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# Numerical Simulation of Evaporation to Assess Water Management Performance of Vehicles

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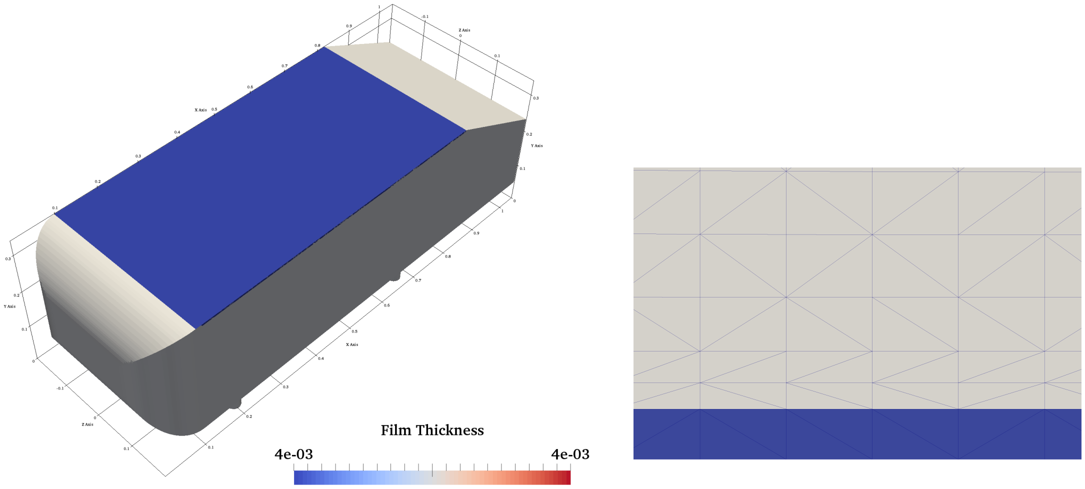
## Abstract

Despite sophisticated design of water management systems in vehicles there exist areas where drainage system is ineffective resulting in accumulation of water droplets/thin films. These areas are susceptible to localized corrosion if the water does not evaporate. Therefore it becomes necessary to determine firstly if evaporation of water occurs and secondly to predict duration of evaporation. Experimental investigations are difficult to perform due to complex geometries and hard to access areas, such as inside sunroof channel and inside internal structure of vehicle's door, and number of parameters involved, such as temperature, humidity, air velocity, and exposed surface area [1], leading to the need of numerical simulations. Furthermore multiphase nature of the flow, moving interfaces, simultaneous heat and mass transfer, and discontinuity of physical properties are part of the challenges of numerical simulation of evaporation phenomena [2]. This paper utilizes multiphase capability of OpenFOAM® v1812 for numerical simulation of evaporation. The methodology used in this paper is based on Volume of Fluid method, implemented in `icoReactingMultiphaseInterFoam` solver and Liquid Film model implemented in `reactingParcelFoam` solver. The numerical simulations will be validated by comparison with the experimental investigations performed by Narusawa *et al.* [3] and Hisatake *et al.* [1]. After completion of the validation cases this paper focuses on predication of evaporation rate of water droplets/thin films on real vehicle geometry.

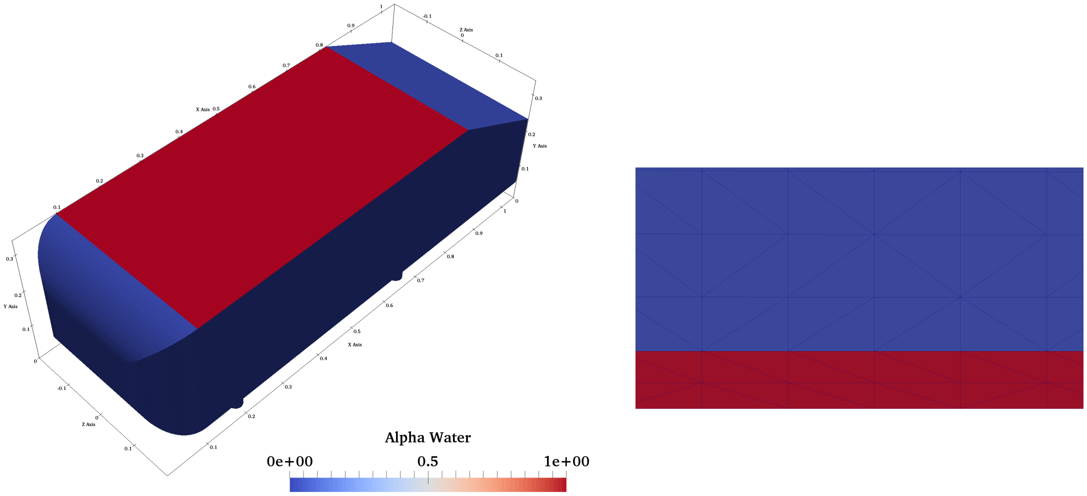
## Surface Wetting

Prior to simulation of evaporation surface wetting should be taken into account. Figure 1 shows two different methods for surface wetting. In the first method the roof of the vehicle is covered with a thin film of $4\,mm$ thickness (1 cell extrusion). This is an efficient method for modeling a 3D phenomena using a 2D approximation [4]. The second method is direct application of VOF method which assigns a scalar quantity, $\alpha$, to each cell. This method might not be practical in applications where film thickness is small in comparison to the other geometrical features [4].



(a) Uniform film thickness

(b) One cell extrusion - 2D approximation



(c) Uniform water thickness

(d) Cells containing water - 3D representation

Figure 1: Comparison between different surface wetting techniques

# Validation

## Validation Case 1: Evaporation Rates of Water in a Vacuum Chamber

Narusawa *et al.* [3] studied the rate of mass transfer during evaporation of water from a stagnant pool and from a flowing surface. For the case of stagnant pool two different cylindrical containers with internal diameters of $7\,cm$ and $5\,cm$ and height of $2\,cm$ were placed in a vacuum chamber, as shown in Figure 2. The method of evaporation rate calculation was by measuring the change in the height of the water level for a period of $5\,min$ using tip of a needle. The measurements were presented by calculation of pressure difference, $\Delta P = P_{sat} - P_{vapor}$. The reduction of the pressure difference leads to reduced evaporation rate. Moreover higher pressure difference causes rise of evaporation rate. Lower pressure difference basically means higher humidity resulting in significant reduction of evaporation rate. Figure 3 shows the computational domain used in this study.

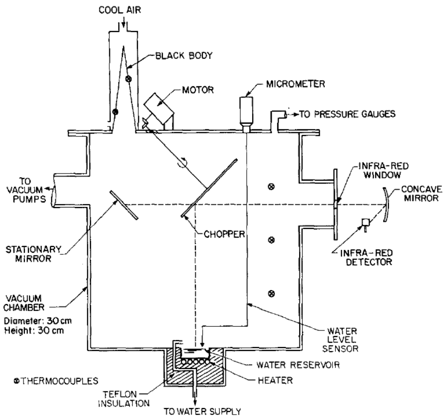


Figure 2: Schematic of apparatus used by Narusawa *et al.*[3]

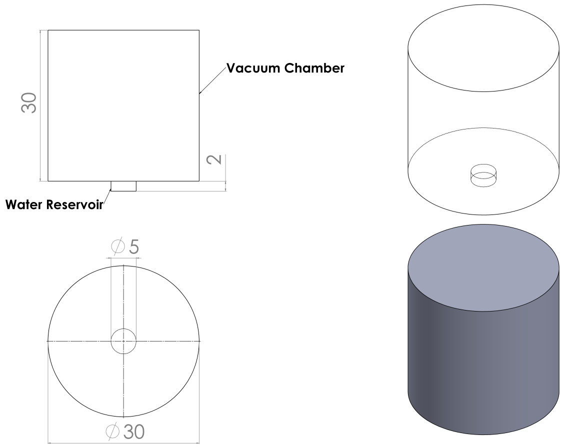


Figure 3: Schematic of computational domain. Scale is in centimeters.

## Validation Case 1 - Initial Results

Figure 4 shows comparison of VOF method with experimental study conducted by Narusawa *et al.* [3]. The experiments were conducted for different surface temperatures ranged from 18 to 27 °C. In this study only water surface temperature of 20 °C is considered. It is concluded that mass transfer rate varies linearly with pressure difference, $\Delta P = P_{sat} - P_{vapor}$. The numerical simulations are in good agreement with experimental study at lower $\Delta P$ however at higher $\Delta P$ error increases. This validation case will further investigate the rate of evaporation using liquid film model.

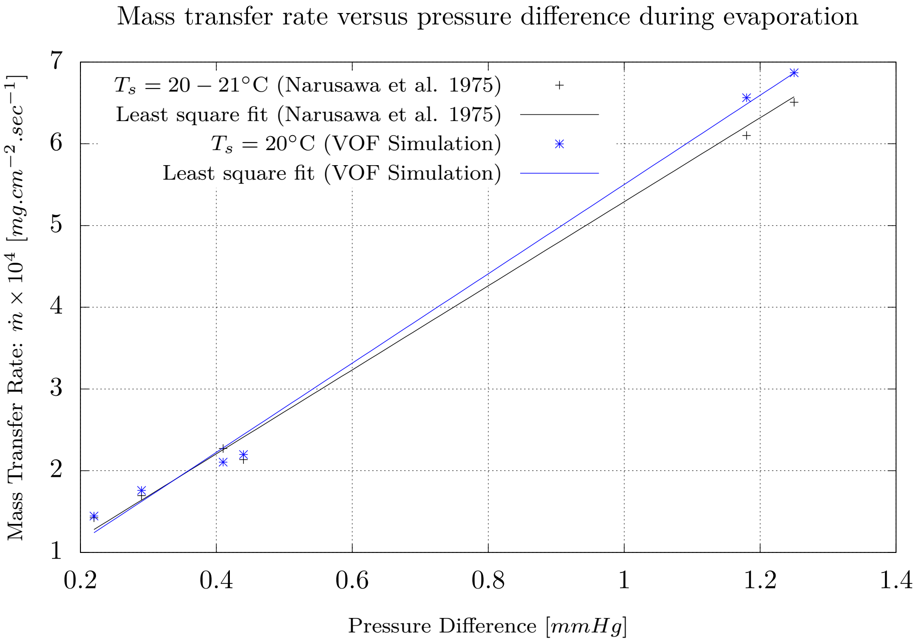


Figure 4: Comparison with experimental investigation conducted by Narusawa *et al.* [3].

## Validation Case 2: Evaporation of Water in a Vessel

Hisatake *et al.* [1] performed experiments for evaluating evaporation rate of water by using a wind tunnel. Two water vessels were placed side by side in the working station of the wind tunnel test section as shown in Figure 5, one used for temperature measurement and one used for measurement of evaporation rate by weighting. Air velocity was set at $0.4, 1.5$, and $5\,m/s$.In addition to the results obtained in the former experiment [5], this experimental setup allowed Hisatake *et al.* [1] to study the effect of evaporation rate with respect to the flow direction as well. Flow was directed parallel (horizontal) to the water surface and perpendicular (vertical) to the water surface using a vertical wind tunnel. In the present study only one of the vessels is considered to be water-filled as shown in Figure 6. The water level is set as $5\,mm$ below the top of the rim of the vessel resulting in water height of $8\,mm$.

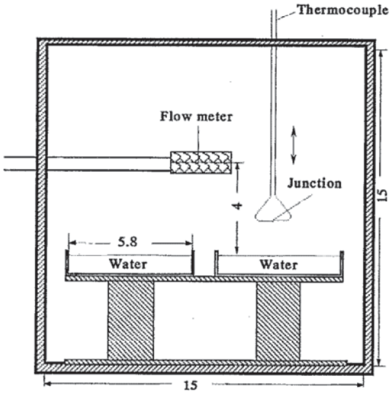


Figure 5: Schematic of apparatus used by Hisatake *et al.* [1]. Scale is in centimeters.

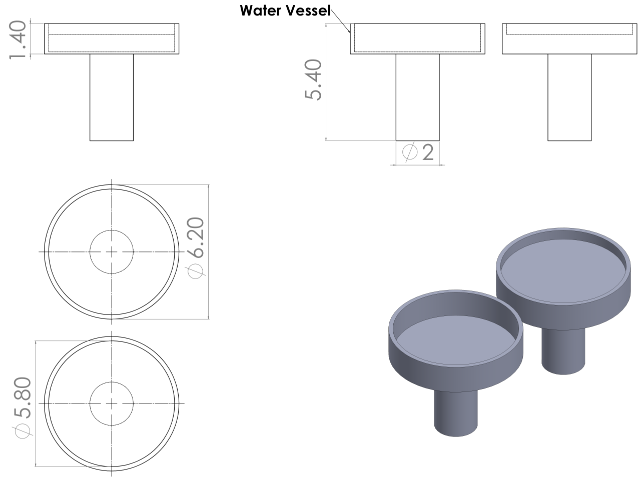
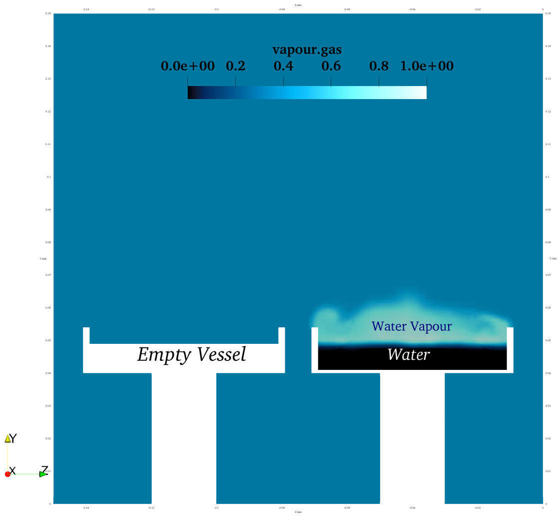


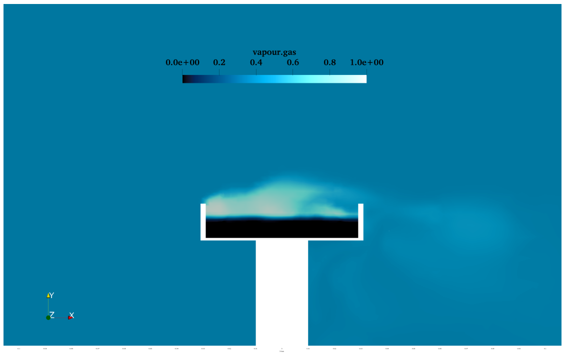
Figure 6: CAD Geometry. Scale is in centimeters.

## Validation Case 2 - Initial Results

Figure 7 shows vapour concentration at air velocity of $0.4\,m/s$, air temperature of $286.6\,K$, and relative humidity of 36% using VOF model. Figure 8 shows water vapour concentration at air velocity of $0.4\,m/s$ and air temperature of $286.6\,K$. It is evident from both figures that the phase change models are capable of correct prediction of evaporation which according to Cengel [6] occurs at the *liquid-vapour* interface in contrast to boiling which occurs at *solid-liquid* interface. Furthermore the effects of air temperature, velocity, and relative humidity on the rate of evaporation will be investigated in this validation case.

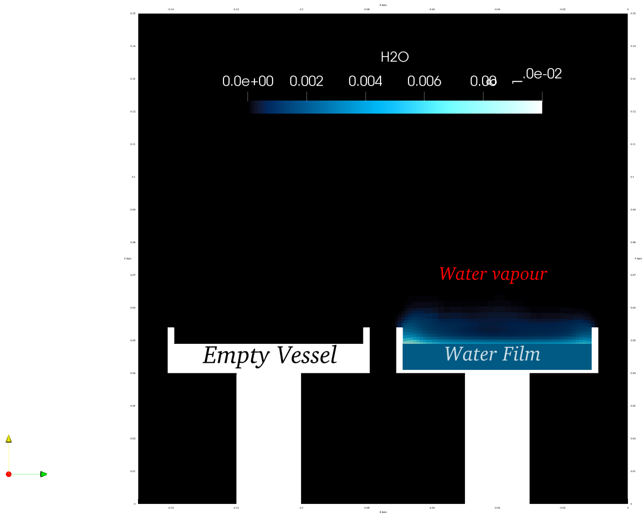


(a) Front view

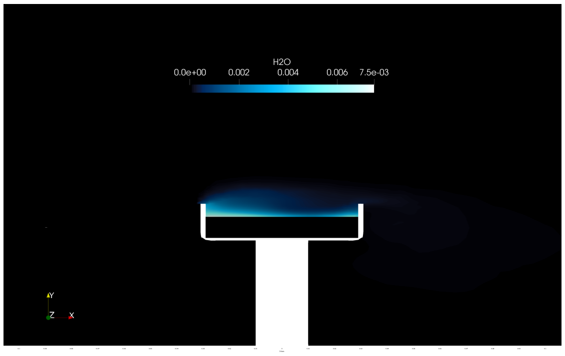


(b) Side view

Figure 7: Initial results of numerical simulation - VOF Model



(a) Front view



(b) Side view

Figure 8: Initial results of numerical simulation - Film Model

# Evaporation on a Real Vehicle

The aim of this study after comparison of numerical simulations with the experimental investigations performed by Narusawa *et al.* [3] and Hisatake *et al.* [1] will be prediction of evaporation rate on a real vehicle geometry considering the effects of air temperature, relative humidity, and air velocity. The implementation of the best methodology will be depending on the complexity of the geometry and the results of the validation cases for the predication of evaporation rate.

# Future Scope

In future the surface film model shown in this paper can be added to `icoReactingMultiphaseInterFoam` solver which can eventually lead to reduction of computational time of a VOF simulation while keeping the same accuracy and benefiting from the key advantage of VOF method which according to Wörner [2] is the excellent conservation of mass of the phases. The coupling of these methods should carefully consider an accurate implementation of a phase change model capable of handling the transition from surface film model to VOF method.

# References

[1] Kazuo Hisatake, Misako Fukuda, Junko Kimura, Mami Maeda, and Yoshiko Fukuda. Experimental and theoretical study of evaporation of water in a vessel. *Journal of applied physics*, 77(12):6664–6674, 1995.

[2] M.Wörner. *A Compact Introduction to the Numerical Modelling of Multiphase Flows.* Forschungszentrum Karlsruhe, 2003.

[3] Uichiro Narusawa and George S Springer. Measurements of evaporation rates of water. 1975.

[4] Hrvoje Jasak. Openfoam: a year in review. In *5th OPENFOAM Workshop, Gothenburg, Sweden, June*, pages 21–24, 2010.

[5] Kazuo Hisatake, Satoko Tanaka, and Youko Aizawa. Evaporation rate of water in a vessel. *Journal of applied physics*, 73(11):7395–7401, 1993.

[6] Yunus A Cengel. *Heat Transfer- A Practical Approach.* McGraw-Hill New York, 2nd edition, 2003.