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CO_2 Flow Metering through Multi-Modal Sensing and Statistical Data Fusion

Dates: Sept 2014 – June 2016, Value: £205k@100% fEC

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Industrial sponsor: KROHNE Ltd (T. Wang)

Key researchers: L. Sun (RA)
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Motivation, Aim and Objectives

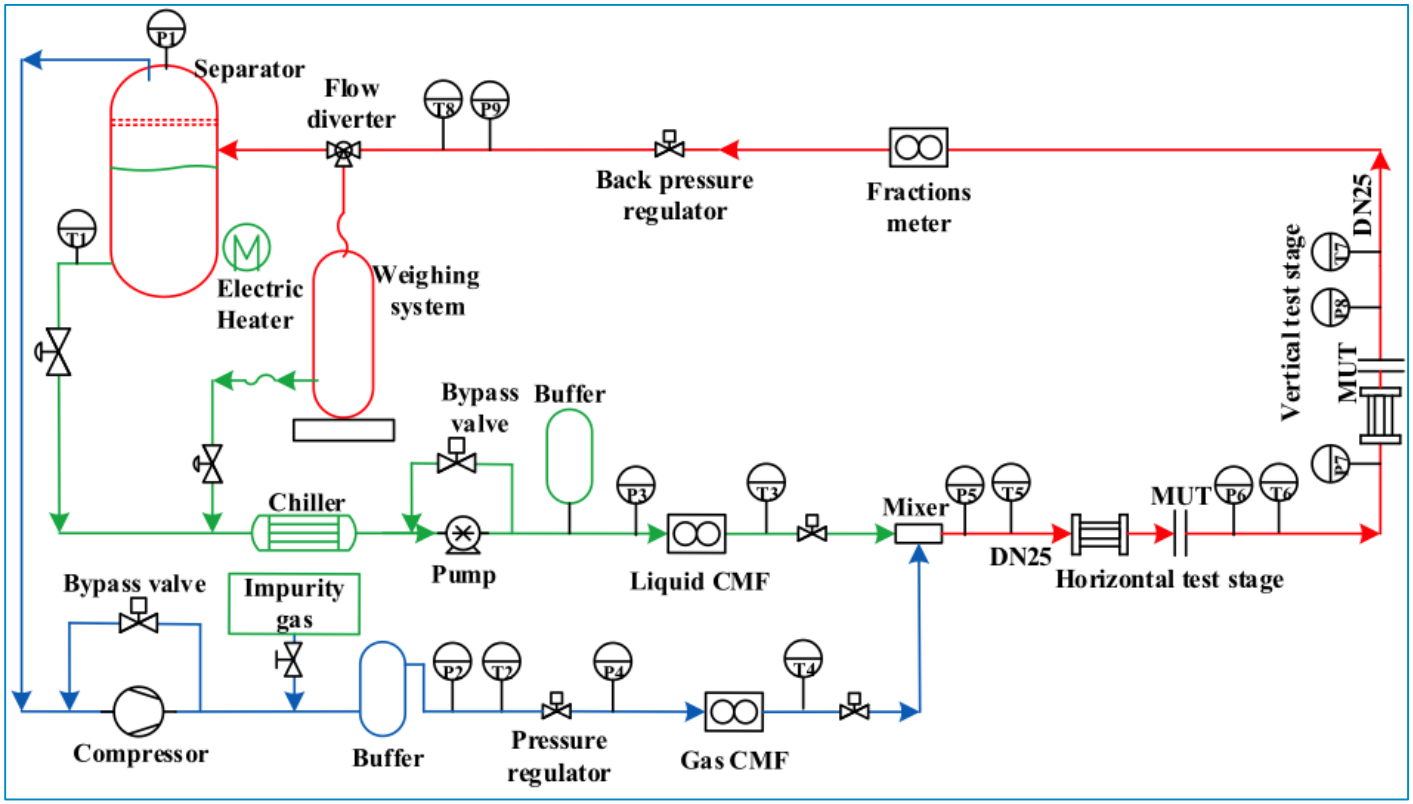
- Measurement of CO_2 flow across the CCS chain is essential to ensure accurate accounting of CO_2 flow and prevent leaking during transportation.
- Significant changes in physical properties of CO_2 (gas, liquid, two-phase or supercritical) mean that CO_2 flows in pipelines are complex in nature.
- The project aimed to develop a cutting-edge technology for CO_2 flow metering in CCS pipelines. The objectives are,
  - to establish a mass reference platform for CO_2 flowmeter calibration;
  - to develop a prototype multi-modal sensing system and data fusion algorithms for mass flow metering of CO_2;
  - to evaluate the performance of the multi-modal sensing system under single-phase and two-phase CO_2 flow conditions.

Summary of Main Activities

- A dedicated flow test facility was developed for CO_2 flowmeter calibration and evaluation under CCS conditions.
- The facility is capable of providing single-phase (liquid or gas) or two-phase (liquid/gas) CO_2 flows in one-inch bore, horizontal and vertical pipelines with pressures up to 72 bar.
- Two-phase flow regimes (stratified, bubbly, plug and slug flows) can be created. Impurity gases can also be injected into the test section to assess their impact on the performance of CO_2 flowmeters.
- The facility incorporates Krohne Coriolis flowmeters and intelligent data fusion algorithms, being capable of measuring the mass flow rate of CO_2 under single-phase (gas or liquid) and two-phase (gas/liquid) flow conditions.
- The gas volume fraction of CO_2 under two-phase flow conditions can also be predicted.

Summary of Main Activities

- Schematic of the CO_2 flow test facility



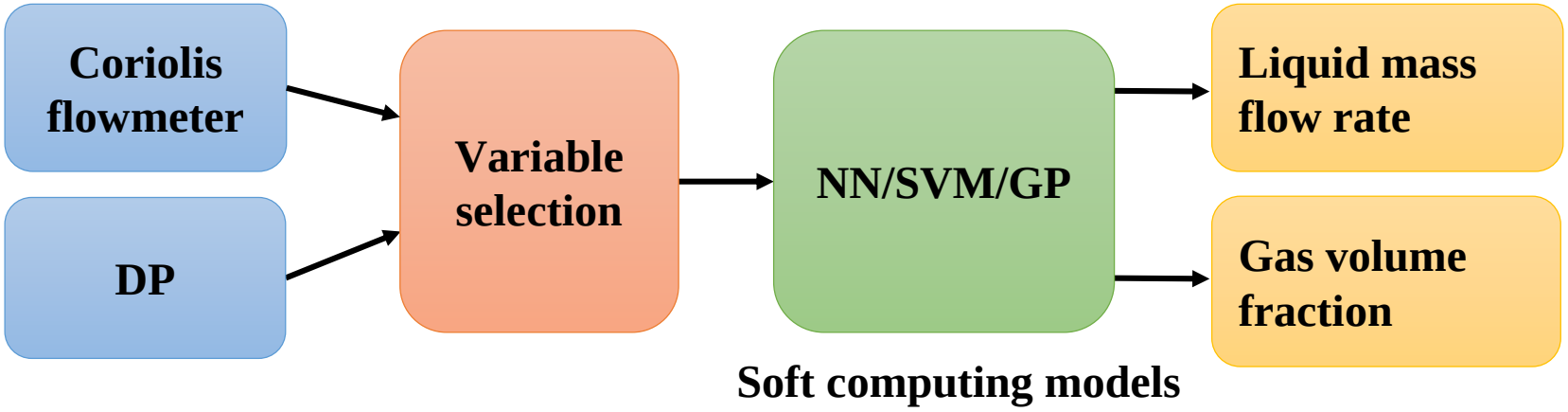
Summary of Main Activities

- **Overview of the CO_2 flow test facility**

- Low uncertainty: 0.06% (k=2) for liquid by weighing method; 0.16% (k=2) for liquid/0.3% (k=2) for gas by master meter method
- Versatility: simulate single phase gas/liquid flows and various two-phase flow regimes under CCS conditions

Summary of Main Activities

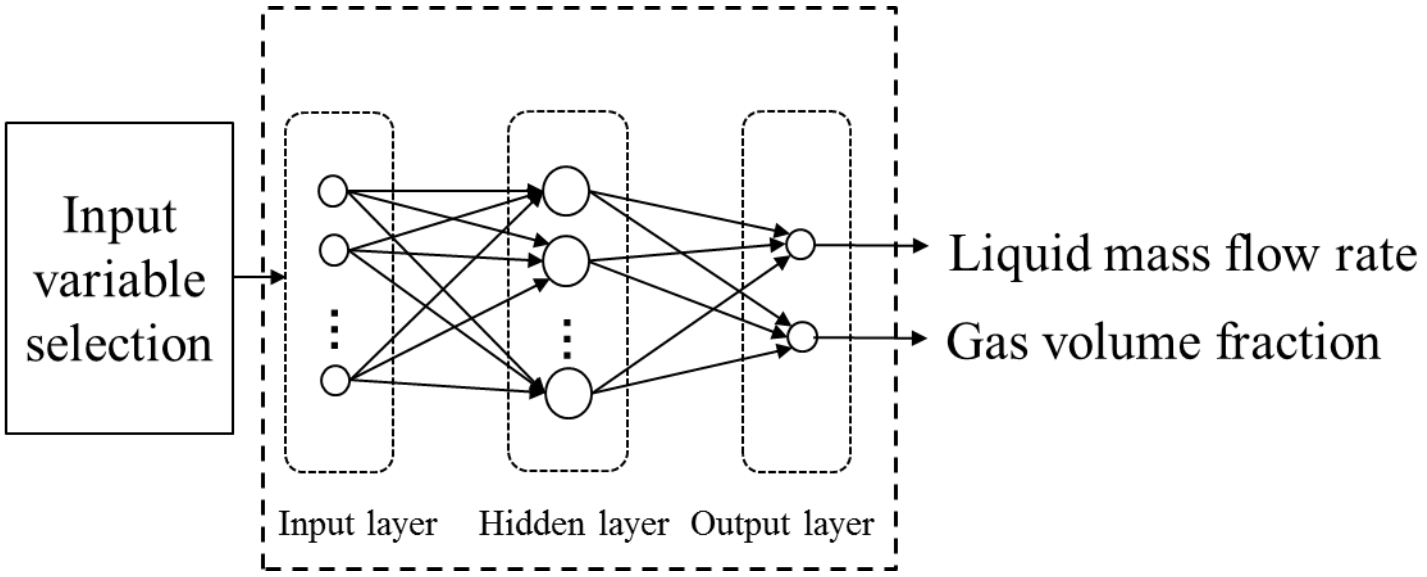
- **Flow measurement approach- Soft-computing**



Schematic of the CO_2 flow measurement system

Summary of Main Activities

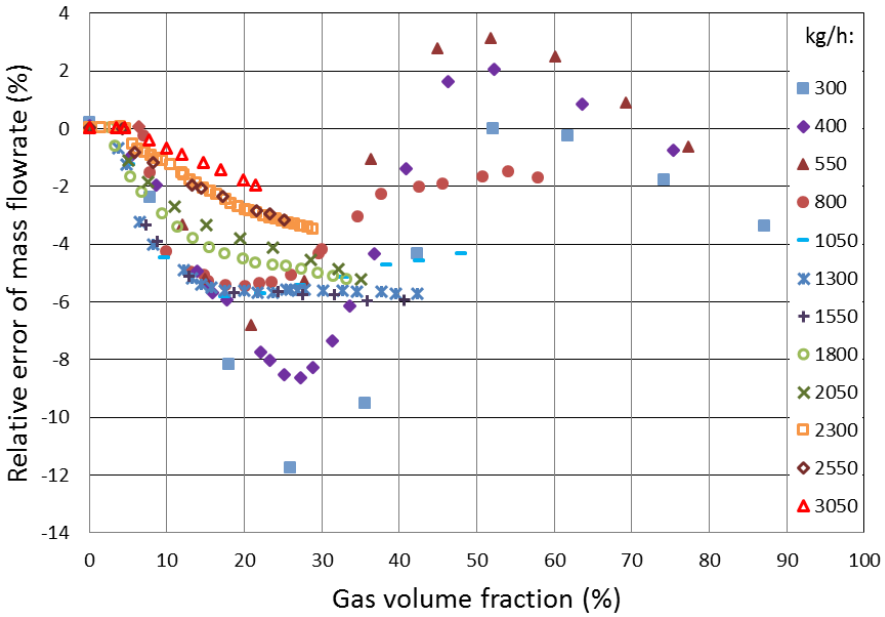
- **Flow measurement approach- Soft-computing**



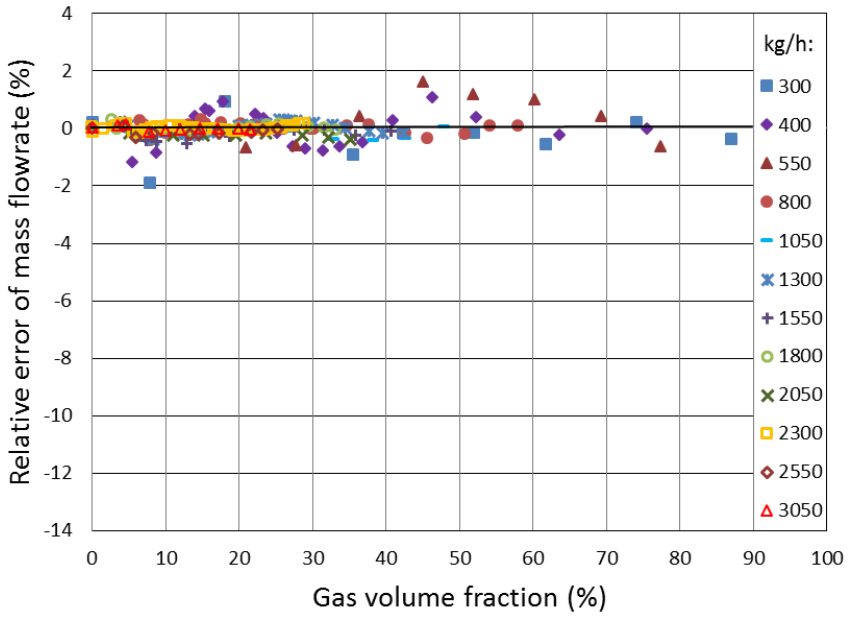
ANN for CO_2 flow measurement

Summary of Main Activities

- **Example test results on the CO_2 flow test facility**



Original error from the vertical test section



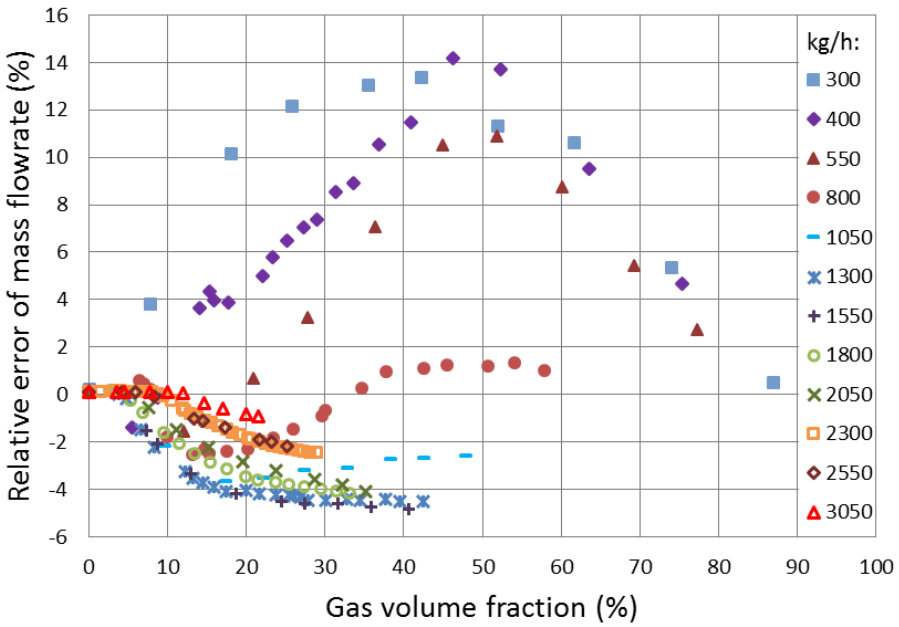
Corrected mass flowrate

Remark:

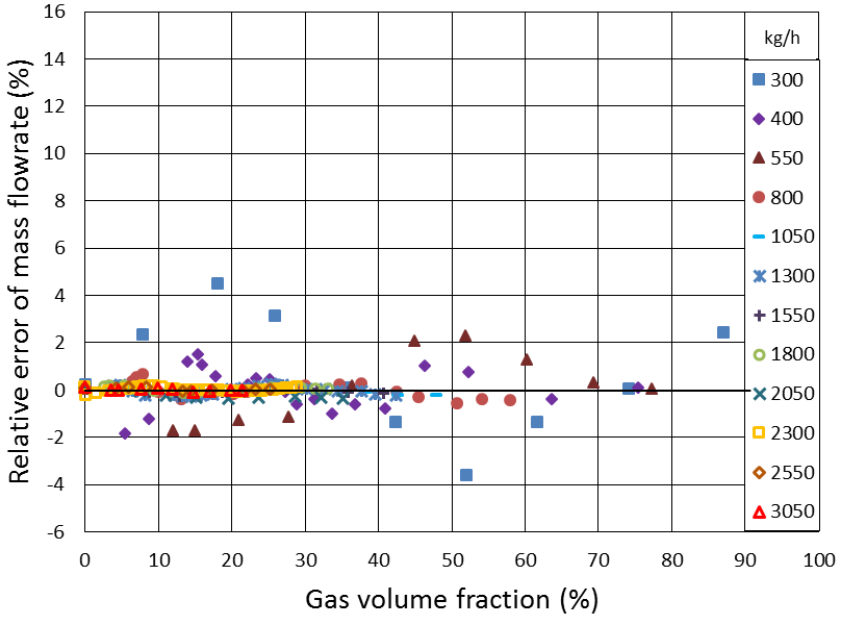
- Performance of the optimized NN for the measurement of liquid mass flow rate: Reduced from ±12% to mostly ±1.5%
- Performance of the optimized NN for the prediction of gas volume fraction: mostly within ±10%

Summary of Main Activities

- **Example test results on the CO_2 flow test facility**



Original error from the horizontal test section



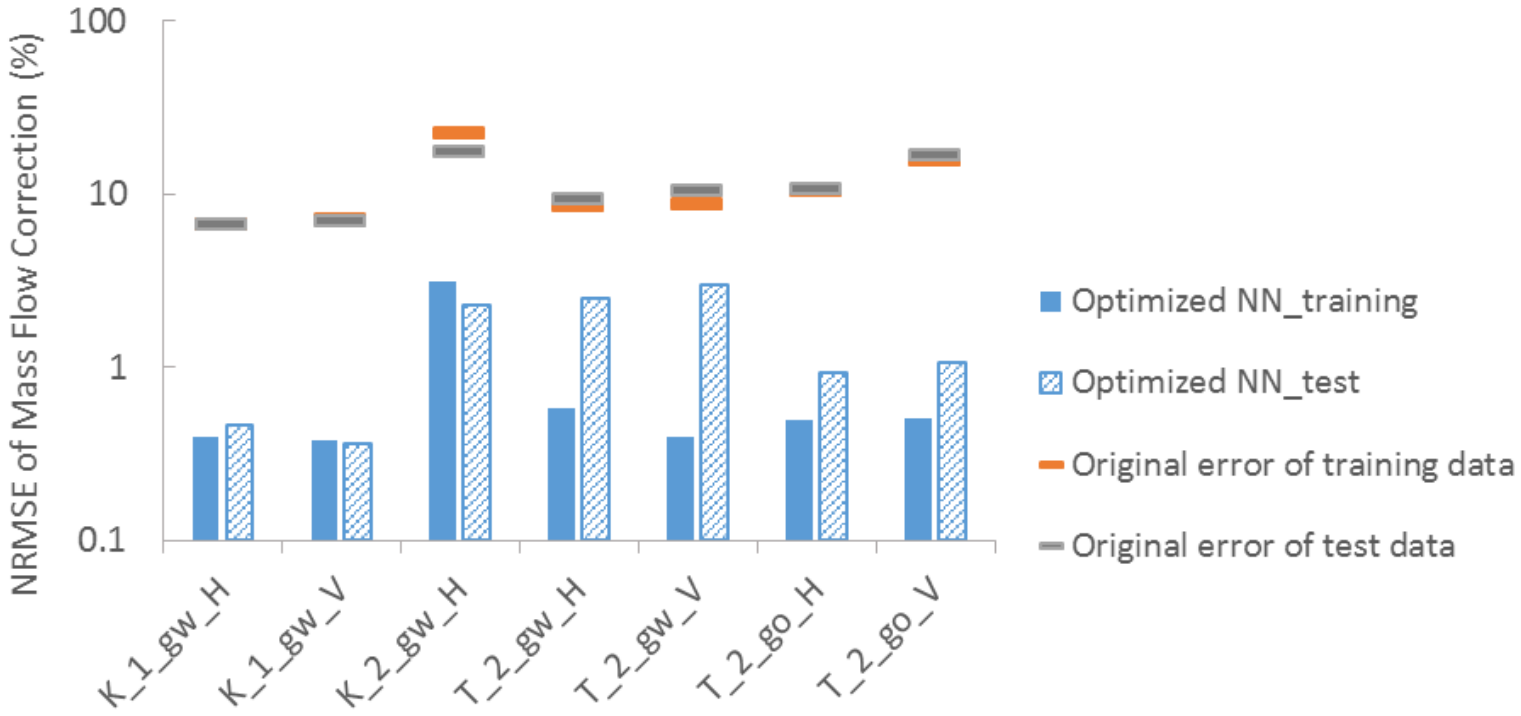
Corrected mass flowrate

Remark:

- Performance of the optimized NN for the measurement of liquid mass flow rate: Reduced from ±14% to mostly ± 2%
- Performance of the optimized NN for the prediction of gas volume fraction: mostly within ±10%

Summary of Main Activities

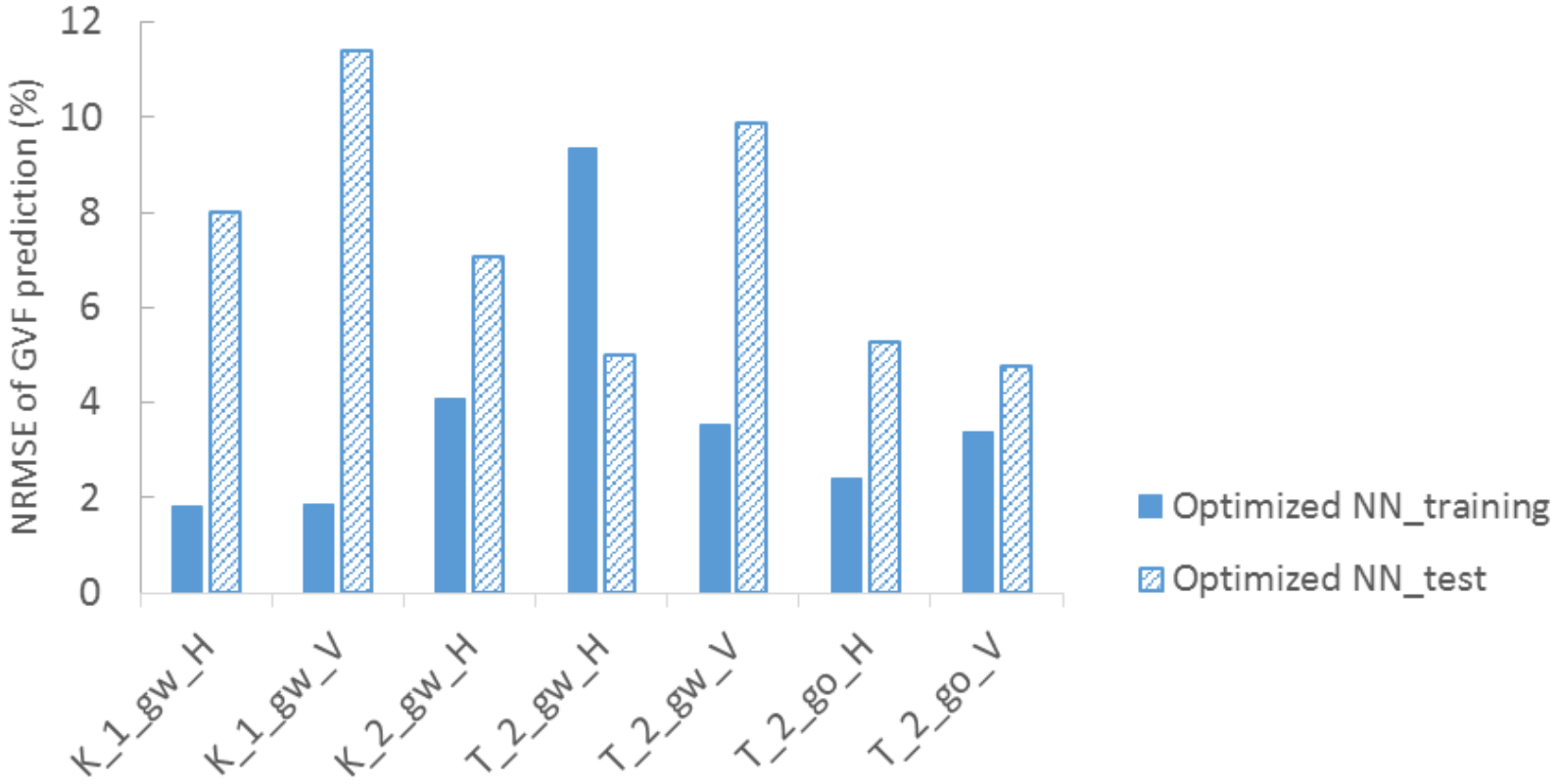
- **Multiphase flow (air/oil/water) test results at Krohne Ltd and Tianjin University**



Performance of the optimized NN for the measurement of liquid mass flow rate: Reduced from maximum 22% to 3%

Summary of Main Activities

- **Multiphase flow (air/oil/water) test results at Krohne Ltd and Tianjin University**



Performance of the optimized NN for the prediction of gas volume fraction: Less than 12%

Key Findings/Outcomes

- The developed CO_2 flow facility has served its purpose as a reference platform for CCS applications and is probably one of the very few CO_2 flow facilities in the world.
- Coriolis flowmeters incorporating intelligent data models are capable of providing mass flow measurements of CO_2 within ±1.5% under two-phase flow conditions.
- The flowmeters have achieved errors within ±0.15% and ±0.25%, respectively, for single-phase liquid and gaseous CO_2.
- The flowmeters incorporating intelligent data models can meet the ±1.5% uncertainty requirements set by the EU-ETS (Emissions Trading Scheme).

Key Findings/Outcomes

Publications

1. L. Wang, J. Liu, Y. Yan, X. Wang, T. Wang. Mass flow measurement of two-phase carbon dioxide using Coriolis flowmeters. Proceedings of IEEE I2MTC'2017, pp. 1299-1303, Torino, Italy, May 22-25, 2017.
2. L. Wang, Y. Yan, X. Wang, T. Wang. Input variable selection for data-driven models of Coriolis flowmeters for two-phase flow measurement. Meas. Sci. Techno., vol. 28, no. 3, pp. 1-12, 2017.
3. L. Wang, J. Liu, Y. Yan, X. Wang and T. Wang. Gas-liquid two-phase flow measurement using Coriolis flowmeters incorporating artificial neural networks, support vector machine and genetic programming algorithms. IEEE Trans. IM, vol. 66, no. 5, pp. 852-868, 2017.
4. L. Wang, Y. Yan, J. Liu, X. Wang, T. Wang. Gas-liquid two-phase flow measurement using Coriolis flowmeters incorporating neural networks. Proceedings of IEEE I2MTC'2016, pp. 747-751, Taipei, Taiwan, May 23-26, 2016.
5. L. Sun, K. Adefila, Y. Yan, T. Wang. Development of a CO_2 two-phase flow test rig for flowmeters calibration. Proceedings of 9th Int. Symposium on Meas. Tech. for Multi. Flows, 23-25 Sept 2015, Sapporo, Hokkaido, Japan.
6. L. Sun, Y. Yan, T. Wang, X. Feng, P. Li. Development of a CO_2 two-phase flow rig for flowmeters calibration under CCS conditions. Proceedings of the 17th Int. Flow Meas. Conf., pp. 1-5, Sydney, Australia, Sept 26-29, 2016.

Possible Applications/Collaboration

- Tests under gas-liquid CO_2 conditions with impurity gases.
- Trials of the flow metering technology on a CCS plant.
- Future development of the technology may reduce further the measurement uncertainty, enabling more accurate accounting of CO_2 in the CCS industry.