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Laminar Film Condensation From Moist Air In Vertical Tubes

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Excellent Women Mechanical Engineers

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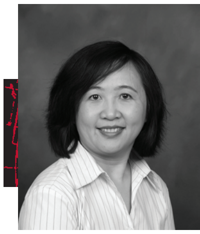

President's Message/Message de la Présidente

Christine Wu, Ph.D., P.Eng., FCSME

President's Message

Since the United Nations declared International Women's Day a "Day for Women's Rights and International Peace" in 1977, much progress has been made in achieving equality for women on many aspects, but there is still a long way to go. According to the World Economic Forum's Global Gender Gap report for 2012, Iceland has claimed the top spot as the Best Place in the World to be a Woman. Canada ranked the 21st place out of 135 countries, one above the United States. Canadian women can expect to earn about 73cents for every dollar a man gets, placing us 35th in the ranking. Also, all of Canada's 21 Nobel prize winners have been men.

Significant funding and efforts have been put to promote women in science and engineering in Canada and in many countries. Remarked from MIT's report on Status of Women Faculty in the Schools of Science and Engineering at MIT, the progress in gender equity in science and engineering is truly a "Celebration with Caveats". In spite of the progress, the discrimination that women still experience in the workplace, work-life balance and performance measurement and management are the three primary challenges among others according to a recent Harvard Business Review article "The Labyrinth of Leadership". Research has repetitively showed that mentorship is helpful to both men and women for their career advancement. It is especially important to women to overcome challenges specifically encountered by women. Research has also recognized the powerful influence of women leaders, and there is no doubt that cultivating women leaders benefits all aspects of our profession and society. In this issue, we showcase five of the many Canadian women who take the leadership in the mechanical engineering profession and serve as role models for others. This is the beginning of an on-going project aiming at inspiring and empowering women to embark on engineering as their careers while celebrating the achievements of women mechanical engineers. I look forward to seeing many more inspiring career profiles from women mechanical engineers.

Christine Wu, Ph.D., P.Eng., FCSME
Professor and NSERC Industrial Research Chair Department of Mechanical and Manufacturing Engineering, University of Manitoba

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Depuis que les Nations Unies ont déclaré la Journée Internationale de la Femme une "Journée des Droits de la Femme et la Paix Internationale" en 1977, beaucoup de progrès ont été accomplis en matière d'égalité pour les femmes sur de nombreux aspects, mais il reste encore un long chemin à parcourir. Selon "World Economic Forum's Global Gender Gap" pour 2012, l'Islande occupe la première place comme le meilleur endroit au monde pour être une femme. Le Canada s'est classé au 21e rang sur 135 pays, juste un point au-dessus des Etats-Unis. Les Canadiennes peuvent s'attendre à gagner environ 73 cents pour chaque dollar qu'un homme gagne, nous plaçant 35e au classement. En outre, l'ensemble des 21 lauréats du prix Nobel au Canada ont été des hommes.

Des fonds considérables et des efforts ont été mis pour promouvoir les femmes en sciences et en génie au Canada et dans de nombreux pays. Remarquer d'après le rapport du MIT sur le statut de la Faculté des Femmes dans les écoles de sciences et de génie du MIT, les progrès dans l'égalité des sexes en science et ingénierie est vraiment une "célébration de mises en garde". En dépit de ces progrès, la discrimination dont les femmes ont toujours dans la mesure du lieu de travail, équilibre travail-vie et de la performance et de la gestion sont les trois principaux défis, entre autres, selon un récent article du Harvard Business Review "Le Labyrinthe du Leadership". La recherche a montré de façon répétitive que le mentorat est utile à la fois aux hommes et aux femmes pour leur avancement de carrière. Il est particulièrement important à surmonter les défis rencontrés par les femmes en particulier. La recherche a également reconnu l'influence de femmes dirigeantes, et il ne fait aucun doute que la culture des femmes dirigeantes profite à tous les aspects de notre profession et de la société. Dans ce numéro, nous présentons cinq des nombreuses femmes canadiennes qui prennent le leadership dans la profession d'ingénieur mécanique et serve de modèles pour d'autres. C'est le début d'un projet en cours visant à inspirer les femmes à se lancer dans l'ingénierie de leur carrière, tout en célébrant les réalisations des femmes ingénieurs en mécanique. J'ai hâte de voir de nombreux profils de carrière plus inspirantes de femmes ingénieurs mécaniques.

Christine Q. Wu, CSME Président

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LAMINAR FILM CONDENSATION FROM MOIST AIR IN VERTICAL TUBES

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Abstract— A numerical analysis is performed for condensing downward flow of moist air in vertical tubes with constant wall temperature. The parabolic governing equations are solved for steady, two-dimensional laminar flow in the liquid film and in the vapour-gas mixture. A complete two-phase model, based on the conservation of mass, momentum, and energy in each phase, is presented. Detailed results are presented in both the film and mixture regions. Those results include radial-direction profiles of velocity, temperature, and gas mass fraction, as well as axial variation of film thickness, Nusselt number, and interface temperature. In all the cases studied, the interface temperature is very close to the wall temperature, and the condensation rates are small due to the very high inlet gas mass fractions.

The effects of varying the inlet Reynolds number (500 to 2000), the inlet relative humidity (60% to 100%), the inlet temperature (25°C and 40°C), and the tube radius (3 mm to 12.5 mm), are examined. It was found that decreasing the inlet relative humidity reduced the heat transfer rate and that the condensate film thickness increased with an increase in the inlet Reynolds number, temperature, and relative humidity. For a fixed Reynolds number, decreasing the tube radius increased the condensation rate.

Keywords- film condensation; numerical model; vertical tube

I. INTRODUCTION

Condensation heat transfer is relevant to many industrial applications [1]. Applications involving condensing two-phase flow phenomena occur in the refrigeration, chemical processing, and thermal power generation industries. Numerous studies have been made on modelling the fluid flow and heat and mass transfer in condensing two-phase flows in order to provide predictions that could improve the design of equipment in those application areas. Models of filmwise condensation in downward flow in a vertical tube have been developed for flows of pure vapour and of vapour-gas mixtures in both laminar and turbulent flows regimes.

For laminar pure vapour flows in a vertical tube, Dobran and Thorsen [2] modelled laminar flow in both the film and the vapour. Starting from the full governing equations, they obtained a set of ordinary differential equations by using an integral analysis and profile assumptions for the velocity in the liquid and in the vapour. They also used a fully-developed inlet velocity profile and studied the effect of selected dimensionless groups.

For laminar film condensation from a gas-vapour mixture in a vertical tube, Groff *et al.* [3] and Dharma Rao *et al.* [4] modelled film condensation from an air-water mixture. Groff *et al.* [3] solved the complete parabolic set of governing equations for laminar film and vapour flow. They presented results on the effects changing the inlet Reynolds number, the inlet-to-wall temperature difference, the inlet pressure, and the inlet gas mass fraction. Inlet gas mass fraction values were limited to 0.80 or less.

Dharma Rao *et al.* [4] used an implicit finite difference method to solve the parabolic momentum, energy, and diffusion equations in the mixture region with a marching scheme along the tube. They based the mixture solution on the vapour density variation rather than the gas mass fraction, and applied an impermeability condition as an equation for the interface mass flow rate. They coupled the mixture region solution to a Nusselt-method-based solution in the film with an approximate equation for the film thickness. They also used an iterative scheme for the interface temperature based on the energy balance at the interface. Dharma Rao *et al.* changed the relative humidity of the inlet air-water-vapour mixture from 60% to 100%. Although they did not explicitly state the inlet vapour density or equivalent gas mass fraction, this range of relative humidity corresponds to very high inlet gas mass fractions (*i.e.*, well above 0.8).

Other models have been developed for the case of turbulent flow of a gas-vapour mixture. Some of those are simplified theoretical models (*e.g.*, [5, 6, 7, 8, 9, 10, 11]) and others are detailed models based on the governing differential equations (*e.g.*, [12, 13]). Among the examples listed, some considered a laminar film and a turbulent mixture flow. All of these and other models for turbulent mixture flow did not study the case of very high gas mass fraction. Therefore, to the authors' best knowledge, besides [4] there have been no other published models for laminar film condensation for downward flow of moist air in a vertical tube.

This article presents the results from a complete two-phase model for laminar film and mixture downward flow in a vertical tube. The model is based on work of Groff *et al.* [3]. It solves the complete parabolic set of governing equations for conservation of mass, momentum, and energy in the film and in the mixture. Inertia terms and energy convection terms are not neglected and conservation of energy and shear at the liquid-mixture interface are accounted for fundamentally. Furthermore, the variation of thermophysical and transport properties is also included. An efficient, fully coupled numerical solution approach is employed that enables conditions with very large inlet gas mass fraction to be solved easily.

Axial variation of film Reynolds number, interface temperature, local Nusselt number, and film thickness are presented. In addition, radial profiles of axial velocity, temperature, and gas mass fraction are presented at various axial stations to illustrate the evolution of the two-phase flow. The effects of changes to the inlet velocity, inlet temperature, inlet relative humidity, and tube radius are examined.

II. Mathematical Model

Figure 1 is a diagram of the physical model being considered. A mixture of vapour and a non-condensable gas enters the tube with a uniform velocity u_{in}, mass fraction W_{in}, temperature T_{in}, and pressure P_{in}. The tube wall is maintained at T_{wall}, which is below the inlet temperature of the mixture. As the mixture flows down the vertical tube, the vapour condenses and forms a liquid film of thickness δ.

In the formulation of the mathematical model, it was assumed that the flow is steady, axisymmetric, and laminar in both the liquid and the mixture; that the liquid-mixture interface is smooth; that both the liquid and mixture are Newtonian fluids; that the pressure is uniform within the tube's cross-section; and that axial diffusion of heat, momentum and mass are negligible. In addition, the vapour-gas mixture is treated as an ideal gas mixture and saturation conditions are assumed at the liquid-mixture interface.

Due to the axisymmetric nature of the flow, the governing equations are written in the r–z coordinate system shown in Fig. 1. The following governing equations are for the conservation of mass, momentum and energy respectively in the liquid region:

$$\frac{\partial}{\partial z}(\rho_L u_L) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho_L v_L) = 0 \tag{1}$$

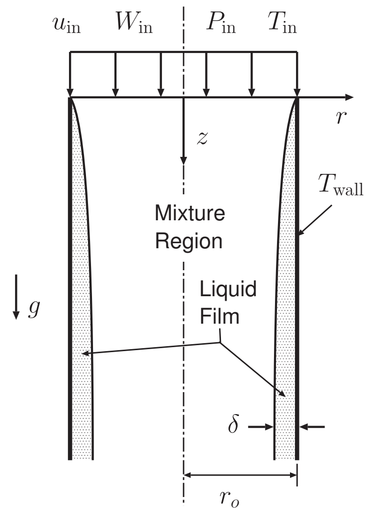

Figure 1. Model domain

$$\frac{\partial}{\partial z}(\rho_L u_L u_L) + \frac{1}{r}\frac{\partial}{\partial r}(r\,\rho_L v_L u_L) = -\frac{dP}{dz} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\,\mu_L \frac{\partial u_L}{\partial r}\right) + \rho_L g \tag{2}$$

$$\frac{\partial}{\partial z}(\rho_L u_L C_{p,L} T_L) + \frac{1}{r}\frac{\partial}{\partial r}(r\,\rho_L v_L C_{p,L} T_L) = \frac{1}{r}\frac{\partial}{\partial r}\left(r\,k_L \frac{\partial T_L}{\partial r}\right) \tag{3}$$

Similarly, the governing equations for the mixture are:

$$\frac{\partial}{\partial z}(\rho_M u_M) + \frac{1}{r}\frac{\partial}{\partial r}(r\,\rho_M v_M) = 0 \tag{4}$$

$$\frac{\partial}{\partial z}(\rho_M u_M u_M) + \frac{1}{r}\frac{\partial}{\partial r}(r\,\rho_M v_M u_M) = -\frac{dP}{dz} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\,\mu_M \frac{\partial u_M}{\partial r}\right) + \rho_M g \tag{5}$$

$$\frac{\partial}{\partial z}(\rho_M u_M C_{p,M} T_M) + \frac{1}{r}\frac{\partial}{\partial r}(r\,\rho_M v_M C_{p,M} T_M) = \frac{1}{r}\frac{\partial}{\partial r}\left(r\,k_M \frac{\partial T_M}{\partial r}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(r\,\rho_M D\,(C_{p,g} - C_{p,v})\frac{\partial W}{\partial r} T_M\right) \tag{6}$$

$$\frac{\partial}{\partial z}(\rho_M u_M W) + \frac{1}{r}\frac{\partial}{\partial r}(r\,\rho_M v_M W) = \frac{1}{r}\frac{\partial}{\partial r}\left(r\,\rho_M D \frac{\partial W}{\partial r}\right) \tag{7}$$

Equation (7) is conservation of mass for the gas.

In Equations (1) to (7), the thermophysical and transport properties were calculated as functions of local pressure, temperature and mixture composition. Details of these calculations can be found in [14].

The following boundary conditions are prescribed:

- at the centre line ($r = 0$):

$$\frac{\partial u_M}{\partial r} = \frac{\partial T_M}{\partial r} = \frac{\partial W}{\partial r} = 0 \tag{8}$$

$$v_M = 0 \tag{9}$$

- at the interface ($r = r_o - \delta$):

$$u_L = u_M \tag{10}$$

$$T_L = T_M = T_{\text{sat}} \tag{11}$$

$$\mu_L \frac{\partial u_L}{\partial r} = \mu_M \frac{\partial u_M}{\partial r} \tag{12}$$

$$\rho_L v_L + \rho_L u_L \frac{d\delta}{dz} = \rho_M v_M + \rho_M u_M \frac{d\delta}{dz} = J_i'' \tag{13}$$

$$k_L \frac{\partial T_L}{\partial r} = k_M \frac{\partial T_M}{\partial r} - J_i'' h_{fg} \tag{14}$$

$$J_i'' W - \rho_M D \frac{\partial W}{\partial r} = 0 \tag{15}$$

- at the tube wall ($r = r_o$):

$$u_L = v_L = 0 \tag{16}$$

$$T_L = T_{\text{wall}} \tag{17}$$

Using the governing equations (Equations (1) to (7)) and the boundary conditions, the velocities and temperature in each phase and the gas mass fraction may be determined. The film thickness can also be found; its equation is discussed in the next section.

An extra equation is needed to determine the pressure gradient, dP/dz. This extra equation is derived from the overall conservation of mass:

$$\int_0^{r_o-\delta} \rho_M u_M r dr + \int_{r_o-\delta}^{r_o} \rho_L u_L r dr = \frac{\dot{m}_{\text{in}}}{2\pi} \tag{18}$$

For the model discussed above, the required input variables are u_{in}, W_{in}, P_{in}, T_{in}, T_{wall}, r_o, and the properties. Alternatively, one may specify Re_{in} in place of u_{in}, or ϕ_{in} in place of W_{in} (as discussed in Section IV.).

As condensation occurs along the tube, the profiles of velocity, temperature, and gas mass fraction are continuously changing. If the condensation rate is very high, or if there is pure vapour, then flow reversal can occur, at which point the present model is no longer applicable. In this work, the inlet gas mass fraction is high, so the condensation rates are small, and no flow reversal occurs.

III. Numerical Solution Method

A transformation of coordinates was performed before discretising the governing equations [15]. This transformation was done to ensure that the computational grid would clearly define the liquid-mixture interface at each station along the length of the tube. The r–z coordinates were transformed as follows:

$$\chi = z, \qquad \text{for all } z \tag{19}$$

$$\eta = \frac{r}{r_o - \delta}, \qquad \text{for } 0 \leq r \leq (r_o - \delta) \tag{20}$$

$$\eta = 2 - \frac{r_o - r}{\delta}, \qquad \text{for } (r_o - \delta) \leq r \leq r_o \tag{21}$$

The solution domain was divided into a structured grid of control volumes in the transformed coordinates. In the mixture region, the control volumes contracted geometrically in the radial direction towards the liquid-mixture interface; in the liquid region, the control volumes were uniformly spaced in the radial direction; and in the axial direction, the control volumes expanded exponentially. A finite volume method was applied to the transformed equations resulting in a set of non-linear algebraic equations for the seven nodal unknowns: u_L, J_L, T_L, u_M, J_M, T_M, and W, and for the scalar unknowns δ and $dP/d\chi$ at each axial station. Note that J was used in the equation set in place of v. In addition, the transformed version of Equation (14) is used as the equation for δ.

The solution is advanced in a marching procedure, starting with the inlet boundary conditions as the initial guess for the solution at the first axial station. At each axial station, the seven nodal unknowns at all grid points across the radius and the two scalar values are all computed through iteration of the fully coupled equation set. The linearized equation set was solved using a bordered matrix algorithm and a block TDMA. Convergence of the solution at an axial station was declared when the largest relative change of all nodal values and the two scalar values was less than 1×10^{-7}. Computation proceeded, station by station, along the tube until the prescribed tube length, L, was reached. Details of the advection schemes, the linearisations, and the marching solution of the coupled equations are described by Groff [15]. The numerical solution was implemented in a well-tested in-house computer code using double precision.

The structured grid system was arranged as follows. In the η direction, the mixture region contained `NM` control volumes and the liquid region contained `NL` control volumes. The z direction was divided into `NZ` stations. Grid independence tests consisted of running the code using various grid sizes and comparing the velocity, temperature, and gas mass fraction profiles at various z locations for each case. The ranges of values used in these tests were: $60 \leq$ `NM` ≤ 240, $30 \leq$ `NL` ≤ 120, and $1000 \leq$ `NZ` ≤ 4000. A grid with `NM`= 120, `NL`= 60 and `NZ`= 4000 had range-normalised maximum percentage differences of velocity, temperature and gas mass fraction profiles of less than 0.44%, 0.72% and 0.70%, respectively, when compared with finer grids. These differences are considered suitably small, so that grid was used for all the results presented in this work.

IV. Inlet Gas Mass Fraction Specification

In models for condensation from gas-vapour mixtures that are not applied to the case of moist air, saturation conditions are usually assumed at the inlet. In that situation, it is sufficient to specify the inlet pressure and gas mass fraction. Then, the partial pressure of the vapour at the inlet is computed from:

$$\frac{P_{v,\mathrm{in}}}{P_{\mathrm{in}}} = \frac{(1 - W_{\mathrm{in}})}{(1 - W_{\mathrm{in}}(1 - r_m))} \tag{22}$$

where r_m is the ratio of the molar masses of vapour and gas, (M_v/M_g); for water and air, $r_m = 0.62185$. The inlet temperature is the saturation temperature for the partial pressure of the vapour. This corresponds to a relative humidity of 100%.

When the inlet flow is moist air, it is appropriate to specify the inlet relative humidity instead of the inlet gas mass fraction. In this situation, the inlet temperature is specified in addition to the inlet pressure. Then, the inlet gas mass fraction is computed from the inlet relative humidity, pressure, and temperature as follows. First, the amount of water vapour in the air is given by the specific humidity. Therefore, the specific humidity at the inlet is:

$$\omega_{\mathrm{in}} = \frac{m_{v,\mathrm{in}}}{m_{a,\mathrm{in}}} \tag{23}$$

The inlet gas mass fraction is then related to the inlet specific humidity by:

$$W_{\mathrm{in}} = \frac{1}{(1 + \omega_{\mathrm{in}})} \tag{24}$$

For an ideal gas mixture of water vapour and air, the specific humidity is related to the total pressure, P, and the partial pressure of the vapour, P_v:

$$\omega_{\mathrm{in}} = r_m \frac{P_{v,\mathrm{in}}}{(P_{\mathrm{in}} - P_{v,\mathrm{in}})} \tag{25}$$

Next, the relative humidity at the inlet is:

$$\phi_{\mathrm{in}} = \frac{P_{v,\mathrm{in}}}{(P_{v,\mathrm{sat}})_{\mathrm{in}}} \tag{26}$$

where $(P_{v,\mathrm{sat}})_{\mathrm{in}}$ is the saturation pressure of water at T_{in}.

Finally, combining Equations (24), (25), and (26), the inlet gas mass fraction is computed from the inlet relative humidity, pressure, and temperature (via $(P_{v,\mathrm{sat}})_{\mathrm{in}}$) using:

$$W_{\mathrm{in}} = \frac{\left(P_{\mathrm{in}} - \phi_{\mathrm{in}}(P_{v,\mathrm{sat}})_{\mathrm{in}}\right)}{\left(P_{\mathrm{in}} - \phi_{\mathrm{in}}(P_{v,\mathrm{sat}})_{\mathrm{in}}(1 - r_m)\right)} \tag{27}$$

Table I lists sample values of W_{in} for two inlet temperatures and various values of ϕ_{in} at a pressure of 1 bar. Note that, for a fixed inlet temperature, decreasing ϕ_{in} produces an increase in W_{in}. Likewise, decreasing the inlet temperature for a given relative humidity also increases W_{in}.

Table I. Sample inlet gas mass fractions for a pressure of 1 bar

ϕ_{in} (%)	W_{in}	
	$T_{\mathrm{in}} = 25^\circ$C	$T_{\mathrm{in}} = 40^\circ$C
100.0	0.9800495	0.9527564
80.0	0.9840782	0.9624210
60.0	0.9880875	0.9719759
40.0	0.9920775	0.9814228

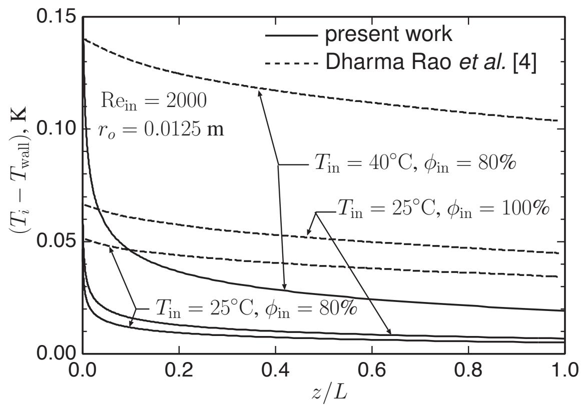

Figure 2. Comparison with Dharma Rao *et al.* [4] for interface temperature

V. Comparison With Previous Work

The results obtained using the present numerical solution were compared with Dharma Rao *et al.* [4]. The axial variations of T_i and Re_L were selected for comparison because they reflect model predictions of the gas effects in the mixture and the condensation. In all comparisons $T_{\mathrm{wall}} = 25^\circ$C, $L = 1$ m, $r_o = 0.0125$ m, $\mathrm{Re}_{\mathrm{in}} = 2000$, and $P_{\mathrm{in}} = 1$ bar. The comparisons are made for three combinations of inlet temperature and relative humidity.

The effects of changing ϕ_{in} and T_{in} on the liquid-mixture interface temperature, T_i, are shown in Fig. 2 in terms of $(T_i - T_{\mathrm{wall}})$ versus z/L. It is immediately noted that the difference $(T_i - T_{\mathrm{wall}})$ is much less than 1 K in all cases. This small temperature difference across the liquid yields very small condensation rates. Comparing curves for $T_{\mathrm{in}} = 25^\circ$C, it is seen that T_i decrease as ϕ_{in} decreases. This decrease in T_i is due to the increase in inlet gas mass fraction with decreasing ϕ_{in} (seen in Table I). Increased gas mass fraction decreases the partial pressure of the vapour, which decreases the vapour temperature. Because saturation is assumed at the interface, T_i is decreased. Comparing curves for $\phi_{\mathrm{in}} = 80\%$, it is seen that T_i increases with T_{in}, as expected. Figure 2 also shows that the results from the present work and those of Dharma Rao *et al.* have similar trends, and that there is a large discrepancy between the values. This discrepancy is expected to be due to significantly different methods used by the two models to calculate the interface temperature and interface mass flow rate.

Figure 3 shows the local condensate Reynolds number, Re_L,

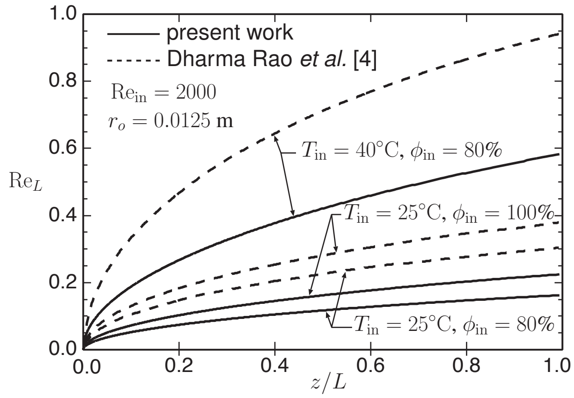

Figure 3. Comparison with Dharma Rao *et al.* [4] for film Reynolds number

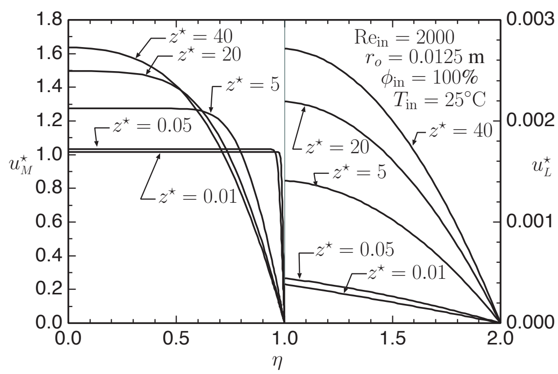

Figure 4. Dimensionless axial velocity profiles

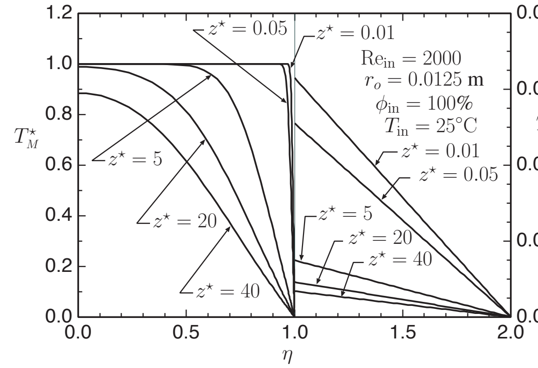

Figure 5. Dimensionless temperature profiles

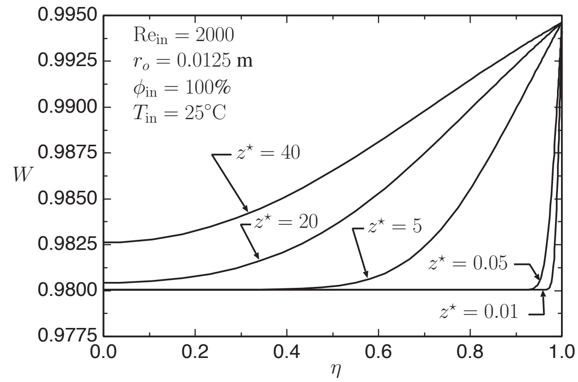

Figure 6. Gas mass fraction profiles

as a function of the dimensionless axial distance z/L. The cases shown are the same as in Fig. 2. The results are consistent with those in Fig. 2: as $(T_i - T_{\mathrm{wall}})$ decreases, the condensation rate decreases, so the growth rate of Re_L decreases. Again, the results compare well qualitatively but not quantitatively between the work of Dharma Rao *et al.* and the present work.

VI. Results and Discussion

Results were obtained for a moist air entering the tube with inlet Reynolds numbers between 500 and 2000, inlet relative humidity between 60% and 100%, an inlet temperature of $25°\mathrm{C}$ and $40°\mathrm{C}$, and tube radius between 0.003 m and 0.0125 m. In all cases the inlet pressure is 1 bar, the wall temperature is $5°\mathrm{C}$, and the tube length is 1 m.

The results presented in Figs. 4 to 6 are profiles of dimensionless axial velocity, dimensionless temperature, and gas mass fraction at various axial stations along the tube.

The conditions used for these results are an inlet Reynolds number of 2000, an inlet temperature of $25°\mathrm{C}$, an inlet relative humidity of 100%, and a tube radius of 0.0125 m. The mixture region corresponds to $0 \leq \eta \leq 1$ and the liquid film region corresponds to $1 \leq \eta \leq 2$.

From the dimensionless velocity profile in Fig. 4, it can be observed that as $z^\star$ increases, the velocity in the mixture attains a more parabolic profile, while the velocity in the liquid film increases. This trend is due to the small transfer of mass from the mixture to the liquid. The mixture is losing mass only slowly and the liquid film is slowly gaining mass and accelerating.

Figure 5 shows that the temperature profiles in the liquid region are nearly linear. It is also observed that $T^\star$ is very small at $\eta = 1$ at all stations shown. This means that the interface temperature is very close to the wall temperature, as seen in Fig. 2. Because the inlet gas mass fraction is very high, even a small condensation mass flow causes a large gas mass fraction at the interface (seen later in Fig. 6). The large gas mass fraction at the interface reduces T_i to a value very near T_{wall}. Therefore, there exists a complex balance between J_i'', W_i, and T_i that is enforced by the present model. The small condensation rate raises W_i enough to lower T_i so that a small driving force for condensation $(T_i - T_{\mathrm{wall}})$ is obtained. It is also observed that the interface temperature and the slope of the mixture temperature are decreasing along the length of the tube.

The profiles of W in Fig. 6 show that, near the inlet (up to

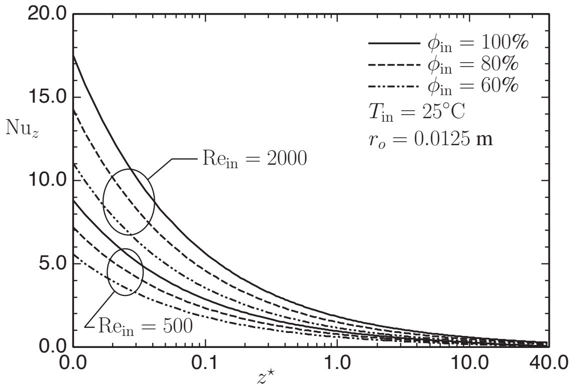

Figure 7. Local Nusselt number variation with Re_{in} and ϕ_{in}

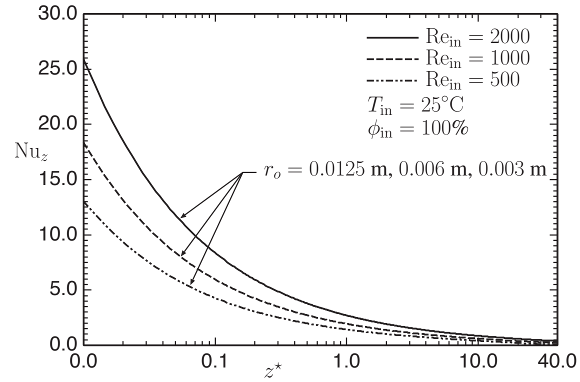

Figure 9. Local Nusselt number variation with r_o and Re_{in}

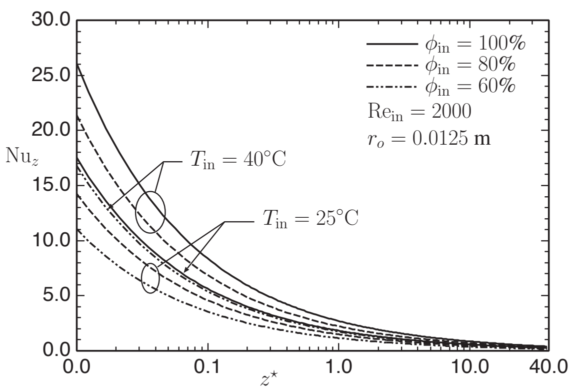

Figure 8. Local Nusselt number variation with T_{in} and ϕ_{in}

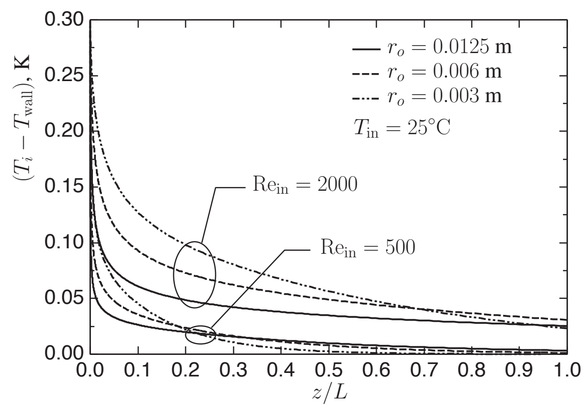

Figure 10. Axial variation of $(T_i - T_{wall})$ with Re_{in} and r_o

$z^\star$ = 0.05), W is equal to W_{in} for most of the cross section and increases rapidly near the interface due to the interface impermeability condition. Along the tube, the values of W_i (W at $\eta = 1$) are slightly less than 0.994556, which corresponds to saturation conditions at T_{wall} (5°C) and P_{in} (1 bar). Along the tube, the gas mass fraction increases at the centre line and the slope near the interface decreases.

Figures 7 and 8 show the effect of ϕ_{in}, Re_{in} and T_{in} on the local Nusselt number. The local Nusselt number is defined in the Nomenclature and the local heat transfer coefficient is

$$h_z = \frac{q''_{wall}}{(T_{in} - T_{wall})} \tag{28}$$

Note that the temperature difference in the definition of h_z uses T_{in} (and not T_i or an average mixture temperature).

Figure 7 shows that, at fixed values of of T_{in} and Re_{in}, Nu_z decreases with a decrease in ϕ_{in}. This trend is a result of the increase in inlet gas mass fraction with decreasing ϕ_{in}. For all values of ϕ_{in}, higher Re_{in} (*i.e.*, higher inlet velocity) improves heat transfer. The increase is the result of smaller film thickness and higher interface temperature at a fixed axial location when Re_{in} increases.

Figure 8 shows again that Nu_z decreases with decreasing ϕ_{in} at fixed values of T_{in} and Re_{in}. This figure also shows an increase in Nu_z with increasing T_{in}. Because T_{wall} is fixed, increasing T_{in} increases the temperature difference across the film, and thus the heat transfer rate.

The effect of tube radius is investigated through the plots in Figs. 9 to 11. These figures show axial variations of local Nusselt number, interface temperature and dimensionless film thickness, respectively, for various combinations of Re_{in} and r_o; all the plots are for $T_{in} = 25°C$ and $\phi_{in} = 100\%$.

When plotting the Nu_z versus $z^\star$ as in Fig. 9, it is seen that Nu_z increases with Re_{in} and that it is independent of the radius for a given inlet Reynolds number. The independence with respect to radius is discussed shortly with reference to more details about the axial variations of T_i and δ.

Figure 10 shows that $(T_i - T_{wall})$ increases with Re_{in} for a given tube radius. At the same tube radius, higher Re_{in} corresponds to higher inlet velocity. A higher inlet velocity tends to move air away from the interface and thus keep W_i lower;

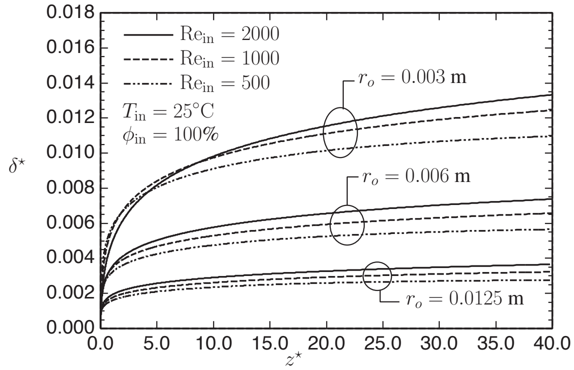

Figure 11. Axial variation of $\delta^\star$ for various values of Re_{in} and r_o

TABLE II. Sample values of $(T_i - T_{\text{wall}})$, $\delta^\star$ and their ratio

r_o [m]	$(T_i - T_{\text{wall}})$ [K]	$\delta^\star$	$\frac{(T_i - T_{\text{wall}})}{\delta^\star}$ [K]
		$z^\star = 5$	
0.003	0.17421	0.008130	21.43
0.006	0.10744	0.005008	21.45
0.0125	0.05581	0.002562	21.79
		$z^\star = 20$	
0.003	0.11763	0.011482	10.24
0.006	0.06686	0.006524	10.25
0.0125	0.03418	0.003254	10.50
		$z^\star = 40$	
0.003	0.08876	0.013253	6.70
0.006	0.04920	0.007343	6.70
0.0125	0.02493	0.003638	6.85

this contributes to a higher values of T_i. For a fixed value of Re_{in}, smaller radius corresponds to higher inlet velocity, so T_i increases with decreasing tube radius, as seen in Fig. 10.

The plots of $\delta^\star$ in Fig. 11 are consistent with the interface temperature trends in Fig. 10: the previous trends that cause an increase in T_i also cause an increase in the heat transfer rate, and thus an increase in δ.

The independence of Nu_z with respect to tube radius seen in Fig. 9 can be explained with the use of data from Figs. 10 and 11. As a reasonable approximation for a thin film with a linear temperature profile, the wall heat flux could be taken as:

$$q''_{\text{wall}} = \frac{k_L (T_i - T_{\text{wall}})}{\delta} \tag{29}$$

By using Equation (29) in Equation (28), h_z becomes:

$$h_z = \frac{k_L (T_i - T_{\text{wall}})}{\delta (T_{\text{in}} - T_{\text{wall}})} \tag{30}$$

Substituting Equation (30) into the definition of Nu_z yields:

$$\text{Nu}_z = \frac{(T_i - T_{\text{wall}})\, 2r_o}{\delta (T_{\text{in}} - T_{\text{wall}})} = \frac{2}{(T_{\text{in}} - T_{\text{wall}})} \frac{(T_i - T_{\text{wall}})}{\delta^\star} \tag{31}$$

so that Nu_z is proportional to $(T_i - T_{\text{wall}})/\delta^\star$. Values of $(T_i - T_{\text{wall}})$ and $\delta^\star$ were taken from Figs. 10 and 11 at three axial stations for the three values of tube radius, and are shown in Table II. Also shown in the table are the corresponding values of the ratio $(T_i - T_{\text{wall}})/\delta^\star$. The table values show that although $(T_i - T_{\text{wall}})$ and $\delta^\star$ decrease with increasing tube radius, the ratio of $(T_i - T_{\text{wall}})/\delta^\star$ remains relatively constant; this explains why the Nu_z versus $z^\star$ plot is independent of tube radius at a given value of Re_{in}.

VII. SUMMARY AND CONCLUSIONS

A numerical solution was presented for laminar film condensation in a vertical tube. The model is based on the complete parabolic governing equations. The fully coupled solution method permits the prediction of flow conditions with very high inlet gas mass fractions.

Results were obtained by specifying the following values at the inlet to the tube: Reynolds number, pressure, temperature, and relative humidity. The tube radius, tube length, and wall temperature were also specified.

The results presented in this paper include profiles of dimensionless velocity, dimensionless temperature, and gas mass fraction. Other results included the axial variation of the film Reynolds number, the interface temperature, the local Nusselt number, and the dimensionless film thickness. The effects of changing the inlet Reynolds number, temperature and relative humidity as well as the tube radius were studied.

The high concentrations of air in the mixture were found to greatly inhibit the heat transfer process. Small condensation rates and a mixture-liquid interface temperature very near the tube wall temperature were observed for all cases presented. Condensation decreased with decreasing relative humidity for a fixed inlet temperature. The condensation rate increased with increasing inlet Reynolds number, with increasing inlet temperature, and with decreasing tube radius. The axial variation of the local Nusselt number was found to be independent of tube radius when plotted versus $z/(2r_o)$.

ACKNOWLEDGMENT

The financial support of NSERC is gratefully acknowledged.

NOMENCLATURE

C_p	specific heat $[\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}]$
D	diffusion coefficient $[\text{m}^2\,\text{s}^{-1}]$
g	gravitational acceleration $[\text{m}\,\text{s}^{-2}]$
h_{fg}	latent heat of vapourisation $[\text{J}\,\text{kg}^{-1}]$
h_z	local heat transfer coefficient $[\text{W}\,\text{m}^{-2}\,\text{K}^{-1}]$, Eq. (28)
J	mass flow at η-direction control volume faces $[\text{kg}\,\text{s}^{-1}]]$
J''_i	η-direction mass flux at the interface $[\text{kg}\,\text{m}^{-2}\,\text{s}^{-1}]$
k	thermal conductivity $[\text{W}\,\text{m}^{-1}\,\text{K}^{-1}]$

L tube length [m]
m mass [kg]
$\dot{m}$ total mass flow rate [$\mathrm{kg\,s^{-1}}$]
M molar mass [$\mathrm{kg\,kmol^{-1}}$]
NL number of grid spacings in the η-direction in the liquid
NM number of grid spacings in the η-direction in the mixture
Nu_z local Nusselt number ($h_z 2r_o/k_L$)
NZ number of grid spacings in the z-direction
P pressure [$\mathrm{N\,m^{-2}}$]
r radial coordinate [m]
r_m ratio of molar masses (M_v/M_g)
r_o radius of tube [m]
$\mathrm{Re_{in}}$ inlet Reynolds number ($\rho_{\mathrm{in}} u_{\mathrm{in}} 2r_o/\mu_{\mathrm{in}}$)
T temperature [K]
$T^\star$ dimensionless temperature ($(T - T_{\mathrm{wall}})/(T_{\mathrm{in}} - T_{\mathrm{wall}})$)
u velocity in the z direction [$\mathrm{m\,s^{-1}}$]
$u^\star$ dimensionless velocity in the z direction ((u/u_{in}))
v velocity in the r direction [$\mathrm{m\,s^{-1}}$]
W gas mass fraction
z axial coordinate [m]
$z^\star$ dimensionless axial coordinate ($z/(2r_o)$)

Greek Symbols

δ condensate film thickness [m]
$\delta^\star$ dimensionless condensate film thickness ((δ/r_o))
η transformed coordinate defined by Eqs. (20) and (21)
μ dynamic viscosity [$\mathrm{kg\,m^{-1}\,s^{-1}}$]
ρ density [$\mathrm{kg\,m^{-3}}$]
ϕ relative humidity
χ transformed coordinate [m], Eq. (19)
ω specific humidity

Subscripts

a air
g gas
i interface
in tube inlet
L liquid
M vapour-gas mixture
v vapour
v, sat vapour, saturation
wall wall

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CRISTINA AMON

Cristina Amon is the Dean of the University of Toronto's Faculty of Applied Science & Engineering and Alumni Professor of Bioengineering in Mechanical and Industrial Engineering. She is responsible for the strategic and visionary leadership of one of the world's most distinguished Engineering schools, the administration of over 750 faculty, researchers and staff with an annual operating and research budget of $250M, and the education of more than 5,000 undergraduate and 2,000 graduate students.

Since her appointment in 2006, Dean Amon has created programs to foster collaborative scholarship, enhance student experience, encourage active learning, promote research excellence and accelerate innovation. Under her leadership, U of T Engineering has become a global intellectual hub for interdisciplinary research and education. She has introduced a number of initiatives, including undergraduate programs in energy systems, global engineering and engineering business, and professional masters with a focus on entrepreneurship, leadership, innovation and technology in engineering, and cities engineering and management. She has also led the creation of cross-Faculty centres and institutes in the areas of healthcare engineering, sustainable energy, global engineering, identity, privacy and security, design innovation, and leadership education in engineering. Under her leadership, research and graduate programs have experienced unprecedented growth, with an increase of over 50 per cent in the number of doctoral students and more than double the number of professional master's students.

Dean Amon received her Mechanical Engineering diploma from Simón Bolívar University and continued her education at the Massachusetts Institute of Technology, where she earned her MS and ScD degrees in 1985 and 1988, respectively. Prior to her appointment at the University of Toronto, she was the Raymond J. Lane Distinguished Professor and Director of the Institute for Complex Engineered Systems at Carnegie Mellon University.

A pioneer in the development of Computational Fluid Dynamics for formulating and solving thermal design problems subject to multidisciplinary competing constraints, Dean Amon continues her research at the University of Toronto in nanoscale thermal transport in semiconductors, energy systems and bioengineered devices.

Dedicated to outreach, Dean Amon was the architect of U of T Engineering's Skule Mentorship program and Carnegie Mellon's Engineering Your Future program, designed to introduce pre-university underrepresented students to the excitement of engineering careers.

Cristina Amon serves on the BoD of MKS Instruments Inc., a leading global provider of instruments and process control solutions for advanced manufacturing of semiconductor devices, energy generation and electro-optical products. She is chair of the research committee of NCDEAS (National Council of Deans of Engineering and Applied Science in Canada), past chair of the Global Engineering Deans Council, and has served on advisory boards for several institutions including Penn, Stanford, UCLA and Waterloo.

Dean Amon has received numerous awards, including the ASME Gustus Larson Memorial Award, ASEE Westinghouse Medal and the ASME Heat Transfer Memorial Award. Most recently, she was recognized as one of Canada's most Influential Women in 2012 and was honoured with the Society of Women Engineers' (SWE) highest honour, the 2011 SWE Achievement Award, for her outstanding contributions to engineering over more than 20 years. She is also the recipient of the prestigious YWCA Toronto Woman of Distinction award, which recognizes her achievement in improving the lives of girls and women in science and engineering.

Dean Amon has been inducted into four academies, the Canadian Academy of Engineering, the Spanish Royal Academy, the Royal Society of Canada and the U.S. National Academy of Engineering. She has been elected fellow or honorary member of all major professional societies in her field and has contributed 350 refereed articles in education and research literature.

Questions & Answers

Q. *Why did you choose a career in a STEM field?*

A. I was attracted to engineering because I wanted to create things that could have a direct, immediate impact on society and on people's lives. Einstein said, "Scientists investigate that which already is, engineers create that which never was." I love that quote.

Q. *What advice can you give to young women who are interested in engineering?*

A. Don't let anyone tell you no. No, you're not smart enough. No, you don't have the math, sciences and creativity aptitude. If you love it, if you find pleasure in discovering how things work, in creating what didn't exist before, and you want to make the world better, don't listen to "no". Don't be afraid to make mistakes.

Q. *How does your work as an engineer benefit humanity?*

A. My primary research work is in the area of Computational Fluid Dynamics (CFD) for formulating and solving thermal design problems subject to multidisciplinary competing constraints. It benefits humanity in several ways, for example, more heat-efficient semiconductors and on-demand recuperative transient thermal technologies for wearable computers. I have also done research on transport in biological systems, intravenous blood oxygenators and abdominal aortic aneurysms. My research group has been also investigating energy generation in micro-scale direct methanol fuel cells and in wind farms, which has the potential to lead to improvements in energy systems.

My work as Dean enables me to provide strategic and visionary leadership of one of the world's most distinguished Engineering Faculties, and help shape the education of the next generation of engineers.

ELIZABETH CROFT

Dr. Elizabeth Croft is a full professor with tenure in Mechanical Engineering at UBC and the founding director of the Collaborative Advanced Robotics and Intelligent Systems (CARIS) Laboratory, an internationally respected research group that specializes in Human Centred Robotics Technologies. As the NSERC Chair for Women in Science and Engineering, BC & Yukon (2010-2015), she also serves as the Chair for the NSERC Chairs for Women in Science and Engineering Network. Prior to becoming NSERC Chair she was Associate Head, External (2007-2010), for the Department of Mechanical Engineering at UBC. She is a founding instructor of the MECH2 program, which won the 2005 ASME Curriculum development award, the 2007 UBC Alfred Scow award and the 2008 Alan Blizzard Award. Moreover, Dr. Croft is a registered Professional Engineer, and a member of ASME and IEEE.

As director of the CARIS Lab, Dr. Croft oversees an interdisciplinary research group including three other faculty members, from Mechanical Engineering, Computer Science, and Human Kinetics. Her engineering research program is funded by General Motors, Hyundai Heavy Industries, the Canada Foundation for Innovation, and NSERC.

Dr. Croft currently leads a ~$1M NSERC Collaborative Research and Development (CRD) Grant (2011-2014) with four Co-Principal Investigators at three institutions and an industry partner. This research project exploits an emerging paradigm-shift for manufacturing systems, which relies on the use of intelligent robotic assistants that can collaborate both directly and physically with human co-workers in their assembly tasks as part of the production team. The project aims to advance methods for interacting with robotic assistants through developments in the perception, communication, control, and safe interaction technologies and techniques centered on supporting workers performing complex manufacturing tasks.

Dr. Croft has been a member of the Division for Advancement of Women in Engineering and Geoscience (DAWEG) of the Association of Professional Engineers of BC (APEGBC) since 1995. She has served in many positions with this group including Co-Chair (98/99) and is currently on the Advisory Board. Dr. Croft has given numerous talks and educational sessions to promote women in engineering from elementary school through graduate studies, academe and industry careers. For her many activities promoting women in engineering, she received the APEGBC Professional Service Award in 2005, the Award for the Support of Women in the Engineering Profession, Canadian Council of Professional Engineers in 2006, and was made a Fellow of Engineers Canada in 2008 and of the American Society of Mechanical Engineers in 2009.

In 2010, as NSERC Chair, Croft founded Westcoast Women in Engineering, Science, and Technology (WWEST) in order to: attract, recruit, and retain women in engineering and science. WWEST works at national, regional, and local levels with organizations engaged in increasing the number of women in science, engineering, and technology (SET) disciplines through multilateral partnerships spanning community, academic, and private sector partners. WWEST serves as the premier hub for activity and dialogue about meaningful inclusion and increased participation of women in SET disciplines on Canada's west coast. WWEST has engaged with 16 organizations through the WWEST Partners grant program to foster exciting new initiatives that promote the outreach, recruitment, and retention of girls, young women, and industry professionals in science, engineering, and technology.

Serving as a role model for women in Science in Engineering, Dr. Croft participates in a many profile-raising events and activities. She is frequently featured in the media, speaks regularly at community events, and has been featured in both a local museum exhibit as an inventor and as a BC Year of Science Featured Scientist. She has been a keynote speaker for events like the SCWIST 2011 Gala, the Association of Professional Engineers and Geoscientists of Alberta 2011 Mentoring Conference, and the 2012 WISEST Lectureship at the University of Alberta.

Questions & Answers

Q. *Who inspired you to become a Mechanical Engineer?*

A. Dr. Phil Hill, a professor of mechanical engineering at UBC and Mr. E. Hart, my high school physics teacher. Both of these very kind gentlemen gave me great encouragement to pursue a career in engineering, and Dr. Hill particularly encouraged me to pursue mechanical engineering.

Dr. Hill showed me drawing for the Boeing 767 just at the time that it was being developed. I was amazed and inspired by the idea of designing something like that, and I absolutely loved poring over the engineering drawings.

Q. *Who (other than family members) do you admire most?*

A. From recent history:

The famous 5 (Emily Murphy, Henrietta Muir Edwards, Louise McKinney, Nellie McClung, Irene Parlby) – who fought for Canadian Women to be declared "persons".

Professor Ursula Franklin, first female professor of engineering at the University of Toronto, pacifist and feminist, author of the "Real World of Technology" and holder of the Governor General's Award in Commemoration of the Persons Case, and the Pearson Medal of Peace.

Margaret Ann Armour, another holder of the Governor General's Award in Commemoration of the Persons Case, President of the Canadian Centre for Women in Science, Engineering, Trades and Technology, and a tireless campaigner for encouraging and including women in Science, Engineering, Trades and Technology careers.

Q. *What do you feel has been your most important professional accomplishment to date?*

A. This is a hard question. There are a number of things I am very pleased with but all involve the contributions and collaborations with many others – for example the highly successful and award-winning MECH 2 program at UBC; the establishment of the UBC Engineering Tri-mentoring program; the establishment of, and research coming out of, the CARIS lab at UBC (which has received some great international recognition) are a few of the things I feel very good about. I don't think it is possible to put my finger one "crowning" achievement but perhaps I'm not there yet… abdominal aortic aneurysms. My research group has been also investigating energy generation in micro-scale direct methanol fuel cells and in wind farms, which has the potential to lead to improvements in energy systems.

My work as Dean enables me to provide strategic and visionary leadership of one of the world's most distinguished Engineering Faculties, and help shape the education of the next generation of engineers.

JEAN ZU

Jean Zu iis Professor and Chair of the University of Toronto's Department of Mechanical and Industrial Engineering. Her research focuses on vibrations and dynamics, particularly in relation to automotive belts and serpentine belt drive systems, and has resulted in a number of extremely successful partnerships with automotive firms. Jean Zu has contributed over 250 publications in her field, including 116 journal papers, 141 conference papers and one book chapter. Her research funding has totaled close to $4M and her work has resulted in 2 patents. In her academic career, she has supervised 27 PhD and 30 Master's students, as well as 29 post-doctoral fellows.

Jean Zu has served the academic and professional communities with genuine dedication. She serves on the Canadian National Committee for the International Union of Theoretical and Applied Mechanics and served as President of the Canadian Society of Mechanical Engineering (CSME) in 2006-2008,. She is currently Associate Editor of the ASME Journal of Vibrations and Acoustics. She is currently President of the Engineering Institute of Canada.

Jean Zu has been honoured by a number of organizations for her achievements; she is a Fellow of the American Society of Mechanical Engineers, the Canadian Society for Mechanical Engineering, American Society of Mechanical Engineers, the Canadian Academy of Engineering, the Engineering Institute of Canada, and the American Association for the Advancement of Science. In 2012 she received the Robert W. Angus Medal from CSME.

Jean Zu's research is focused on mechanical vibrations and dynamics. Her most notable contributions have been in the modelling and simulation of nonlinear vibration systems, particularly automotive belt drives. She has applied her findings to several successful collaborations with industrial partners, most notably her 14 year collaboration with Tesma International Inc. and Litens Automotive Group (both subsidiaries of Magna International Inc.). She has been awarded eight contracts with these companies as a result of the advances created through their partnerships. In recent year, her research has been extended to bio-instrument and energy harvesters.

Jean Zu's research advances have had a significant impact on the Canadian automotive industry. As a result of the in-house design capabilities enabled by her research, her industrial collaborators have thrived at a time when the automotive industry in general is in decline (Litens, for example, has experienced a 10% increase in sales over the past ten years). Professor Zu and her research team have developed two commercial software packages on static and dynamic analysis of automotive accessory belt drive systems and automotive timing belt drive systems, respectively. This software has greatly enhanced her industrial partners' product design, function and reliability, resulting in a significant competitive advantage and increased revenues at a time when the automotive industry in North America is facing serious economic challenges.

Questions & Answers

Q. *What's one piece of advice you would give to Women in Engineering?*

A. Be patient and perseverant. Stick to your principle. Your effort will eventually get paid off.

ELIZABETH CROFT

Catherine Mavriplis is a Professional Engineer registered in Virginia and is currently an Associate Professor of Mechanical Engineering at University of Ottawa. Catherine spent 25 years in the US after obtaining her Bachelor's degree in Mechanical Engineering from McGill. Graduate studies in Aeronautics and Applied Mathematics at MIT led her to a postdoc at Princeton and a tenured Associate Professor position at the George Washington University where she spent 14 years in the Department of Mechanical and Aerospace Engineering, Catherine also enjoyed her two years as a program manager at the US National Science Foundation's (NSF) Division of Mathematics. As a research fellow at the University of Oklahoma and the US NOAA National Severe Storms Laboratory, she broadened her interests to meteorology.

What do all of these experiences have in common, you ask? A love for computational fluid dynamics modeling in different fields: first in aerodynamics, then in combustion and MEMS, and finally in severe weather modeling. Catherine's expertise is in high order adaptive methods for direct numerical simulation – which means she loves to use math and computers to calculate complex and beautiful flows that approach turbulence.

Back in Canada since 2008, Catherine has returned to aerodynamics with the Canadian Aeronautics community so vibrant and has expanded to biomedical flows as well.

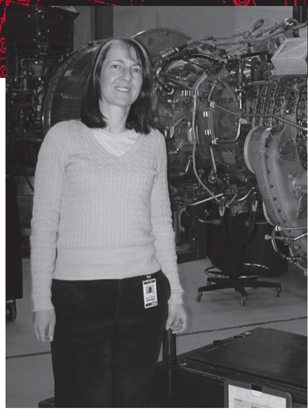
Since 1996, Catherine has been designing and delivering funded programs to advance women in science and engineering, first through the FORWARD program with colleagues from George Washington and Gallaudet University, and more recently as the NSERC / Pratt & Whitney Canada Chair for Women in Science & Engineering.

Catherine has had significant involvement in the US NSF ADVANCE program since its inception with two Leadership Awards for the FORWARD to Professorship workshop, which has offered information and advice to over 1300 doctoral science and engineering women since 2003. At the University of Oklahoma, she led an ADVANCE PAID project to advance women in the Central US States. Attending the ADVANCE Principal Investigators Meeting in Alexandria, Virginia a few weeks ago was certainly exhilarating as the breadth, scope and success of ADVANCE projects were clearly visible.

Work with the Pratt & Whitney Canada's Inaugural Women's Leadership Forum in 2007 and presenting her work at the two International PROMETEA conferences on Women in Engineering in Paris in 2007 and 2009 added industrial and international experience in this field. Through Pratt & Whitney Canada's generous support of the bid for the NSERC Chair, Catherine is able to offer programs for and conduct research on women in science & engineering, for the entire spectrum "from the classroom to the boardroom". Examples include cultural diversity sessions on teamwork and communications in engineering at Pratt & Whitney Canada as well as for the general engineering public in Ottawa and Take the Final Step, a bilingual workshop for science and engineering women associate professors of Ontario and Québec seeking promotion to the highest rank of Full Professor.

Catherine serves on the Board of Directors of the Computational Fluid Dynamics Society of Canada, the WINSETT Center and the Ottawa Branch of the Canadian Aeronautics and Space Institute.

IZABELA WITKOWSKA



Izabela Witkowska iBorn, raised and educated in Europe (Poland).

Attended the TECHNICAL UNIVERSITY OF LODZ (POLAND), Department of Mechanical Engineering and completed post graduate studies obtaining her MASTER'S DEGREE in MATERIALS SCIENCE in 1986. Immediately after graduation she was hired by the TECHNICAL UNIVERSITY OF LODZ, Materials Engineering Department as a Professor's Assistant. Until 1989 her experience included the areas of Failure Analysis, research work on thermo-chemical heat treatments and corrosion protection coatings (CVD, PVD). Fluent in three languages (Polish, Russian and German) she left Poland in 1989 (one year sabbatical from University) to travel to Indiana, USA, to study English. The same year she applied in Canadian Consulate in Chicago for immigration to Canada and obtained the landed immigrant entry visa. She arrived in Canada in 1990 and that's when her North American engineering journey started. Having advantage of being able to communicate in English (verbally and in writing) she found employment after one week of immigration. Working for local Winnipeg companies she was exposed to the wide range of materials, processes and other aspects of the mechanical engineering profession in Canada.

Working together with (and being mentored by) Professional Engineers she became aware of differences between engineering in Poland vs. engineering in Canada, identified a need for additional training and gained invaluable experience and expertise in her profession. The process of becoming recognized as a Professional Engineer in the province of Manitoba took few years due to lack of time (full time employment) and also financial constraints (no support). After challenging three professional knowledge exams prepared by the Association of Professional Engineers in Alberta she obtained the Professional Engineer status in 1996. This was a milestone in her carreer, since it opened up multiple options for professional employment, providing similar opportunities, positions and benefits offered to Engineers educated and trained in Canada.

Since 1996 she is working for a major international aerospace company, StandardAero Ltd. (SAL) in Winnipeg, currently holding the position of the Principal Engineer.

Soon after joining SAL she was "moving up" within the organization – a few times - for constantly more responsible/challenging positions – including a managerial job in charge of over 10 engineers. After four years working for SAL her knowledge, international experience and expertise was recognized by the higher management and she was promoted to work as Airworthiness Engineer for the Design Approval Organization (DAO). Working for the DAO she is able to fully utilize her skills, education and abilities in metallurgy / materials science / mechanical engineering / compliance approvals and achieve a level of excellence within the company.

In 2005 she obtained the Delegation of Authorization from Transport Canada in functional specialty Powerplants (Engines, Propellers and Gas Turbine Auxiliary Power Units). As a TC Delegated Engineer she is authorized to approve major repairs in her area of specialty on behalf of the Minister of Transport, including issuance of Major Repair Designs Approvals (RDA)and Limited Supplemental Type Certificates (LSTC).

In 2008 she was appointed by the Royal Australian Air Force (Department of Defence) as a Deputy Senior Design Engineer for C130J aircraft Propulsion Systems.

In December 2012 she celebrated 12 years with the DAO (16 years with SAL). She continues to provide support for the DAO, Research and Development projects, processes, training and mentoring for majority of engineers within the organization.

Questions & Answers

Q. *What's one piece of advice you would give to Women in Engineering?*

A. Mechanical Engineering is for you if :

- you like job flexibility, challenges and working in a fast pace environments
- you come across some situations thinking that anything someone can do you could do better
- you enjoy creativity/research/implementation and working on projects with logical, rationally thinking team members
- you would like to develop your carrier globally
- you want to combine your interests in traveling the world, making observations and using your experiences to solve problems and make a difference
- you are decisive and ready to accomplish great things

The 24th Canadian Congress of Applied Mechanics (CANCAM) Saskatoon, SK, Canada, June 2-6, 2013

The 24th Cannadian Congress of Applied Mechanics (CANCAM) will be held in Saskatoon, from June 2 to 6, 2013. The Department of Mechanical Engineering at University of Saskatchewan will host the meeting. This is the twenty-fourth in a series of biennial conferences that began in 1967 at l'Université Laval. The Congress provides an international forum for communicating the most recent advances in the field of Applied Mechanics.

The conference covers all areas of applied mechanics, including:

- Dynamics • kinematics •Vibrations
- Fluid Mechanics
- Thermodynamics
- Heat and Mass Transfer
- Mechanics of Solids and Structures
- Computational Mechanics
- Biomechanics
- Manufacturing Systems
- Materials Science
- Mechatronics
- Education in Applied Mechanics
- History and Philosophy of Mechanics
- Emerging Fields

For details of the congress please check the home page of the conference:
http://spencer.usask.ca/affiliation/cancam2013/index.html

The 24th International Congress of Theoretical and Applied Mechanics (ICTAM2016)
Montreal, Quebec, Canada, August 21-26, 2016

The 24th International Congress of Theoretical and Applied Mechanics (ICTAM2016) will be held in Montreal, Quebec, Canada, from August 21 to 26, 2016. The National Research Council Canada will host the congress. For detailed information of this congress, please check the webpage at http://www.ictam2016.org/ or contact:

Congress Management Office - ICTAM 2016
National Research Council Canada
1200 Montréal Road, Building M-19
Ottawa, ON Canada K1A 0R6
e-Mail: ICTAM2016@nrc-cnrc.gc.ca

Bureau de gestion du congrès - ICTAM 2016
Conseil national de recherches Canada
1200, chemin Montréal, Édifice M-19
Ottawa (Ontario) Canada K1A 0R6
courriel: ICTAM2016@nrc-cnrc.gc.ca

This is the twenty-fourth in a series of quadrennial conferences that began in Delft, The Netherlands in 1924. In 1946, during the sixth congress in Paris, the International Union of Theoretical and Applied Mechanics (IUTAM) was founded. ICTAM congress is the largest gathering of researchers and engineers in the general area of mechanics from the world. It provides an international forum for communicating the most recent advances, sharing findings, refining ideas, and building partnerships.

The most recent ICTAM Congress was the 23rd Congress in Beijing in 2012. The last and the only ICTAM Congress held in Canada is the 15th Congress in 1980 in Toronto.

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Department of Mechanical Engineering

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Department of Mechanical Engineering

UNIVERSITY OF BRITISH COLUMBIA
Department of Mechanical Engineering

UNIVERSITY OF MANITOBA
Department of Mechanical and Industrial Engineering

ROYAL MILITARY COLLEGE OF CANADA
Department of Mechanical Engineering

Laurentian University / Université Laurentienne
Department of Mechanical Engineering

RYERSON UNIVERSITY
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Carleton UNIVERSITY
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