# New condensation correlation test of TASS/SMR-S code for PRHRS

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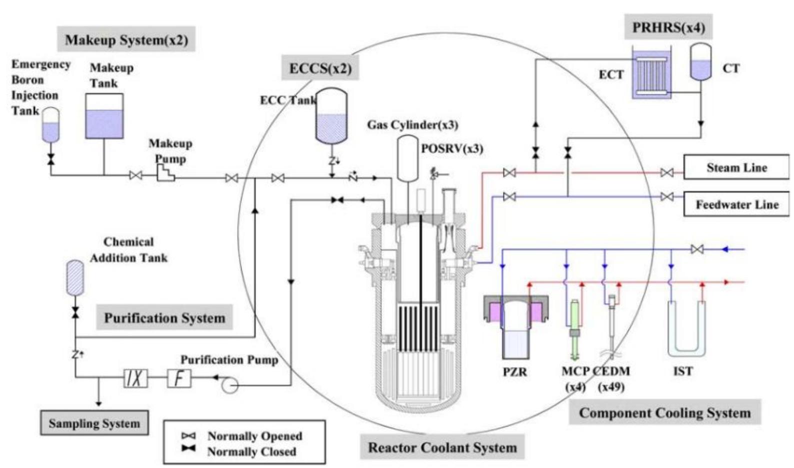
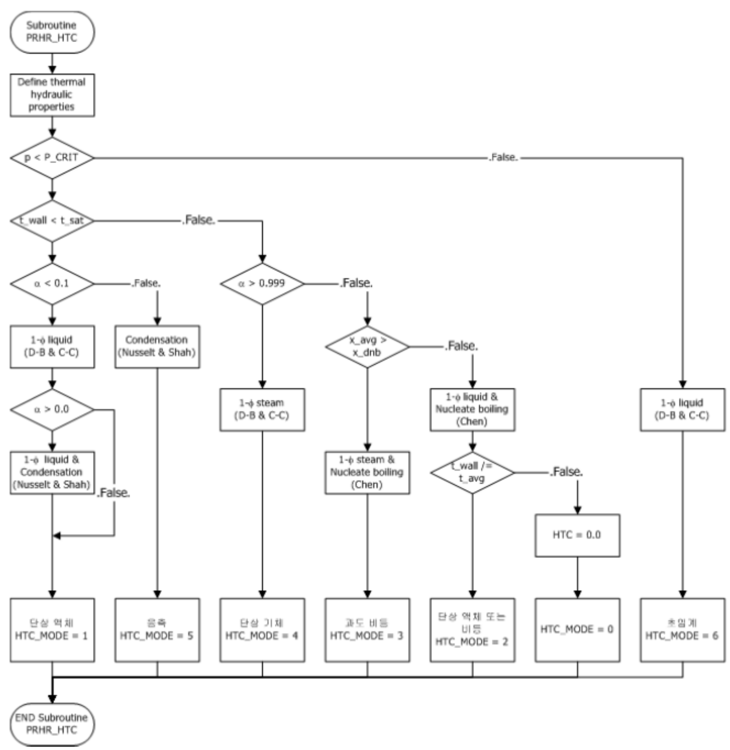
# Introduction

- PRHRS in SMART
  - Removes the core decay heat and the sensible heat by a natural circulation in the case of emergency conditions
- TASS/SMR-S code
  - Analyzes the TH performance of SMART



# PRHRS module in TASS code

- Calculate heat removal rate in PRHRS
- Heat transfer in PRHRS
  - Tube/Shell



# Review on previous condensation correlation

- Nusselt
  - Vertical flat plate
- Shah
  - Vertical/horizontal/inclined tube
  - Not recommended to low flow rate

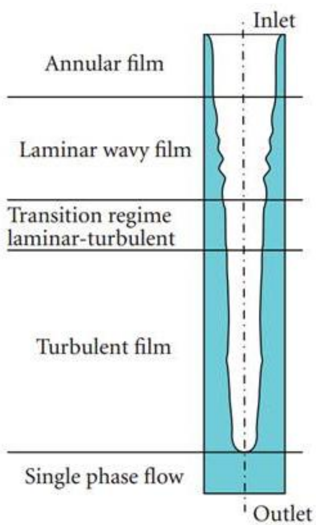
| Parameter | Tested range | Recommended range |
|---|---|---|
| Flow channel | Pipes, annulus | Pipes, annuli |
| Flow direction | Horizontal, vertical, 15° inclined to horizontal | all directions |
| Pipe ID, mm | 7.4-40 | 7-40 |
| $T_s$, ℃ | 21-310 | 21-310 |
| x, % | 0-100 | 0-100 |
| q, $W/m^2$ | 158-1893000 | All values |
| G, $kg/m^2h$ | 30000-5758400 | 39000-5758400 |
| p, $10^6$ $N/m^2$ | 0.07-9.8 | 0.07-9.8 |
| Pr | 0.0019-0.44 | 0.002-0.44 |
| $Re_L$ | | |
| pipes | 104-62900 | 350 and higher |
| annulus | 670-6700 | 3500 and higher |
| V, m/s | 3-300 | 3-300 |
| $Pr_l$ | 1-13 | >0.5 |
| Flow patterns | All | All |

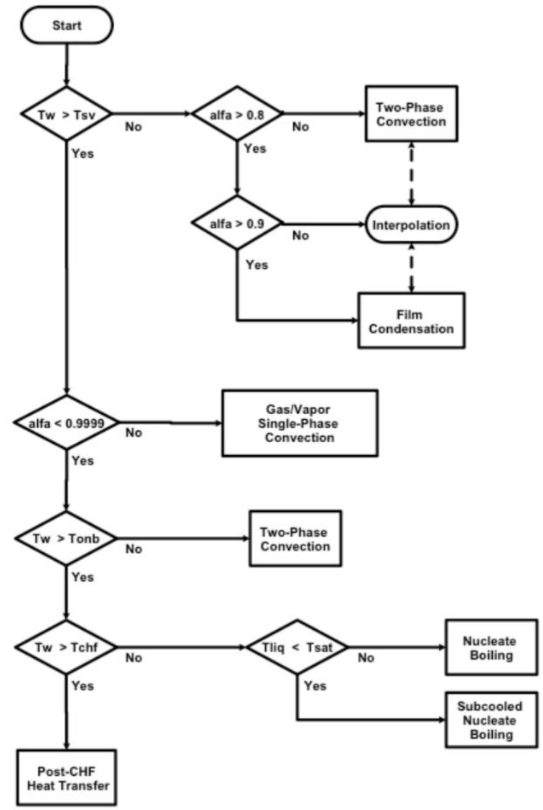
# Review on previous condensation correlation

| Reference | Condition | Correlation |
|---|---|---|
| Kim (2000) | Tube length : 1.8 m<br>Tube ID/OD : 46/50.8 mm<br>Pressure : 0.35-7.2 MPa | $h=\frac{f_D}{(1-\alpha)}\mathrm{Re}_f^{0.8}\mathrm{Pr}_f^{0.4}\frac{k_f}{D}$<br>$\alpha=\left(1+X_{tt}^{0.6}\right)^{-0.15}$<br>$X_{tt}=\left(\frac{\mu_f}{\mu_g}\right)^{0.25}\left(\frac{1-x}{x}\right)^{0.75}\left(\frac{\rho_g}{\rho_f}\right)$<br>$f_D=0.0182\left[1-0.24\left(1-4.47D^{0.5}\right)\right]^4$ |
| Lee (2007) | Tube length : 2.8 m<br>Tube ID/OD : 13/18 mm<br>Pressure : 0.1-0.13 MPa | $h=h_{Nu}\times 0.8247\tau_g^{0.3124}$<br>$\tau_g=\frac{0.5\rho_g u_g^2 f}{g\rho_f L}$ |
| Incropera | | $\mathrm{Re}_\delta=\frac{4g\rho_f\left(\rho_f-\rho_g\right)\delta^3}{3\mu_f^2},\ L_c=\left(v_f^2/g\right)^{1/3}$<br>$\frac{hL_c}{k_f}=\begin{cases}1.47\,\mathrm{Re}_\delta^{-1/3} & \text{for } \mathrm{Re}_\delta\le 30\\ \frac{\mathrm{Re}_\delta}{1.08\,\mathrm{Re}_\delta^{1.22}-5.2} & \text{for } 30\le\mathrm{Re}_\delta\le 1800\\ \frac{\mathrm{Re}_\delta}{8750+58\,\mathrm{Pr}^{-0.5}(\mathrm{Re}_\delta^{0.75}-253)} & \text{for } \mathrm{Re}_\delta\ge 1800\end{cases}$ |
| TRACE | | $Nu_{wl}=\left(Nu_{lam}^2+Nu_{turb}^2\right)^{1/2}$<br>$Nu_{lam}=2\left(1+1.83\times10^{-4}\,\mathrm{Re}_f\right)$<br>$Nu_{turb}\approx\frac{1}{4}Nu_{Gnielinski}$<br>$Nu_{Gnielinski}=\frac{(f/2)(\mathrm{Re}-1000)\mathrm{Pr}}{1+12.7(f/2)^{1/2}\left(\mathrm{Pr}^{2/3}-1\right)}$<br>$f=\left[1.58\ln\left(\mathrm{Re}_f\right)-3.28\right]^{-2}$<br>for $2300\le\mathrm{Re}_f\le 5\times10^6,\ 0.5\le\mathrm{Pr}\le 2000$ |

# TRACE

- Heat transfer regime selection logic for pre-CHF and condensation regimes



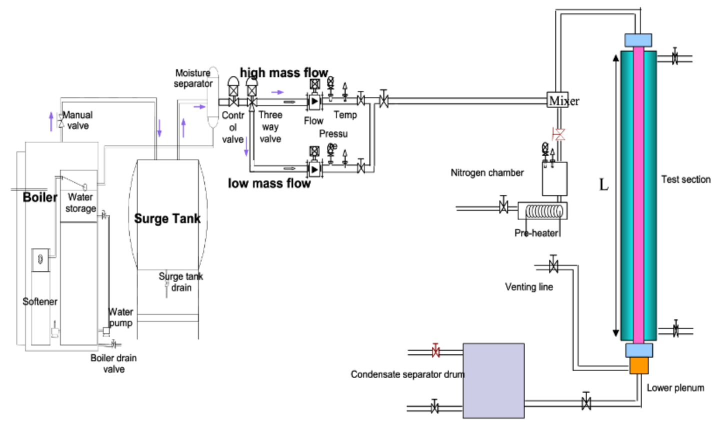



# New correlation of TASS for PRHRS

| Previous | | New | |
|---|---|---|---|
| Criterion | Correlation | Criterion | Correlation |
| α>0.1 | Max(Nusselt, Shah) | α>0.9 | $h_{Lee} = h_{Nu} \times 0.8247\tau_g^{0.3124}$<br>$\tau_g = \frac{0.5\rho_g u_g^2 f}{g\rho_f L}$ |
| | | 0.8<α<0.9 | Interpolation |
| α<0.1 | Interpolation with Dittus-Boelter corr. | α<0.8 | Dittus-Boelter corr. |

# Validation of new correlation

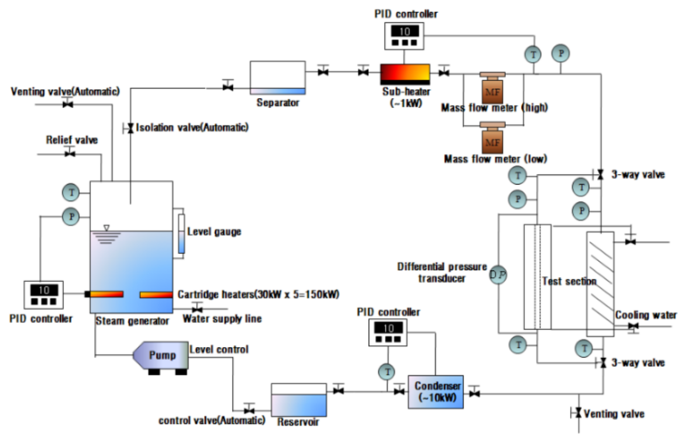
- POSTECH Ambient press. test
  - Tube length : 3 m
  - Tube ID/OD : 13/18 mm




| Exp. No | Inlet Temp.(℃) | Inlet steam flow rate |
|---|---|---|
| P1 | 100.07 | 0.58 |
| P2 | 100.06 | 0.76 |
| P3 | 100.22 | 1.00 |
| P4 | 100.09 | 1.23 |
| P5 | 100.51 | 1.43 |
| P6 | 100.81 | 1.64 |

# Validation of new correlation

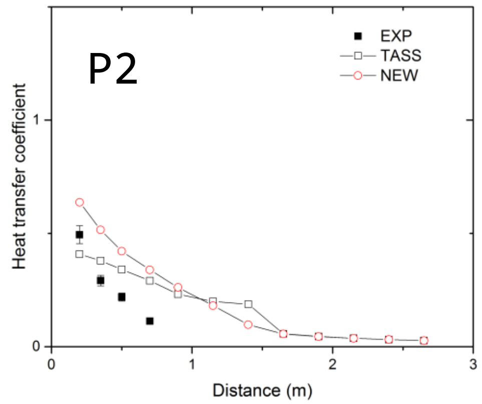
- POSTECH High pressure test
  - Tube length : 1.5 m
  - Tube ID/OD : 15.8/21.34 mm
  - Pressure : 1.0-6.0 MPa

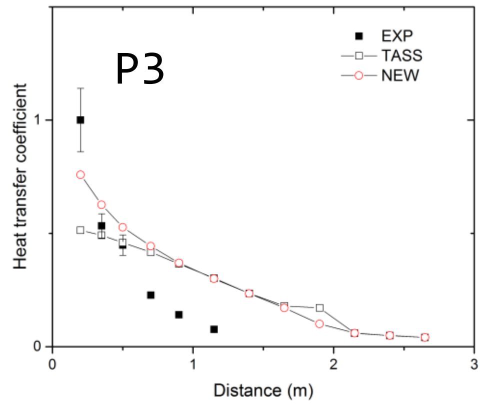


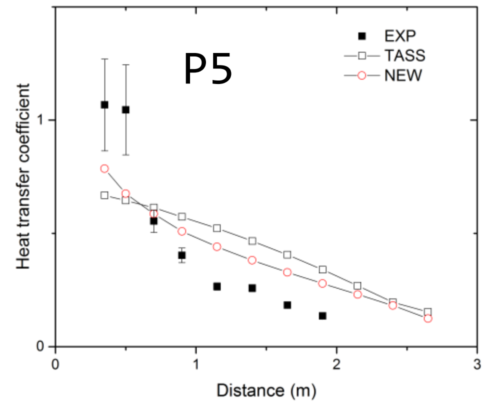

| Press. (MPa) / Flow rate | 1 | 2 | 4 | 6 |
|---|---|---|---|---|
| Low | O | O | O | O |
| Mid | O | O | O | O |
| High | O | O | O | O |

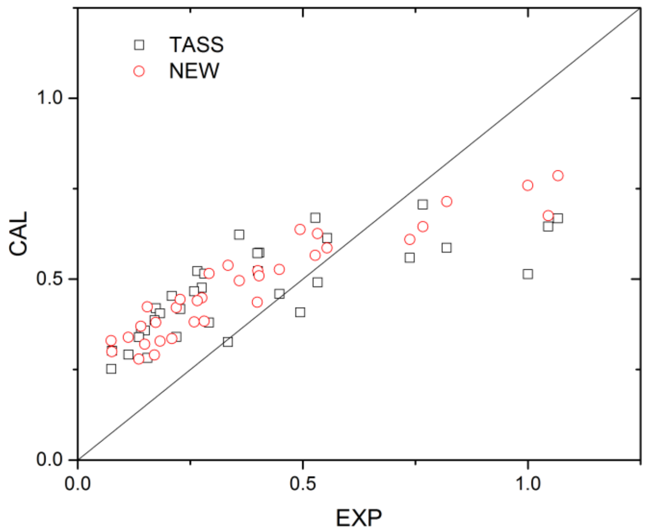
# Validation of new correlation

- POSTECH Ambient Test



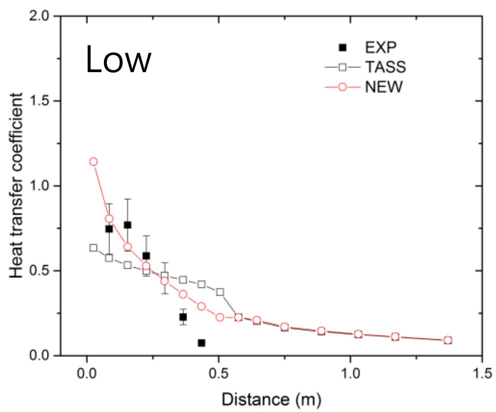



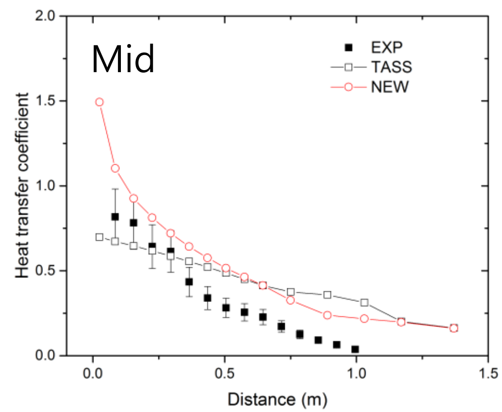



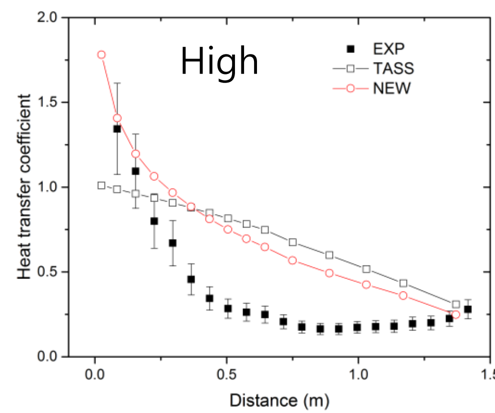

| | TASS | NEW |
|---|---|---|
| Avg. Std. Dev. (%) | 80.001 | 41.765 |
| Avg. RMSE ($kW/m^2K$) | 5.018 | 3.862 |

# Validation of new correlation

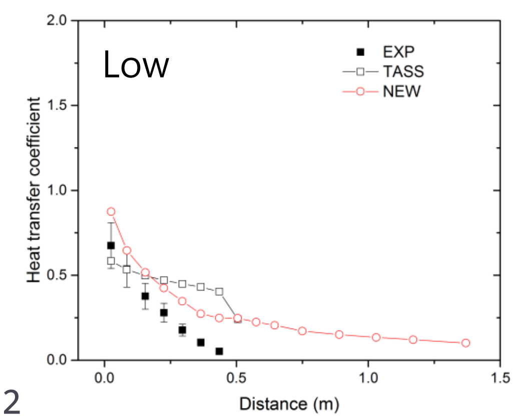
- POSTECH High Pressure Test
  - 1 MPa

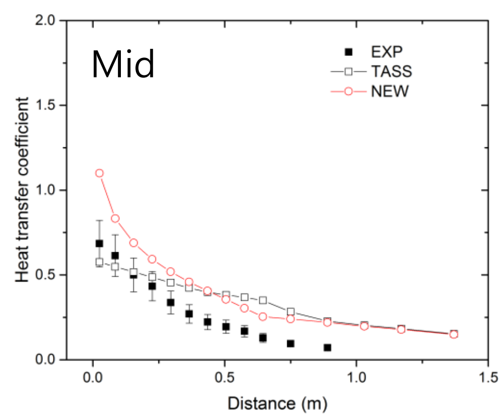


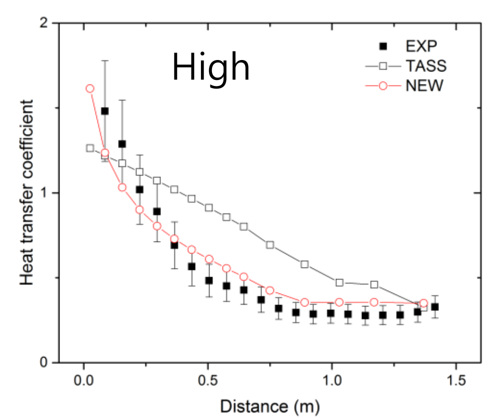




  - 2 MPa

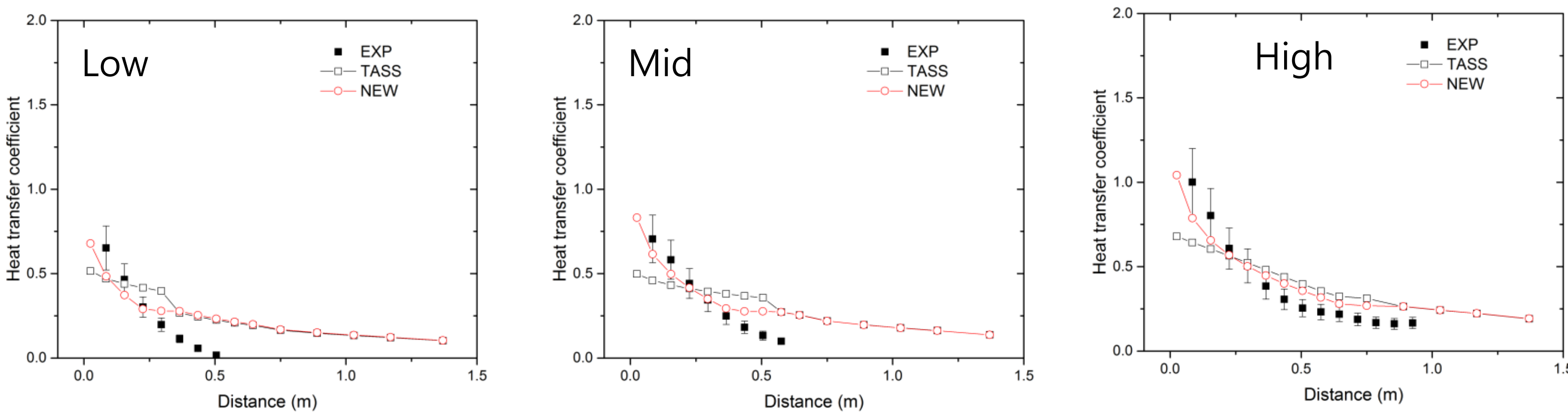


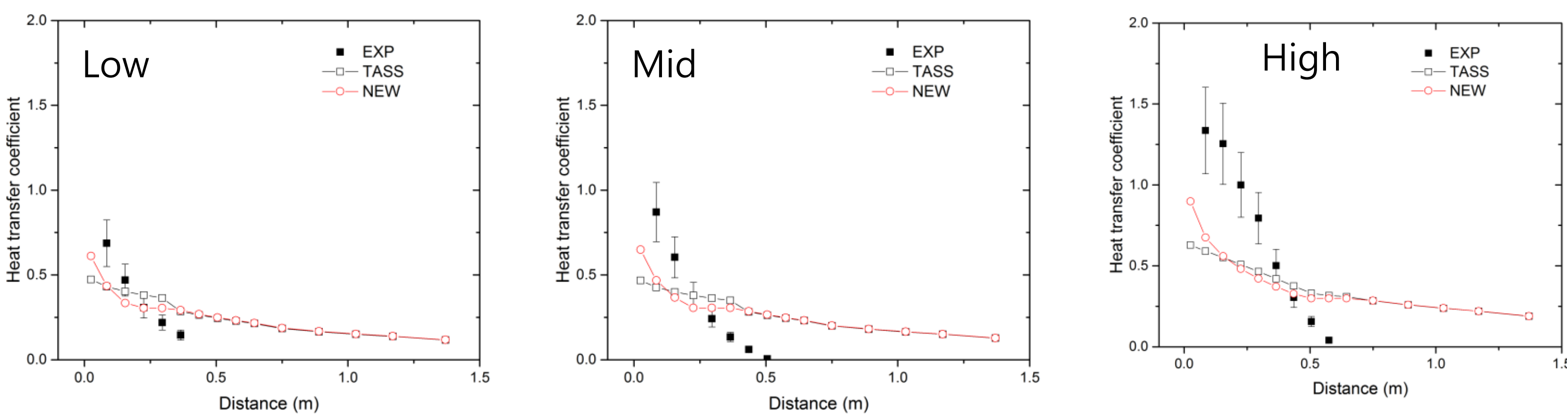



# Validation of new correlation

- POSTECH High Pressure Test
  - 4 MPa

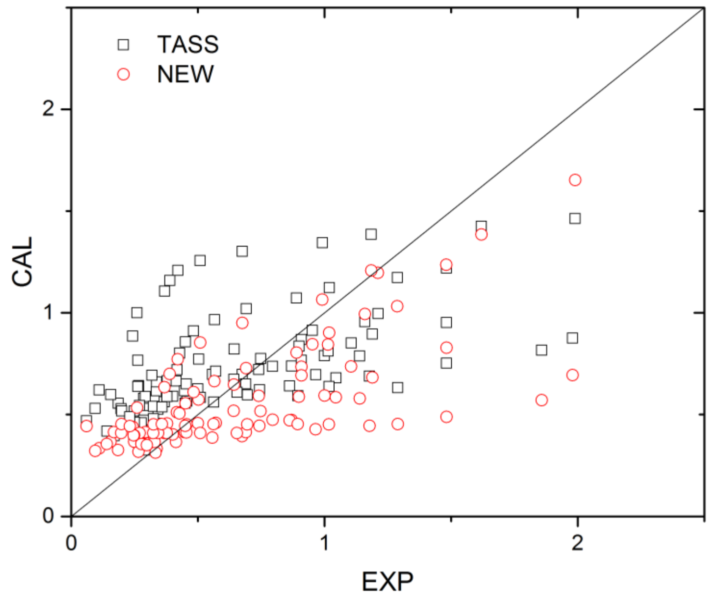



  - 6 MPa



# Validation of new correlation

- POSTECH High Pressure Test




| | TASS | NEW |
|---|---|---|
| Avg. Std. Dev. (%) | 91.744 | 64.362 |
| Avg. RMSE (kW/m$^2$K) | 1.835 | 1.892 |

# Conclusion

- New condensation correlation is suggested for PRHRS module in TASS code and validated with POSTECH condensation experiment.

- New condensation correlation is based on TRACE heat transfer regime selection logic and it gives better results compared to previous one.
  - Over-estimate in low pressure and under-estimate in high pressure

- Further optimization must be followed in case of different pressure and flow rate.