model.

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