Chemical Science and Technology Laboratory
National Institute of Standards and Technology

Industrial and Analytical Instruments and Services
Measurement Standards

Sonic Nozzles as Primary Standards

Measurements of the discharge coefficient of critical flow venturi (CFVs) flow meters coupled with theoretical predictions of the discharge coefficient are reducing the uncertainty of gas flow measurements. Improvements in the theoretical model will reduce uncertainties from CFVs used as flow standards from the 0.5% level presently provided by the ISO 9300 standard to less than 0.1%. NIST aims to provide state-of-the-art data and validated theoretical models that predict sonic nozzle discharge coefficients.

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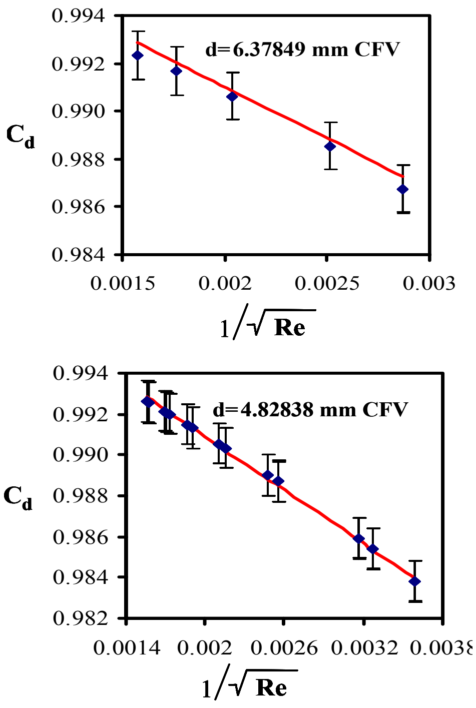
Convergent-divergent nozzles of a specific geometry operated at conditions resulting in sonic gas velocities through the nozzle throat (so called sonic nozzles or critical flow venturies), are widely used as working standards, transfer standards, and even primary standards. This type of flow meter is recognized as one of the most precise gas flow meters available today, and they are used for metering gas flows from about 1 g/min to 500 kg/min or more. Prior studies at NIST and other flow laboratories have shown that sonic nozzles maintain their calibration stability for more than 30 years within 0.2%. The ISO-9300 standard documents procedures for calculating flow from nozzles at the 0.5% relative uncertainty level via theoretical discharge coefficients. Because the dominant contributor to uncertainty in tests of sonic nozzle performance was the primary system used to calibrate them, recent improvements in NIST primary standards to uncertainties as low as 0.02% allow much better validation of the theoretical calibration predictions. This will have a significant impact of flow measurement accuracy in industries where sonic nozzles are used as flow standards.

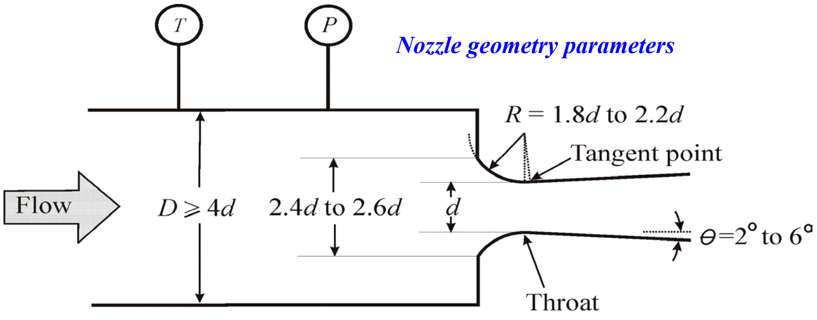
Calibrations of a set of sonic nozzles were completed using our new 34 L, 677 L, and 26 L *PVTt* primary gas flow standards, having uncertainties ranging from 0.02% to 0.13%. Additionally, the NIST Precision Engineering Division made nozzle shape and throat diameter measurements with an uncertainty of 1 µm. The dimensional and experimental flow data were compared with the results of theoretical models and the agreement was excellent (<0.05%). This work validates the theoretical discharge coefficient predictions in addition to identifying limitations of the model. It also identifies applications where users must exercise caution when using nozzles without flow calibrations (at conditions near the laminar to turbulent transition in the nozzle boundary layer). The results also show the importance of using the true nozzle shape, particularly, the ratio of the throat radius to the radius of curvature, in calculating the discharge coefficient from the theoretical model.



The graphs indicate experimentally determined discharge coefficients (symbols) and theoretical predictions. (The uncertainty bars on the plotted experimental data are ± 0.1 %)

Impact: NIST is providing industry with simple, portable, and inexpensive gas flow measurement standards having accuracies competitive with those presently achieved in many National Metrology Institutes. The approach extends to flows that are too large to measure by conventional primary standard designs.

Future Work: This effort will be extended to smaller flows and smaller nozzle diameters where dimensional metrology capabilities are rapidly improving and we have extensive nozzle calibration data. We will also study the significance of nozzle shape defects, dirt deposited by flow, and unusual gas properties in causing departures from the expected flow behavior.


Nozzle geometry parameters