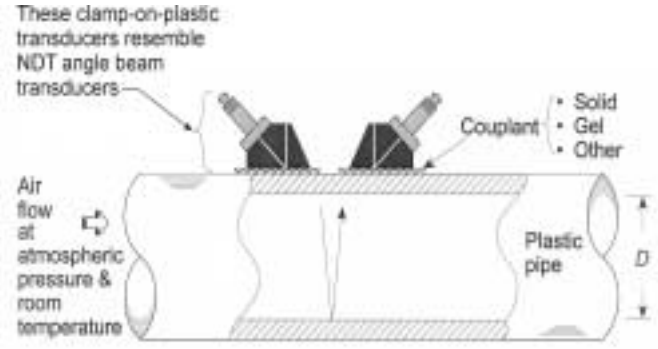
PART 4 OF 5 PARTS*

(D) Clamp-On Applications in Slightly-Pressurized Air, Steam, Nasty Gases and Methane

At present, for the transit time clamp-on method to achieve an accuracy of 2%, it is generally required that the gas have an acoustic impedance comparable to that of air at six bar or greater; pipe diameter *D* at least 75-mm but not over about 600 mm; the pipe must be of good quality; and flow not fast enough to cause significant beam drift, which means, Mach number less than 0.1. Dry gas is easier than wet, but condensate, if not excessive, can be tolerated. [1, 48] As one tries to expand this envelope the probability increases for difficulties to be encountered. However, within this envelope, clamp-on gas flow measurements have been achieved in many field locations. A few are summarized in the captions below.

Just as for flare gas, it should be remembered that this measurement yields *V* and *c*. The *c* can be useful in its own right as an indicator of *MW* or *T*, as well as a contributor, when applicable, to mass flowrate M_F.



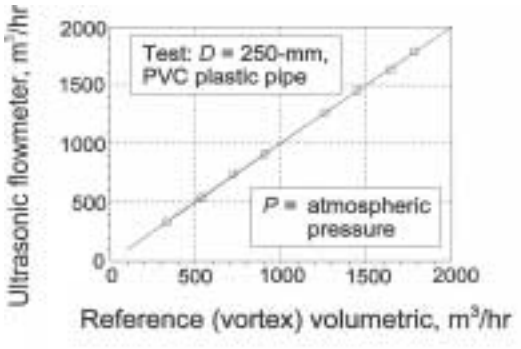
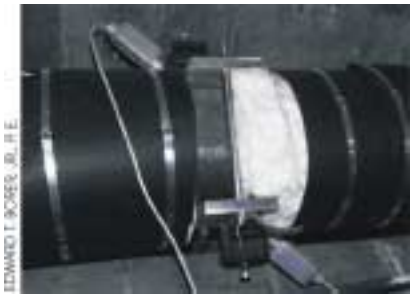


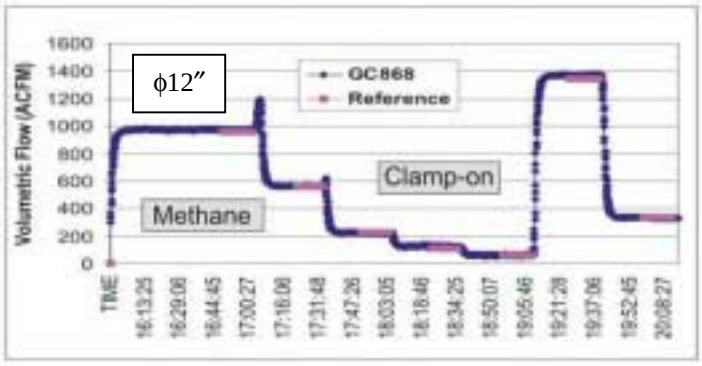
Figure 8. **(a)** Clamp-on experiment on a *plastic* pipe using electronics, transducers and clamping hardware designed for liquids. **(b)** Test result for the situation in (a), obtained by Oleg Khrakovsky.



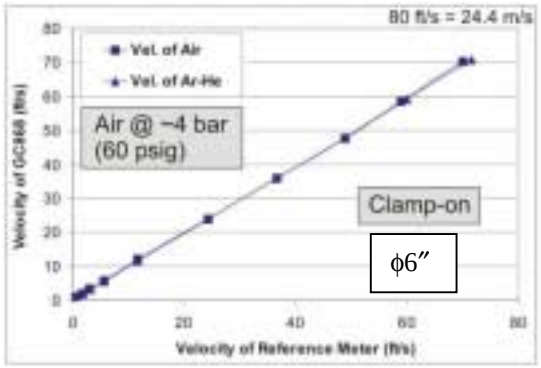
(c) Clamp-on hardware installed on a steam pipe; clamp due to Jim Hurd and John True; photo courtesy of Ted Borer.

(d) Photo shows clamps and electronics module. Note aligned transducers on opposite sides of pipe.

* Part 1: Beginning to end of §A. Part 2 = §B. Part 3 = §C. Part 4 = §D. Part 5 = §E to end.



(e) Data from a single-channel GC868 flowmeter installed on 12-inch pipe measured at the same time as the 8-inch pipe at GTI Metering Research Facility at SwRI on May 24, 2001. This location was about 50 feet upstream from the other measurement point. The instrument was programmed with a different averaging mode. For details see Ao et al. [1]



(f) Calibration of a GC868 clamp-on against a 2-path *wetted* ultrasonic flowmeter IGM868. The gas was either compressed air or an argon-helium mixture. Both sets of data were obtained at a pressure of approximately 60 psig at ambient temperature. Velocity data is averaged over 4 minutes and the standard deviation is less than 0.5% at all velocities above 1.6 ft/s. For details see Ao et al. [1].

Clamp-on transducer installation on a 6″ sch 40 carbon steel steam pipe @ 205 psi and 440°F inside steam distribution tunnel at Princeton University.

As at left except 8″ sch 40 pipe.

As above except 12″ sch-40 pipe (ϕ300 mm) and *outside* steam distribution tunnel at Princeton University.

Figure 8 (g-i). Steam is *not yet* on the list of gases approved for this clamp-on system. However, in beta sites, steam flow was measured in several pipes in the past two years (2000-2002) at [*T, P, D* & *V*] conditions in steam distribution pipes in New Jersey and Massachusetts as follows: [177 to 232°C]; [150 to 210 psig]; [ϕ4″-ϕ12″ (100 to 300 mm)]; [up to 30 m/s]. The photos above show three of these situations, namely, ϕ6-, 8-, and 12-inch steam pipes, courtesy of Princeton University. Reliable measurements depended on pipe conditions, access to both sides of pipe for proper preparation and careful alignment and other factors. It should not be concluded that *every* combination of the stated [*T, P, D* & *V*] will yield a satisfactory flow measurement.

Experts in ultrasonic flowmetering, including inventors such as [53] or [33] are among the many investigators and users who have sought a solution to measuring the flow of gases from outside a steel pipe. Until recently, (1) the combination of low signal, attributed in part to the orders-of-magnitude acoustic impedance mismatch between steel and gases even at several tens of bar pressure, and (2) the strong coherent acoustic crosstalk caused by ultrasound traveling around the pipe, yielded a *SNR* (signal to noise ratio) so low as to discourage solutions other than wetted-transducer solutions.

At the same time that we report herein the successful measurement of a number of gas flows in steel pipes, as with any new technique, one must strive for balance and list the technical problems too. No technique ever solved all problems. The envelope of "likely to succeed" gas flow problems addressable with today's clamp-on solution favors pressures above six bar, temperatures below 200°C, pipe of good condition and diameters above 75 mm, but not too large, and flow velocities somewhat below Mach 0.1, today. These are not fundamental restrictions, but rather, guidelines based on limited field experience to date. Recognizing that clamp-on *gas* is generally much more difficult than clamp-on *liquid*, in the past year we applied certain parts of the GC868 system to troublesome liquid problems and found significant improvement, e.g. success replacing previous failure. Over time, transducers, electronics, algorithms etc. will evolve that are more robust and provide solutions that work even when the application lies beyond the boundaries of today's envelope.