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ALUATION OF LENGTH-OF-STAIN GAS INDICATOR TUBES FOR MEASURING CARBON MONOXIDE IN AIR

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16. Abstract Techniques for measurement of carbon monoxide (CO) in air are of utility in many aspects of automotive safety. Concentrations ranging from less than 0.01 to about 10 percent CO are of interest. Gas indicator tubes for carbon monoxide (CO) were considered to be potentially useful for this application. An empirical study was conducted to determine the degree of precision obtained from these tubes. A breadboard model of a semi-automated analyzer was constructed. The coiled tube sample reservoir permitted gas transport by following purge air with little mixing or dilution. One brand and type of indicator tube was evaluated at several different CO concentrations, gas flow rates, and at two different sample volumes. All tests were conducted at room temperature. The averaged values for ten tests at each experimental condition were found to fit very well to power-curve equations of the type predicted by theoretical analysis. The standard deviations for each group of tests indicated that any single measurement might differ from the true value by ±30 per cent.

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INTRODUCTION

Techniques for detection and measurement of carbon monoxide (CO) in air are of interest and utility in many aspects of automotive safety. CO concentrations may range from less than 100 parts per million (ppm), or 0.01 per cent, to about 10 per cent, by volume. Some applications require a relatively high degree of accuracy over a dynamic range of less than one order of magnitude; other uses may be satisfied with a lesser degree of accuracy but demand a dynamic range of three to five orders of magnitude.

Gas indicator tubes have been used for many years primarily as detectors of hazardous gases in a work environment. These tubes contain a chemical filling which indicates the concentration of a specific gas by a change in color of the filling. For the usual safety test application, a high degree of accuracy or repeatability in reading is not essential. However, if such tubes could provide satisfactory precision for a given application, they appeared to offer a potentially low cost solution to this measurement problem.

The objective of the study described herein was to determine the accuracy and reproducibility achievable in the measurement of carbon monoxide concentrations using length-of-stain gas indicator tubes.

EXPERIMENTAL STUDY

BREADBOARD ANALYZER CONFIGURATION

For the breadboard analyzer, two sample reservoir and gas transport configurations were considered. One would use a cylinder, piston and check valves to define the sample volume. A gas sample would be inducted by one stroke of the piston; the return stroke would expel the sample through the indicator tube. Two additional strokes probably would be required to pass clean purge air through the cylinder and system to the detector tube, and then to return the piston to start position. This design would be relatively bulky, heavy and expensive. An alternative design was selected which is mechanically simpler, more compact, lighter and more economical. The sample was collected in a coiled length of small diameter (0.305 in. inside diameter) stainless steel tubing. Transport of the sample out of this reservoir through a valve and connecting tubing and through the gas indicator tube was accomplished by injection of purge air at the "back", or inlet, end of the coil. The small diameter of the tubing and the low flow velocity encouraged "plug flow" of the sample ahead of the purge air with little mixing or dilution of the sample.

A breadboard length-of-stain CO analyzer was constructed. It consisted of a coiled tube sample reservoir; purge air pump; solenoid valves for sample and purge air inlet and for reservoir discharge either to overflow (dump) or to length-of-stain tube; flowmeter; and a multiple-cam sequence timer to control all events. A functional block diagram is shown in Figure 1; Figure 2 is a photograph of the breadboard unit with a loosely-coiled 200cc reservoir. Sample volume could be varied by substituting coiled tube reservoirs of the desired capacities. Sample gas was provided from one of a number of high pressure tanks containing known concentrations of CO in nitrogen. Additional sample concentrations were prepared by dilution of these reference gases with nitrogen. The timer was adjusted to allow discharge through the indicator tube at a preset flow rate for a period corresponding to about 125% of the volume of the sample reservoir. Thus the last 25% of the volume which passed through the indicator tube was clean, uncontaminated purge air, and the reservoir was left filled with clean air.

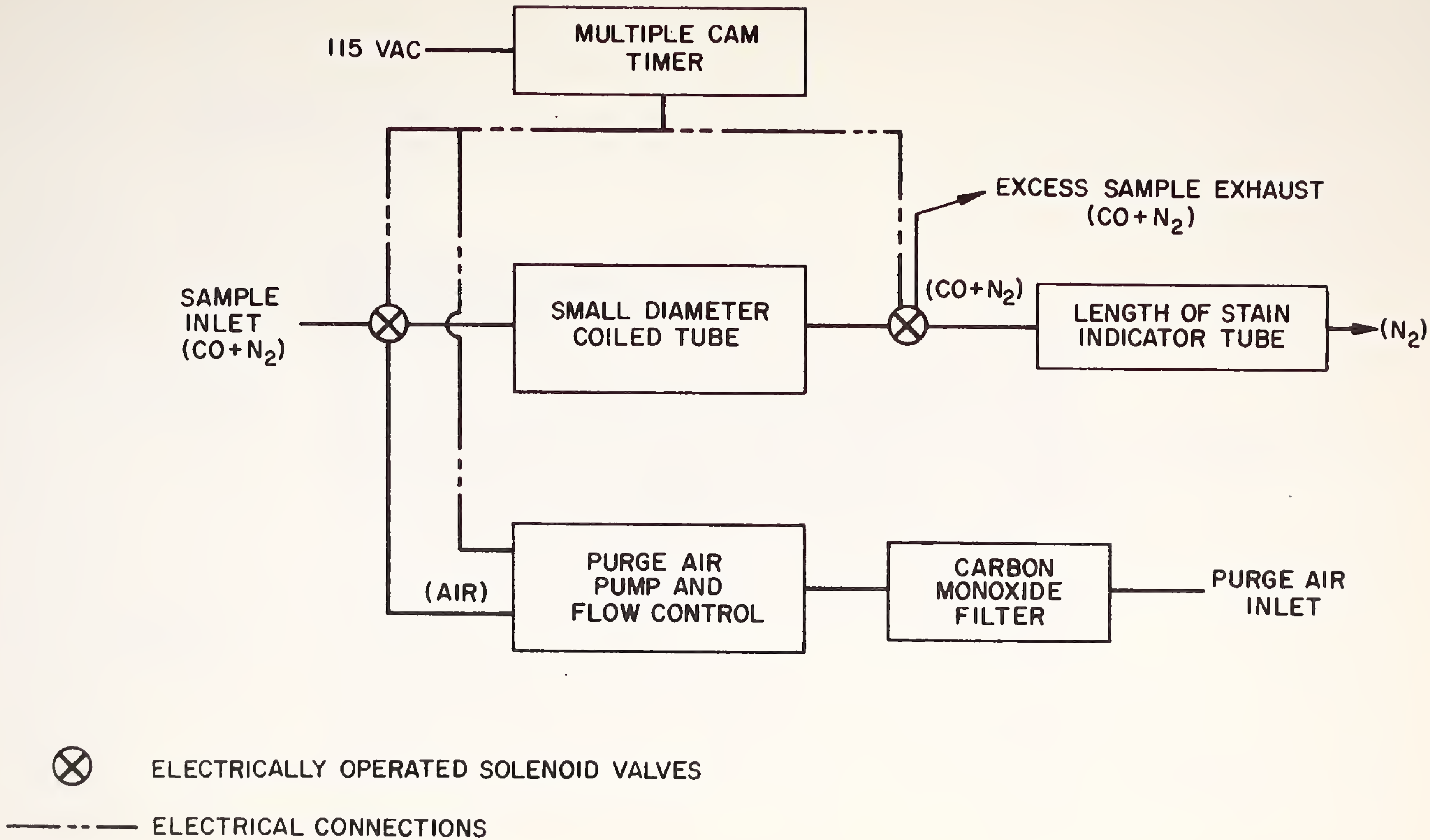

Figure 1. Functional Block Diagram of Breadboard CO Length of Stain Analyzer

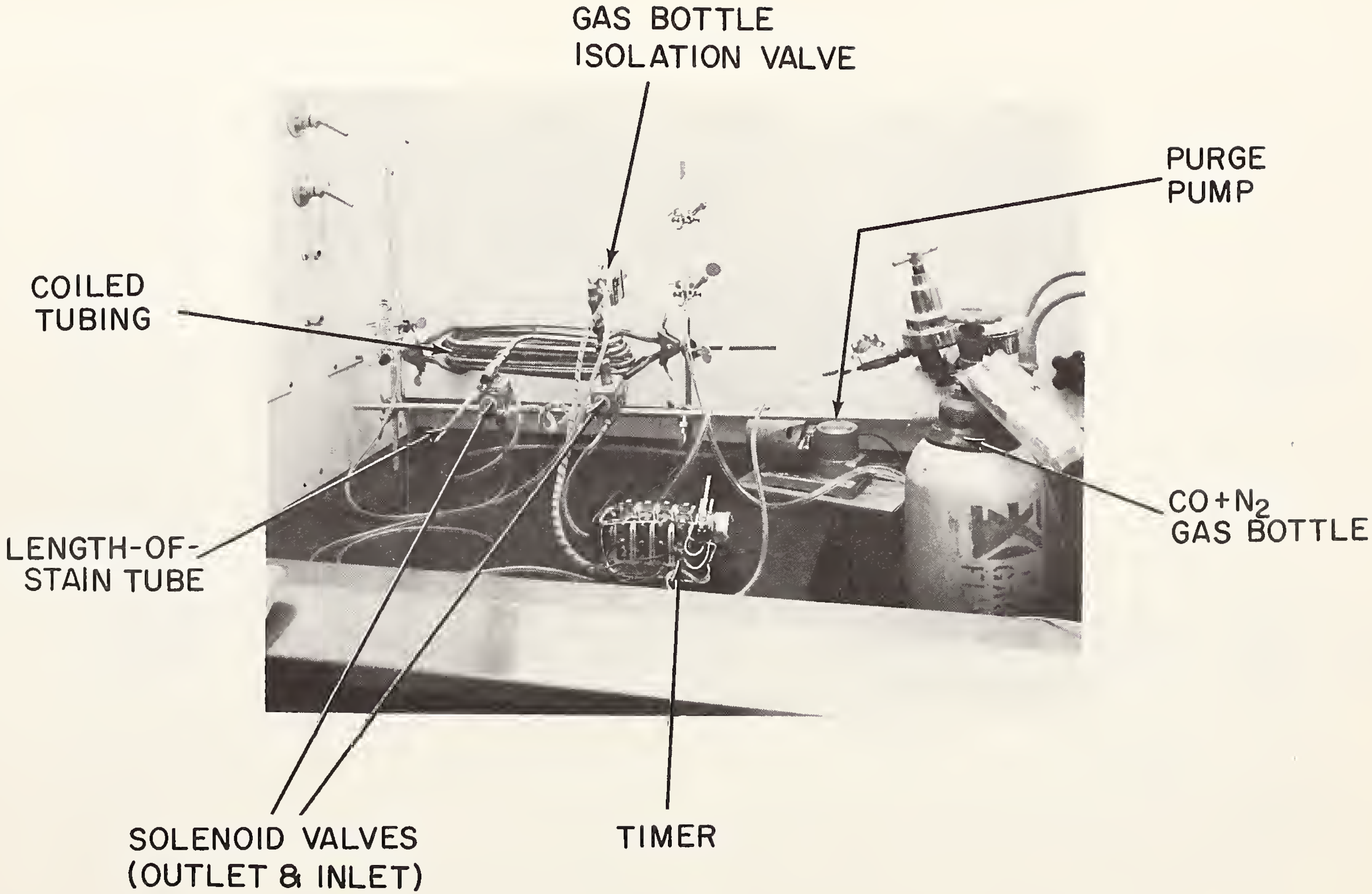

Figure 2. Coiled Tube Length-of-Stain Analyzer, 200 cm^3 Volume

EXPLORATORY TESTS

Exploratory tests were conducted on two different types of indicator tubes in various configurations to survey general performance. In the first test, five Draeger (Lubeck, Germany) type 10/b tubes were connected in series to simulate a single tube with a nominal 10-inch indicating length. A 200cc sample of 1.04% CO was passed through the assembly. The stain front (i.e., transition zone from dark, stained indicator to light, unstained material) moved at apparently constant velocity along the tubes with no discernible time lag in jumping from one tube to the next. Stain front was sharp. In a second test, two Bacharach (Bacharach Instrument Company, Pittsburgh, PA) 0.2% tubes were connected in series to provide a 2-inch total indicator length, and a 200cc sample of 105 ppm CO was passed through. The stain front was over 1 inch long. All subsequent tests used only one tube per measurement.

EVALUATION TESTS

Ten measurements were made at each individual test condition using one tube per test. The ten tubes of each group were selected at random from at least three shipping boxes (ten tubes per box). Draeger type 0.3%/a tubes were evaluated, using a 200cc sample reservoir, at four CO concentrations with flow rate fixed at 500cc/min.; and at three different flow rates with a single CO concentration. The same type tubes were used with a 100cc sample reservoir for tests at three CO concentrations with a fixed 500cc/min. flow rate. For reasons of experimental convenience, initial tests were made with CO levels corresponding approximately to engine exhaust. If results indicated, further tests would be made with CO concentrations at 100 ppm CO and below.

Only about 20% of the tubes produced stain fronts which were approximately planar and normal to the tube axis; most of the stain fronts observed either were tilted or had a region protruding beyond the main front. These effects generally are caused by non-uniform packing of the indicator material in the tubes which produces some inhomogeneity of gas velocity across the tube cross-section. Accordingly, for each tube both the maximum and minimum lengths of stain were measured. Thickness of the stain front (i.e., length along the tube axis) also was estimated.

For each test condition, the ten readings were averaged and the standard deviation of the group was calculated. Equations for stain length vs. CO concentration were calculated for the average stain lengths by least-squares fit to a power function. Such a power function relationship for these parameters was predicted in a theoretical analysis of gas indicator tube performance by Saltzman.[1] The experimental data are given in Tables 1-3; equations for stain length vs. CO concentration are shown and plotted in Figures 3 and 4. Stain length vs. sample flow rate data (average values) are plotted in Figure 5; since equilibrium reaction conditions evidently were not being achieved, there was no fundamental relationship which could be used to relate these parameters, and no equation was derived.

TABLE 1

LENGTH OF STAIN VS. CO CONCENTRATION
AT CONSTANT FLOW RATE[(1)], 200 CC SAMPLE

Draeger 0.3%/a Indicator Tubes

Per Cent CO	Average Stain Length[(2)] Max. Inch	Min. Inch	Average Transition Zone Length[(2)] Inch	Standard Deviation[(2)] σ_L max Inch	σ_L min Inch
0.104	0.320	0.259	0.066	0.025	0.020
0.52	0.850	0.780	0.072	0.044	0.027
1.04	1.399	1.291	0.095	0.105	0.072
1.50	1.823	1.718	0.090	0.057	0.059

(1) Flow rate 500cc/minute
(2) For ten tests each point

1. Saltzman, B.E., "Basic Theory of Gas Indicator Tube Calibration", Ind. Hy. J., 112-26, March-April, (1962).

TABLE 2

LENGTH OF STAIN VS. CO CONCENTRATION AT CONSTANT FLOW RATE(1), 100 CC SAMPLE

Draeger 0.3%/a Indicator Tubes

Per Cent CO	Average Stain Length(2) Max. Inch	Average Stain Length(2) Min. Inch	Average Transition Zone Length(2) Inch	Standard Deviation(2) σL max Inch	Standard Deviation(2) σL min Inch
0.52	0.450	0.375	0.052	0.041	0.020
1.04	0.639	0.560	0.068	0.052	0.037
2.02	1.222	1.117	0.078	0.084	0.073

(1) Flow rate 500cc/minute
(2) For ten tests each point

TABLE 3

LENGTH OF STAIN VS. FLOW RATE AT CONSTANT CO CONCENTRATION(1), 200 CC SAMPLE

Draeger 0.3%/a Indicator Tubes

Flow Rate cc/min	Average Stain Length(2) Max. Inch	Average Stain Length(2) Min. Inch	Average Transition Zone Length(2) Inch	Standard Deviation(2) σL max Inch	Standard Deviation(2) σL min Inch
340	1.292	1.160	0.064	0.100	0.046
500	1.399	1.291	0.095	0.105	0.072
1000	1.622	1.452	0.170	0.098	0.054

(1) Concentration 1.04% CO in nitrogen
(2) For ten tests each point

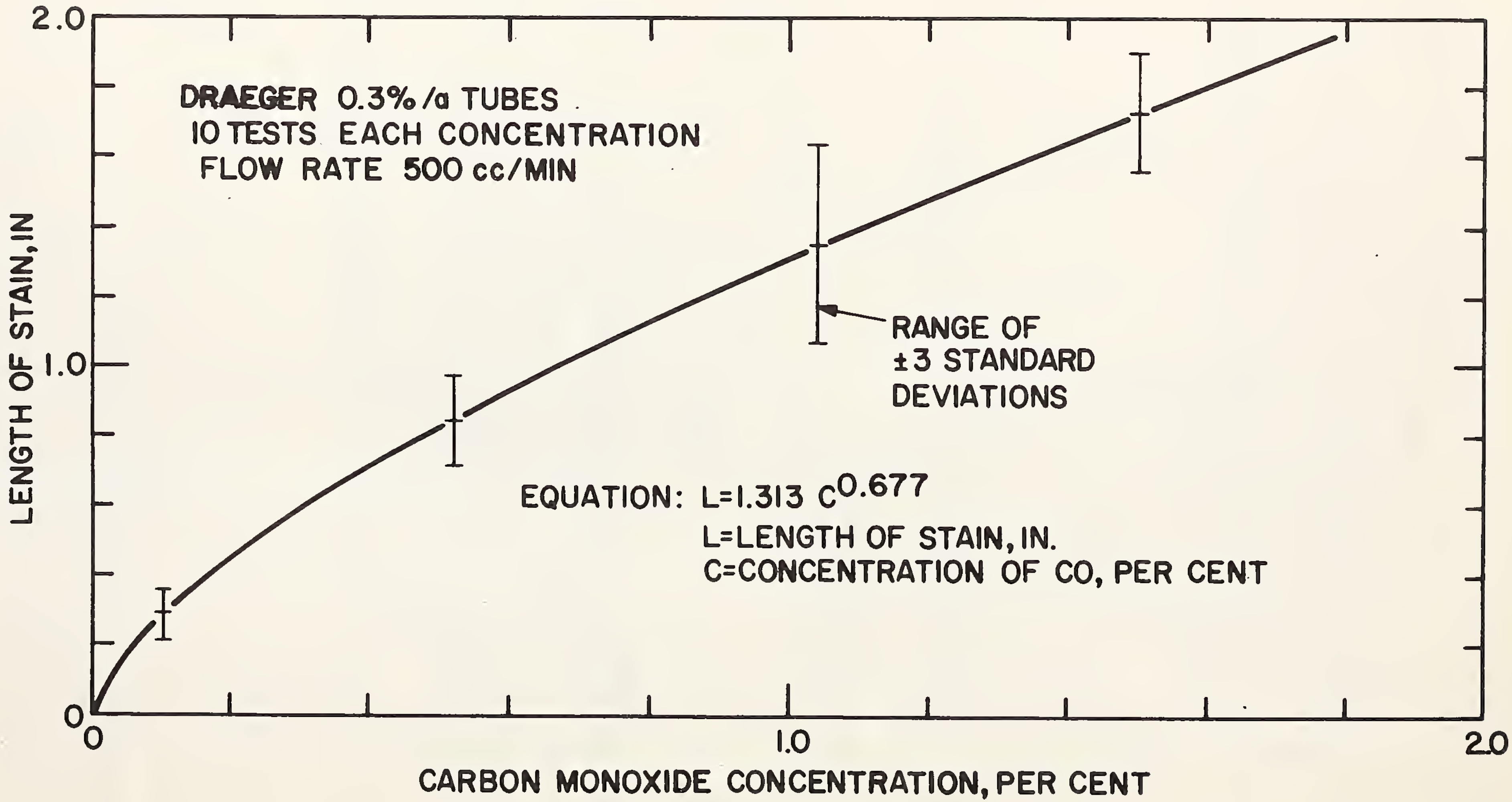

Figure 3. Length of Stain vs. Carbon Monoxide Concentration at Constant Flow Rate, 200 cc Sample

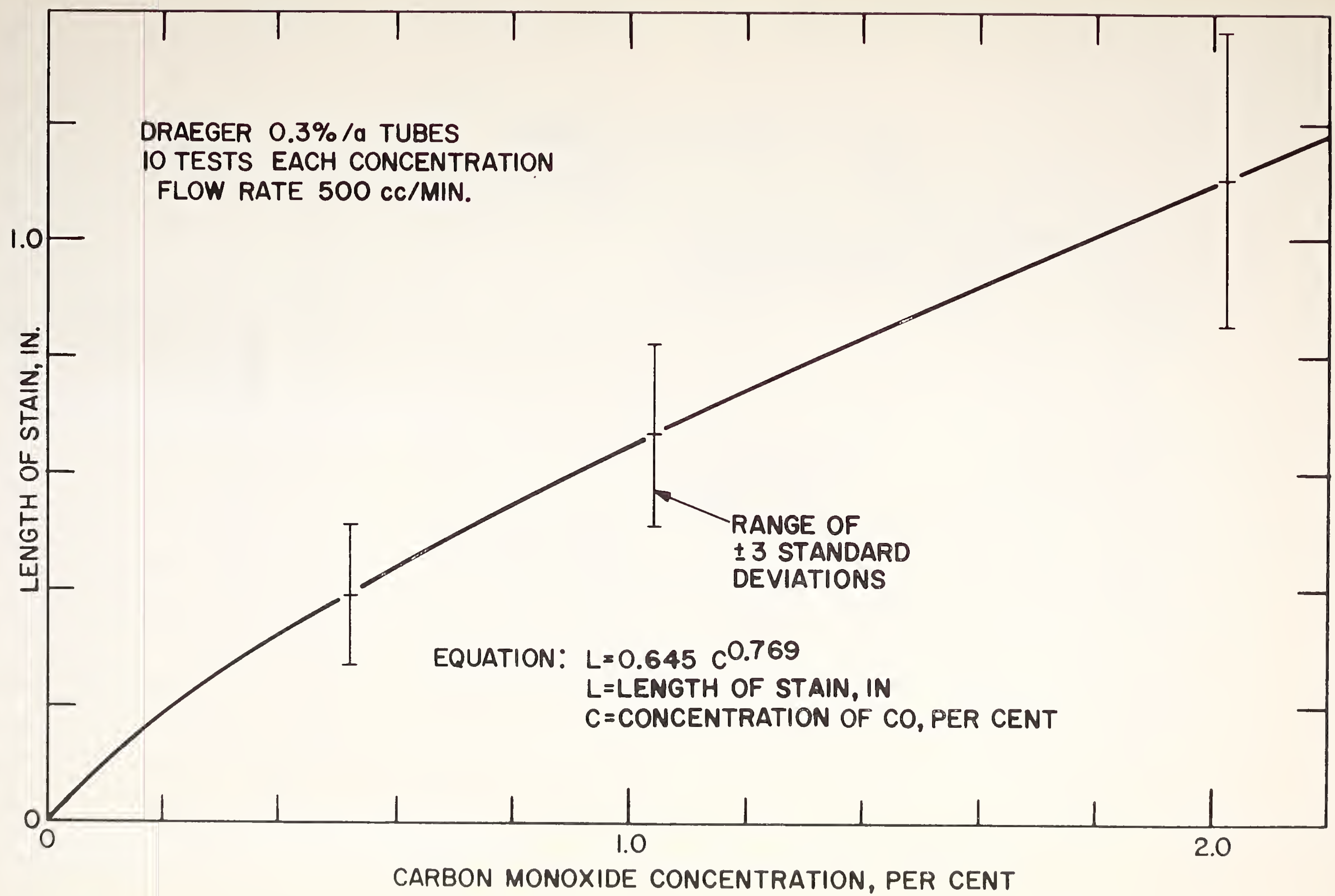

Figure 4. Length of Stain vs. Carbon Monoxide Concentration at Constant Flow Rate, 100 cc Sample

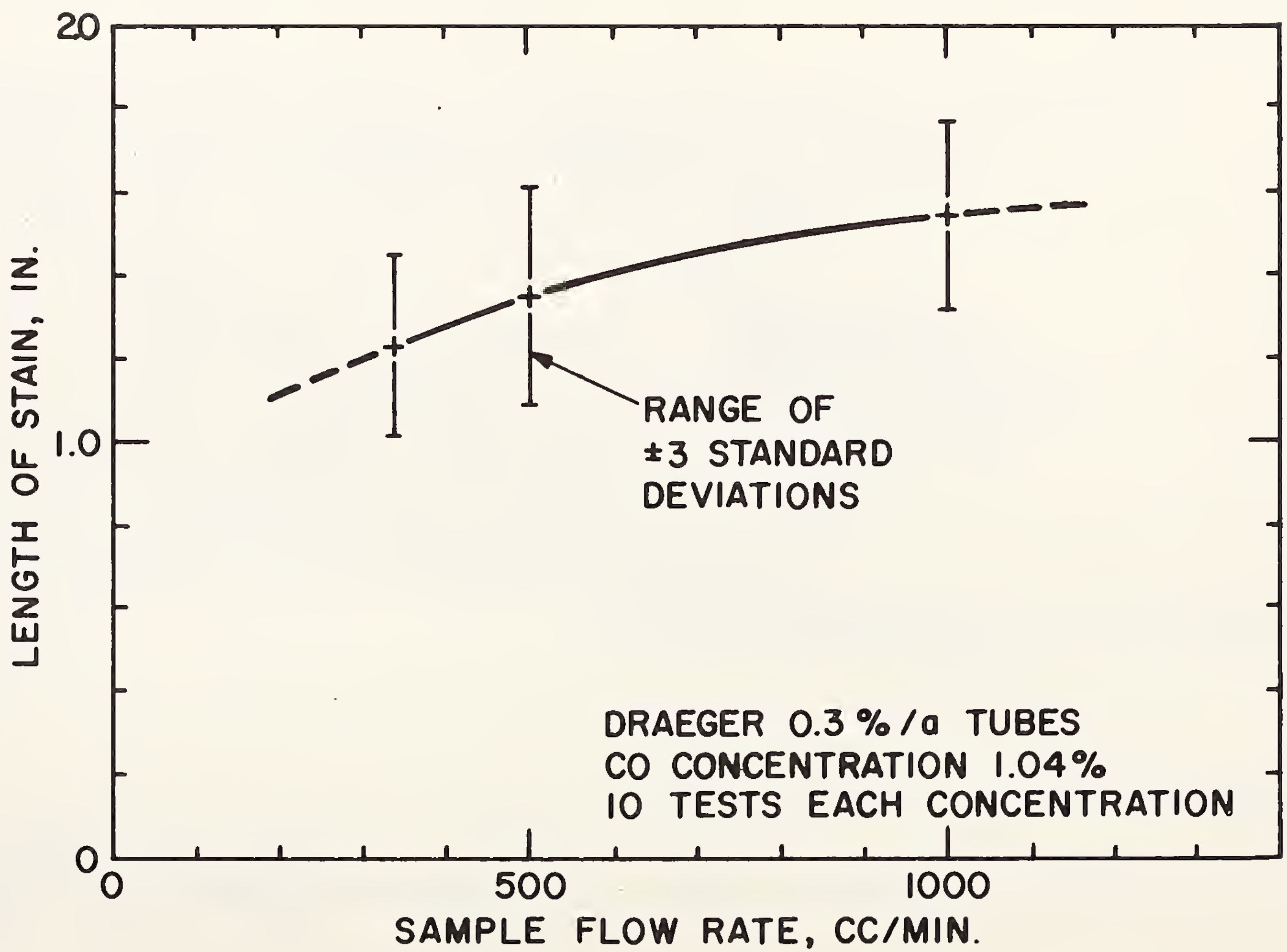

Figure 5. Length of Stain vs. Flow Rate at Constant Carbon Monoxide Concentration, 200 cc Sample

CONCLUSIONS

Mechanical operation of the breadboard analyzer was completely satisfactory. The fit of the 10-test average values to the derived curves was extremely good; this shows that the overall performance of the system, the indicator tubes and the operator was reproducible. This conclusion is based on the correlation coefficients obtained when deriving equations to fit the test data. The correlation coefficients (which indicate how well the data fit the curve of the derived equation; perfect fit is 1.0, no correlation is 0) ranged from 0.98 to over 0.99.

Consistency of average values of numerous tests, such as described above, is essential if the device is to be useful; however, for the application intended for this instrument, consistency of averages was not sufficient. When testing a vehicle for self-contamination at an inspection station, probably only one measurement would be made at each test condition--and perhaps only one test condition would be involved. Hence the range over which any single measurement might be expected to occur is significant.

This range of possible error is best estimated from the statistics of the experimental data. Statistical theory predicts that, for a large group of measurements, 99.5% of all readings will be distributed around the average value within limits of ± 3 times the standard deviation. This means that any one measurement may deviate from the average (here, the true) value by as much as ± 3 standard deviations. For the data reported, this deviation of any single reading could be as much as ± 30 per cent of the true value (i.e., the value which would be obtained by averaging the results of a number of tests).