Vertically installed Venturi tubes for wet-gas flow measurement: possible improvements to ISO/TR 11583 to extend its range of applicability

by

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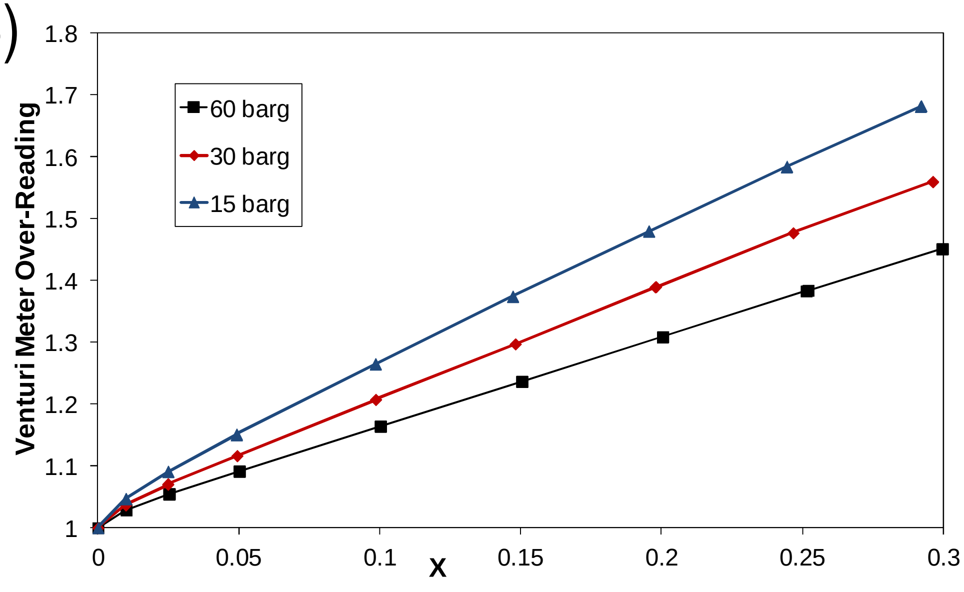
NEL

Introduction

- Venturi tubes are commonly used for wet-gas flow measurement
- Liquid causes the meter to over-read the gas flowrate
- It is necessary to ‘correct’ for this using an empirical correlation
- Correlations available for horizontal orientation of Venturi tubes in 2-phase wet-gas flows
  - NEL correlation (ISO/TR 11583)
  - de Leeuw correlation

What about vertical flows ???



Well known wet-gas correlations

- Murdock – orifice plates — ***X***
- Chisholm – orifice plates — ***X, DR***
- de Leeuw – Venturi tubes

  (modified Chisholm eqn) — ***X, DR, Fr_g***
  - Limited parameters β=0.4, 4"
- NEL – Venturi tubes

  (modified Chisholm eqn) — ***X, DR, Fr_g, β, H***
  - Uses wet-gas discharge coefficient
  - Limited validation for water-oil mixtures
- All for 2-phase wet-gas flows

$$X = \frac{m_{liq}}{m_{gas}}\sqrt{\frac{\rho_{1,gas}}{\rho_{liq}}} \qquad DR = \frac{\rho_{1,\mathrm{gas}}}{\rho_{\mathrm{liq}}} \qquad Fr_{\mathrm{gas}} = \frac{v_{\mathrm{gas}}}{\sqrt{gD}}\sqrt{\frac{\rho_{1,\mathrm{gas}}}{\rho_{\mathrm{liq}}-\rho_{1,\mathrm{gas}}}}$$

Use of wet-gas correlations

$$q_{m,\text{gas}} = \frac{C}{\sqrt{1-\beta^4}}\,\varepsilon\,\frac{\pi}{4}d^2\,\frac{\sqrt{2\Delta p\,\rho_{1,\text{gas}}}}{\phi}$$

modifying n

$$\phi = \sqrt{1 + C_{\text{Ch}}X + X^2}$$

$$C_{\text{Ch}} = \left(\frac{\rho_{\text{liquid}}}{\rho_{1,\text{gas}}}\right)^n + \left(\frac{\rho_{1,\text{gas}}}{\rho_{\text{liquid}}}\right)^n$$

Chisholm $n=0.25$

de Leeuw $n=0.41$ for $0.5 \le Fr_{gas} < 1.5$

$$n = 0.606\left(1-e^{-0.746 Fr_{\text{gas}}}\right) \quad \text{for } Fr_{gas} \ge 1.5$$

NEL $n = \max(0.583 - 0.18\beta^2 - 0.578e^{-0.8Fr_{gas}/H}, 0.392 - 0.18\beta^2)$

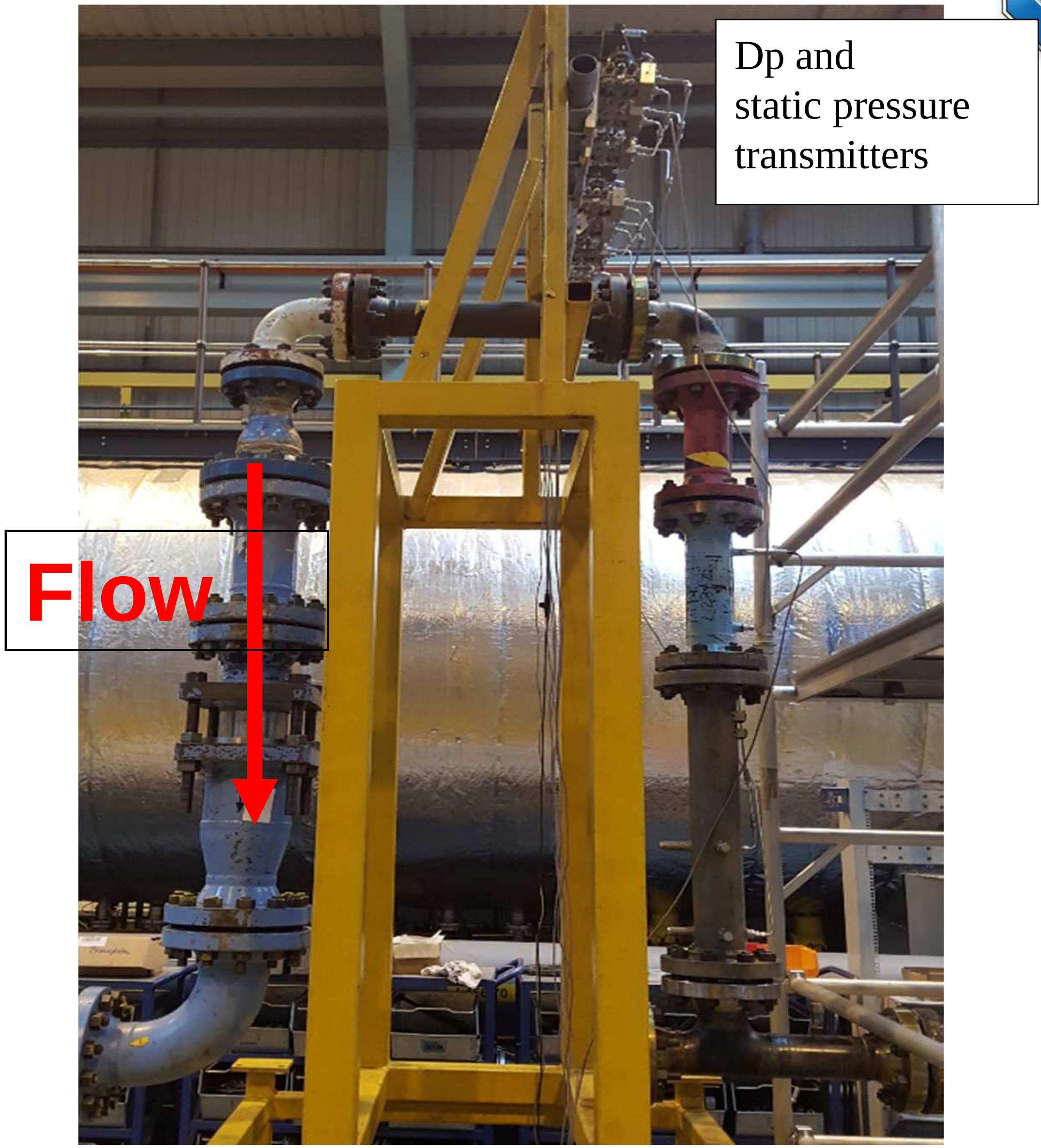
NEL $C = 1\text{-}0.0463e^{-0.05Fr_{\text{gas,th}}}\min\left(1, \sqrt{\frac{X}{0.016}}\right)$

Use of ISO/TR 11583 wet-gas correlations

NEL $$n = \max(0.583 - 0.18\beta^2 - 0.578e^{-0.8Fr_{gas}/H}, 0.392 - 0.18\beta^2)$$

H = 1 for liquid hydrocarbon
H = 1.35 for water

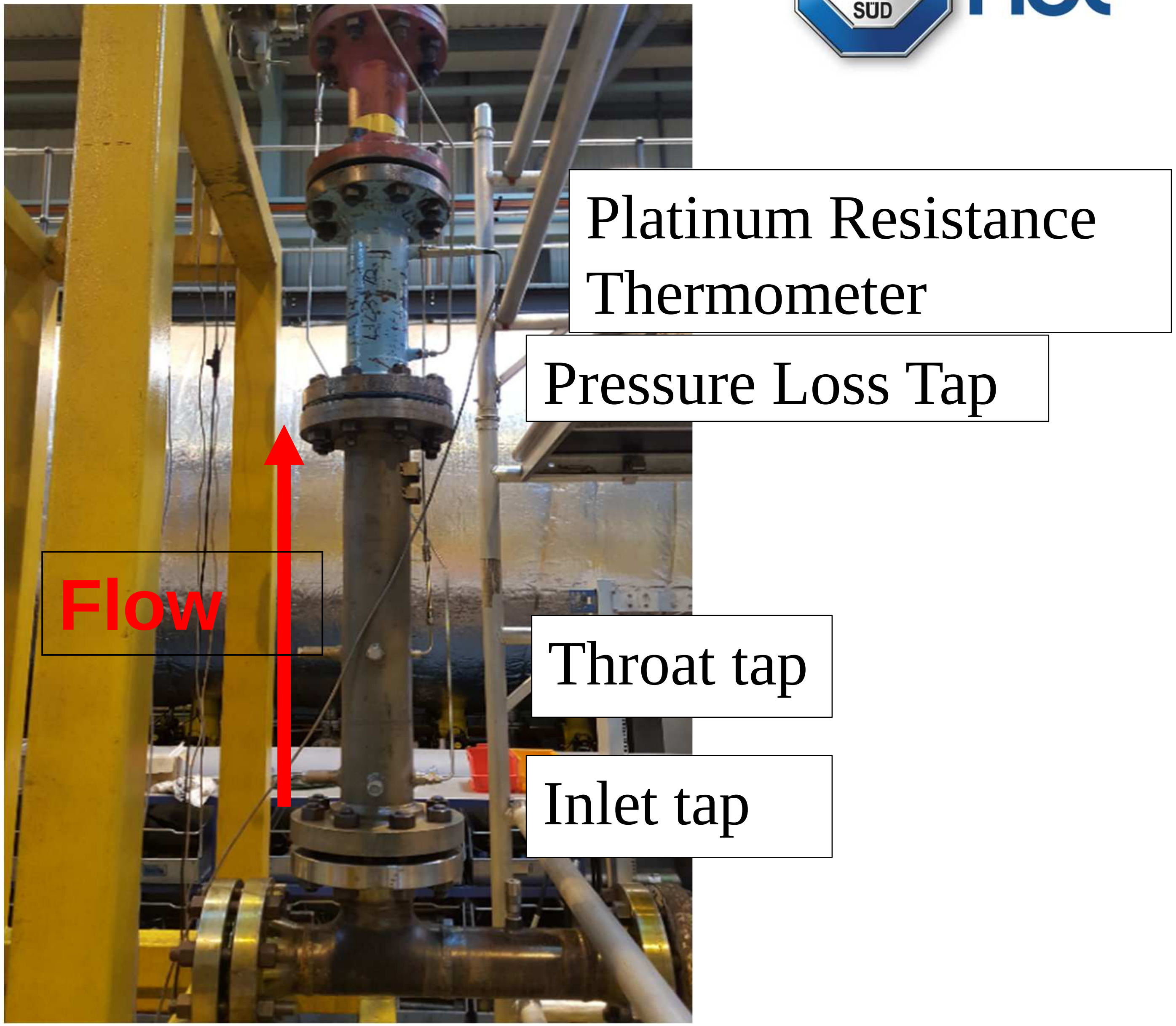
Venturi Tests at NEL (4-inch)



Test Conditions

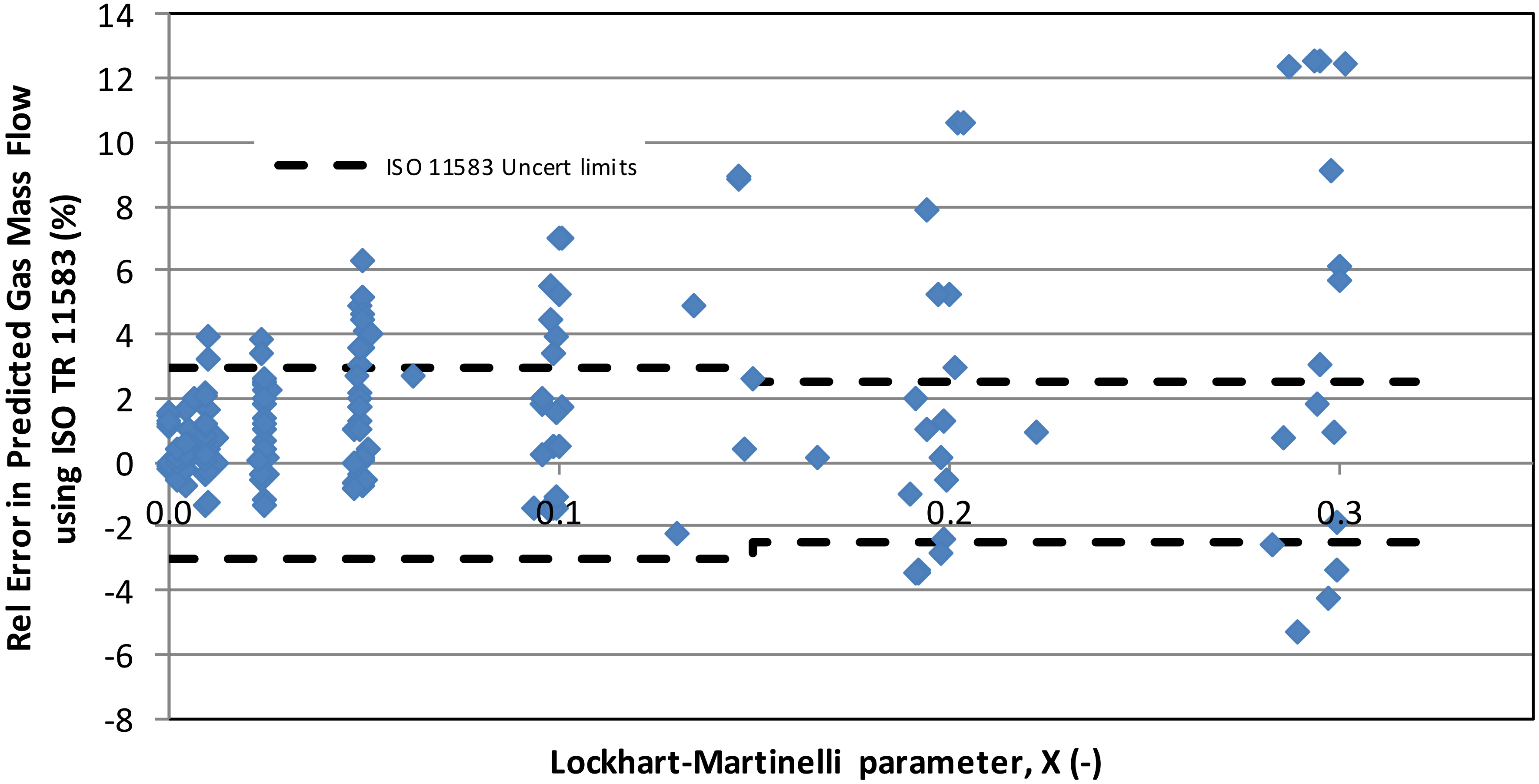
Venturi diameter ratio, *β* (-)	**Line Pressure (barg)**	**Gas Froude number, Fr_g (-)**	**Density Ratio, *DR* (-)**
0.4	15 30 60	1, 2, 2.5 1.5, 2, 3 1.5, 3, 4	0.023 0.046 0.088
0.6	15	1.5, 2.5, 3	0.024
0.75	15 30 60	2, 3, 4, 5 1.5, 4.5 2, 5.5	0.025 0.044 0.088

Venturi Tests at NEL (4-inch)

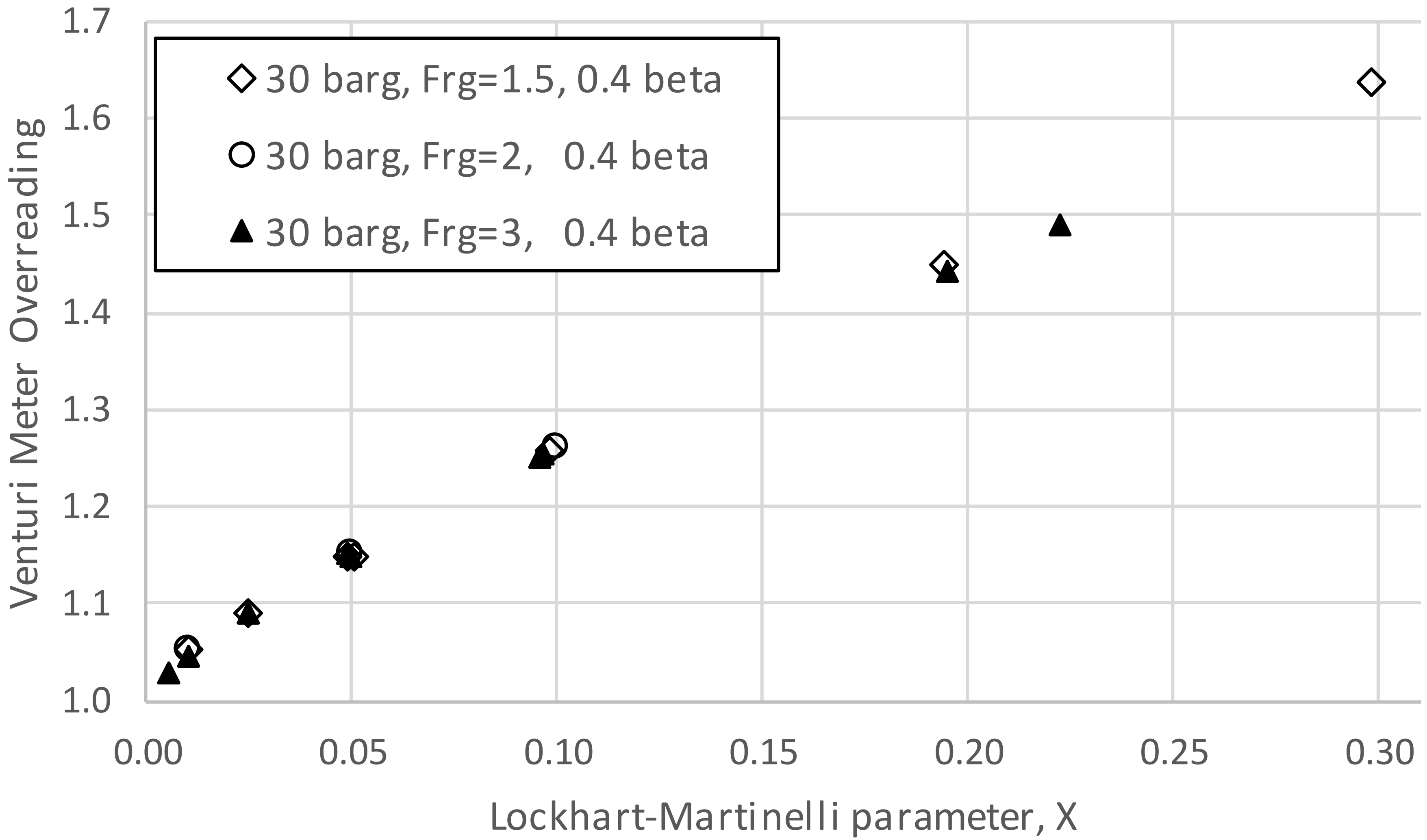


- Fluids used: gas (nitrogen) and oil (kerosene substitute Exxsol D80)
- In the impulse lines it was assumed that the fluid was gas; in the Venturi tube it was assumed that the fluid was a homogeneous mixture of gas and oil.
- If a zero is inconsistent with this assumption data are rejected.

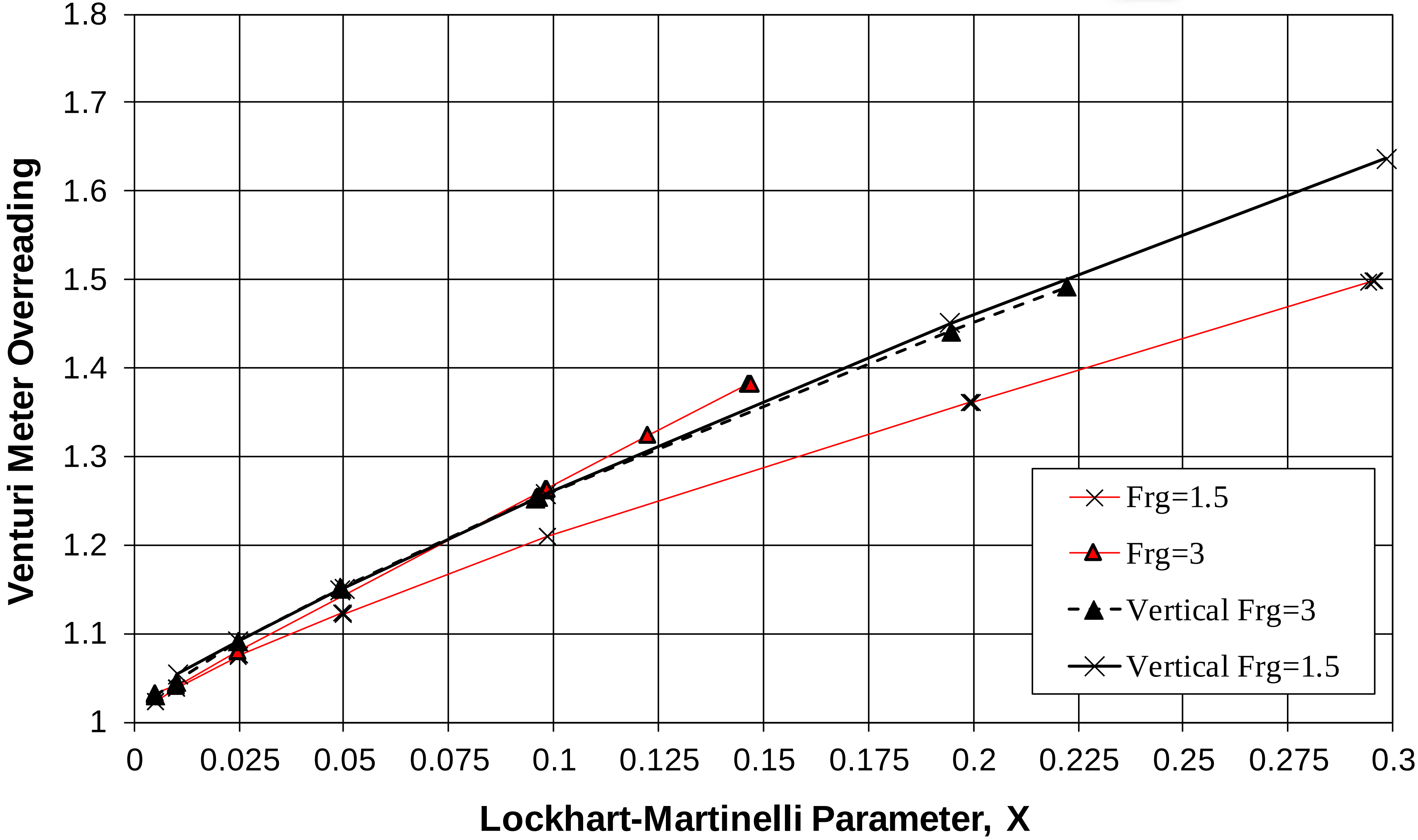
Applying the ISO/TR 11583 correlation to the experimental data for vertically oriented Venturi tubes



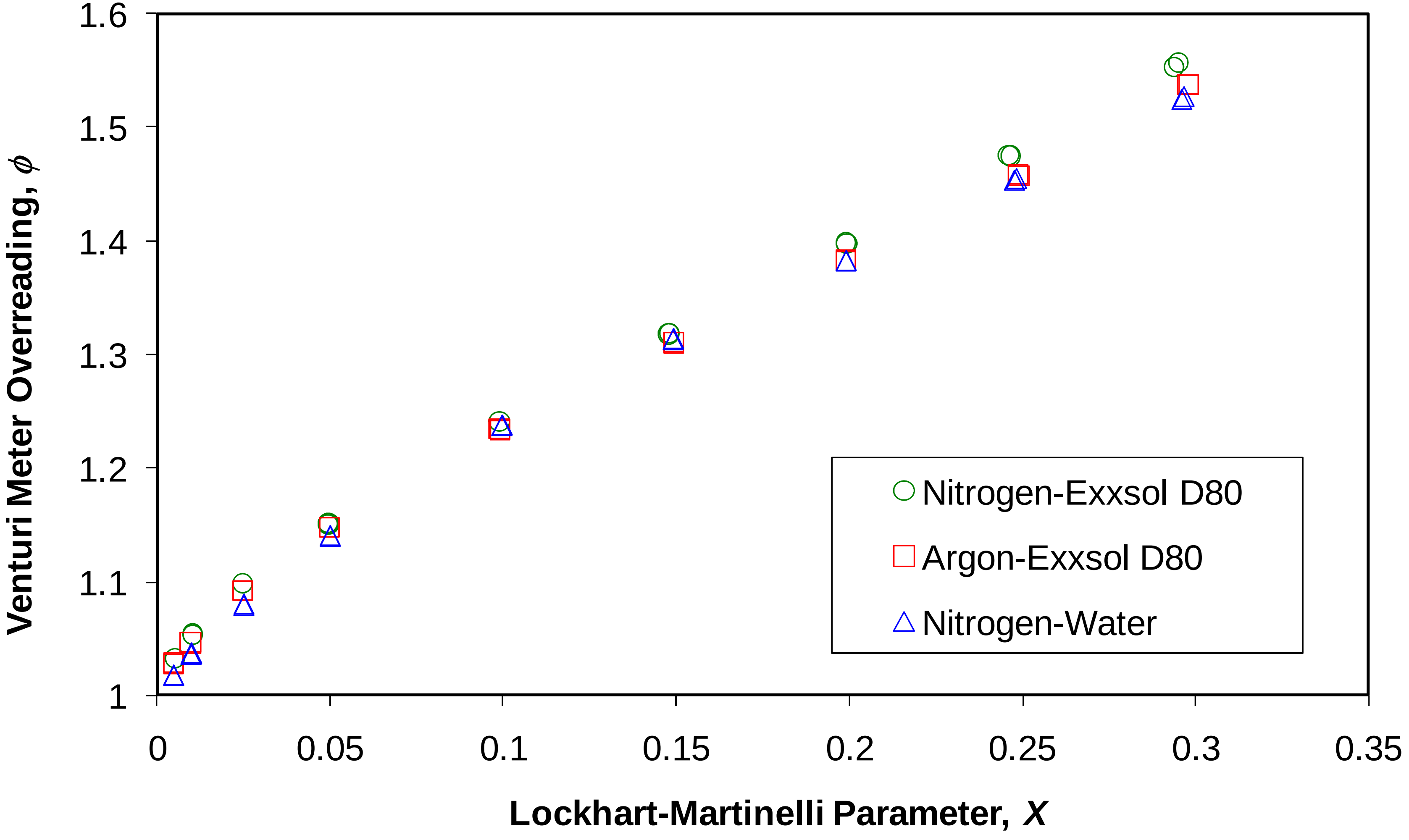
Over-reading for β=0.4 vertical Venturi



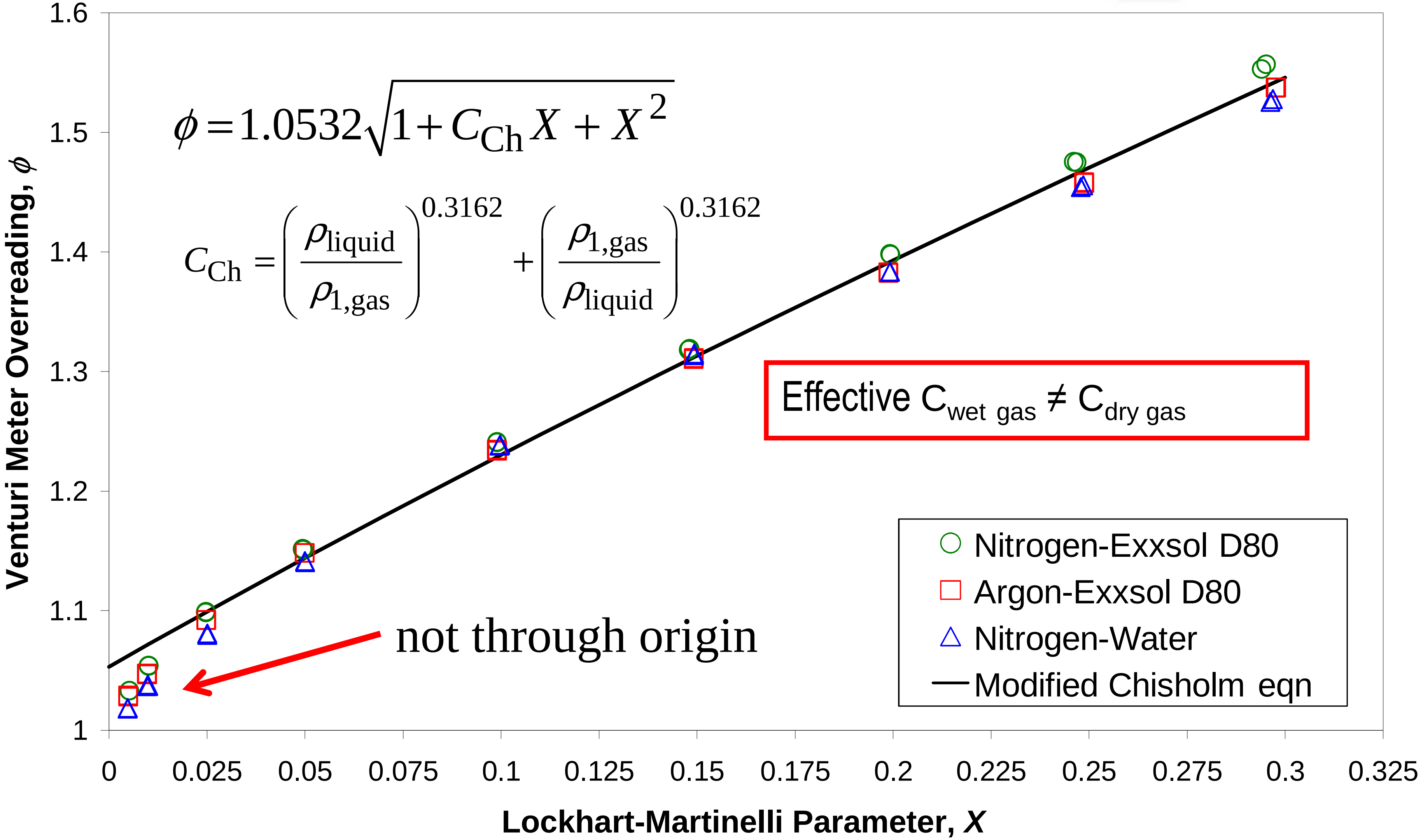
Over-reading for β=0.4 horizontal and vertical Venturis



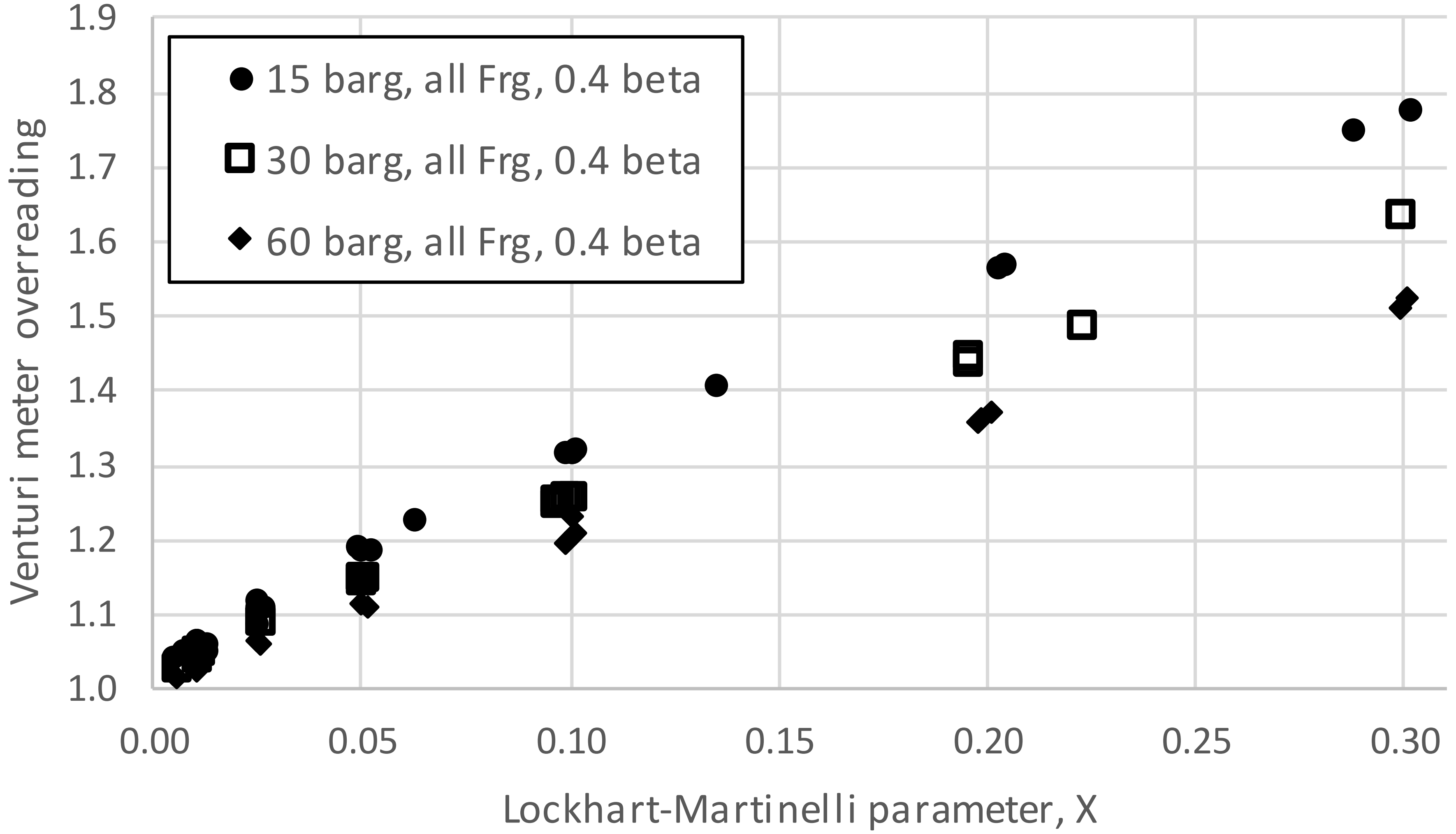
4" Venturi β = 0.6 Horizontal, $\rho_{1,gas}/\rho_{liquid}$ = 0.024, Fr_{gas} = 1.5



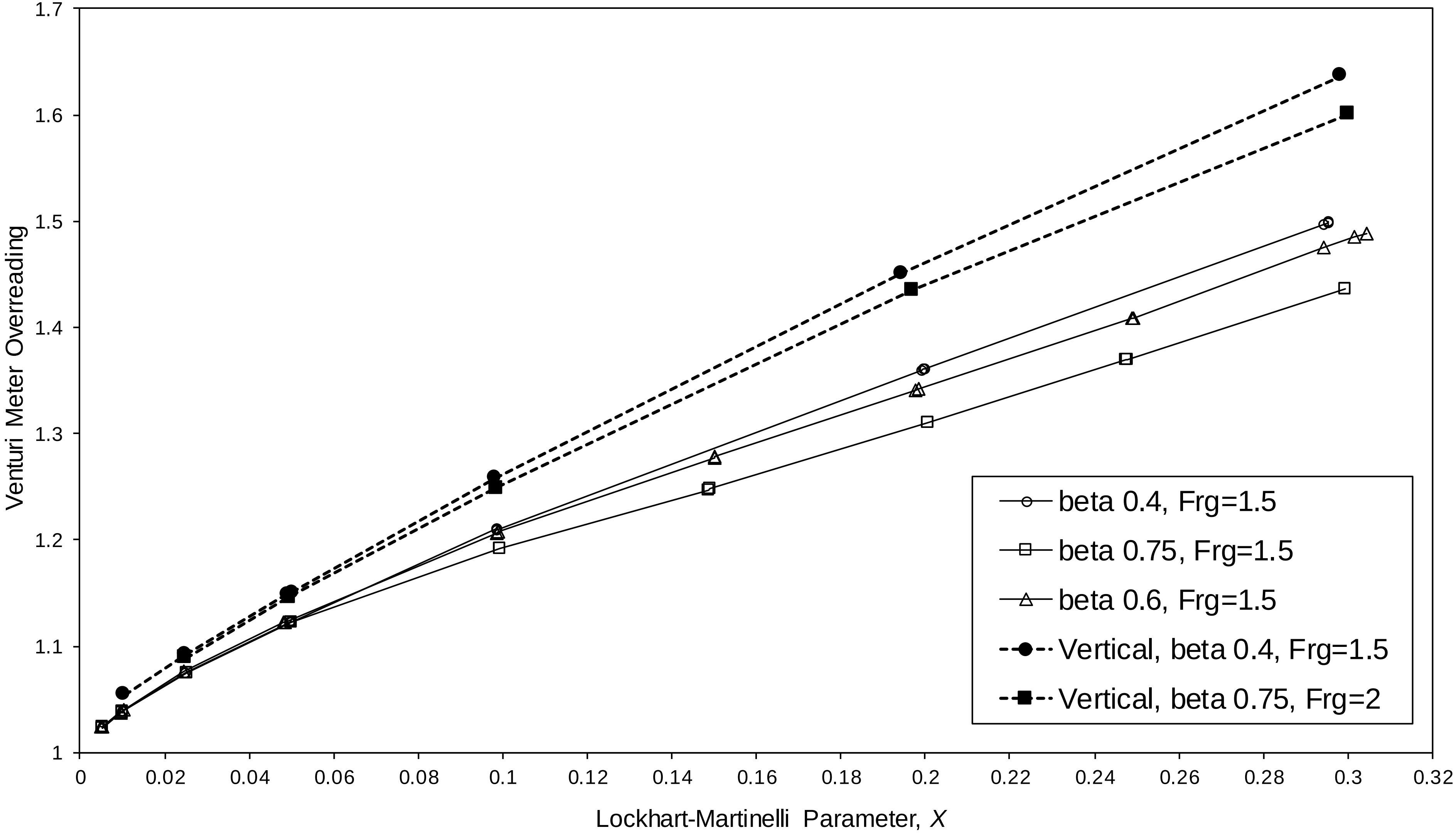
4" Venturi β = 0.6, Horizontal, $\rho_{1,gas}/\rho_{liquid}$ = 0.024, Fr_{gas} = 1.5



Over-reading for vertically installed β=0.4 Venturi at all pressures and gas Froude numbers



Over-reading for horizontally and vertically installed Venturis over a range of β



Use of wet-gas correlations with horizontal Venturis

$$q_{m,\mathrm{gas}} = \frac{C}{\sqrt{1-\beta^4}}\,\varepsilon\,\frac{\pi}{4}\,d^2\,\frac{\sqrt{2\Delta p\,\rho_{1,\mathrm{gas}}}}{\phi}$$

modifying *n*

$$\phi = \sqrt{1 + C_{\mathrm{Ch}} X + X^2} \qquad C_{\mathrm{Ch}} = \left(\frac{\rho_{\mathrm{liquid}}}{\rho_{1,\mathrm{gas}}}\right)^n + \left(\frac{\rho_{1,\mathrm{gas}}}{\rho_{\mathrm{liquid}}}\right)^n$$

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NEL $C = 1\text{-}0.0463e^{-0.05Fr_{\mathrm{gas,th}}} \min\left(1, \sqrt{\frac{X}{0.016}}\right)$

Use of wet-gas correlations with vertical Venturis

$$q_{m,\text{gas}} = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \frac{\sqrt{2\Delta p \rho_{1,\text{gas}}}}{\phi}$$

$$\phi = \sqrt{1 + C_{\text{Ch}} X + X^2}$$

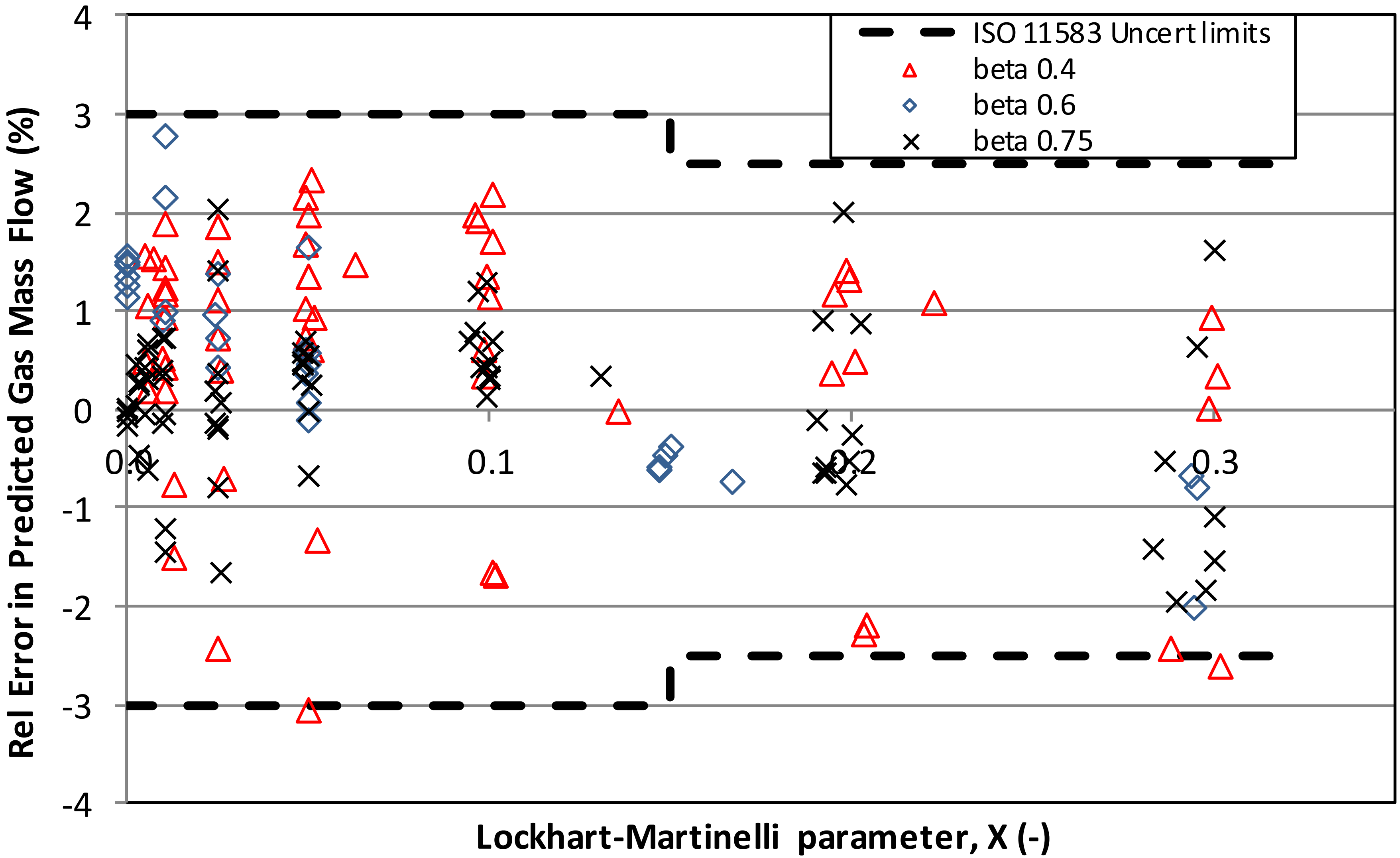
modifying n

$$C_{\text{Ch}} = \left(\frac{\rho_{\text{liquid}}}{\rho_{1,\text{gas}}}\right)^n + \left(\frac{\rho_{1,\text{gas}}}{\rho_{\text{liquid}}}\right)^n$$

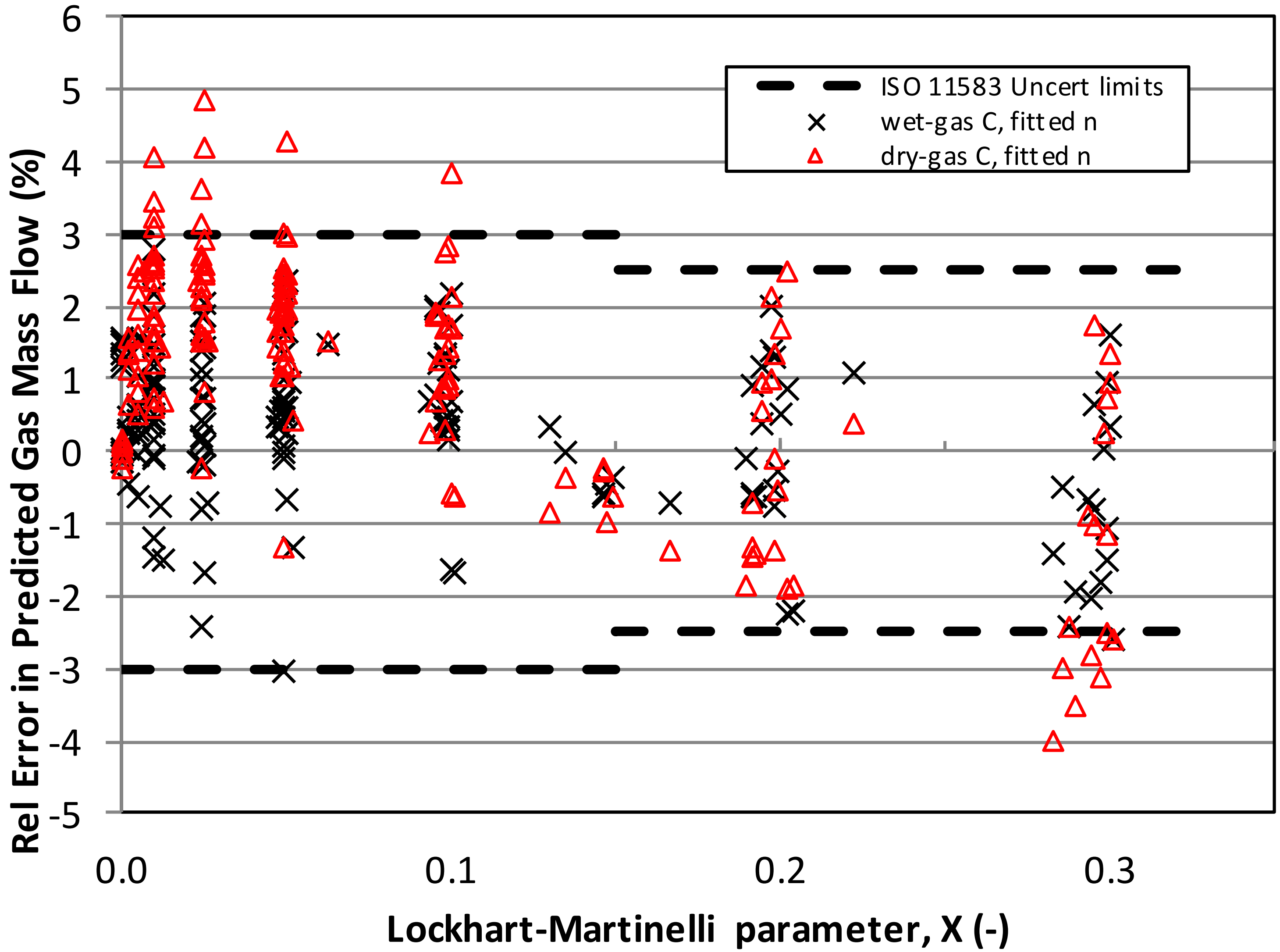
Venturi diameter ratio	Fitted value of *n*
Beta 0.4	0.503
Beta 0.6	0.478
Beta 0.75	0.425

NEL $C = 1\text{-}0.0463\text{e}^{-0.05 Fr_{\text{gas,th}}} \min\left(1, \sqrt{\frac{X}{0.016}}\right)$

Using fitted values of *n* for each Venturi and using wet-gas discharge coefficient from ISO/TR 11583:2012



Using fitted values of *n* for each Venturi and using either wet-gas discharge coefficient from ISO/TR 11583:2012 or dry-gas discharge coefficient



Conclusions

- Tested 4” Venturis vertically
  - β=0.4, 0.6 and 0.75
  - Range of different pressures (15 barg to 60 barg)
  - X from 0 to 0.3
- Over-reading not much affected by the gas Froude number
- β has a smaller impact on the over-reading than for horizontal Venturis but is still significant.
- The ISO/TR 11583 over-reading correlation should not be used for vertical Venturis.
- However, if n is fitted as a function of β and the wet-gas C in ISO/TR 11583 is used, then the gas mass flowrate can be predicted within ± 3%.
- A larger dataset is needed to draw further conclusions and to develop a suitable over-reading correlation for vertical Venturis.

Acknowledgements

- The Flow Programme – funding from UK Department for Business, Energy and Industrial Strategy
- Wet-gas team at NEL

Thank you

Any Questions?