MODELLING POLYMER ELECTROLYTE MEMBRANE FUEL CELLS

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Abstract

The Polymer Electrolyte Membrane (PEM) fuel cell model proposed incorporates both analytical and empirical techniques. The model is based on a comprehensive literature survey and comparative study of fuel cell modelling from both analytical and empirical perspectives. In addition the analytical data and experimental procedures required for determining the parameter values used in the proposed model are specified.

1. INTRODUCTION

Polymer Electrolyte Membrane (PEM) fuel cells are suitable energy converters for electrical vehicles and other mobile applications as they can realise high efficiencies and high power densities. In order to make best use of PEM fuel cells in practical applications, an accurate model is required to simulate the fuel cell performance in system design.

This paper is significant in that it provides a comprehensive overview and comparative study of PEM fuel cell modelling. Also of significance is the proposed model, which is particularly targeted for the engineering design and application of PEM fuel cells. The nomenclature for this paper is provided in the appendix.

2. FUNDAMENTAL OPERATION

The electro-chemistry of the PEM fuel cell involves the oxidation of hydrogen at the anode electrode and the reduction of oxygen at the cathode electrode. Protons (H^+) are transported from the anode to the cathode electrode through the PEM and electrons are carried to the cathode electrode through an external circuit to perform useful work. The overall reaction of the PEM fuel cell is shown below.

$$\tfrac{1}{2}O_2 + H_2 \rightarrow H_2O \qquad (1)$$

Air is often used to supply the oxygen to the cathode electrode. Hydrogen is supplied to the anode electrode by reforming another fuel or by the electrolysis of water. The PEM is an ion conducting membrane that allows protons to pass but does not conduct the reactant gases. Each cell consists of a PEM which is enclosed by an anode and cathode electrode. In addition each electrode is also in contact with a gas diffusion backing which in turn is connected to a bipolar plate. These provide the fuel cell with an electrical connection and allow the transport of the reactants gases. To increase the power output of the system many cells are combined to form a fuel cell stack.

3. MODEL REVIEW

The steady state performance of the fuel cell stack is expressed by the polarisation curve, which is a graph of the voltage versus the load current for a given set of operating conditions. A steady state model can be used to predict the polarisation curve, and hence the steady state performance of the fuel cell stack. The dynamic performance of the fuel cell stack can be modelled with an equivalent circuit that incorporates a general solution of the steady state model.

PEM fuel cell models can be divided into two broad categories, analytical and empirical. Analytical models are based on theory while empirical models are based on experimentation. Unfortunately, PEM fuel cell stacks are complex systems and are difficult to completely model analytically. For this reason, in general the analytical fuel cell models have a theoretical basis while still holding some empirical features.

Thirumalai and White [1] completed a good sensitivity analysis on an earlier model [2] to find the most important operating conditions of the PEM fuel cell stack. They found that the following factors were particularly important:

- Gas mass flows (pressure and stoichiometry of the inlet gases),
- Operating temperature of the fuel cell stack, and
- Relative humidity of the reactant gases, primarily of the anode gas.

3.1 Analytical Model Review

The analytical models can be classified as either simple or complex. Simple models examine the operating fuel cell stack voltage in respect to the maximum theoretical voltage and the major voltage losses. Complex models use more detailed techniques and require detailed information on the materials and makeup of the fuel cell stack.

3.1.1 Simple Analytical Models

Simple analytical models attempt to classify the operation of the fuel cell into short equations that reflect the reversible voltage and any voltage losses. Some earlier work, for example by Berger [3], provided the theoretical background and methodology for calculating the major voltage losses. Other groups aiming to describe the losses in a simple and accurate model developed these further. Amphlett et al. have produced the most comprehensive of these models based on the Ballard IV PEM fuel cell stack [4,5] and have attempted to develop this further into a general PEM fuel cell model [6]. Other models include that of Larminie and Dicks [7] which include the internal current and a simplified dynamic performance model of the fuel cell stack.

3.1.2 Complex Analytical Models

Complex analytical models that address the overall operation of PEM fuel cells have been reviewed [8,9]. In general these can only be used by the authors and require years of expertise in fuel cell modelling. Due to the complex phenomenon of water management in the PEM, much time has been spent modelling this specific aspect [2,10].

The PEM must be hydrated at all times to ensure the conduction of protons. If the PEM is under hydrated performance of the fuel cell stack is compromised and deterioration of PEM results. Non optimal performance also occurs with flooding of the fuel cell stack.

Models on PEM hydration provide insight into the electro-osmotic effect of water, as well as the overall water management issues in the PEM fuel cell stack.

3.2 Empirical Model Review

Because of the complexity and interdependence of variables on the performance of the fuel cell stack an empirical equation can be used to predict the polarisation curve. The advantage of this approach is that it is relatively simple to accurately predict a particular polarisation curve. The disadvantage of this approach is that the polarisation curve must be re-calculated for any change in operating conditions, such as humidity or temperature.

A landmark empirical equation was presented in 1995 by Kim et al. [11] that gave an accurate prediction of the polarisation curve without complete consideration for the electrochemistry. The empirical equation is given below, and has been used to model the polarisation curve for various types of PEM fuel cells [12,13].

$$V_{cell} = V_{0,K} - R_{cell,K}\, j - b_K \ln(j) - m_K \exp(n_K j) \qquad (2)$$

Another type of empirical model was used by Amphlett et al. [5]. When the analytical constants were not fully understood they went about finding an empirical equation for each parameter and for the entire IR loss. This technique is used as a supplement to analytical models and will be used in the proposed model.

Empirical modelling techniques are also used for developing an equivalent circuit that can model the dynamic performance of the fuel cell stack. This technique uses the experimental procedures for current interruption and Electrochemical Impedance Spectroscopy (EIS).

4. PROPOSED MODEL

For the application of PEM fuel cell stacks a simple analytical model is preferred over the other modelling techniques discussed. Complex analytical models require information that is not accessible to applicators of fuel cell stacks. Empirical models although simple require re-evaluation of the model when operating conditions are varied.

The fuel cell stack voltage is determined by subtracting the various voltage losses from the reversible voltage as shown in equation (3). The main voltage losses are the ohmic, activation and concentration voltage losses. Incorporated in these voltage loss terms is an internal current.

$$V_{stack} = V_{reversible} - V_{ohmLOSS} - V_{actLOSS} - V_{conLOSS} \qquad (3)$$

These voltage losses result in an operating voltage that

is less than the reversible voltage as shown in the typical polarisation curve in Fig.1.

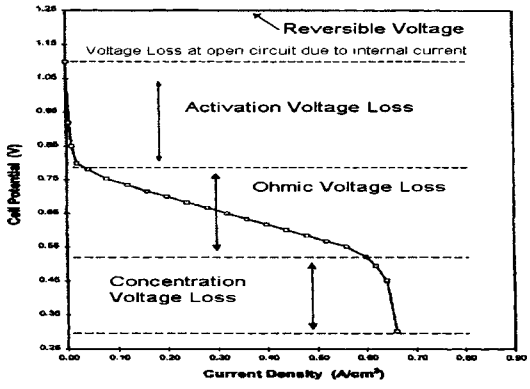

Fig.1 Typical Polarisation Curve [2]

4.1 Reversible Voltage

The reversible voltage is the maximum theoretical voltage of the fuel cell stack. This voltage is derived from the change in Gibbs free energy. The reversible voltage for the PEM fuel cell reaction that produces two electrons per molecule of fuel [14] is given below.

$$V_{reversible} = N_{cell} * \frac{-\Delta \bar{g}_f}{2F} \tag{4}$$

The change in Gibbs free energy varies with different partial pressures of the hydrogen fuel and the oxidant. The reversible voltage of one cell at standard temperature and pressure is 1.229 V. Assuming ideal gases the reversible voltage at the standard temperature and varying pressure is shown in equation (5).

$$V_{reversible} = N_{cell} * \left[V^0 + \frac{RT}{2F} \ln \left[\frac{\dot{p}_{H_2} \left(\dot{p}_{O_2} \right)^{\frac{1}{2}}}{\dot{p}_{H_2 0}} * \left(\frac{1}{P_0} \right)^{\frac{1}{2}} \right] \right] \tag{5}$$

Because of the low operating temperature the enthalpy and entropy of the PEM fuel cell reaction can be approximated at standard temperature conditions [15] as shown in equation (6).

$$\Delta \bar{g}_T \cong \Delta \bar{h}_{298.15K} - T \Delta \bar{s}_{298.15K} \tag{6}$$

Using equations (5,6) the reversible voltage at varying temperature and pressure is shown in equation (7).

$$V_{reversible} = N_{cell} * \left[V^0 + \frac{RT}{2F} \ln \left[\frac{\dot{p}_{H_2} \left(\dot{p}_{O_2} \right)^{\frac{1}{2}}}{\dot{p}_{H_2 0}} * \left(\frac{1}{P_0} \right)^{\frac{1}{2}} \right] - \frac{\Delta \bar{s}_{298.15K}}{2F} (T - 298.15) \right] \tag{7}$$

With pressure in atmospheres and using standard values for the constants in equation (7) the reversible voltage reduces to equation (8) given below.

$$V_{reversible} = N_{cell} * \left[1.229 + (4.308 * 10^{-5}) T * \ln \left[\dot{p}_{H_2} \left(\dot{p}_{O_2} \right)^{\frac{1}{2}} \right] - (8.453 * 10^{-4})(T - 298.15) \right] \tag{8}$$

4.2 Ohmic Voltage Loss

The ohmic voltage loss relates to the resistance of the non-ideal electrodes and the resistance to proton flow in the PEM. The resistance of the electrodes and connections remain constant in the fuel cell stack however the resistance to proton flow is not constant. It changes with the fuel cell stack current and temperature, and the hydration of the PEM.

An increase in current will increase the fuel cell stacks overall resistance and an increase in temperature will decrease it [5,6]. The PEM proton resistance will increase slightly as the current is increased because the electro-osmotic water drag will slightly dry the PEM at higher operating currents.

The overall resistance of the fuel cell stack can be empirically modelled with a first order fit of the current and temperature of the fuel cell stack [5] as described in equation (9).

$$V_{ohmLOSS} = iR_{ohmic} = i(\varepsilon_1 + \varepsilon_2 i + \varepsilon_3 T) \tag{9}$$

4.3 Activation Voltage Loss

The activation voltage loss of the fuel cell stack relates to the rate of the reactions taking place on the surface of the electrodes [7]. In 1905, Tafel described the relationship of the activation voltage loss. This was later expanded to its current form [7] shown below,

$$V_{actLOSS} = N_{cell} * \frac{RT}{2\alpha_m F} \ln \left(\frac{i}{i_{0.m}} \right) \tag{10}$$

An activation voltage loss exists at the anode and cathode electrodes however the activation voltage loss at the cathode electrode dominates. Berger [3] defined the analytical relationship of the exchange current at each electrode and this was later used by Amphlett et al. [4].

The exchange current for each electrode can be inserted into equation (10) and the activation voltage loss for each electrode can be calculated. The total activation voltage loss is shown in equation (11) and incorporates the analytical expression for the exchange currents. The physical meanings for δ_1, δ_2, δ_3, δ_4, and δ_5 [4] are shown in equations (12-16).

$$V_{actLOSS} = N_{cell} * \left[\delta_1 T \ln(i) + \delta_2 + \delta_3 T + \delta_4 T \ln(C_{O_2}) + \delta_5 T \ln(C_{H_2})\right] \quad (11)$$

$$\delta_1 = \frac{R}{2\alpha_c F} + \frac{R}{2\alpha_a F} \quad (12)$$

$$\delta_2 = \frac{\Delta F_c}{2\alpha_c F} + \frac{\Delta F_{ec}}{2\alpha_a F} \quad (13)$$

$$\delta_3 = -\left(\frac{R \ln(n_c F A k_c^{\,0})}{2\alpha_c F} C_{proton}^{\,1-\alpha_c} C_{H_2O}^{\,\alpha_c}\right) \quad (14)$$

$$\delta_4 = -\frac{R(1-\alpha_c)}{2\alpha_c F} \quad (15)$$

$$\delta_5 = -\left(\frac{R \ln(n_a F A k_a^{\,0})}{2\alpha_a F}\right) \quad (16)$$

The constants A, F and R are known and n_a, n_c ΔF_c, ΔF_{ec} and C_{H2O} are constants that are initially unknown. The parameters α_a, α_c, k_a^0 k_c^0 and C_{proton} are approximately constant for the reaction and are assumed constant [4].

4.4 Concentration Voltage Loss

The concentration voltage loss relates to the reduction of gas concentration in the gas channels. Concentration voltage loss is usually derived from the Nernst diffusion layer thickness equation and is called Fick's first law [14], as shown in equation (17). The dependence of the parameters B and i_L on the operating conditions must be found empirically.

$$V_{conLOSS} = -B \ln\left(1 - \frac{i}{i_L}\right) \quad (17)$$

4.5 Internal Current

An internal current in the fuel cell stack originates from reactant gases that pass through the PEM without producing useful work [7]. The internal current is small and only affects the voltage losses that occur at small operating currents. The only voltage loss that is significant at small currents is the activation voltage loss. If the internal current term is included in the activation voltage loss described in equation (11) then this becomes,

$$V_{actLOSS} = N_{cell} * \left[\delta_1 T \ln(i + i_n) + \delta_2 + \delta_3 T + \delta_4 T \ln(C_{O_2}) + \delta_5 T \ln(C_{H_2})\right] \quad (18)$$

Including the internal current results in a model that is accurate at open circuit condition. Most simple analytical models are not accurate in the open circuit condition as they do not include this term.

4.6 Dynamic Performance

The dynamic performance can be described with the use of an equivalent circuit. The equivalent circuit for the PEM fuel cell stack is shown in Fig.2. Values of the resistor and the real part of the concentration impedance can be found by using the proposed modelling equations (3,8,9,17,18). The capacitor value and the imaginary part of the concentration impedance can be found by the parameter determination techniques described in section 5.

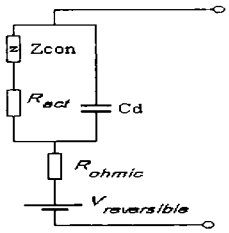

Fig.2 PEM Fuel Cell Stack Equivalent Circuit [16]

Complex electrode phenomenon exists in the PEM fuel cell called the charge double layer. This acts as a capacitor and gives the fuel cell stack a smooth dynamic voltage output. When the load on the fuel cell stack changes, the voltage output has an initial ohmic voltage loss from the resistance of the fuel cell stack and then it slowly moves to the new voltage.

5. PARAMETER DETERMINATION

The two main experimental methods for parameter determination are the current interrupt and Electrochemical Impedance Spectroscopy (EIS) methods. The current interrupt method is the simplest of these. It is performed by interrupting the current under constant load conditions.

Often the current interrupt technique is used when the operating current is low enough so that the concentration voltage loss is insignificant. The ohmic and activation voltage losses can be read from the DSO as illustrated in Fig.3. At higher currents the concentration impedance can also be determined using this technique.

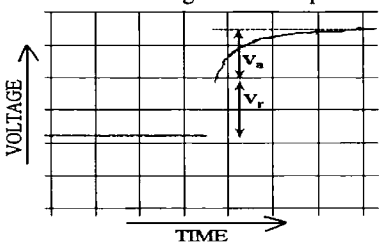

Fig.3 DSO Output [7]

EIS can be used for more detailed impedance measurements. During EIS experiments, small amplitude AC signals (5-20 mA) of varying frequencies are applied to the fuel cell stack. This small signal is applied with a DC bias that is equal to the DC voltage output of the fuel cell stack. The impedance of the fuel cell stack is then recorded. Instruments used to record and analyse these measurements are commercially available.

During operation, the temperature of the fuel cell stack and the partial pressures of the reactant gases at the inlet to the fuel cell stack can be used to determine the reversible voltage. The ohmic voltage loss and activation voltage loss can be calculated using the current interrupt method. The current interrupt method or EIS method can then be used to determine the concentration voltage loss.

The ohmic parameters of the fuel model are found by measuring the resistance of the PEM fuel cell stack while varying the temperature and current. Shown in equation (17) is the concentration voltage loss which must be linearised so that the values of B and i_L can be determined from a single graph for a given set of operating conditions. The main operating conditions are the fuel cell stack temperature, as well as the reactant gas partial pressures, stoichometric ratios and humidities. These are varied to find their empirical dependence on B and i_L. This process must also be done for the activation voltage loss. When the temperature and reactant gas concentrations are held constant, the activation voltage loss can be modified to the form,

$$V_{actLOSS} = A_{stack} \ln\left(\frac{i + i_n}{i_0}\right) \quad (19)$$

This is graphed as a Tafel plot. Curve fitting techniques using the least squares equations can be used to find the internal current, the Tafel slope, and the exchange current of the fuel cell stack. By varying the temperature and reactant gas concentrations and re-calculating the parameters of equation (19), the empirical constants of equation (18) can be determined.

Using the proposed model a polarisation curve for a 500W PEM fuel cell stack was modelled and compared with experimental data as shown in Fig.4. The polarisation curve of the experimental data shows that the current was not high enough to produce any significant concentration voltage loss.

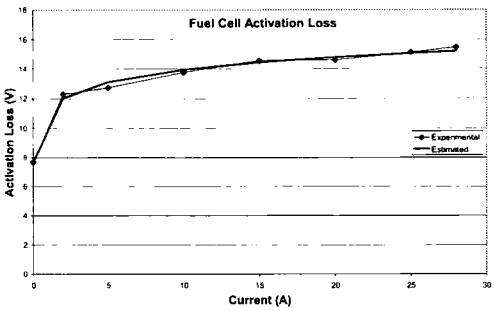

Fig.4 Modelled and Measured Polarisation Curve

6. CONCLUSION

This paper gives a detailed review on PEM fuel cell modelling and describes a proposed model including parameter determination techniques. The steady state performance has been accurately described in the form of a polarisation curve and an accurate fit of experimental data for the 500W PEM fuel cell stack was obtained using the proposed model. An equivalent circuit that describes the dynamic performance of the fuel cell stack has been given.

7. ACKNOWLEDGMENT

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8. REFERENCES

[1] Thirumalai D. and White R.E. 1997, *'Mathematical Modelling of Proton-Exchange-Membrane Fuel-Cell Stacks'*, Journal of the Electrochemical Society Vol 144, pp.1717-1723.

[2] Nguyen T.V. and White R.E. 1993, *'A Water and Heat Management Model for Proton-Exchange-Membrane Fuel Cells'*, *ibid* Vol 140, pp.2178-2186.

[3] Berger C. 1968, *Handbook of Fuel Cell Technology*, Prentice Hall, New York.

[4] Amphlett J.C., Baumert R.M., Mann R.F., Peppley B.A. and Roberge P.R. 1995, *'Performance Modeling of the Ballard Mark IV Solid Polymer Electrolyte Fuel Cell I. Mechanistic Model Development'*, Journal of the Electrochemical Society Vol 142, pp.1-8.

[5] Amphlett J.C., Baumert R.M., Mann R.F., Peppley B.A. and Roberge P.R. 1995, *'Performance Modeling of the Ballard Mark IV Solid Polymer Electrolyte Fuel Cell II. Empirical Model Development'*, *ibid* Vol 142, pp.9-15.

[6] Mann R.F., Amphlett J.C., Hooper M.A.I, Heidi M.J., Peppley B.A. and Roberge P.R. 2000, *'Development and application of a generalised steady-state electrochemical model for a PEM fuel cell'* Journal of Power Sources 86 (2000) pp.173-180.

[7] Larminie, J.E. and Dicks, A. 2000, *Fuel Cell Systems Explained*, John Wiley & Sons, Chichester, England.

[8] Murgia G., Pisani L. Valentini M. and D'Aguanno B. 2002, *'Electrochemistry and Mass Transport in Polymer Electrolyte Membrane Fuel Cells – I. Model'*, Journal of the Electrochemical Society Vol 149, pp.A31-A38.

[9] Bernardi D.M. and Verbrugge M.W. 1992, *'A Mathematical Model of the Solid-Polymer-Electrolyte Fuel Cell'*, *ibid* Vol 139, pp.2477-2491.

[10] Eikerling M., Kharkats Y.I., Kornyshev A.A. and Volfkovich Y.M. 1998, *'Phenomenological Theory of Electro-osmotic Effect and Water Management in Polymer Electrolyte Proton-Conducting Membranes'*, *ibid* Vol 145, pp.2684-2699.

[11] Kim J., Lee S, Srinivasan S. and Chamberlin C.E. 1995, *'Modelling of Proton Exchange Membrane Fuel Cell Performance with an Empirical Equation'*, *ibid* Vol 142, pp.2670-2674.

[12] Eriksen J., Aaberg R.J., Ulleberg Ø and Ingebretsen F. 2001, *'System Analysis of a PEMFC-Based Stand Alone Power System'*, 1st European PEFC Forum, Switzerland.

[13] Pisani L., Murgia G., Valentini M. and D'Aguanno B. 2002, *'A new semi-empirical approach to performance curves of polymer electrolyte fuel cells'*, Journal of Power Sources Vol 108, pp.192-203.

[14] EG&G Services Parsons, Inc. Science Applications International Corporation 2000, *Fuel Cell Handbook*, Fifth Edition, U.S. Department of Energy, Office of Fossil Energy, West Virginia

[15] Brady J.E. and Holum J.R. 1996, *Chemistry: The Study of Matter and Its Changes*, John Wiley & Sons, Brisbane, Australia.

[16] Gabrielli C. 1998, *Identification of Electrochemical Processes by Frequency Response Analysis – Technical Report Number 04,* Solatron Analytical, Texas USA.

9. APPENDIX

α_m	Charge transfer coefficient of the anode or cathode electrode
ΔF_c	Standard free energy of activation for the cathode reaction
ΔF_{ec}	Standard free energy of activation for chemical absorption
$\Delta \bar{g}_f$	The molar change in Gibbs free energy of formation in a reaction
$\Delta \bar{g}_T$	Change in Gibbs free energy per mole at temperature T and standard pressure
$\Delta \bar{h}_{298.15K}$	Change in molar enthalpy of formation, STP
$\Delta \bar{s}_{298.15K}$	Change in the molar entropy, STP
δ_m	Empirical coefficients for $V_{actLOSS}$
ε_m	Empirical coefficients for $V_{ohmLOSS}$
A	Area of each cell in the stack (cm^{-2})
B	Empirical coefficient for $V_{conLOSS}$
b_k	Tafel slope (mV / decade)
C_d	Double layer capacitance
C_m	Concentration of H_2,O_2,H_2O, or total protons concentration of PEM
F	Faraday's constant
i	Current of the PEM fuel cell stack (A)
i_L	Limiting current for the concentration voltage loss of the PEM fuel cell stack (A)
i_n	Internal current of the stack (A)
$i_{0,m}$	Exchange current of the PEM fuel cell stack at the anode or cathode electrode (A)
j	Current density of the fuel cell stack (A/cm^2)
k_m^0	Intrinsic rate constant for the anodic or cathodic reaction
m_k	Concentration loss coefficient (mV)
n_m	Number of electrons transferred per mole of the electrolysed component of the anodic or cathodic reaction
N_{cell}	Number of cells in the PEM fuel cell stack
n_k	Concentration voltage loss coefficient (cm^2/mA)
p_m^*	Partial pressure of species m
P_0	Standard pressure in the pressure units used
R	Universal gas constant
R_{act}	Activation equivalent resistance
R_{ohmic}	Total resistance of the fuel cell stack (Ω)
$R_{cell,K}$	Ohmic resistance ($\Omega.cm^2$)
T	Temperature of the fuel cell stack (K)
V^0	Reversible fuel cell voltage at STP
$V_{0,K}$	Open circuit voltage of the cell (mV)
$V_{actLOSS}$	Activation voltage loss (V)
$V_{conLOSS}$	Concentration voltage loss (V)
V_{cell}	Individual cell voltage of the stack (V)
$V_{ohmLOSS}$	Ohmic voltage loss (V)
$V_{reversible}$	Maximum theoretical voltage(V)
V_{stack}	Measured voltage of the fuel cell stack (V)
Zcon	Concentration impedance


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Message from the Conference Chairman

It gives me great pleasure to welcome you all to the Australasian Universities Power Engineering Conference (AUPEC 2002). AUPEC traditionally rotates among the venues in the Australasian region and we are delighted to host the 2002 conference at Monash University, Melbourne Australia.

AUPEC is the only annual conference organised by the Australasian Committee for Power Engineering (ACPE). The primary aim of this conference is to provide a national forum for academia and industry to share innovation, development and experiences in a friendly environment. The other key aim of AUPEC is to provide postgraduate students with the opportunity to present their research findings in front of experts from both academia and industry for scholarly feedback. It also provides university academics and Industry the opportunity to interact with the technical community, to share experiences and gain the benefit from the latest developments in technology presented at the conference.

We were very pleased with the response received from our call for papers. The conference secretariat received more than 180 abstracts from prospective authors from various countries including Australia, New Zealand, Canada, Malaysia, Singapore, Japan, India, China, Finland, Egypt, Czech Republic and Iran. Members of the organizing committee selected 158 abstracts suitable for presentation at the AUPEC conference. Papers were reviewed by 60 independent reviewers from around the world. Finally, after a two-stage independent peer review process, 138 papers successfully passed the process and were accepted for presentation and discussion at the 27 technical sessions of the conference. All papers published in the conference proceedings for AUPEC 2002 have been fully refereed, having satisfied the requirements of this peer review process. My sincere thanks to all the reviewers for their time and effort toward the review process.

We are also very pleased to put forward four outstanding keynote speakers in the mornings of day one and day two of the conference.

Finally, I would like to thank all the members of the AUPEC 2002 organizing committee for their dedication and effort, without which the conference would not have been possible.

On behalf of the conference committee let me welcome you to AUPEC 2002, which is all set to be a rewarding experience in all respects.

Dr. A. Zahedi
Chairman - AUPEC 2002
29 September 2002