International Journal of Research in Engineering, Science and Management
Volume-1, Issue-10, October-2018
www.ijresm.com | ISSN (Online): 2581-5792

Numerical Investigation of the Effective Parameters on Cooling Characteristics of Sub Cooled Boiling Nuclear Reactor System

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***Abstract*—The two phase liquid-vapour flow in a Nuclear reactor core is an important part of the nuclear power generation process. In order to improve the safety and economics of a Nuclear reactor, it is essential to understand the mechanisms governing this flow and the mechanism governing the formation of vapour bubbles at the Critical Heat Flux. While prior research exists about nucleation and heat transfer at normally achievable temperatures and pressures, not enough is known about nucleation at nuclear conditions. In this work we investigate the present capabilities of computational fluid dynamics for wall boiling. The computational model used combines the Euler/Euler two-phase flow description with heat flux partitioning. This kind of modelling was previously applied to boiling water under high pressure conditions relevant to nuclear power systems. Current study is mainly focused on the geometrical parameters' which one is play a major role in nuclear reactor cooling; here we are investigating the effect of CCD (Coolant Chanel dia.) and centre to centre distance of tube variations on cooling characteristics of moderate water in nucleate boiling channel system. CFD Simulation results shows an excellent stable flow stream in whole system and finally we analyzed that higher value of both parameters temperature drop is increasing but pressure is dropped which is desirable for cooling purposes and safety of the system.**

***Index Terms*— Boiling Flow, Bubble Pump, CFD, Subcooled flow boiling; Computational fluid dynamics simulation; Heat flux partitioning; Two-fluid model reactor coolant system, nuclear reactor etc.**

I. INTRODUCTION

The importance of heating surface conditions to boiling processes has been recognized for decades. It has been found that bubbles originate from pre-existing vapor or gas pockets captured in pits, cavities, scratches and grooves (all generally referred as cavities) on a heating surface. The cavity size and shape have proved to be critical to entrap vapor and/or gas and to initiate a bubble, and have already been explored by various researchers. In addition, the active nucleation site density is a key parameter to predicting the boiling heat flux, and has been extensively studied. The following section gives some of the important research on nucleation sites, their densities and distributions.

A. Bubble Dynamics

During a boiling process, energy from the heating surface is first transferred to superheated liquid layer adjacent to the wall, and the majority of the energy is then transferred to bubbles in the form of latent heat. The remaining energy is transferred to the bulk flow through single phase convection. Bubbles play an important role during the boiling process since, (1) size and number of bubbles directly determine the amount of latent heat transferred by bubbles, and (2) single phase forced convection is greatly enhanced by bubble motion through departure and lift-off. In this section, some fundamental bubble dynamics knowledge is presented from review of the literature.

II. LITERATURE REVIEW

During the past decades, extensive efforts have been devoted to understanding boiling phenomena, including both pool boiling and flow boiling. These efforts include direct experimental measurements and observations, theoretical analyses, empirical correlations, model developments, etc. In recent years, with the help of state-of-the art technologies, such as high-speed digital cameras and thermo chromic liquid crystals, more insightful information has been obtained to understand the boiling process. Some of the latest findings include knowledge on fundamental bubble dynamics, active nucleation site densities, bubbles and nucleation site interactions, heat flux predictions, critical heat flux models, etc. The literature review presented in this chapter will mainly focus on several key topics of sub cooled flow boiling heat transfer. These include activation of nucleation sites, their densities and distributions, bubble dynamics, and sub cooled flow boiling heat transfer correlations and models.

III. OBJECTIVE OF THE STUDY

The purpose of this study is to demonstrate the modeling of forced convection sub cooled nucleate boiling using the in-built boiling model available under Eulerian multiphase model.This study demonstrates how to do the following:

- Create a single phase flow solution and use the fully-developed outlet as an inlet

- For the multiphase calculation.
- Define solution-dependent material properties as piecewise-linear functions of temperature.
- Use outlet profiles from one simulation as inlet conditions for another simulation.
- Set up the Eulerian multiphase model to predict boiling.
- Run the calculation to obtain a steady-state solution.
- Post process the resulting data.

IV. METHODOLOGY

Computational fluid dynamics (CFD) is a computer-based simulation method for analyzing fluid flow, heat transfer, and related phenomena such as chemical reactions. This project uses CFD for analysis of flow and heat transfer. Some examples of application areas are: aerodynamic lift and drag (i.e. airplanes or windmill wings), power plant combustion, chemical processes, heating/ventilation, and even biomedical engineering (simulating blood flow through arteries and veins). CFD analyses carried out in the various industries are used in R&D and manufacture of aircraft, combustion engines, as well as many other industrial products. It can be advantageous to use CFD over traditional experimental-based analyses, since experiments have a cost directly proportional to the number of configurations desired for testing, unlike with CFD, where large amounts of results can be produced at practically no added expense. In this way, parametric studies to optimize equipment are very inexpensive with CFD when compared to experiments.

1) *Pre-processing: CAD Modeling*

Creation of CAD Model by using CAD modeling tools for creating the geometry of the part/assembly of which you want to perform FEA.CAD model may be 2D or 3d.

2) *Meshing*

Meshing is a critical operation in CFD. In this operation, the CAD geometry is discretized into large numbers of small Element and nodes. The arrangement of nodes and element in space in a proper manner is called mesh. The analysis accuracy and duration depends on the mesh size and orientations. With the increase in mesh size (increasing no. of element), the CFD analysis speed decrease but the accuracy increases.

3) *Type of Solver*

Choose the solver for the problem from Pressure Based and density based solver.

4) *Physical model*

Choose the required physical model for the problem i.e. laminar, turbulent, energy, multi-phase, etc.

5) *Material Property:*

Choose the Material property of flowing fluid.

6) *Boundary Condition*

Define the desired boundary condition for the problem i.e. temperature, velocity, mass flow rate, heat flux etc.

7) *Solution*

- Solution Method : Choose the Solution method to solve the problem i.e. First order, second order
- Solution Initialization: Initialized the solution to get the initial solution for the problem.
- Run Solution: Run the solution by giving no of iteration for solution to converge.

8) *Post Processing*

For viewing and interpretation of Result. The result can be viewed in various formats: graph, value, animation etc.

V. RESULTS

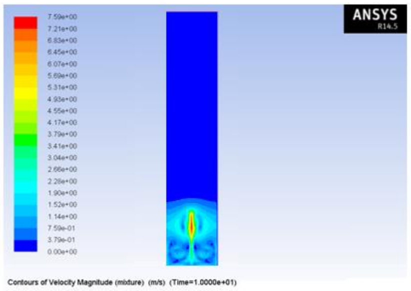

Fig. 1. Contours of Velocity magnitude (Liquid moderator) in time step bubble formation process

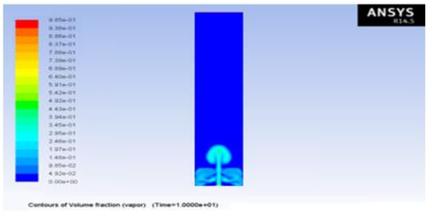

Fig. 2. Complete bubbles formation in vapour form

A. *Application of Nucleate Boiling in Nuclear Reactor*

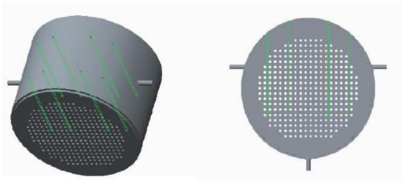

Fig. 3. CAD Model of reactor palate

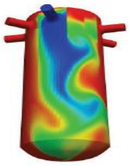

Fig. 4. Temperature profile in reactor Surface

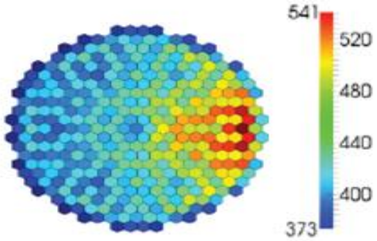

Fig. 5. Pressure profile in Tube bundles Surface

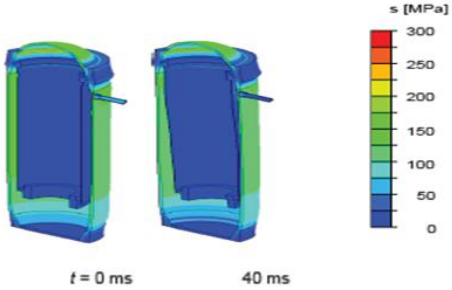

Fig. 6. Volume fraction of vapour pressure profile in reactor wall Surface

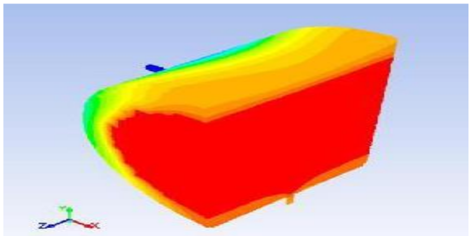

Fig. 7. Contour of Heat flux in Reactor Surface

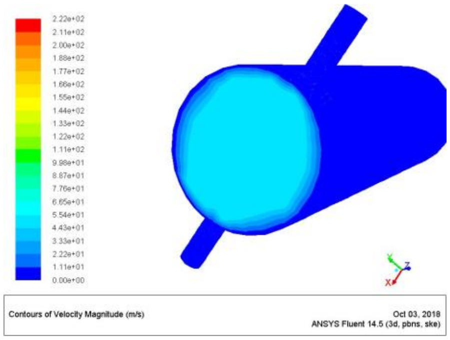

Fig. 8. Contour of Velocity magnitude in Reactor Surface

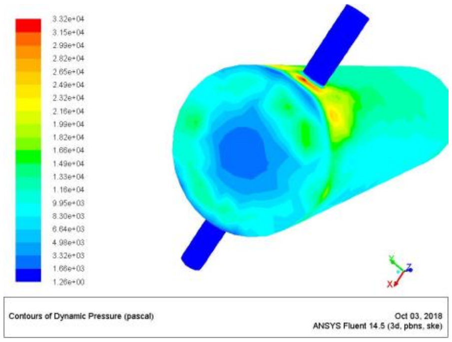

Fig. 9. Contour of Total Pressure in Reactor Surface

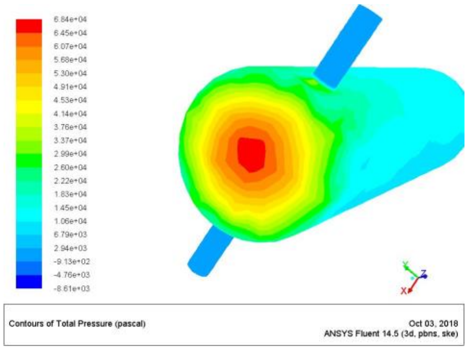

Fig. 10. Contour of Dynamic Pressure in Reactor Surface

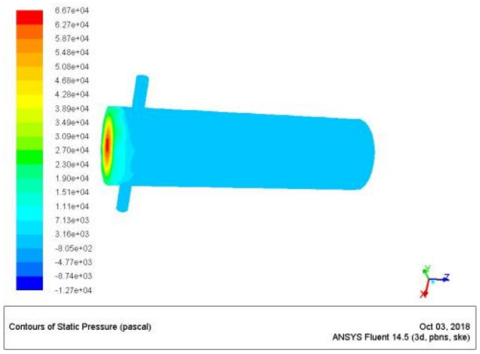

Fig. 11. Contour of static Pressure in Reactor Surface

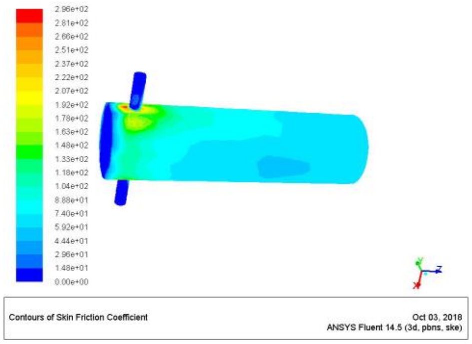

Fig. 12. Contour of friction coefficient in Reactor Surface

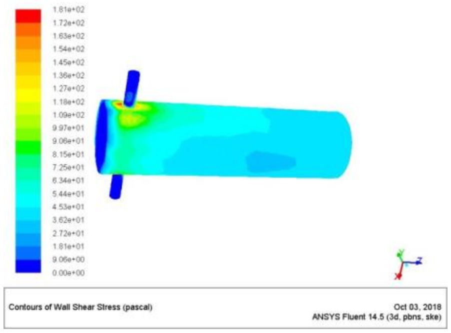

Fig. 13. Contour of wall shear stress in Reactor Surface

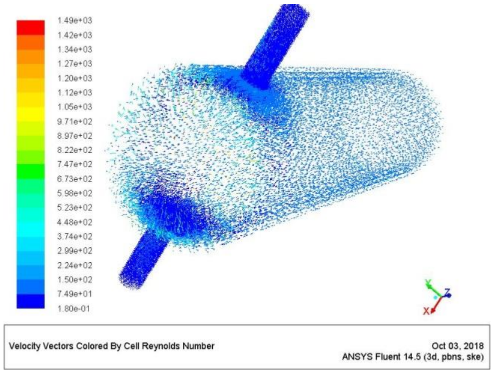

Fig. 14. Contour of Reynolds Number in Reactor Surface

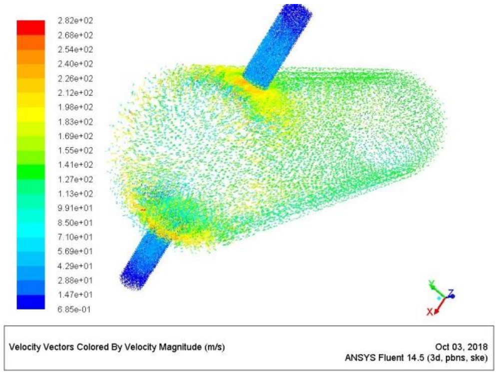

Fig. 15. Contour of velocity vector in Reactor Surface

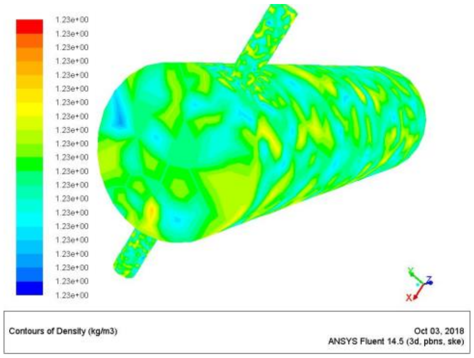

Fig. 16. Contour of density in Reactor Surface

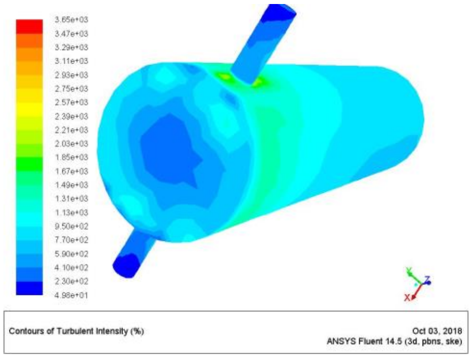

Fig. 17. Contour of Turbulence Intensity in Reactor Surface

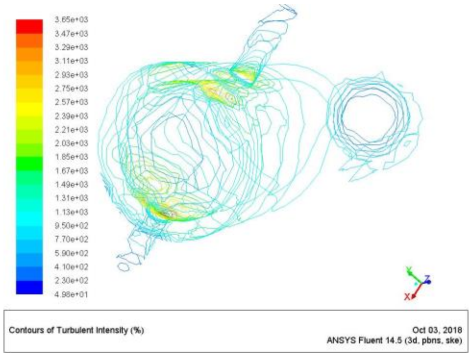

Fig. 18. Contour of Turbulence Intensity (wireframe) in Reactor Surface

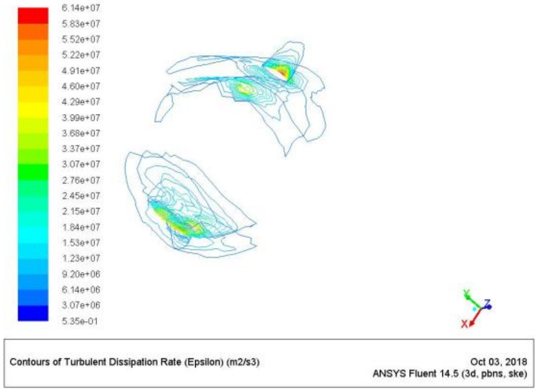

Fig. 19. Contour of Turbulence dissipation rate (wireframe) in Reactor Surface

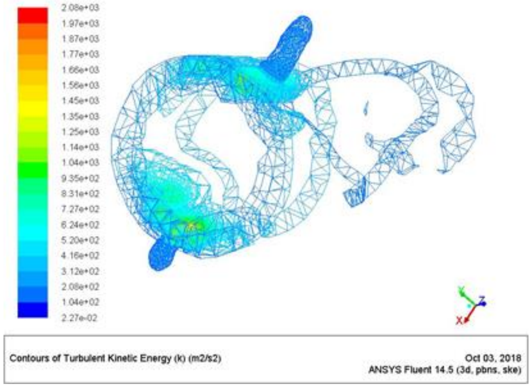

Fig. 20. Contour of Turbulence kinetic energy (wireframe) in Reactor Surface

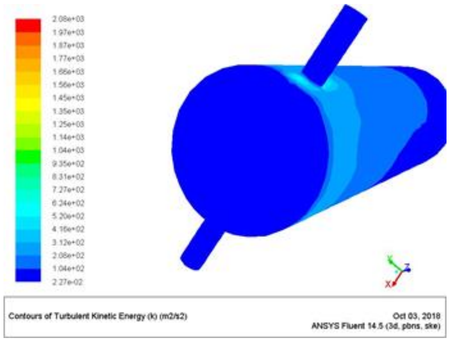

Fig. 21. Contour of Turbulence kinetic energy (layer form) in Reactor Surface

TABLE I
RESULTS

CASES	Tube (Centre to Centre distance) mm	CCD (Coolant Channel Dia) mm	Hot Leg Temperature (K)	Cool Leg Temperature (K)	Effective mass flow rate (Kg/s)	Temperature drop (k)	Pressure (Pa)
CASE 1	228.6	107.7	4000	1270	2.4	2730	317
CASE 2	228.6	102.7	4200	1300	1.9	2900	329
CASE 3	228.6	112.7	3850	1320	2.5	2530	310
CASE 4	228.6	117.7	3700	1450	2.7	2250	295
CASE 5	218.6	122.7	3800	1300	2.2	2500	300
CASE 6	238.6	127.7	3520	1654	3.2	1866	270
CASE 7	248.6	132.7	3350	1700	3.8	1650	240

VI. CONCLUSION

Understanding of the flow field under the reactor vessel head is very important for an after cooling process of the reactor when there is a various number of reactor coolant system loops (CSL) connected to the reactor. This is, especially, of great importance in the case of the emergency regime, because heat dissipation from the primary circuit is not always operating with full number coolant loops in this case. The aim of these calculations was to determine the velocity profile and the flow rate at the upper perforated plate under the reactor vessel head in case of a various number of coolant loops. These parameters are the main factors affecting the cool down of the reactor cover, because deformed velocity profiles lead to an asymmetrical flow field, which has the impact on the temperature field under the reactor cover. In present case two sides of the reactors which is hot leg and cool leg is investigated by various geometrical cases applying CFD tools and results shows a stable flow phenomenon. Simulative results with different cases are analyzed to complete system as per pressure, temperature drop and flow rate of moderate water. CCD (Coolant Chanel dia.) or CCL (Coolant Chanel loop) and center to center distance of coolant tube are very effective in sub cooled nucleate boiling in nucleate reactor. In current study we are taken CCD and tube distance as variable parameters in investigate the cooling characteristics of moderate water by nucleate boiling phase. These are the final conclusion points which occurs by CFD Simulation results and shown in results table no. 1-

- When we decrease the CCD, temperature drop and effective mass flow rate is decreasing but pressure is in a higher range which is not a desirable condition for cooling of nuclear reactors.
- As we increased the CCD, pressure is decreasing and other parameters like mass flow rate & temperature drop is increasing. Temperature drops the difference between hot leg temp. And cool leg temperature, which shows the cooling characteristics of the moderate water at nucleate phase.
- Similarly, by the shorter distance between tubes have a negative effect on the cooling characteristics of fluid and increase the pressure of the entire system which is not required for the better cooling and safety of the reactor walls.
- CTC of Tube have a great effect on the cooling capacity of the system as we increased the CTC distance with 10 mm intervals , pressure is decreasing in a efficient manner while temperature drop and effective mass floe rate is getting higher range.
- Finally we conclude by the investigation of all the cases as per CFD Simulation results that the CCD and CTC of Tube play a major role in nuclear reactor cooling by nucleate boiling process.

REFERENCES

[1] V. Pržulj & M. Shala Ricardo Software, Ricardo UK Limited Shoreham-by-Sea,West Sussex, UK Multi-phase mixture modelling of nucleate boiling applied to engine coolant flows Computational Methods in Multiphase Flow V 135.
[2] B. Končar E. Krepper Y. Egorov CFD Modeling Of Subcooled Flow Boiling For Nuclear Engineering Applications International Conference Nuclear Energy for New Europe 2005 Bled, Slovenia, September 5-8, 2005 .
[3] Roland Rzehak and Eckhard Kreppe “CFD for Subcooled Flow Boiling : Parametric Variations Hindawi Publishing Corporation Science and Technology of Nuclear Installations, 2013.
[4] Z. E. Karoutas, Y. Xu, L. David Smith, III, P. F. Joffre, Y. Sung “USE OF CFD To Predict Critical Heat Flux In Rod Bundles” Westinghouse Electric Company 5801 Bluff Rd, Hopkins, SC 2906.
[5] C. Baudry, N. Mérigoux, J. Laviéville, S. Mimouni and M. Guingo Progress On Computation Of Boiling Flow In Fuel Assemblies With Neptune_CFD Electricité de France, R&D Division 6 Quai Watier, 78401 Chatou, France.
[6] C. Baudry, N. Mérigoux, J. Laviéville, S. Mimouni and M. Guingo CFD Simulation Of Forced Convective Boiling In Heated Channels Forschungs zentrum Rossendorf, Germany.
[7] Mohammad Amin Abdollahi, Abtin Ataei, Mohammad Heydari Water Boiling Heat Transfer in Vertical Jacketed Pipe: A CFD Model, International Conference on Chemical, Civil and Environmental Engineering (CCEE-2015) June 5-6, 2015 Istanbul (Turkey).
[8] Roland Rzehak, Eckhard Krepper CFD simulation of DEBORA boiling experiments, archives of thermodynamics Vol. 33(2012), No. 1, 107–122
[9] Vijaya Raghava Paravastu Pattarabhiran, Experimental Investigation Of Effects Of Coolant Concentration On Subcooled Boiling And Crud Deposition On Reactor Cladding At High Pressures And High Temperatures, International Journal of Fluid Mechanics & Thermal Sciences 2015; 1(2): 36-41
[10] Michael P Rile. Development Of A Correlation For Nucleate Boiling Heat Flux on a Hemispherical Downward Facing Surface archives of thermodynamics Vol. 33(2012), No. 1, 107–122.
[11] Lionel Nelson Lobo, Photographic Study of Nucleate Boiling on the Surface of a Heated Rod Applied and Computational Mechanics 1 (2007) 499 – 506.
[12] Kazuaki Kobayashi, Osamu Nakamura Yoichi Haraguchi- Water Quenching Cfd (Computational Fluid Dynamics) Simulation With Cylindrical Impinging Jets Nippon Steel & Sumitomo Metal Technical Report No. 111 March 2016

[13] Hariswaran Sitaraman, Gilberto Moreno, Local-Scale Simulations Of Nucleate Boiling On Micrometerfeatured Surfaces, Proceedings of ASME Summer Heat Transfer Conference SHTC2017 July 9-14, 2017, Bellevue, Washington, USA.

[14] Hemant Punekar and Saurish Das, Numerical Simulation of Sub cooled Nucleate Boiling in Cooling Jacket of IC Engine, SAE International by ANSYS Inc, Monday, September 14, 2015.

[15] Hussam Jouhara , Bandar Fadhl , Luiz C. Wrobel , Three-Dimensional CFD Simulation Of Geyser Boiling In A Two-Phase Closed Thermosyphon.

[16] H.B. Zhang Y.Y. Yan , Y.Q. Zu ,Numerical modelling of EHD effects on heat transfer and bubble shapes of nucleate boiling, Applied Mathematical Modelling 34 (2010) 626–638

[17] C.D. Moyes, M.L. Sharma, C. Lyons, S.C. Leary, M. Leon, A. Petrie, S.G. Lund, B.L. Tufts, Origins and consequences of mitochondrial decline in nucleated erythrocytes Biochimica et Biophysica Acta 1591 (2002) 11-20.

[18] G.H. Yeoh , J.Y. Tu, Two-fluid and population balance models for subcooled boiling flow Australian Nuclear Science and Technology Organisation (ANSTO), B40, ANSTO, Private Mail Bag, Menai, NSW 2234, Australia b School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Vic. 3083, Australia

[19] Zhihui Xie, Lingen Chen, Fengrui Sun Geometry optimization of T-shaped cavities according to constructal theory Postgraduate School, Naval University of Engineering, Wuhan 430033, China Mathematical and Computer Modelling 52 (2010) 1538–1546

[20] Vedanth Srinivasan , Kil-Min Moon , David Greif , De Ming Wang , Myung-hwan Kim, Numerical simulation of immersion quenching process of an engine cylinder head Numerical simulation of immersion quenching process of an engine cylinder head Advanced Simulation Technologies, AVL Powertrain Engineering Inc., Plymouth, MI 48170, USA b Advanced Technology and Analysis Team, R&D Div. for Hyundai Motor Company and Kia Motors Corp., 772-1 Jangduk-Dong Hwaseong, Republic of Korea c AVL Advanced Simulation Technologies (AST), Maribor, Slovenia

[21] Ci Chu, Kun Qu, Franklin L. Zhong, Steven E. Artandi, and Howard Y. Chang Genomic Maps of Long Noncoding RNA Occupancy Reveal Principles of RNA-Chromatin Interactions 1Howard Hughes Medical Institute and Program in Epithelial Biology, Stanford University School of Medicine, Stanford, CA 94305, USA.

[22] J. Wobst a,b , Apurwa Sharma d , Marc I. Diamond d , Erich E. Wanker b, Jan Bieschke The green tea polyphenol ()-epigallocatechin gallate prevents the aggregation of tau protein into toxic oligomers at sub stoichiometric ratios Heike .

[23] Polyamines Loı¨c Hamon, Philippe Savarin, Patrick A. Curmi, and David Pastre, “Rapid Assembly and Collective Behavior of Microtubule Bundles in the Presence of Polyamines,” Biophysical Journal Volume 101 July 2011 205–216

[24] PKim Lau Nielsen, Viggo Failure by void coalescence in metallic materials containing primary and secondary voids subject to intense shearing, International Journal of Solids and Structures 48 (2011) 1255–1267

[25] Baoyu Chen, Klaus Brinkmann, The WAVE Regulatory Complex Links Diverse Receptors to the Actin Cytoskeleton, Cell 156, 195–207, January 16, 2014 Elsevier Inc.