An investigation of accuracy enhancement by reconstructing MARS-KS constitutive relations with ANN using data augmentation

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Introduction

❖ Computer codes such as MARS-KS, RELAP5 play an important role in nuclear safety analysis. The codes imitate the results of the experiment but there are differences between the code results and the experiment results. The code has been developed to simulate the SET (Separate Effect Test) experiment and IET(Integral Effect Test) experiment well.

❖ Constitutive relations are obtained from a result of many SET experiments. Thus, the constitutive relations are the result of regression analysis of the numerous SET data. Artificial neural network(ANN) shows strength in regression analysis using big data. Theoretically, the ANN can replace the constitutive relations.

❖ It is relatively easy to simulate for single-phase flow, but it is difficult to simulate for two-phase flow.

❖ In this paper, there is little knowledge of how to increase the accuracy of ANN for this application. It is demonstrated that data perturbation helps to improve ANN accuracy.

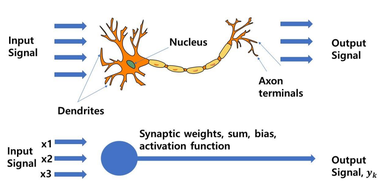


Figure 1. Neural net scheme

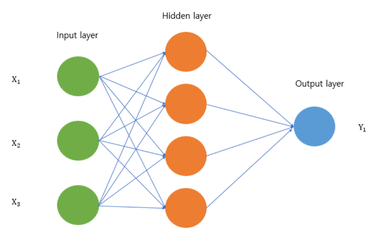


Figure 2. Feed forward neural net

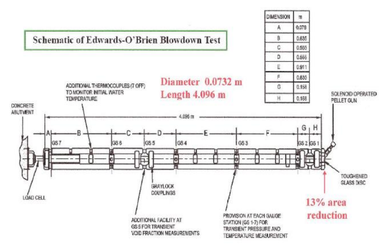


Figure 3. Edward pipe

Method

❖ Edward pipe

Edward pipe problem was used because to narrow down the thermal hydraulic conditions for ANN training. It implicate pressurized water reactor loss of coolant accident strongly.

❖ Wall heat transfer constitutive relations parameters

Input parameters: P, T_l, T_g, T_{wall}, v_l, v_g, α_g, D_{heated}, D_{eq}, angle
Output parameters: Wall heat transfer coefficient liquid & gas

❖ Wall heat transfer correlation equation

$$\mathrm{Nu}_{turb} = 0.023\,\mathrm{Re}^{0.8}\mathrm{Pr}^{0.4}$$

$$\mathrm{Nu}_{lam} = 4.36$$

$$\mathrm{Nu}_L = \left\{0.825 + \frac{0.387(\mathrm{Ra}_L)^{1/6}}{\left[1+\left(\frac{0.492}{\mathrm{Pr}}\right)^{9/16}\right]^{8/27}}\right\}^2$$

Figure 4. Single regime correlation equation

$$h_{con} = C\left[\frac{g\,\rho_g k_g^2(\rho_f-\rho_g)h'_{fg}C_{pg}}{L(T_w-T_{sat})\mathrm{Pr}_g}\right]^{0.25}$$

$$h_{l,rad} = \frac{\sigma_{SB}\left(T_w^2+T_l^2\right)(T_w+T_l)}{R_2(1+R_3/R_1+R_3/R_2)}$$

$$h_{v,rad} = \frac{\sigma_{SB}\left(T_w^2+T_v^2\right)(T_w+T_v)}{R_1(1+R_3/R_1+R_3/R_2)}$$

Figure 5. Film regime correlation equation

❖ Data augmentation

Usually, the number of data increases, the accuracy of ANN increase. In this paper, similar data was created by artificial noise. It is a way of implementing data augmentation. In our study, input variables are perturbed with assuming normal distribution having standard deviation = 0.01, Multiple = 10.

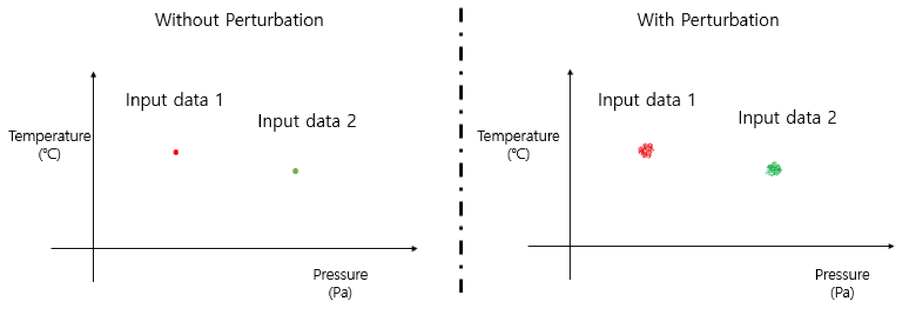
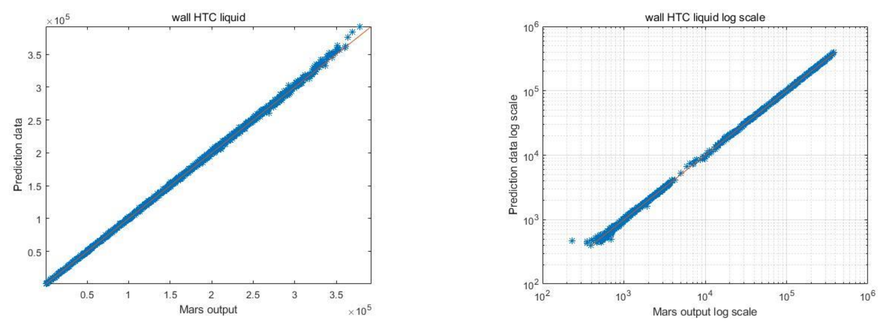


Figure 6. Data perturbation

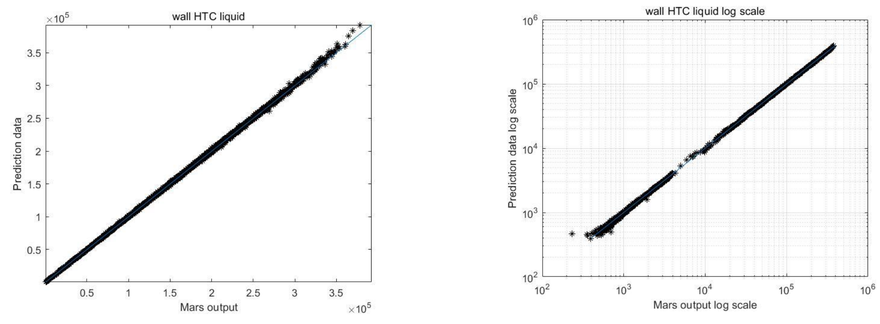
Result

❖ There are two representative way to evaluate effectiveness.
(1) MAPE(mean absolute percentage error)
(2) RMSE(root mean square error)

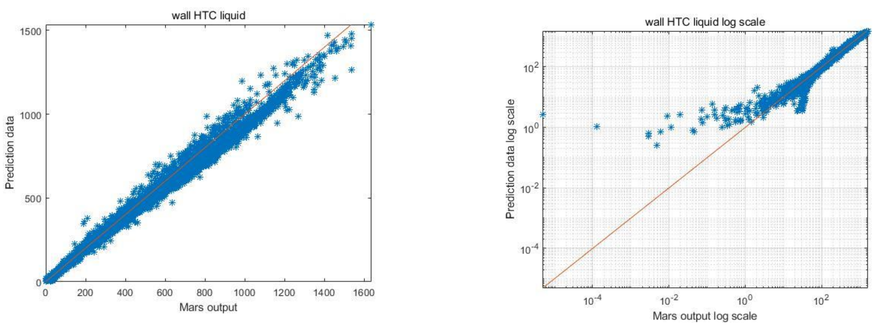
❖ The accuracy is shown for wall heat transfer single regime and film regime.



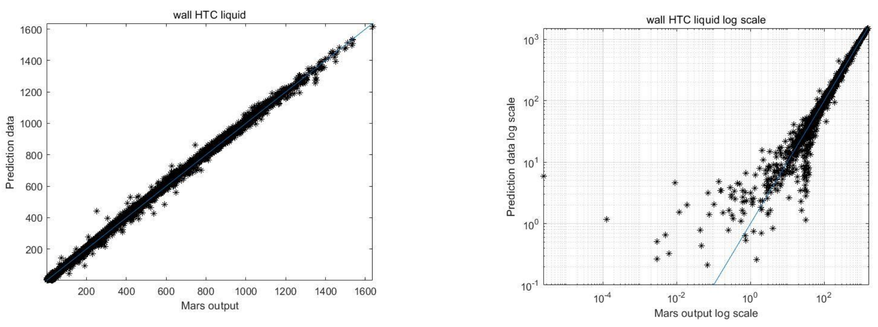
w/o perturbation single liquid regime



w perturbation single liquid regime



w/o perturbation film liquid regime



w perturbation film liquid regime

Figure 7. w, w/o perturbation results

	Wall heat transfer coefficient	Wall heat transfer coefficient with perturbation
MAPE single	2.9654	0.9544
RMSE single	2.763×10^5	1.15×10^3
MAPE film	1.4492	3.24×10^4
RMSE film	285.711	17.3874

Table 1. w and w/o perturbation, MAPE and RMSE

Summary and Conclusion

❖ The RMSE decreases well with data augmentation, but MAPE does not decrease with data augmentation.
❖ The accuracy of ANN has to be improved further to utilize it for modeling complex liquid.
❖ Adding more data augmentation for the ANN training showed some potential for improving accuracy of ANN.