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FIELD EVALUATION OF AN AUTOISOKINETIC STACK PARTICULATE SAMPLING SYSTEM

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FIELD EVALUATION OF AN AUTOISOKINETIC STACK PARTICULATE SAMPLING SYSTEM

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ABSTRACT

The performance of a prototype autoisokinetic stack particulate sampling system designed to maintain automatically isokinetic sampling conditions was evaluated in field tests at stationary sources. Tests were conducted to determine the operating limits and characteristics of the system. Preliminary tests demonstrated the necessity for making several modifications to the existing systems to improve the level of performance for the field program. Improvements were made in the problem areas of the performance of the mass flowmeter, flow totalizer, and flow control valve systems and in the sampling nozzles.

The autoisokinetic sampler was tested at four field installations selected to provide a wide range of sampling conditions. The results of the testing and analysis showed that the sampling system maintained acceptable isokinetic sampling rates of 100% ± 10 at only one of four sources. An inverse relationship between the percent of the isokinetic rate and the temperature of the gas stream being sampled was found. The evaluation revealed that the sampler will operate only in the narrow range of stack gas static pressure of ± 3 inches water column. The physical hardware was found to be fragile and difficult to operate in the field. Overall, the autoisokinetic sampling system failed to meet the design goals.

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ACKNOWLEDGMENTS

The authors gratefully acknowledge Thomas E. Ward of the Environmental Sciences Research Laboratory for his assistance and guidance on this project. The authors also wish to thank Liberty Chair Corporation for their cooperation and assistance in providing a valuable test site.

SECTION 1

INTRODUCTION

A prototype particulate sampling system capable of maintaining isokinetic sampling conditions automatically was designed, manufactured, and tested under EPA contract number 68-02-0546 and described in EPA report number EPA 650/2-74-029. The purpose of this project was to field test the "autoisokinetic" sampling system and define the operating limits and parameters and to make any recommendations toward improving the sampling systems. The design goals are specified below:

- Isokinetic sampling of gas streams having velocities in the range of 6 to 46 meters per second.
- Isokinetic sampling of gas streams having temperatures of -1°C to 535°C.
- A sampling rate of 15 to 60 standard liters per minute.
- A response time capable of following flow fluctuations of ± 10% with a frequency of 30 to 120 cycles per minute.
- Automatic control of the sampling rate.
- Provide a visual output reading.
- Electrical outputs to accommodate continuous recording of sampling rate.

The results of the evaluation tests are summarized in Section 2. Section 3 presents the conclusions and demonstrates the reasoning behind them. The recommendations for improving the sampling system are documented in Section 4 and can be separated into those 1) pertaining to the operating level and 2) concerning the handling characteristics of the equipment.

Details on the testing protocol including sources tested are presented in Section 5. Ten simultaneous tests using an EPA Method 5 train and the autoisokinetic sampling system were scheduled at each source.

Section 6 details the actual equipment evaluation testing procedure and the required modifications. A description of the testing at each of the four sources is also given. Results of the tests are presented in Section 7, along with tables and graphs demonstrating the results. The performance capabilities and the procedure of isokinetic sampling with this system are presented in Section 8.

SECTION 2

SUMMARY OF RESULTS

The autoisokinetic sampling equipment did not function satisfactorily. Modifications to the supplied equipment were made during the preliminary testing period to improve the level of performance.

The percent isokinetic sampling rate was determined from data generated by a dry gas meter and S-type pitot tube which were added to the original system. The carbon-vane pump of the original system was replaced with a leakless pump to preserve the integrity of the dry gas meter readings.

Other modifications were:

(1) The sensitivity of the bias adjustment valve was found to be insufficient. The valve was replaced with a more sensitive valve-control system.

(2) The protective shroud surrounding the nozzle and velocity sensors was removed to eliminate interference with pitot measurements.

(3) The existing nozzles were found to be defective. New nozzles were fabricated and used in place of the defective nozzles.

A summary of results for the field testing program is presented in Table 1. The twenty-seven test average percent isokinetic for the autoisokinetic sampler was 86.2% with a standard deviation of ± 15.8%. While the particulate concentration results of the autoisokinetic samples showed an average positive bias of only 2.65% for the twenty-seven tests, the standard deviation was ± 23.6%.

The Federal Register, Vol. 36, No. 247, December 23, 1971, Method 5, states that the percent isokinetic of the sampling rate must be between 90% and 110% for particulate sampling results to be considered acceptable. Nine out of the ten runs were within the acceptable limits in source #1 in which the effluent consisted of flyash redispersed in air. No acceptable isokinetic values were obtained in tests at source #2 because high negative stack gas static pressure caused the control valve to lock full open, thus making the sampling system operate at the highest sampling rate regardless of the effluent velocity. The design stack gas static pressure limitations were determined to be ± 3 inches water column. For source #3, the neutral pressure boiler stack, only one of the seven tests conducted yielded an acceptable isokinetic sampling rate. The other tests at this source were below the acceptable limit. The percent isokinetic was consistently low on all runs in source #4, the high stack gas temperature wood fired boiler.

TABLE 1. SUMMARY OF FIELD TESTS RESULTS

Source	% Isokinetic ± Standard Deviation Autoisokinetic	Method 5		%Bias of Autoisokinetic From EPA 5 Grain Loading	
	Mean ± Std. Dev.	Mean ±	Std. Dev.	Mean ±	Std. Dev.
1	103.4 ± 4.60	97.3 ±	4.76	-14.3 ±	± 7.73
3	72.6 ± 10.8	103.9 ±	2.55	±13.0	±11.9
4	78.5 ± 9.18	100.3 ±	1.81	±12.3	±30.0
	86.2 ± 15.8	100.1 ±	4.18	+ 2.65	±23.6

SECTION 3

CONCLUSIONS

The autoisokinetic sampler failed to sample isokinetically over the tested operating range. Of the twenty seven tests performed using the autoisokinetic sampler, ten tests were within the acceptable limits for isokinetic sampling. The percent isokinetic ranged from a low of 54% to a high of 112%. By way of comparison, all twenty seven EPA Method 5 tests, which were conducted simultaneously with the autoisokinetic tests, were within acceptable isokinetic limits. The auto sampler performed acceptably on source #1 with the .277 inch nozzle. The autoisokinetic sampler did not exhibit the minimum acceptable performance level for the neutral pressure boiler stack or for the wood fired boiler stack.

The results indicate that the percent isokinetic is inversely related to the temperature of the gas stream sampled. Relationships between the operating percent isokinetic for the autoisokinetic sampler and gas stream velocity, temperature and particulate loading were sought. The particulate loading and gas stream velocity had no noticeable effect on the percent isokinetic. However, a correlation was observed between the gas stream temperature and the percent isokinetic. For the sources tested, the temperature ranged from 74°F to 659°F and the percent isokinetic ranged correspondingly from 112% to 61%.

The mass flowmeter and totalizer gas measurement systems of the sampler are inadequate for source sampling tests. In the sample gas flow range of 0.5 to 2.0 SCFM the mass flowmeter accuracy ranges from +6 to +1% of actual flow, and the totalizer accuracy from +6.5% to +1%. At flows of 0.3 SCFM or less, the errors of both devices are greater than 10%. Calibration curves for both devices are non-linear, further complicating corrections of the output.

The autoisokinetic sampling equipment was designed to operate in stack gas static gage pressures within the range of ± 3 inches of water column. This restricts its use to sampling sites within this range. Sources with stack gas static pressures outside this range are common.

The following general conclusions are based on observations made during operation of the autoisokinetic sampling equipment in the field. Arrangement and location of the probe pitot connections and the sensor line connections make rotation of the probe extremely difficult. Sensor lines attached to the nozzle are fragile in field sampling situations. The weight of the probe, sample box, and umbilical card make remote sampling sites difficult to set up and make sampling traverses difficult and physically demanding to perform. The stiff umbilical makes kinking of the sampling lines a major problem. System leak tests require an open control valve, which causes the following problems. The bias pressure setting must be adjusted far from its normal sampling position to hold the control valve open. The subsequent adjustment back to the proper position for source sampling is tedious and time consuming. Also, care must be taken to insure that no silica gel is carried from the fourth impinger into the control valve because the silica gel can cause the control valve to malfunction. There is no efficient way to clean the nozzle because of the sensor line in its center. The most important failure is reflected in the erratic isokinetic sampling rates observed over the operating range. Even with the modified systems, the apparatus is fragile, cumbersome, and complicated to operate in the field.

SECTION 4

RECOMMENDATIONS

In order to improve the existing system, certain changes should be made. These changes can be classified as affecting one of the two general areas of performance or handling characteristics. The following suggestions are made to improve performance:

- replace totalizer and mass flowmeter with a more accurate means of measuring the totaling flow rates
- increase the nozzle's gas flow sensor sleeve diameter
- provide a visual display of instantaneous percent isokinetic sampling rate
- provide a better method of nozzle-probe connection to reduce time required for connection and chance of damage while making the connection
- fix sample box heating compartment
- provide more detailed operating instructions

The following suggestions are made to improve handling characteristics:

- move the fluidic converter and controller valve to console or other location to give quicker access for adjustment or repair
- increase sensor and pitot lines length
- replace umbilical cord with a lighter more flexible one
- extend the stainless steel tubing the full length of the probe
- change manner of sensor line connections to reduce time and chance of damage

SECTION 5

TESTING PROTOCOL

The original schedule called for an equipment check out and familiarization period to determine if the euqipment was working as described by its accompanying manuals and to allow the testing personnel to learn how to operate the equipment as per instructions (See Figure 1). From that point, the field evaluation testing was scheduled to begin. A rigorous program of ten runs each at a variety of sources was proposed. Each test site was chosen for conditions (i.e., gas stream velocity, temperature, particulate loading, entrained moisture, etc.) which would establish the operating limits and parameters of the autoisokinetic sampling train. Testing at each site would follow standard EPA Method 5 procedures. The four types of sources selected are given below.

Source Simulator -- Controlled medium loading, ambient temperatures and moisture content less than 3%, in addition to controlled gas stream velocities, were characteristics of this effluent. This was a control situation for the field sampling. The EPA Source Simulator was selected for these runs. Simultaneous runs with a standard EPA Method 5 train accompanied various runs. Other runs established sampling probe directional parameters and other limitations of the equipment.

Asphalt Plant With Water Scrubber -- Typical stack effluent from this type of source presents a high concentration of water vapor with possible entrained moisture, low gas stream velocities, low temperatures, moderate to heavy particulate loading and low CO_2 concentration. Particular attention to the functioning of the static balance probe, pitot tube, and gas totaling device was scheduled here.

Coal-Fired Power Plant-- Temperatures and stack gas moisture here were in the middle range, particulate loading heavy, and the CO_2 concentration high. This type of operation was assumed to be a major application for the autoisokinetic sampler.

The sampling probe of the autoisokinetic sampler has an aerodynamic sensor in the center; therefore, a comparison of the particulate collection of this sampling probe design to that of an EPA type train was made. Simultaneous EPA Method 5 samples were run at this site.

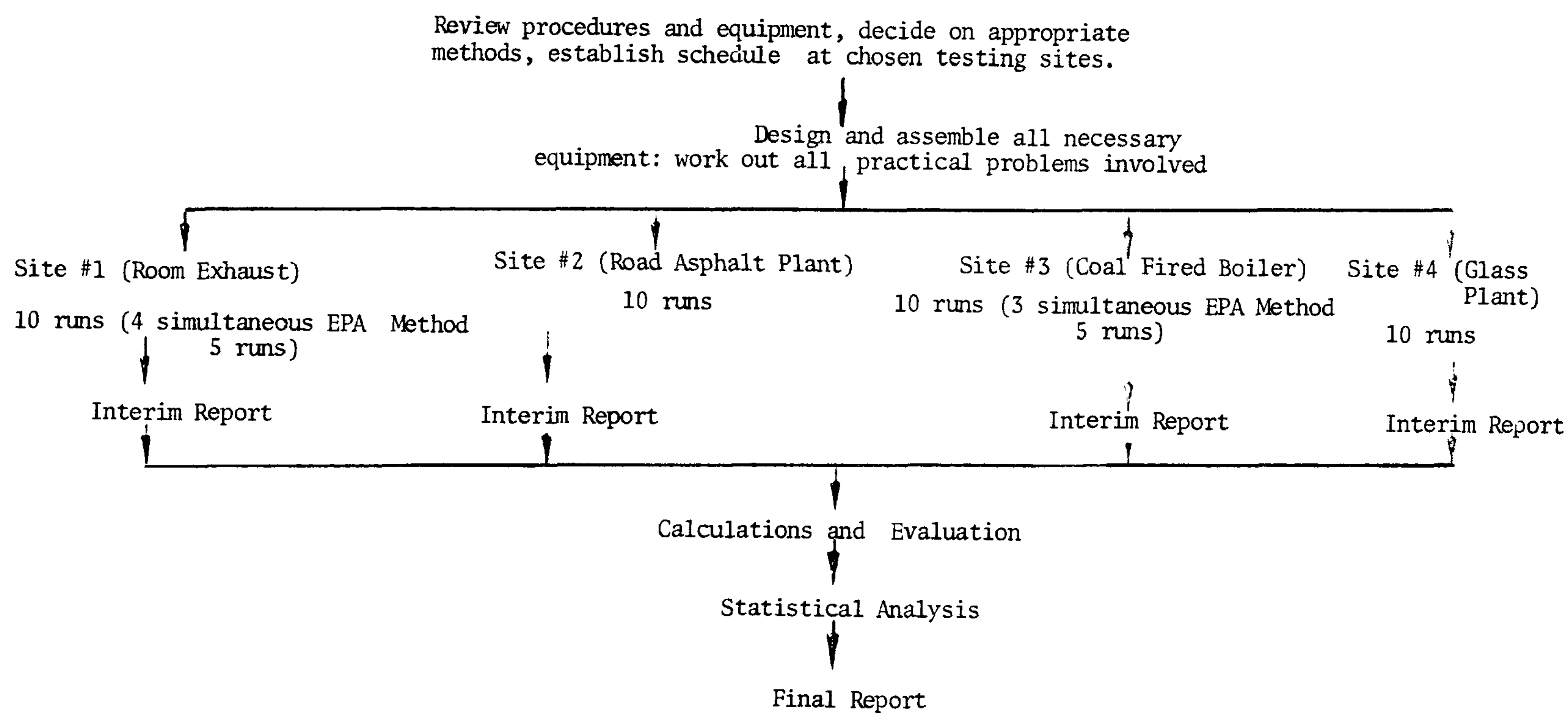


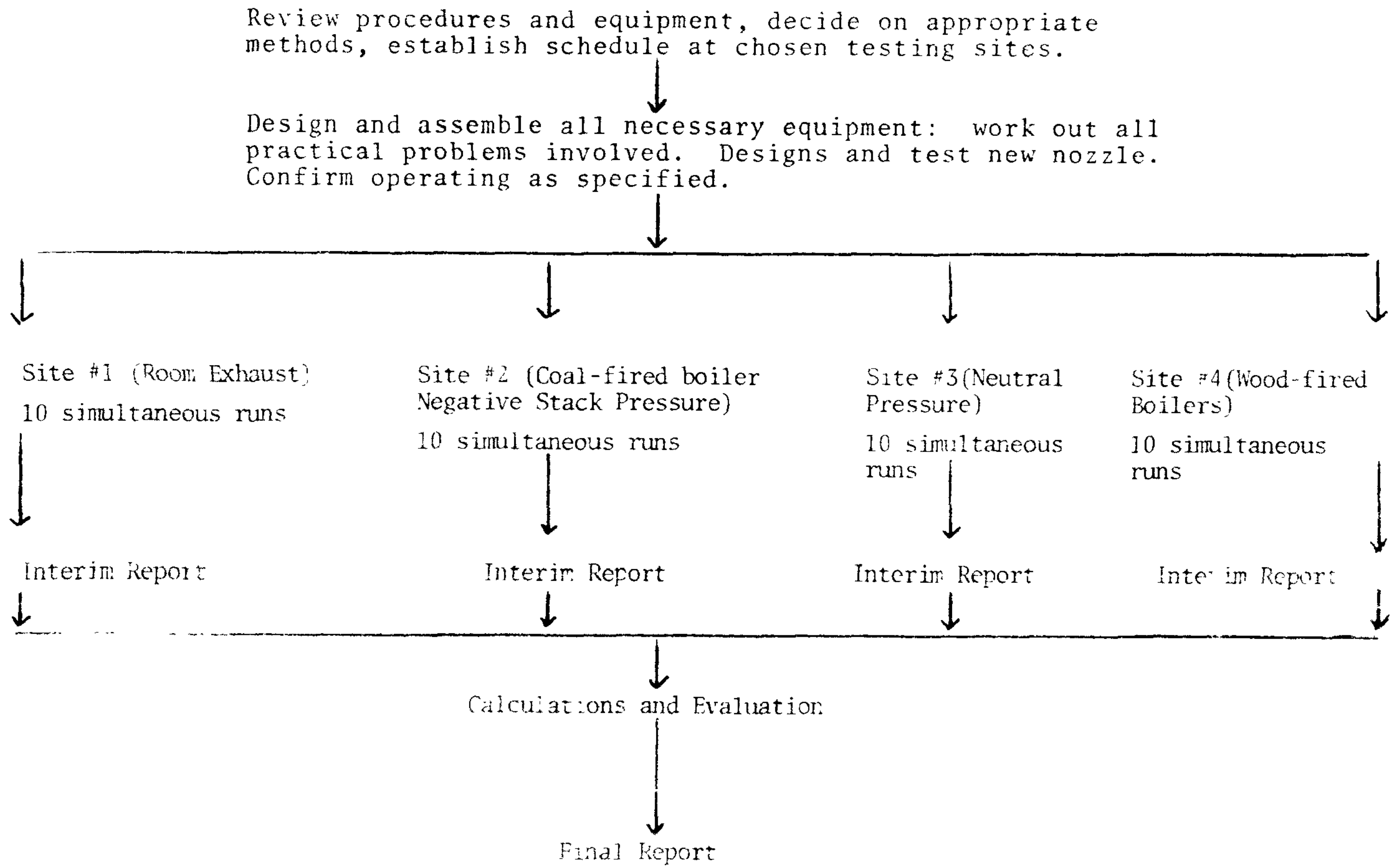
Figure 1. Original test protocol diagram.

Glass Manufacturing Plant-- This source is characterized by high gas stream temperatures and velocities in combination with low moisture and particulate loading. Tests here were scheduled to establish the upper stack gas temperature limits of usefulness of the automatic sampler.

Upon receipt of the contract and the autoisokinetic equipment and after a close inspection of the equipment, the test protocol was revised (See Figure 2). The preliminary inspection and testing programs were expanded to include additional EPA source simulator air testing of the supplied nozzles, to measure the shroud interference with the gas stream flow around the nozzle, and to include the manufacturing and preliminary testing of nozzles to replace the originally defective ones.

New source sites were also chosen, due to the unanticipated closure and lack of availability of two of the proposed sites. The scheduled asphalt plant tests were substituted by a coal-fired boiler having a high negative static pressure. A high temperature wood-fired boiler was exhanged for the high temperature glass manufacturing plant. The original coal fired power plant boiler and the ambient air room exhaust sites remained in the new protocol.

Each series of tests was conducted with an EPA Method 5 particulate sampling train sampling within four to six inches of the autoisokinetic train sampling point.



1. The autoisokinetic and EPA Method 5 runs were performed simultaneously

Figure 2. Revised test protocol diagram

SECTION 6

EVALUATION TESTING

PRELIMINARY TESTING

Soon after the autoisokinetic equipment was received, tests were made to verify that the equipment was in working order and that all of the necessary equipment was at hand. This exercise revealed limitations of the accompanying manual, EPA Report No. 650/2-74-029, regarding assembly of the system by persons unfamiliar with the specific hardware. For example, the functions of the three two-position toggle switches located on the control console, between the temperature readout dial and the sample box heater control, are never mentioned. Color and letter-coding of pneumatic lines proved quite helpful during setup.

During system assembly, the following points were noted:

- Unions from pump-to-mass flowmeter and pump-to-knockout jar missing.
- Glass probe liner broken. (Removal of broken glass from probe liner proved quite difficult).
- Probe heater wires (nichrome) severed in two places, and exposed in numerous others.
- Vacuum line through umbilical kinked at quick-connects on both ends and where line exits umbilical wrapping. Coil springs around vacuum line at these points ineffective due to the weight of umbilical.

These problems were temporarily circumvented to allow immediate shop testing of the system. The broken glass probe liner was by-passed. This arrangement removed the filter and impingers from the system, yet allowed testing of the automatic controller, the most important facet of the equipment.

With the system so assembled and a gas cylinder providing the pneumatic air supply, power was supplied to the control console where all instrumentation appeared to be operational. The fluidic converter was preset for the existing conditions (3/8" nozzle, and 0.1 to 0.2 inches of H_2O pitot readings).

A fan supplied the gas stream and the controller was observed to automatically adjust the sampling flow rate to follow generally the induced fluctuations in the gas stream.

One criterion for evaluating the autoisokinetic equipment is to calculate the percent isokinetic of the sampling rate. To determine the actual percent isokinetic, the gas stream velocity and the volume of gases sampled by the autoisokinetic train must be ascertained. Therefore a S-type pitot tube and a dry gas meter were added to the existing autoisokinetic sampling train in order to gather the needed data.

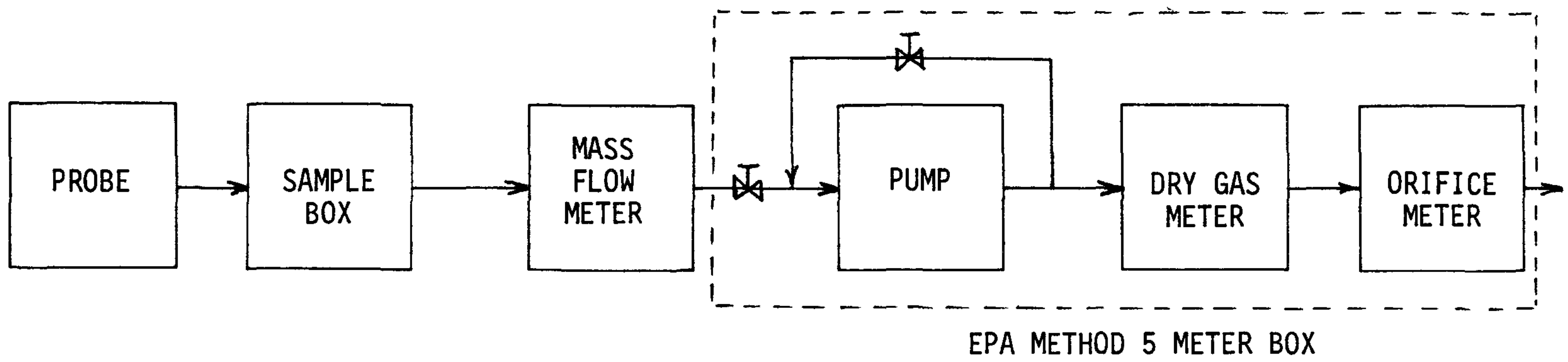
A leakless self-oiling pump of the type used in a typical EPA Method 5 particulate sampling train meter box was substituted for the carbon-vane pump and the dry gas meter was placed inline after the leak-free pump. The mass flowmeter was retained in the system, remaining between the umbilical and the vacuum pump as shown in Figure 3.

With this modified autoisokinetic sampling train, a one hour test run was conducted, with an air flow provided by a fan directed at the 3/8" nozzle which produced pitot readings in the range of 0.5 to 2.5 inches of water. Approximately 15 changes in the gas flow were induced during the course of the test by manual manipulation of the fan. The sampling rate indicated by the Hastings mass flowmeter fluctuated correspondingly, indicating that the system consisting of the null-balance, control valve, and fluidic converter was responding to the fluctuations as described in the manual.

During the test setup and throughout the one hour of testing several potential problem areas were noted: supply air usage rate, low sensitivity of bias adjustment valve, a discrepancy between the digital flow totalizer and the mass flowmeter, and the level of operation appeared to be below acceptable isokinetic conditions.

Pneumatic supply pressure was supplied via a gas cylinder at a rate of approximately 0.75 cfm. Discussions with a General Electric engineer familiar with the system confirmed .75 cfm as a normal usage rate. Over a period of several months of field testing, the cost of compressed air cylinders supplying 0.75 cfm would have become prohibitive, so a compressor was rented to provide the pneumatic air supply.

The bias adjustment valve sensitivity was too low to make the required adjustment to reach the bias setting specified by the instruction manual. This valve was replaced with a more sensitive valve control system.



SAMPLING TRAIN FLOW DIAGRAM, FIELD USE

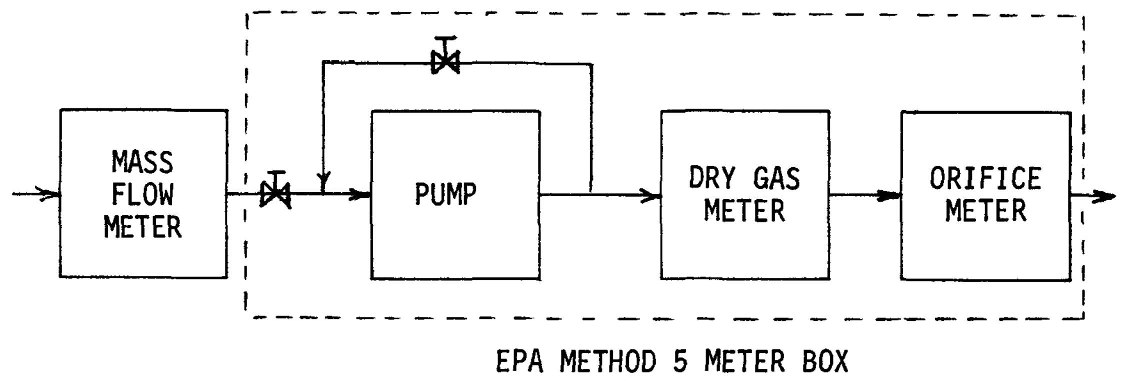


Figure 3. Sampling train flow diagram, calibration

Calibration checks were made on the digital flow totalizer and mass flowmeter with the results as shown in Figure 4. The mass flowmeter was corrected somewhat by adjustment of the calibration potentiometers labeled "meter" and "gain" but the flowmeter was still out of calibration. The totalizer could be calibrated for a given constant flow, but when the flow was decreased, the totalizer read lower than the actual value, and when the flow was increased over the calibrated flow setting, the totalizer read higher than the actual value. The totalizer would not respond to flows less than 0.2 - 0.3 cfm. Calibrations for flow rates are presented in Figure 5. The mass flowmeter was taken to a Hastings-Raydist office for a manufacturer's calibration. The flowmeter was designed to operate at flows up to 5 cfm. Specifications for the flowmeter are ± 1% of full scale. At a flow rate of 0.5 cfm, therefore, an error of 10% is allowed by the specifications. The Hastings-Raydist engineers calibrated both the flowmeter and the totalizer. The final calibration adjustment still yielded a positive 5% bias for both meters. The results are given in Figure 6. Figure 7 gives a typical mass flowmeter calibration curve.

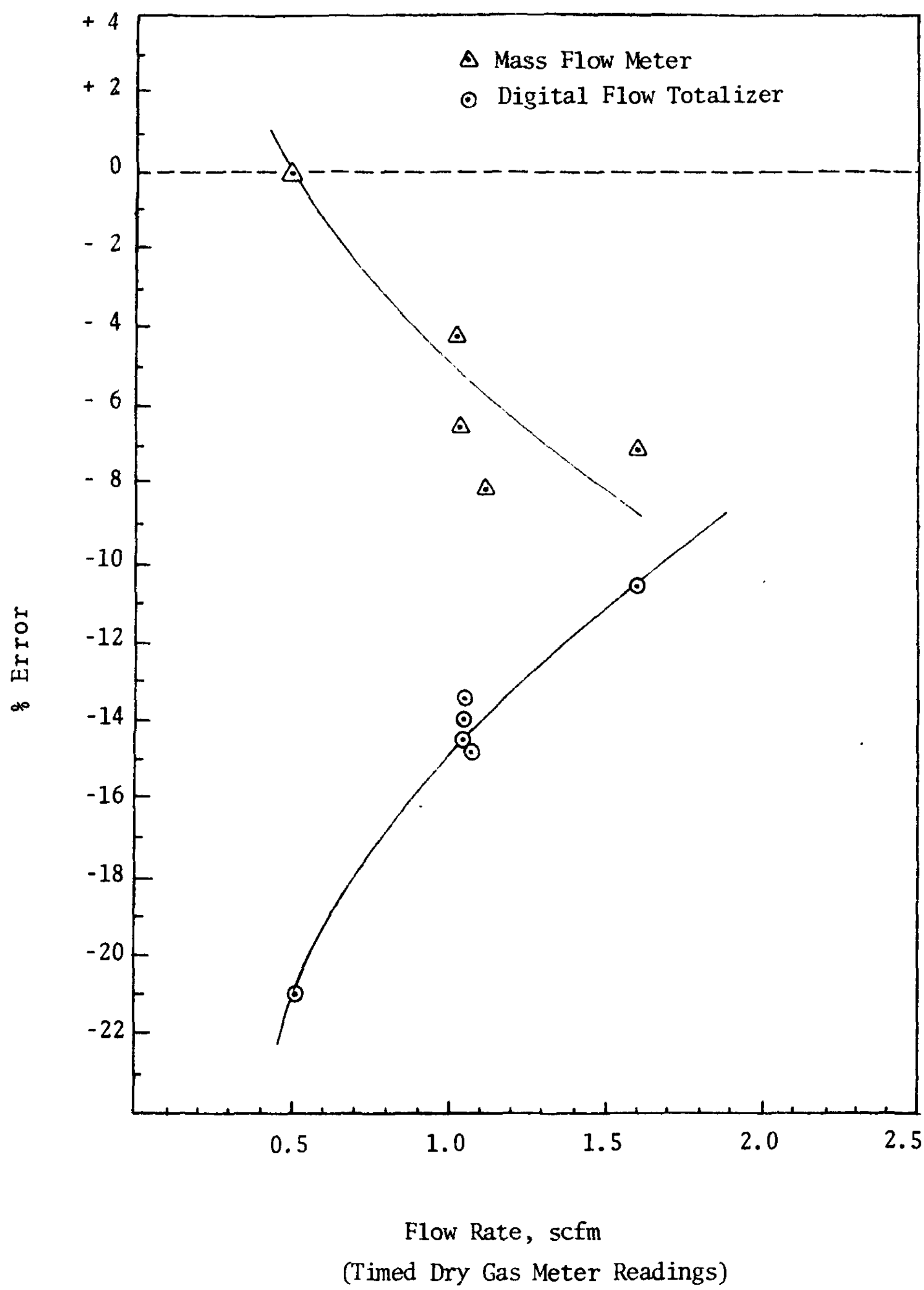


Figure 4. Calibrations of flow meter and totalizer as originally furnished

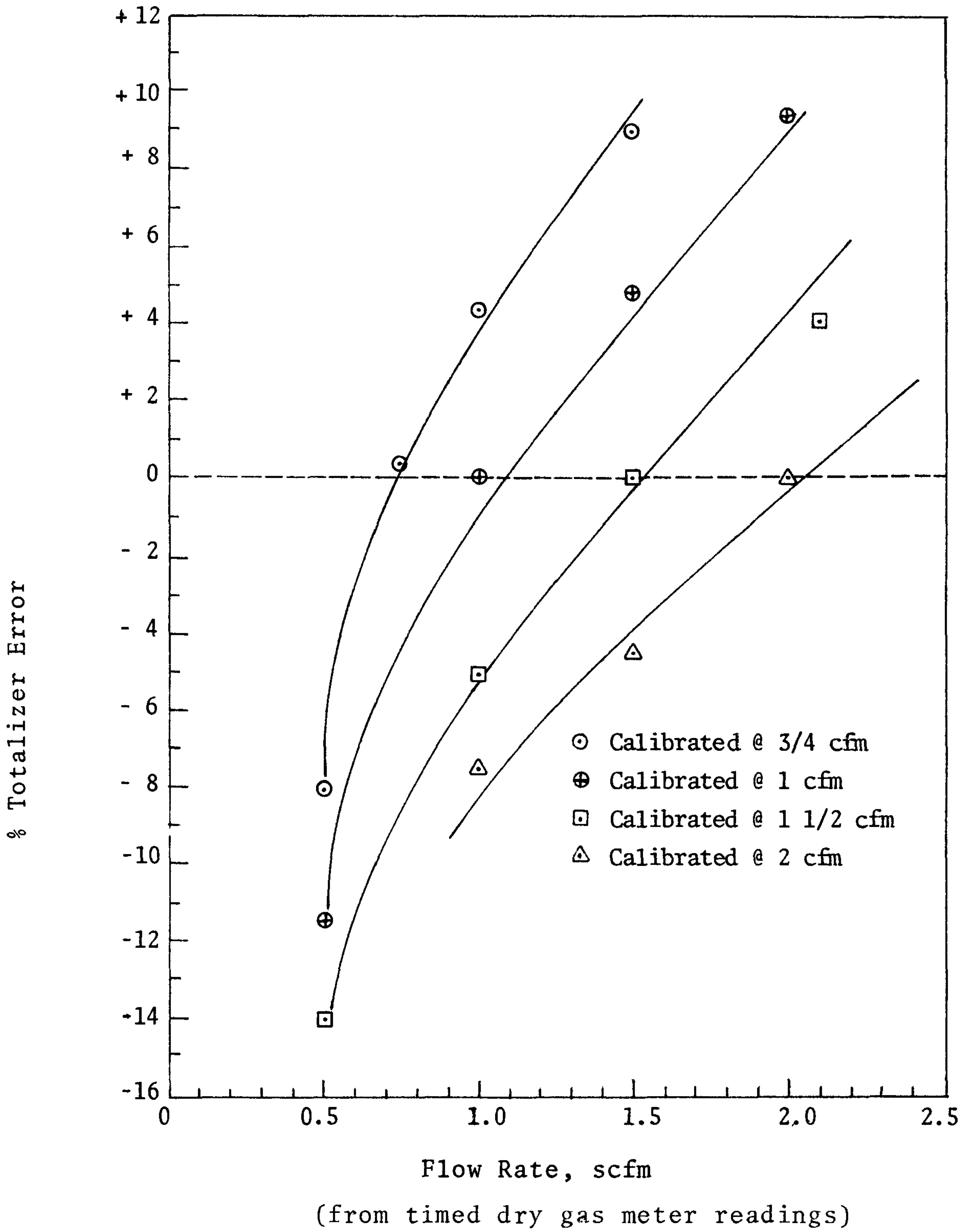
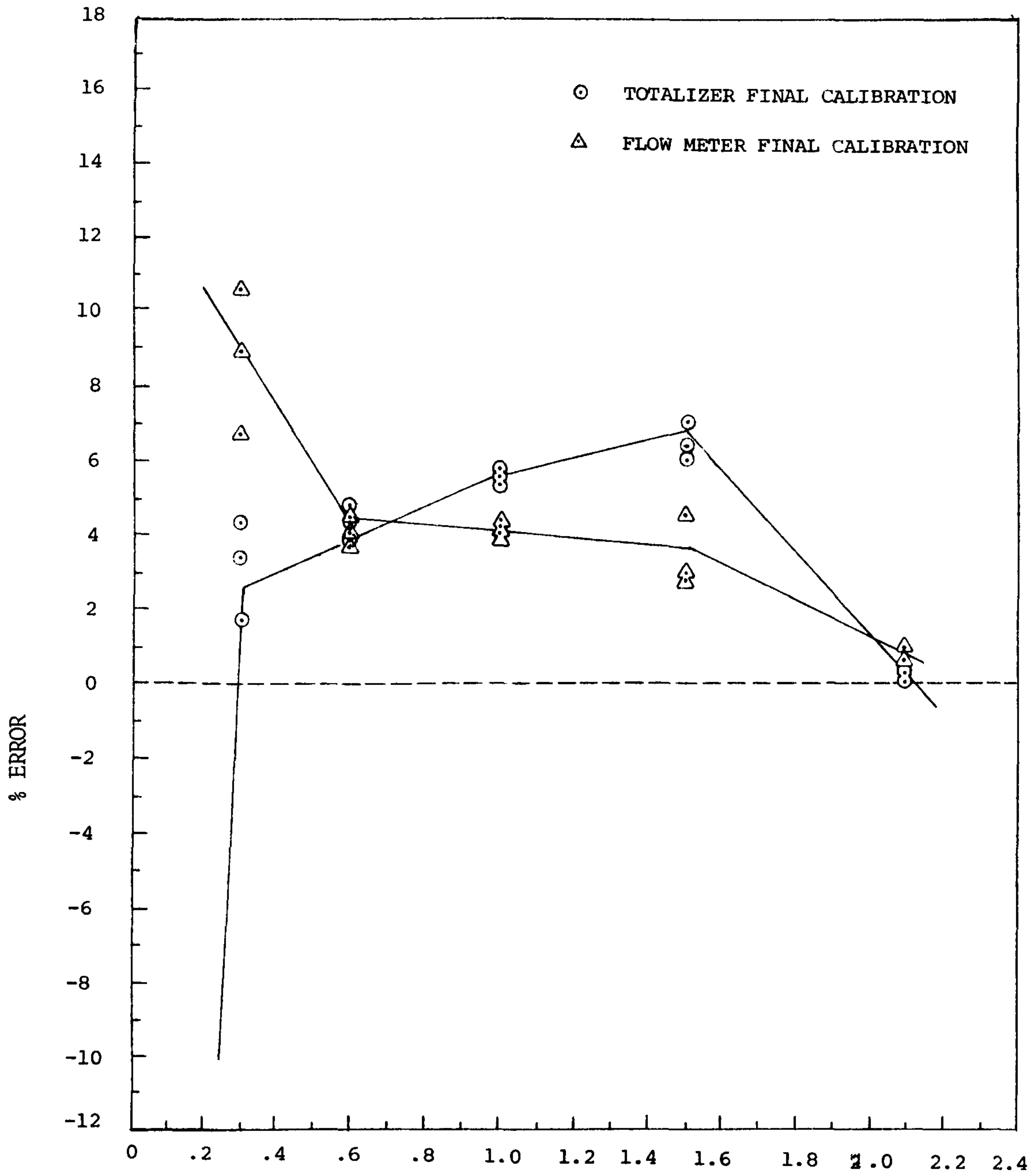


Figure 5. Totalizer calibrations at four flow rates



Flow Rate, scfm
(Timed Dry Gas Meter Readings)

Figure 6. Final calibrations, mass flow meter and totalizer

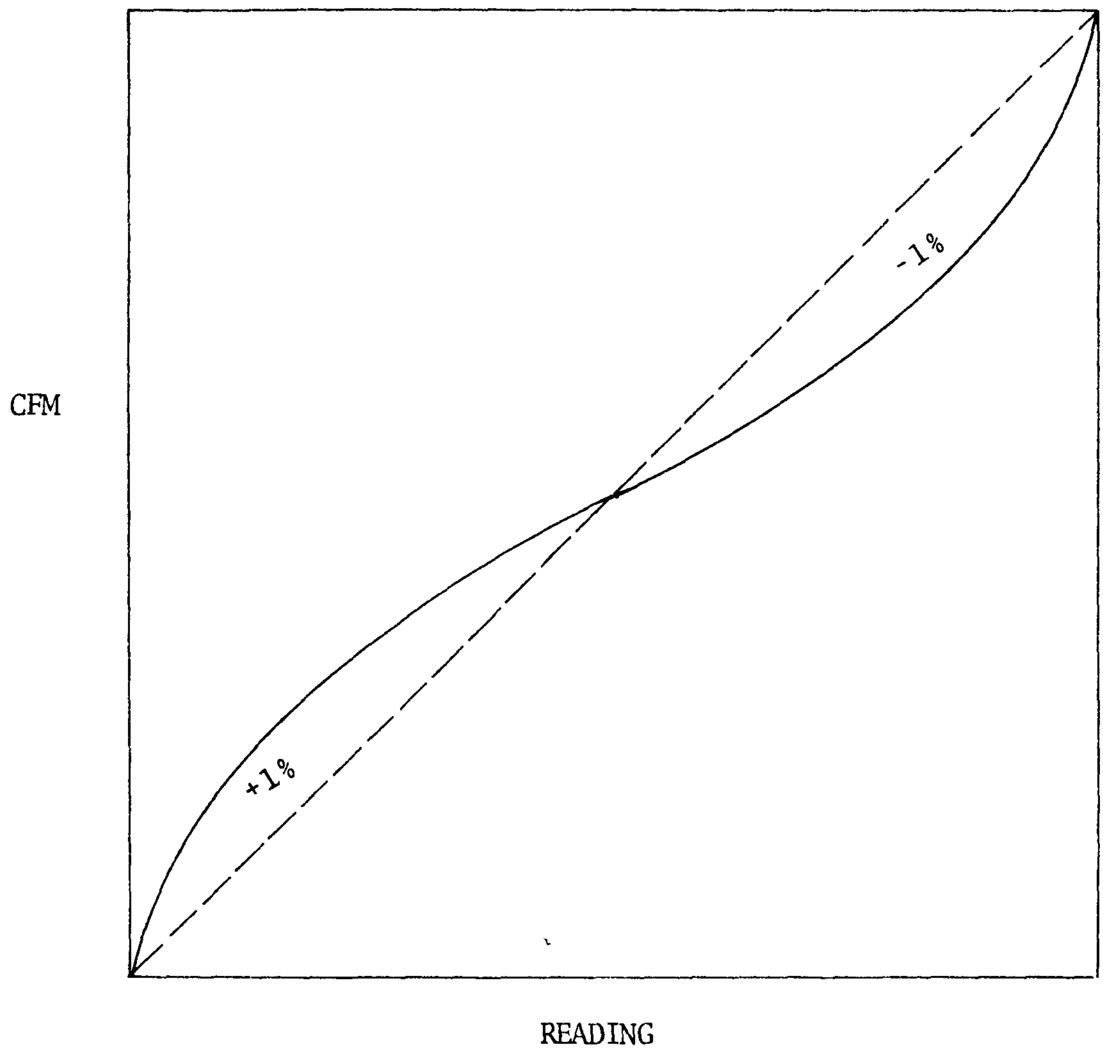


Figure 7. Typical mass flowmeter calibration

Because the proximity of the built-in pitot tube to the nozzle shroud was 1/4 inch of free space, experiments were conducted to determine the accuracy of the pitot tube. The tests determined that one inch of free space was the closest that a pitot tube could be installed without interference by the shroud. The built-in pitot tube, at best, had an error of -10% at zero rotation. Figure 8 shows the data plotted as error versus angle of rotation. Included is typical data from a S-type pitot alone.

Experiments that were designed to demonstrate the performance level of the autoisokinetic controls were then conducted in the EPA Source Simulator Facility (SSF). The nozzle diameters were measured and the results are presented below:

Nominal Size Inches	Actual Nozzle I.D. Inches	Nozzle Static Probe, O.D. Inches	I.D. of Area Equivalent to Annular Area Inches
0.25	0.282	.082	0.269
0.375	0.355	0.128	0.332

To verify that the null-balance method was working, an experiment that removed the fluidic controller and allowed for manually reading a null-balance condition between the sensors was designed and implemented. In addition, tests were made with the fluidic controller operating the null-balance system. The results for each nozzle are presented in Figures 9 and 10. When compared with the data presented in Figures 11 and 12 which are taken from the manual accompanying the autoisokinetic equipment, a definite deterioration in the performance level of the systems was noted.

With the system operating at the above level, no meaningful field data would be collected; therefore, methods of improving the operating level of the autoisokinetic equipment were sought.

In order to improve the performance of the system, the nozzle protective shroud was removed. Large open threaded holes in the sides of each nozzle were discovered upon removal of the shroud. The most inexpensive method to make repairs was to fabricate new nozzles which were constructed using thinner wall tubing and the static pressure sensors from the original nozzles. Also, the new nozzle tips were shortened so that the nozzle and pitot tube were on the same plane. The protective shrouds were left off.

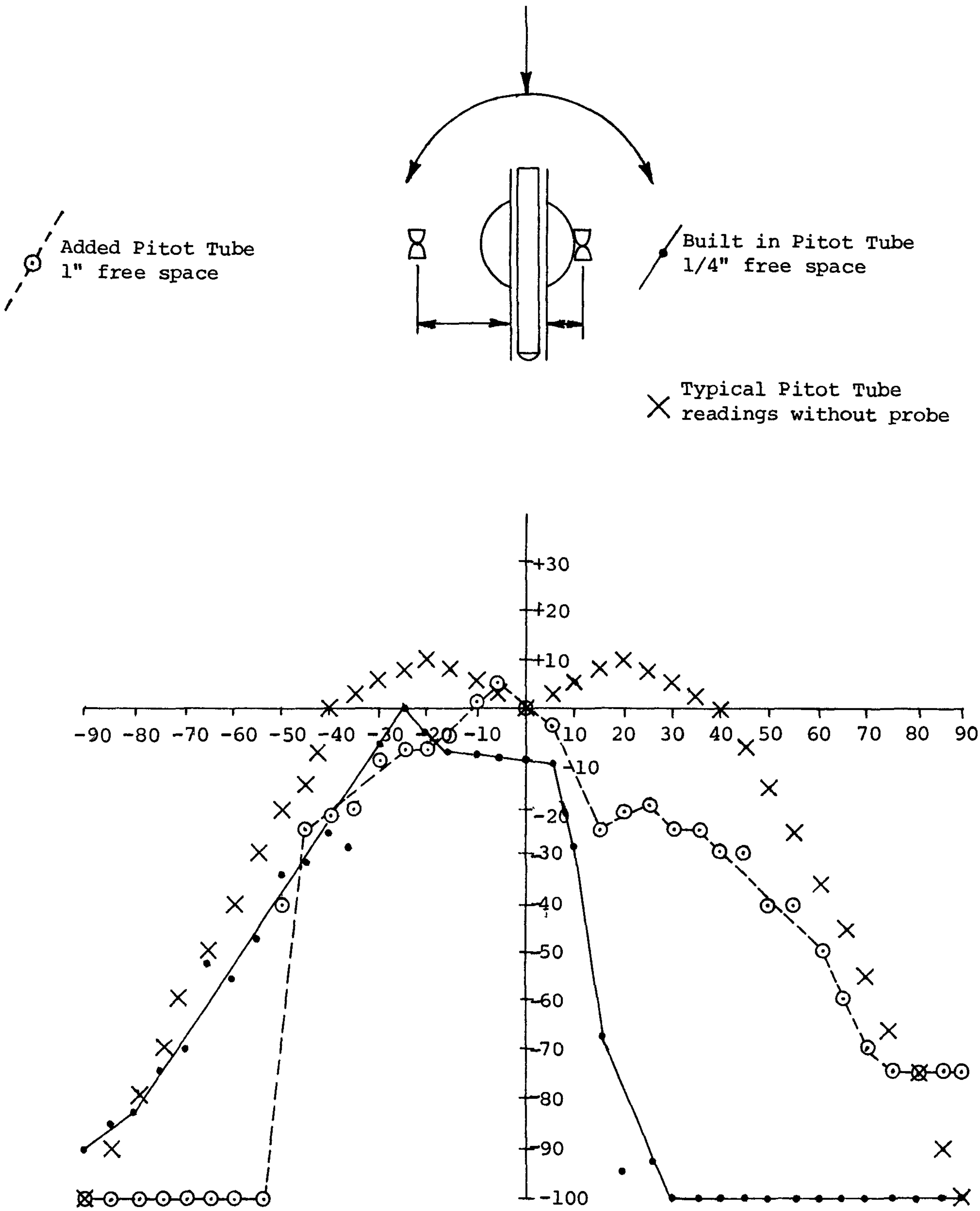


Figure 8. Pitot tube error

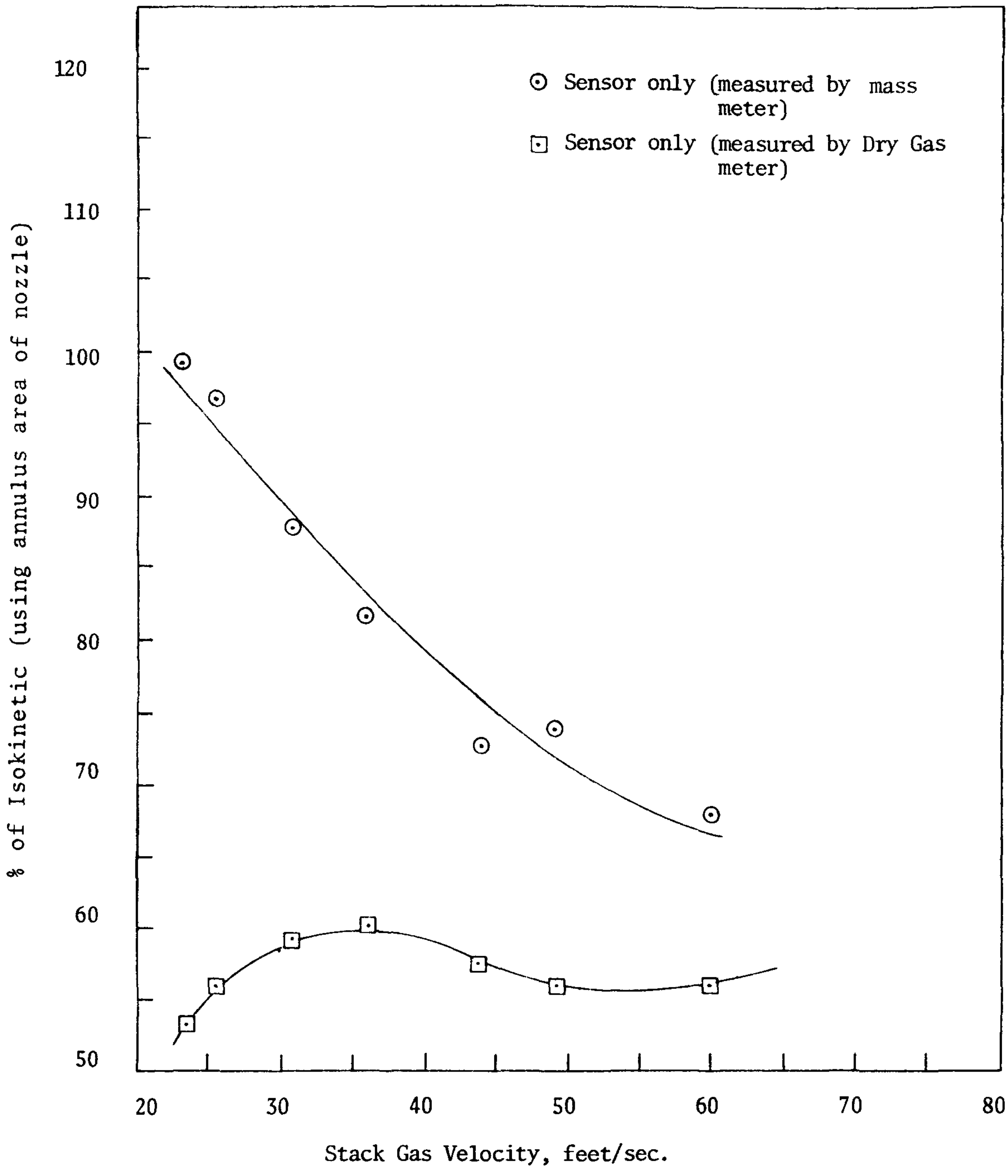


Figure 9. Performance of the 1/4 inch nozzle, as received

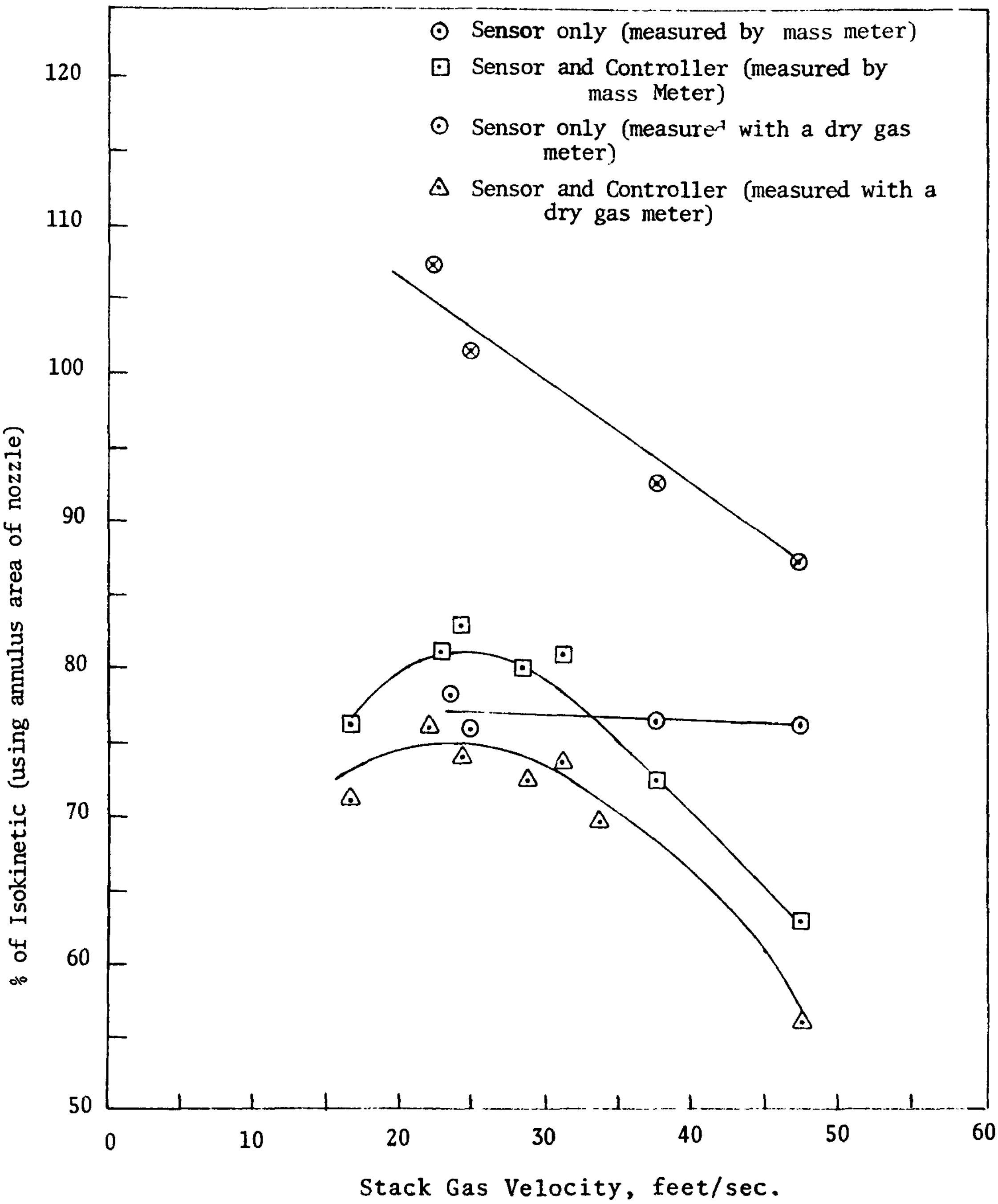


Figure 10. Performance of the 3/8 inch nozzle as received

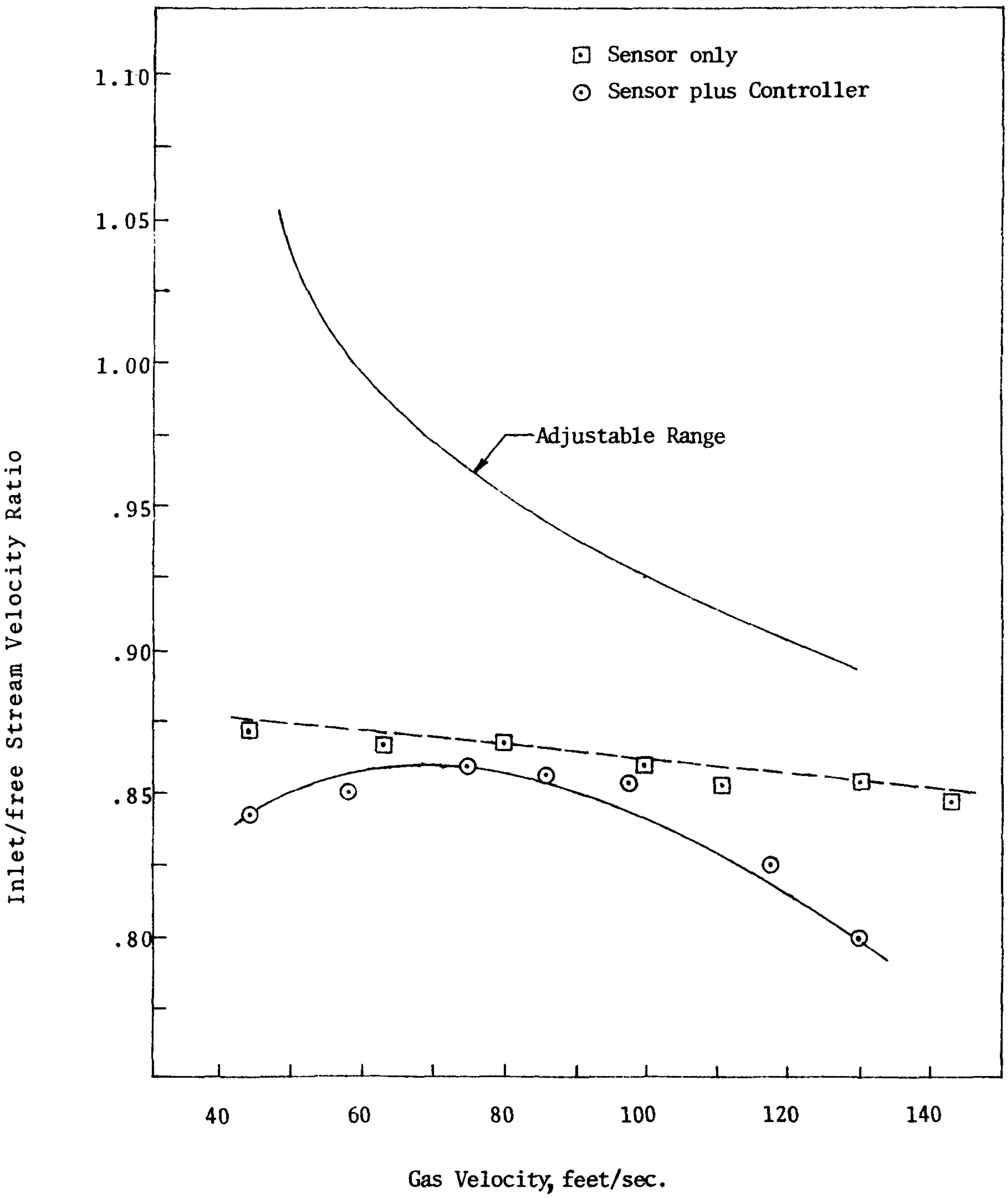


Figure 11. Steady-state calibration 1/4 inch nozzle (taken from manual)

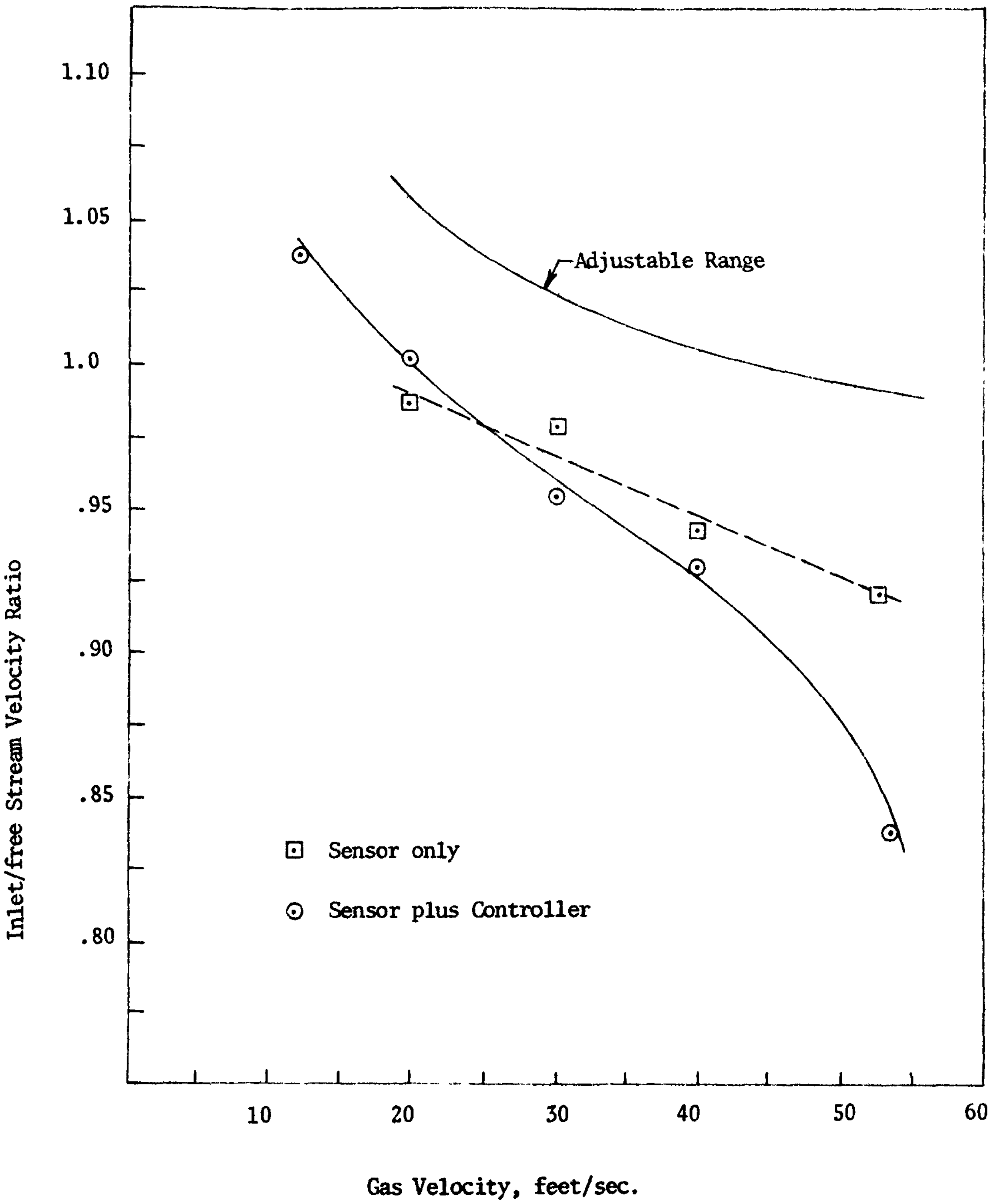


Figure 12. Steady-state calibration 3/8 inch nozzle (taken from manual)

With the new nozzles, the null balance system operation was rechecked, again by-passing the controller, with the results as shown in Figure 13. Both nozzles nulled at 90% isokinetic when operated manually. Past history indicated a drop in performance when the controller operated the system. Therefore, further nozzle modifications were fabricated and tested to achieve an operating level of at least 110% isokinetic when the controller was bypassed. Figures 14 through 19 show the sensor modifications tested and the results therof. Modification #7, consisting of the pressure holes, was finally selected for the new nozzles. The results of the "sensor and controller" tests on the final modified nozzles are presented in Figure 20.

With the new nozzle configuration and with the previously mentioned problem areas corrected (new glass probes, rewiring heater, etc.), the field evaluation program was initiated.

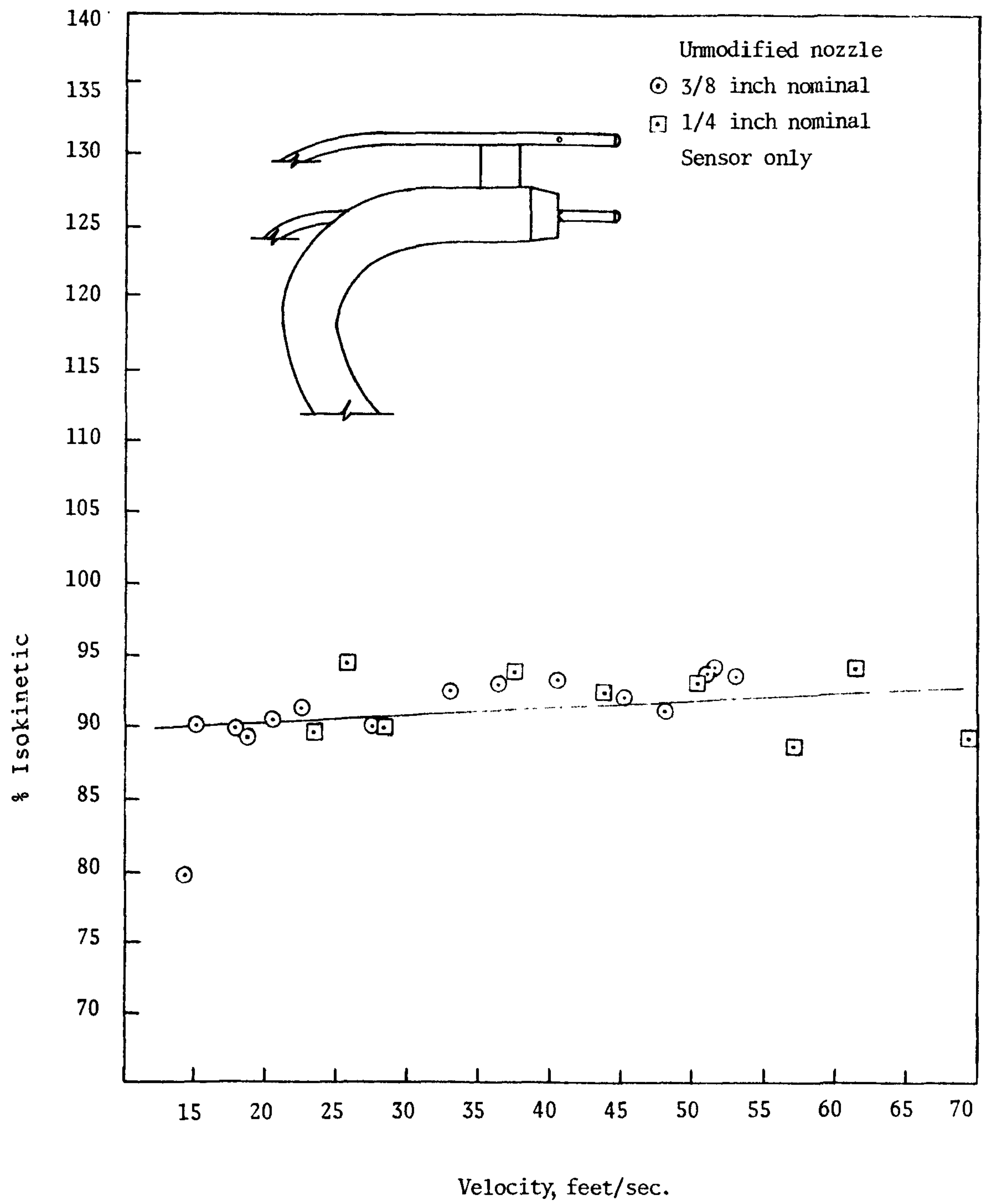


Figure 13. Performance of unmodified nozzles

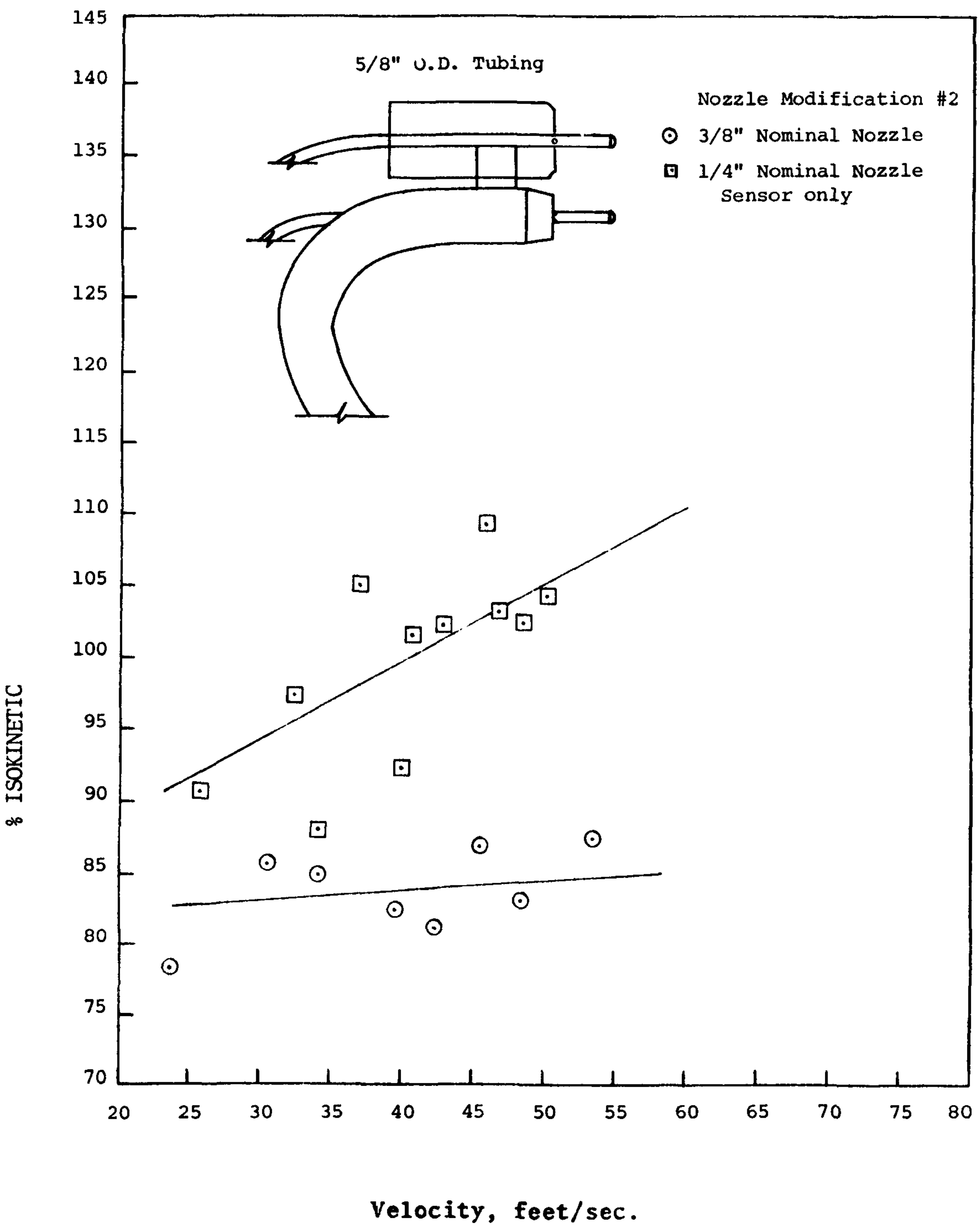


Figure 14. Performance of nozzle modification #2, sensor only

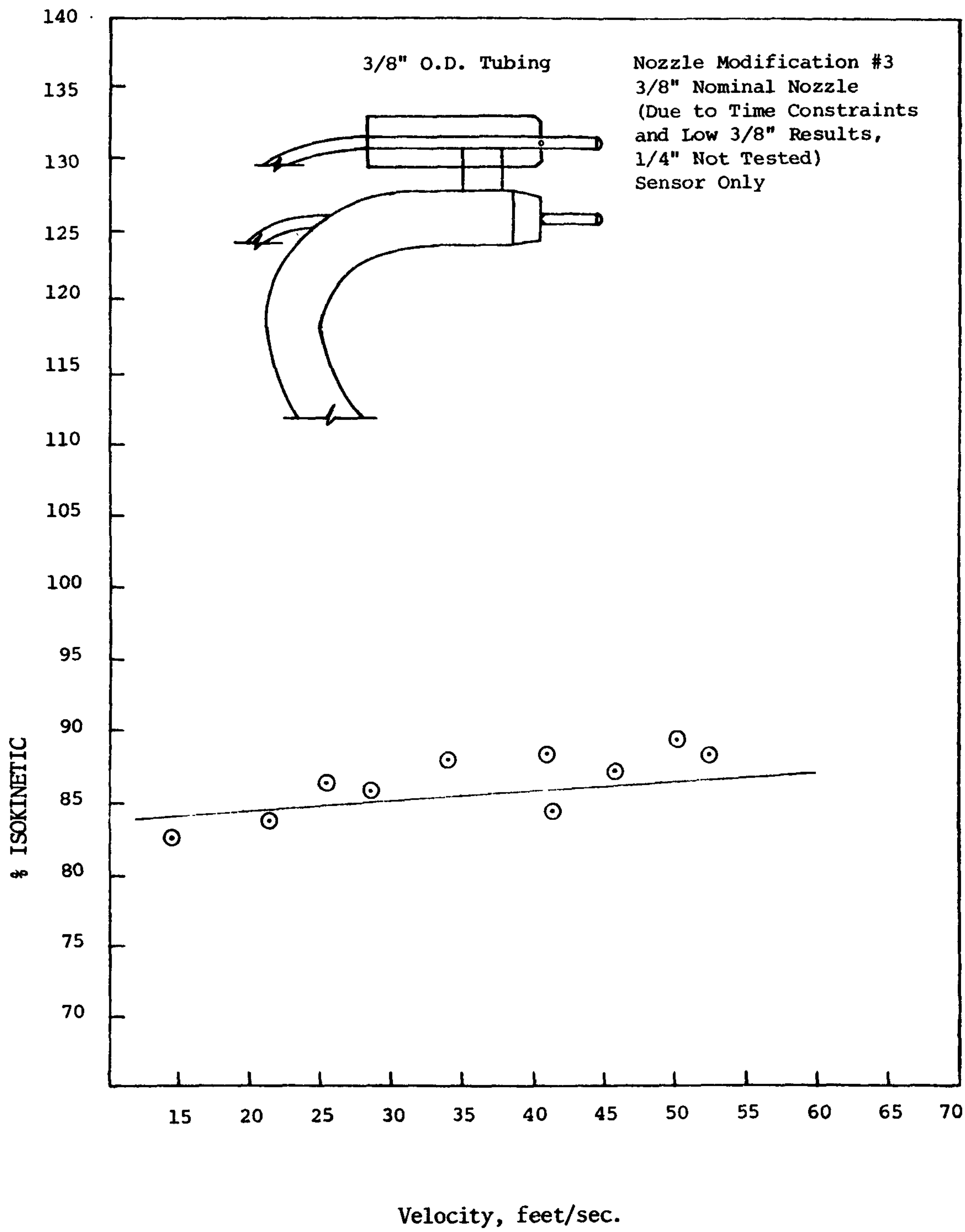


Figure 15. Performance of nozzle modification #3, sensor only

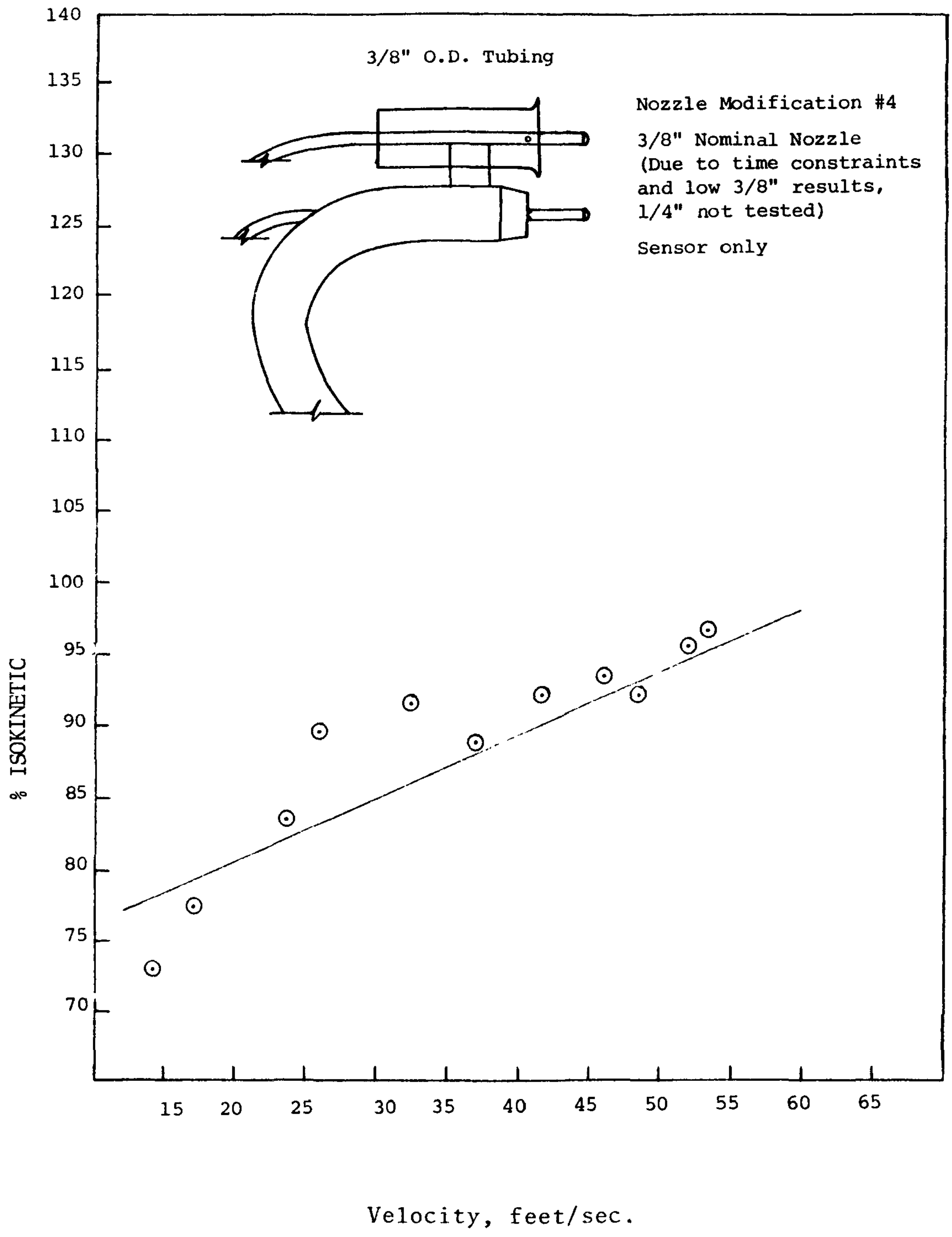


Figure 16. Performance of nozzle modification #4, sensor only

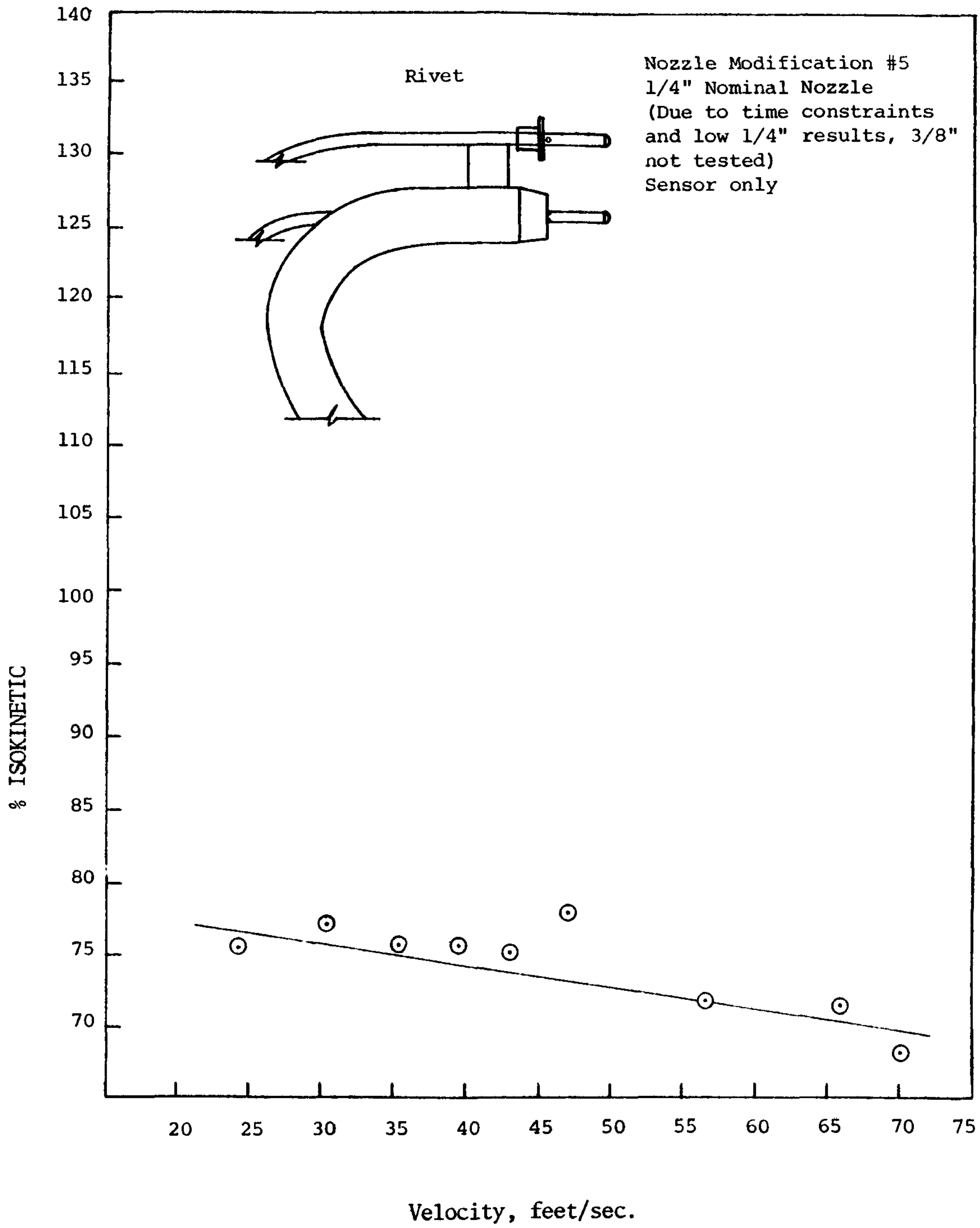


Figure 17. Performance of nozzle modification #5, sensor only

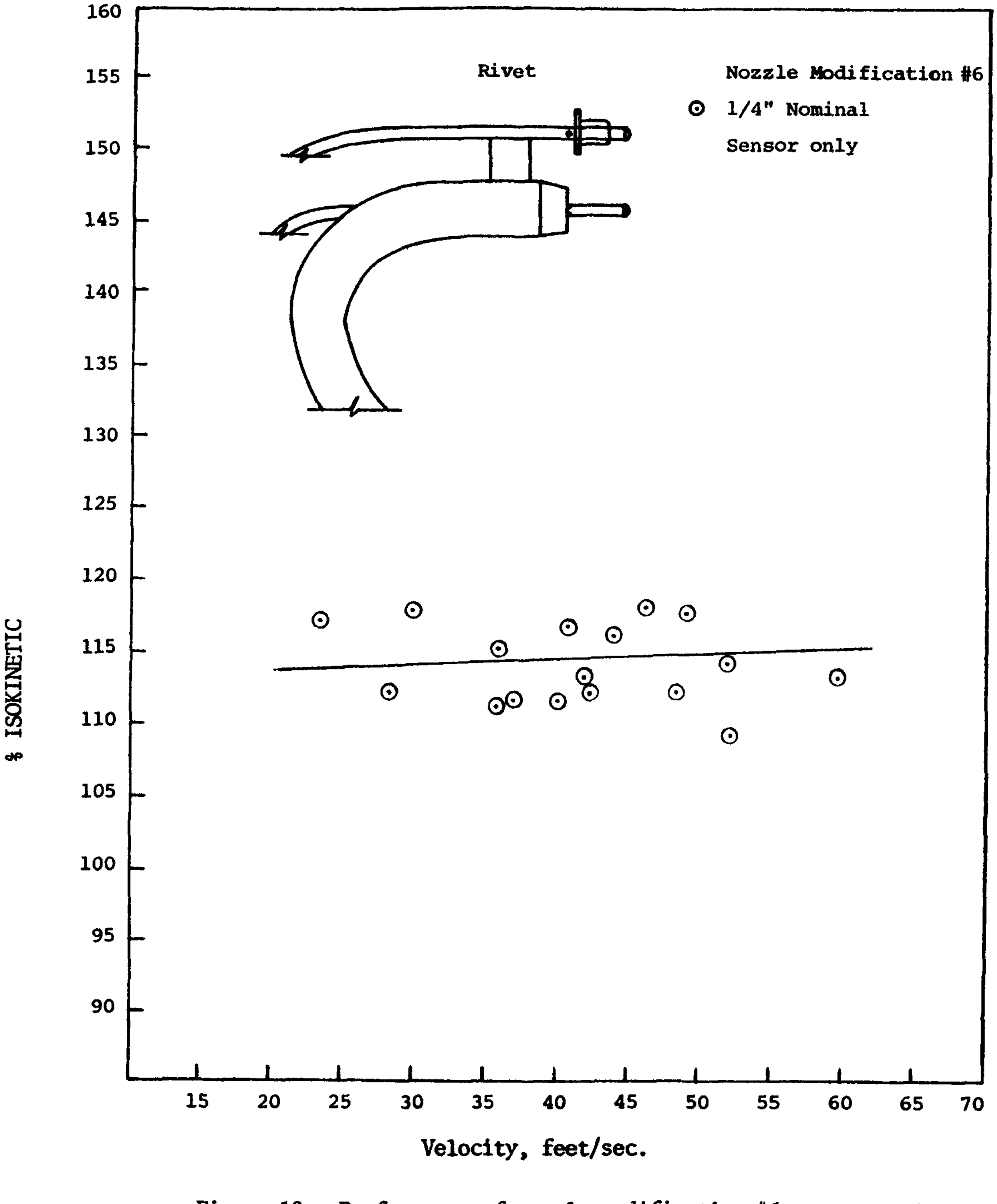


Figure 18. Performance of nozzle modification #6, sensor only

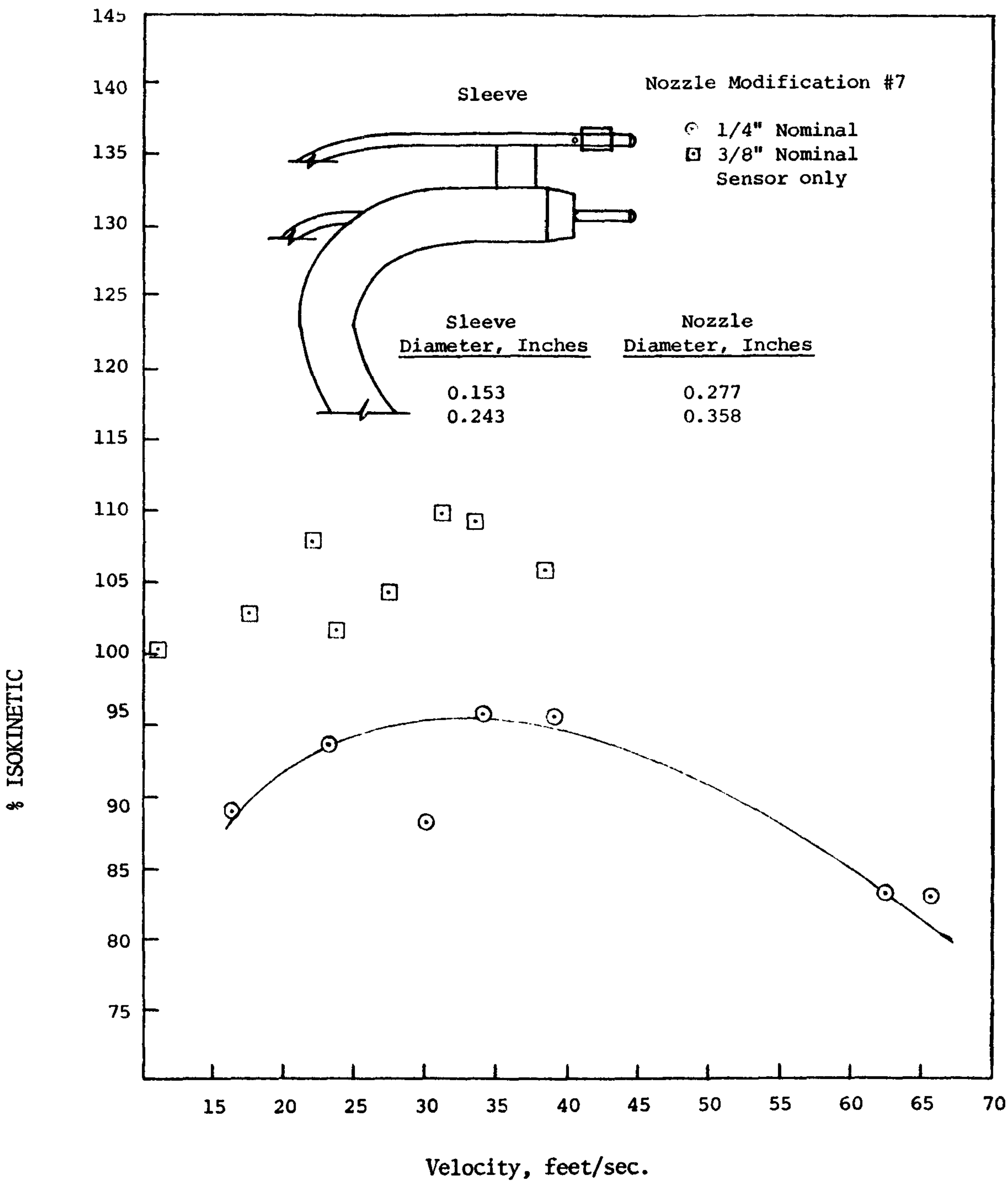


Figure 19. Performance of nozzle modification #7, sensor only

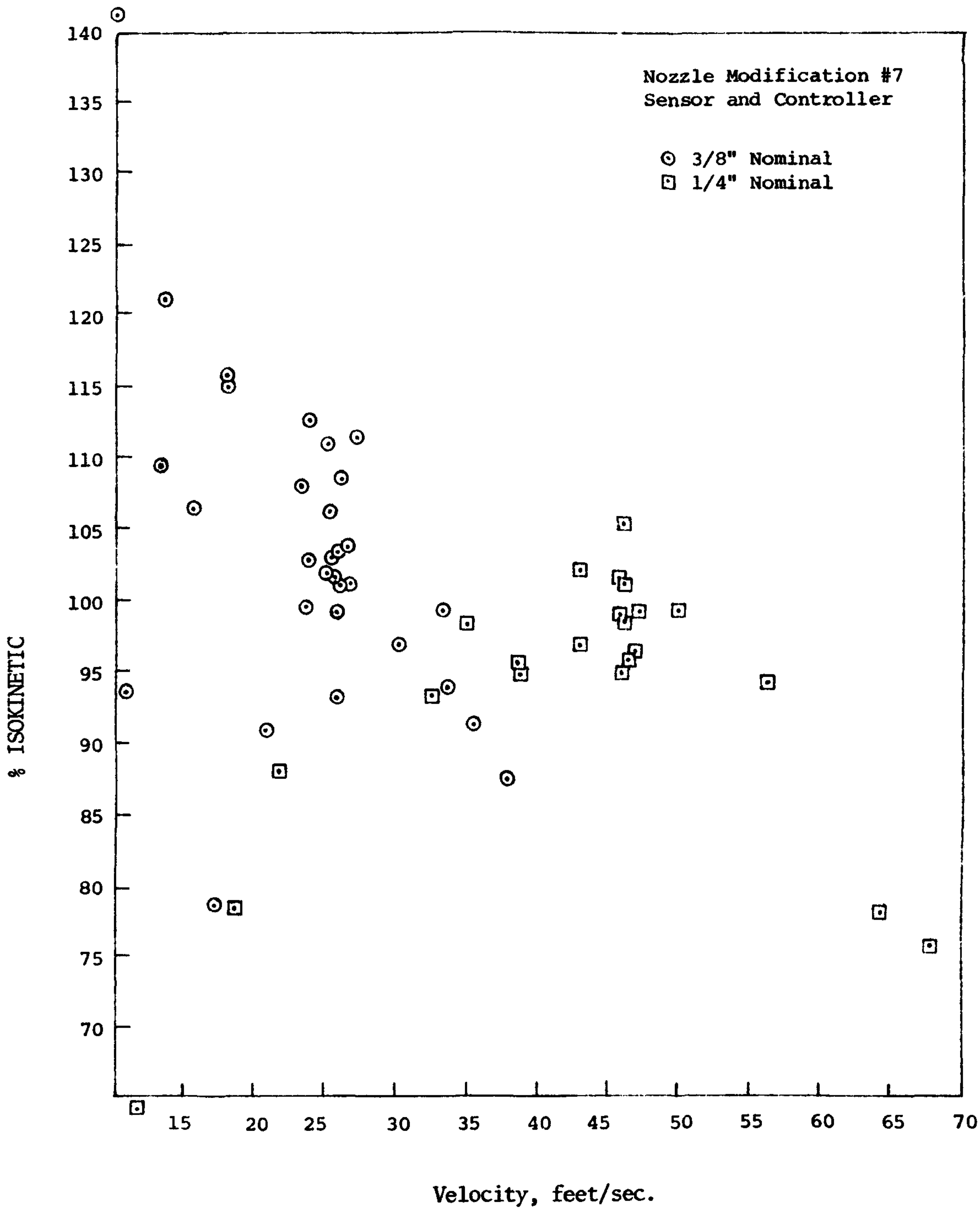


Figure 20. Performance of nozzle modification #7, sensor and controller

FIELD EVALUATION

SOURCE 1 -- The field evaluation period was started with ten simultaneous tests made in the EPA Stationary Source Simulator Facility (SSSF) with moderately heavy particulate loading, medium velocities, and low temperatures. Five tests were made with the 3/8" nozzle and five with the 1/4" nozzle. The probes and nozzles of the two sampling trains were positioned at a proximity of two inches. Test readings were taken at five minutes intervals during the thirty minute runs. The sampling location simulated ideal field conditions: proximity to a well equipped shop, spacious setup and operating areas, the autoisokinetic sampling box and probe mounted on a rolling table, complete control of the source, and room temperature climate conditions. Under these test conditions, the difficulties of obtaining good leak tests were the only drawbacks.

SOURCE 2 -- A coal-fired power plant boiler with a large negative stack gas static pressure was the source for the next series of tests. At this test, the weight of the autoisokinetic sampling box and probe required a table and three people to be properly moved from point to point and from port to port. Two people handled the table-box-probe unit while the third person guided and supported the heavy probe to prevent it from sagging and breaking at the box-probe fastening point.

On each of the four sets of test conducted, the controller valve locked open as soon as the autoisokinetic probe was introduced into the stack. When the probe was removed from the stack, the system would appear most of the time to work as designed. It was determined, after a conference with the designer, that the autoisokinetic equipment was designed to operate only within the stack gas static pressure range of ± three inches of water column. Further testing at this source (- 13 inches of water) was terminated due to the insignificance of any data generated with the controller valve continually forced open by the source.

SOURCE 3 -- A neutral pressure coal-fired power boiler was tested, providing medium temperatures, high velocities, and heavy particulate loading as testing parameters. For these tests, extensive site preparation was required including access ladders to the testing platform and planking for the platform. An identical setup involving the EPA 5 equipment and the autoisokinetic equipment as required at the previous source was needed here, including the table support. The following handling problems for the autoisokinetic sampler are mentioned in detail because no significant problems were encountered with the simultaneous Method 5 tests. The ambient temperature remained below freezing and the 15-20 mph winds caused a considerable chill factor. The handling of the equipment became more awkward and clumsy: the 1/4 inch nozzle was damaged and repaired with new tubing to replace the sensor lines. All of the movement that precipitated the damaging of the nozzle was occasioned by the malfunctioning of the controller valve which was first assumed to be caused by the freezing temperatures but was later determined to be caused by silica gel granules. After the repair of the 1/4 inch nozzle, the scheduled ten tests were completed. Due to the malfunctioning and unpredictability of the boiler, the tests were ended at this source.

During the course of making the seven tests, several recurring problems were encountered: in separate incidents the control valve stuck open and closed, two of four holes in a sensor line were plugged by the particulate matter in the effluent, the heater in the sample box worked erratically and eventually failed (the wire broke but was repaired in the field), and finally the sensor lines on the 1/4 inch nozzle broke and were repaired again. All of these problems created delay while "identify and repair" operations were made.

The control valve malfunction was determined to be caused by silica gel granules which were carried through the check valve into the control valve. This was remedied by removing the check valve and by placing glass wool in the last impinger to catch any silica gel that might be forced into the controller during operation of the sampler.

A major problem not previously encountered was in properly deciding whether to use a 1/4 inch or 3/8 inch nozzle, as the boiler load changed drastically throughout the testing period. For example, during the time required to correct the previously mentioned problems, the boiler loading would deviate from the preliminary pretest data, with the magnitude of the boiler loading change depending on the weather and on other plant operations. If the original nozzle size became inappropriate, changing to the other nozzle required at least an hour,by which time the boiler operation would normally change again. Also, as the loading changed, the static pressure ranged in value from 0 - 1.5 inches of water. This change required tedious, time consuming adjustment of the instrument controls.

SOURCE 4 -- The last source tested was the wood-fired boiler that provided operating parameters of high temperatures, low velocities, and light particulate loading. Again, ten simultaneous tests were scheduled. The EPA Method 5 nozzle was placed in one port within four inches of the autoisokinetic nozzle which was positioned through the other port.

Several new problems occurred, one of which involved the autoisokinetic probe assembly. The one-inch stainless steel sheath for the glass liner does not extend the length of the liner but is instead butt-welded to the larger two-inch diameter outside sheath, which also encompasses the pitot tubes. The butt-weld failed, breaking the glass liner, requiring a new glass liner and repair by using another butt-weld. Another problem was caused by the testing site: a fire during the night burned the compressor air supply line. These were the only time consuming problems encountered and all ten simultaneous tests were completed.

With the completion of the last field test, the equipment was again setup at the SSSF in order to compare the post- test operation with the pre-test operation. The results are shown in Figures 21 and 22. A slight drop in performance seems to have occurred during field tests.

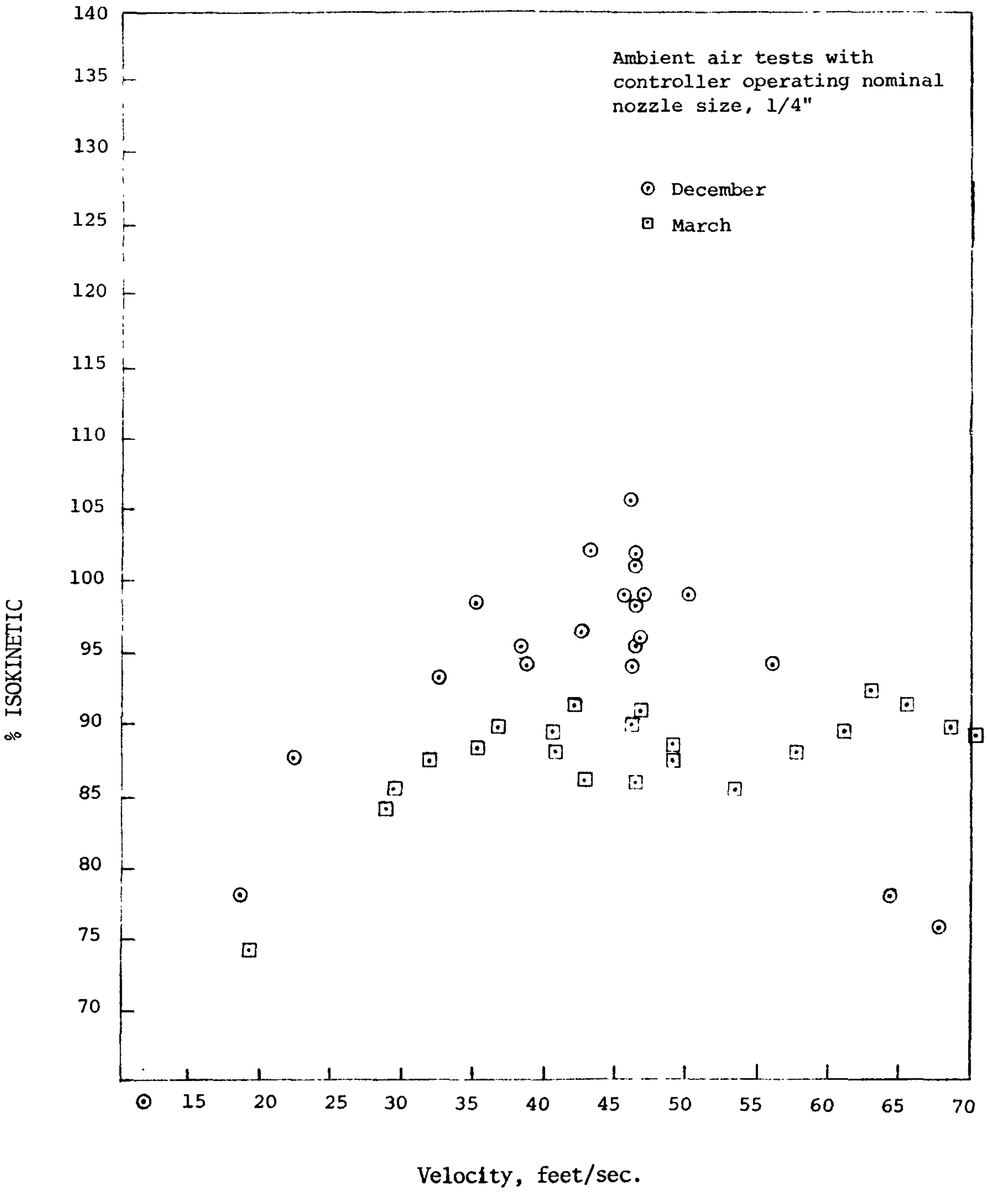


Figure 21. Performance of final 1/4 inch nozzle, pre-field and post-field testing

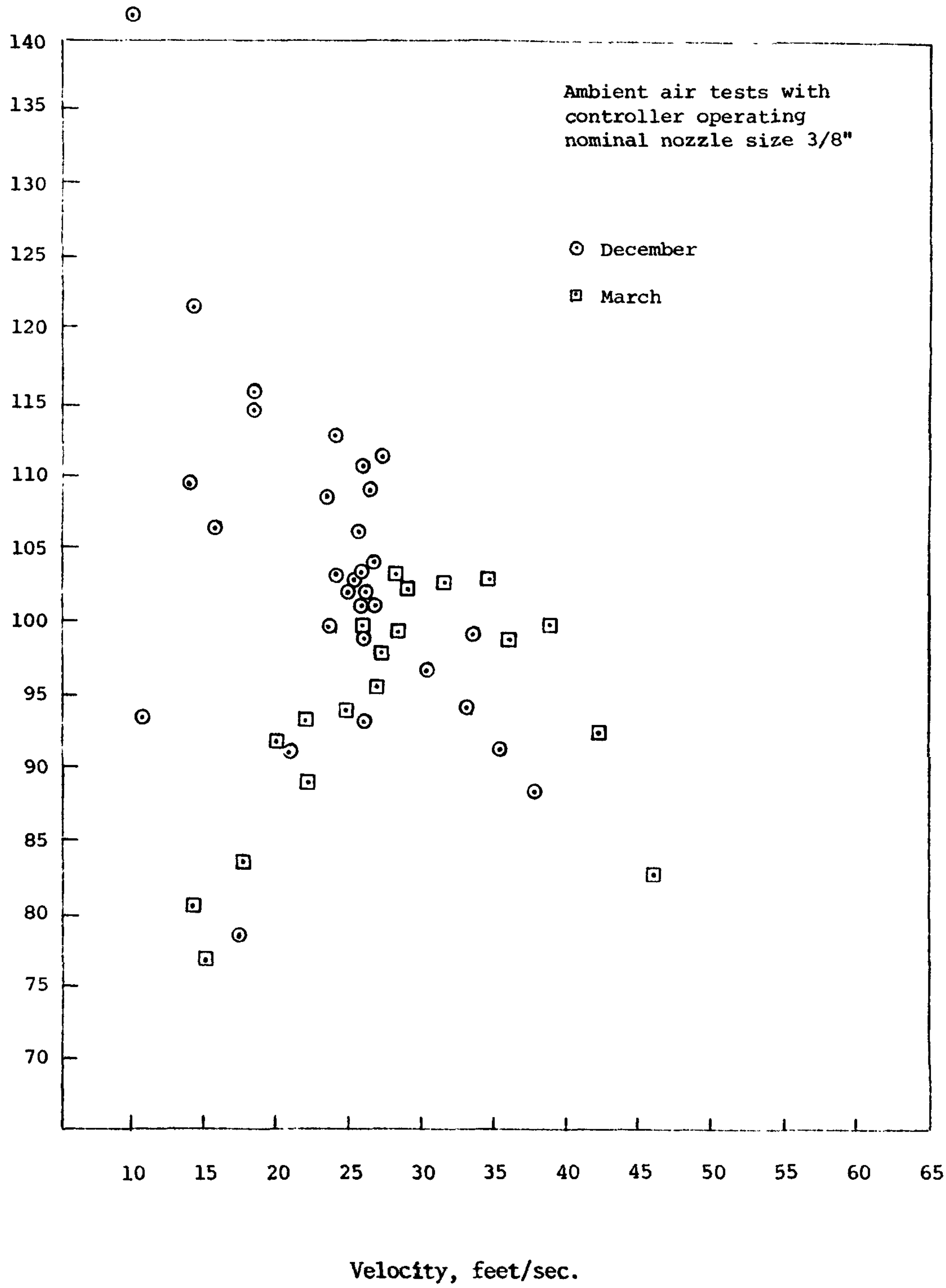


Figure 22. Performance of final 3/8 inch nozzle, pre-field and post-field testing

SECTION 7

FIELD TEST RESULTS

This section presents the results of the field tests. Comments on the design and functionalism of the equipment, and the preliminary testing are covered in Section 8 "Analysis of Testing System."

Ranges for each parameter tested are given in the chart below, along with the source tested which best exemplified the particular range of each parameter.

PARAMETER RANGES

	Low	Medium	High
Temperature	Source 1 20 - 250°	Sources 3 & 4 250 - 500	Source 4 500 & greater
Velocity	Source 4 20 - 43 fps	Source 1 43 - 67	Source 3 67 + greater
Particulate Loading	Source 4 0-0.35 gr/dscf	Source 1 0.35 - 0.63	Source 3 0.63 greater
Static Pressure	Source 1 0-1 in. H_2O	Source 3 1 - 5	Source 2 5 & greater

The results from each test in the specified parameter ranges are plotted versus percent isokinetic in Figures 23,24, and 25. Note that some sources fit into two different parameter ranges.

Tables 2,3, and 4 give the results of tests at each source for each nozzle except for the high vacuum source, source #2. No results are tabulated for source #2 since the control valve was always locked full open, thereby causing the sampler to sample at the highest rate regardless of the stack velocity.

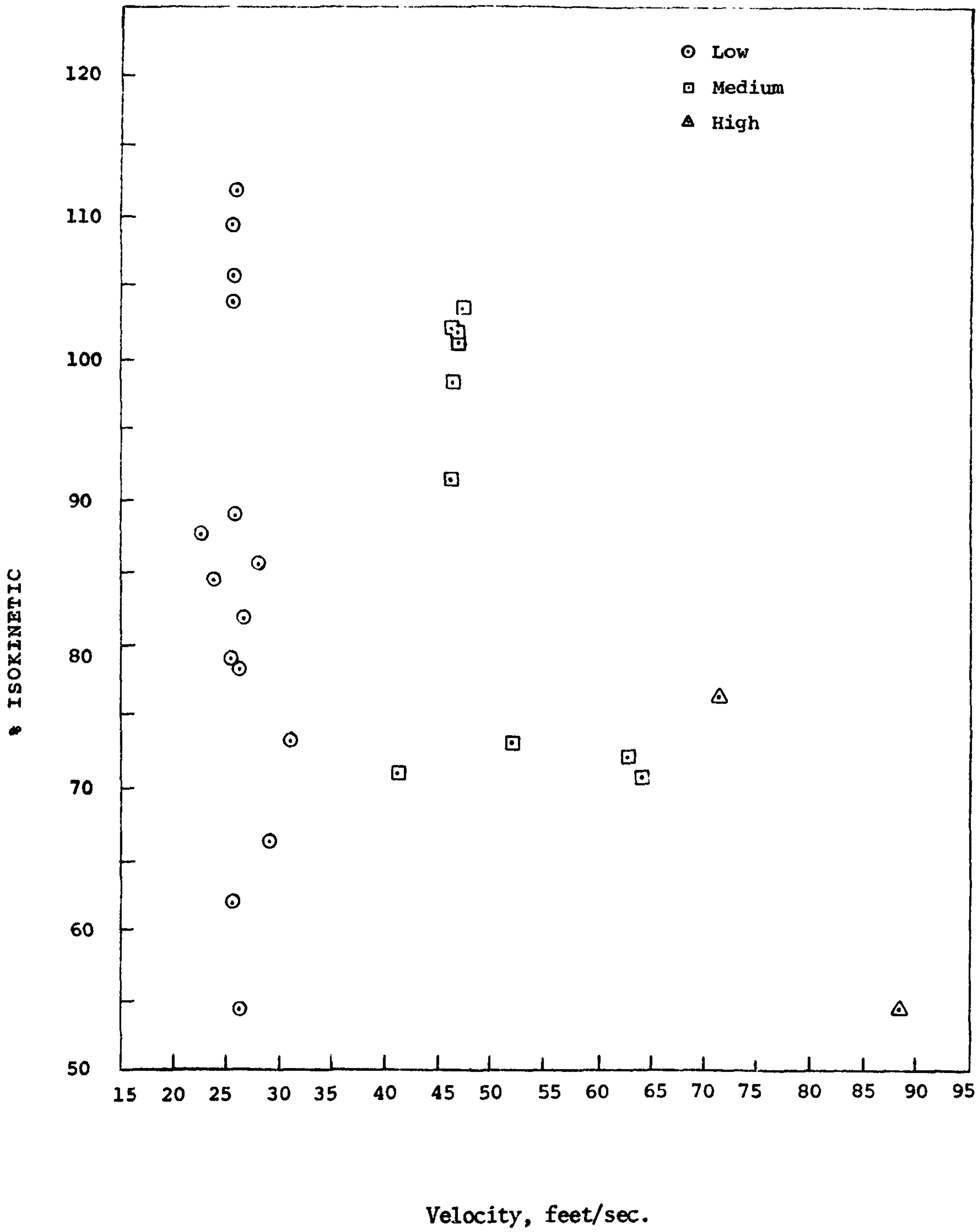


Figure 23. Gas stream velocity versus percent isokinetic

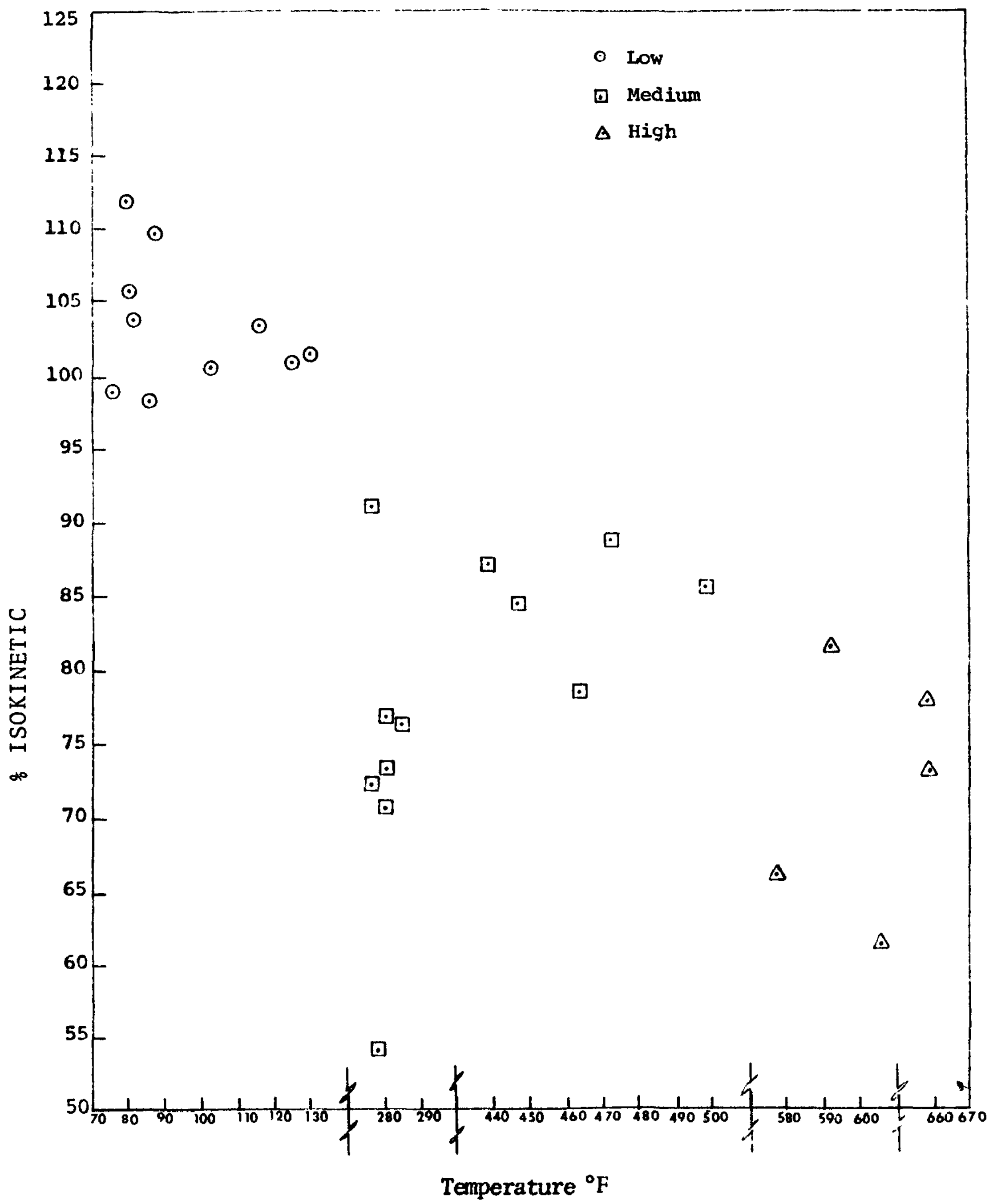


Figure 24. Gas stream temperature versus percent isokinetic

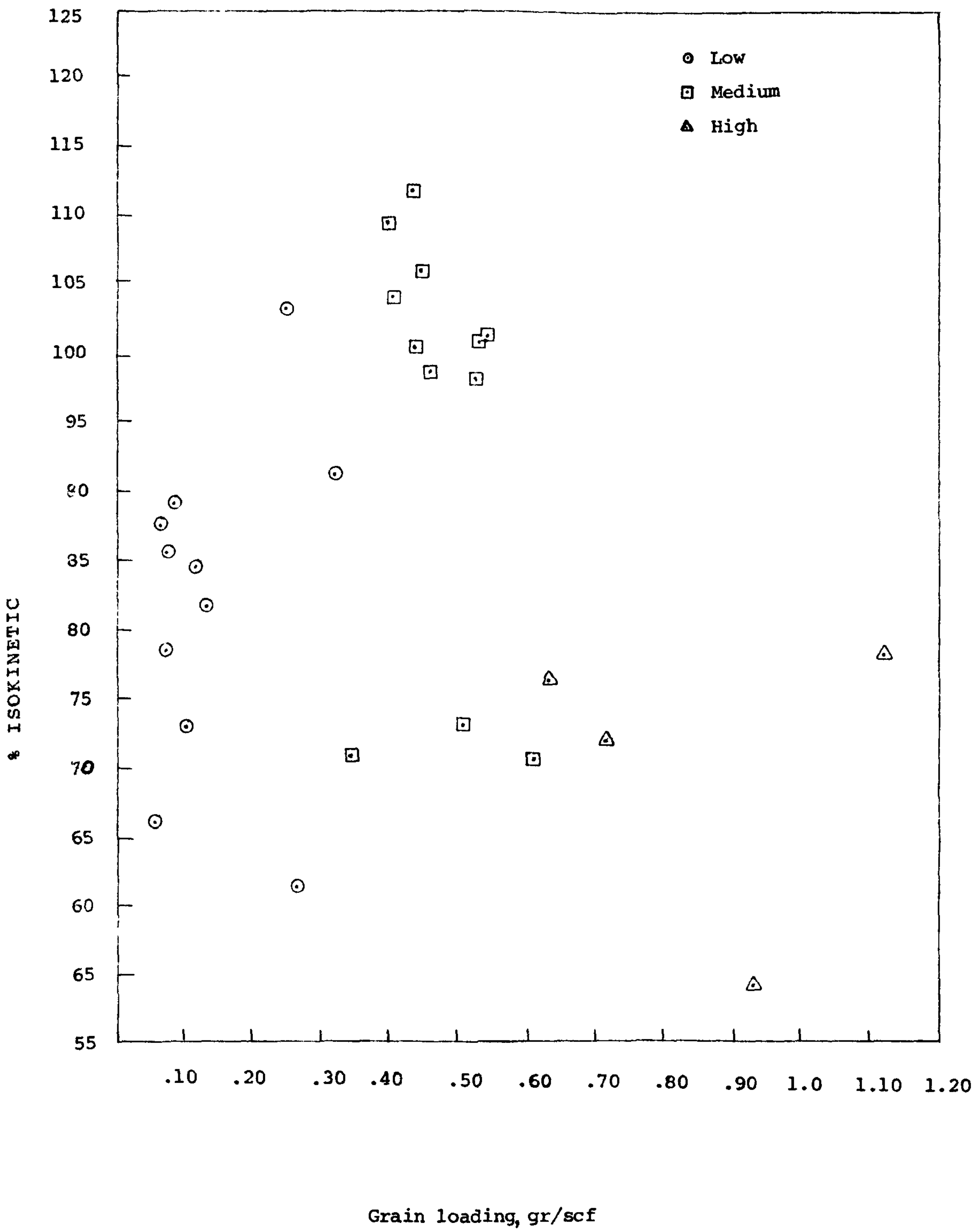


Figure 25. Grain **loading** versus percent isokinetic

TABLE 2. RESULTS FROM THE EPA STATIONARY SOURCE SIMULATOR FACILITY RUNS (SOURCE 1)

Nozzle Size	Auto-Isokinetic Train Concentration GR/DSCF	Auto-Isokinetic Train Isokinetic Conditions,%	EPA Method 5 Concentration GR/DSCF	EPA Method 5 Isokinetic Conditions,%	Auto-Isokinetic Train Particulate Bias,%
0.277	0.520	98.2	0.555	91.5	-6.3
	0.464	100.6	0.500	102.0	-7.2
	0.253	103.0	0.265	92.6	-4.5
	0.523	100.8	0.577	103.1	-9.4
	0.536	101.5	0.589	102.7	-9.0
	Avg.	100.8		98.4	-7.3
	Std. Dev.	±1.74		±5.80	±2.01
0.358	0.476	98.6	0.574	90.9	-17.1
	0.442	112.1	0.567	94.3	-22.0
	0.456	105.7	0.578	96.1	-21.1
	0.416	103.9	0.554	99.4	-24.9
	0.411	109.8	0.522	100.0	-21.3
	Avg.	106.0		96.1	-21.3
	Std. Dev.	±5.27		±3.75	±2.79
Source Overall Avg.		103.4		97.3	-14.3
Standard Deviation		±4.60		±4.76	±7.73

TABLE 3. RESULTS FROM THE NEUTRAL PRESSURE POWER BOILER STACK (SOURCE 3)

Effective Nozzle Size	Auto-Isokinetic Train		EPA Method 5		Auto-Isokinetic Train Particulate Bias
	Concentration GR/DSCF	Isokinetic Conditions,%	Concentration GR/DSCF	Isokinetic Conditions,%	
0.277	0.634	76.1	0.594	107.7	+6.8
	0.373	70.7	0.341	103.1	+9.4
	0.327	91.2	0.332	106.2	-1.6
	Avg.	79.3		105.7	+4.9
	Std. Dev.	±10.6		±2.35	±5.7
0.709	0.709	72.3	0.608	102.0	+16.6
	0.517	73.0	0.478	105.5	+ 8.0
	0.605	70.5	0.523	101.3	+15.6
	0.917	54.1	0.674	101.5	+36.1
	Avg.	67.4		102.6	+19.1
	Std. Dev.	±9.0		±1.97	±12.0
Source Overall Avg. *		72.6		103.9	+13.0
Standard Deviation		± 10.8		± 2.55	±11.9

* Sample Population of 7

TABLE 4. RESULTS FROM THE HIGH TEMPERATURE WOOD-FIRED BOILER STACK (SOURCE 4) USING NOMINAL 3/8" NOZZLE

Auto-Isokinetic Train		EPA Method 5		Particulate Bias
Concentration GR/DSCF	Isokinetic Conditions,%	Concentration GR/DSCF	Isokinetic Conditions,%	Auto-Isokinetic Train, %
1.12	77.4	1.17	99.3	-4.3
0.281	61.4	0.170	97.5	+65.3
0.132	82.2	0.102	100.4	+29.4
0.131	84.6	0.099	100.7	+32.2
0.081	87.3	0.063	99.2	+28.6
0.094	78.3	0.086	102.9	+9.3
0.099	88.8	0.078	101.6	+26.9
0.097	85.4	0.094	102.9	+3.2
0.140	73.4	0.227	100.6	-38.3
0.074	66.0	0.104	98.3	-28.9
Source Overall Avg.	78.5		100.3	+12.3
Standard Deviation	±9.18		± 1.81	±30.9

SECTION 8

ANALYSIS OF TESTING SYSTEM

This analysis is of three areas of the autoisokinetic sampling system: testing procedures, equipment, and performance. Problems and difficulties encountered in each area are discussed and commented upon.

Procedural problems were caused mainly by inadequacies and omissions in the manual accompanying the autoisokinetic equipment EPA Report No. 650/2-74-029. Discrepencies and inconsistent labeling were found in the set-up instructions. In section 3.5, "System Set-Up and Operation", page 3 - 32, paragraph 2, two "left hand knobs" are referenced when there are actually only two knobs total. Figure 3.18 on page 3-29 shows the fluidic controller and labels the left knob "Gain changer" and the right "Gain Adjust", while Table 1, page 3-33, calls the right knob "Variable Gain" and the left "Fixed Gain." No instructions on how to make a leak test were given or specified. In the "Operation and Maintenance Manual" accompanying the equipment, all adjustments are made with the vacuum pump off and out of the stack. Instructions are to turn on the pump when the probe is placed into the stack. This disagrees with the subsequent procedure used in the field evaluation testing, which was verified as proper by the manufacturers of the equipment via a telecon consultation. The new procedure requires that the vacuum pump be on before the probe is placed in the stack. A further point of omission was the fact that the three toggle switches on the control console were not mentioned by either of the supplied manuals and were not labeled on the control console in any way.

Concerning the equipment, discussions will start with the mass flowmeter and the digital flow totalizer. The flowmeter measurement range is so large that at a flow of 0.5 to 1.0 cfm, the meter manufacturer's specifications of ± 1% full scale yield potential errors of 10 to 5%. The problem is that these flow rates are the rates at which most source sampling is performed. The totalizer, calibrated as received, was 10 to 20% low in its readings. After recalibration, the totalizer was 5% high which, for calculating particulate loading, is still inadequate and unacceptable according to EPA requirements. The umbilical line is much too heavy and stiff for sampling purposes, especially when connected to the sampling box which is also too heavy. The connections for the umbilical are unsuited for quickly setting up or disconnecting. The sample box set-up, besides being unwieldy, has poor access to the controller valve or the back of fluidic converter. In fact, the space is so tight that when the fluidic converter was initially removed for checking purposes, it could not be reinstalled completely because of pressure against one of the lead-lag capacitors, which caused the bias pressure to change. It is assumed that the fluidic converter was originally installed with pressure exerting against the capacitor from the controller valve.

The probe is too heavy and cumbersome. The one inch stainless steel sheath does not extend the full length of the glass liner. This creates a flexing condition which resulted in three broken glass liners and in the sheath itself breaking a stainless steel weld. The rotational ability of the probe is severely curtailed due to the pitot connector and the sensor lines. The mode of fastening the nozzle to the probe end is inconvenient due to the hindering sensor tubing and pitot lines. The original nozzles had holes which would have prevented proper equipment operation and source sampling. The sensor lines were very fragile and broke three times through normal sampling circumstances.

Only the low temperature tests were valid. Temperature seemed to affect the performance. As the temperature increased, the percent isokinetic dropped. Stack gas static pressures in excess of 3" water column made the sampler inoperative. The design limits of stack gas static pressure were determined to be ± 3" water column. Surprisingly, the particulate loading and velocity appeared to have no noticeable effect.

Overall, the autoisokinetic sampling train does not fulfill the design criteria and,at its present stage of development, provides no advantage over the established methods of isokinetic sampling.

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

The performance of a prototype autoisokinetic stack particulate sampling system, designed to maintain automatically isokinetic sampling conditions, was evaluated in field tests at stationary sources. Tests were conducted to determine the operating limits and characteristics of the system. Preliminary tests demonstrated the necessity of making several modifications to the existing system to improve the level of performance for the field evaluation program. Improvements were made in the problem areas of the performance of the mass flowmeter, flow totalizer, and flow control valve systems and in the sampling nozzles.

The autoisokinetic sampler was tested at four field installations selected to provide a wide range of sampling conditions. The results of the testing and analysis showed that the sampling system maintained acceptable isokinetic sampling rates of 100% ±10 at only one of four sources. An inverse relationship between the percent of isokinetic rate and the temperature of the gas stream being sampled was found. The evaluation revealed that the sampler will operate only in the narrow range of stack gas static pressures of ±3 inches water column. The physical hardware was found to be fragile and difficult to operate in the field. Overall, the autoisokinetic sampling system failed to meet the design goals.

17. KEY WORDS AND DOCUMENT ANALYSIS

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