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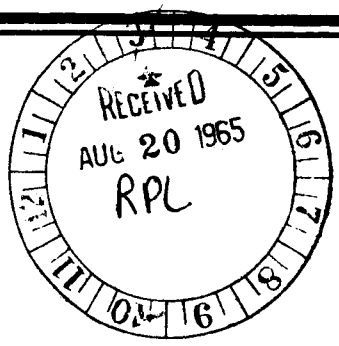

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HYDROGEN SAFETY

Progress Report No. 6
April 1 to June 30, 1965

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Pittsburgh, Pennsylvania

HYDROGEN SAFETY

Progress Report No. 6
April 1 to June 30, 1965

by

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Cleveland Extension, NASA
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INTRODUCTION

This is the sixth in a series of quarterly progress reports on hydrogen safety covering (a) review of existing practices, (b) delineation of areas in which new information needs to be developed, and (c) compilation of a safety manual based on fundamentals so as to be broadly applicable to operations involving hydrogen.

During the present reporting period, several hydrogen detectors were evaluated for performance, conversion of an 18,000-cubic-foot, high-bay facility into one suited for hydrogen plume studies was begun, and visits to hydrogen facilities were made. Experimental work on the hydrogen-explosion hazards phase of the program was curtailed because personnel associated with it have been detailed temporarily to a field investigation that must be conducted during favorable weather.

CURRENT PROGRESS

General Hydrogen Safety Studies (R. A. Van Meter, A. Strasser, S. R. Harris, and J. Grumer)

Hydrogen Safety Practices

The hydrogen safety manual is not yet completed. Work on the initial draft was continued.

Visits were made to the NASA-Lewis Research Center and to its Plumbrook Station to discuss hydrogen technology and to observe its practice. Topics under discussion included vent fires, criteria for flaring waste hydrogen, purging practices, sampling liquid hydrogen for determination of contaminants, operations with liquid hydrogen at its triple-point, response of detectors to very high concentrations of hydrogen, and use of Group D equipment in atmospheres that may contain hydrogen. Hydrogen-use practices observed included a cold-flow run through a Kiwi engine.

Possible hazards that could develop when a liquid hydrogen apparatus is subjected to high levels of radiation were discussed with representatives of Argonne National Laboratory and the Cryogenic Engineering Laboratory, National Bureau of Standards.

Consultation was provided to personnel at Wright-Patterson Air Force Base regarding safety provisions in the operation of their hydrogen-driver shock tube facility in which gaseous hydrogen at pressures up to 30,000 psi is to be used. Ventilation provisions for the facility were reviewed and an analysis was prepared of credible damage that might result if a hydrogen leak were to occur.

Hydrogen Plumes

When hydrogen escapes from confinement, a plume develops within which dangerous accumulations of gas occur. Empirical studies to define the plume formed when liquid hydrogen is spilled have been carried out at the Bureau.[1/] The release of gaseous hydrogen was also considered in the present research and some preliminary results have been reported.[2/] Since these empirical studies are only valid for limited conditions, it is important to be able to predict dangerous plume conditions for two purposes. Judgments will be facilitated in setting up quantity-distance criteria and guidelines for the optimum placement of hydrogen detectors. It is the purpose, therefore, of this part of the study to apply existing theories of jets and plumes to hydrogen plumes and to establish the reliability of these theories to practical application by means of relatively small scale modeling experiments possible here.

Although the literature describes the formation and configuration of jets and plumes, the emphasis is on the meteorological and air pollution aspects of the problem. Here, the formation of clouds, the effect of wind, temperature gradients and lapse rates all assume great importance. In the hydrogen problem, a spill or a leak outdoors involves about the same factors--indoors, additional effects such as those of obstacles and walls have to be considered. The following three publications have direct bearing on the present research. The study of Morton et al.[3/] considers theories of convection dealing with maintained and instantaneous sources of buoyancy injected into fluids with a constant density gradient (decreasing density with height). Morton[4/] later expanded these studies to include forced plumes which manifest both initial momentum and buoyancy. Morton's forced plume model encompasses both the plume resulting from a spill of liquid

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1/ Zabetakis, Michael G., Aldo L. Furno and Henry E. Perlee. Hazards in Using Liquid Hydrogen in Bubble Chambers. Bureau of Mines Report of Investigations 6309 (1963), 39 pp.

2/ Explosives Research Center Hydrogen Safety Progress Report No. 4.

3/ Morton, B. R., G. Taylor and J. S. Turner. Turbulent Gravitational Convection from Maintained and Instantaneous Sources. Proceedings of the Royal Society., v. A 234 (1956), pp. 1-23.

4/ Morton, B. R. Forced Plumes. Journal of Fluid Mechanics, v. 5 (1959), pp. 151-163.

hydrogen and the jet produced by a leak from a high pressure gas container. Turner[5] has considered the shape and speed of the advancing front of a buoyant plume moving in surroundings having no variation of density with height.

The spill of liquid hydrogen develops into a buoyant plume only. Near the source of a leak from a high pressure gas container the flow of hydrogen approximates a pure jet in which momentum predominates over buoyancy; as distance from the source increases, buoyancy becomes more important and the "forced plume" model becomes pertinent. As shown by Morton, a pure jet expands more with distance downstream than a forced plume and the forced plume expands more than a pure plume. Morton, Taylor and Turner assumed that (a) the rate of entrainment of the edge of the plume is proportional to the vertical velocity on the axis of the plume, (b) the profiles of mean vertical velocity and mean buoyancy force in horizontal sections are the same at all heights, and (c) the largest local variations of density in the field of motion are small compared with the density of the ambient fluid at the level of the source. The authors used both square and Gaussian error curves to represent the profiles of fluid velocity and buoyancy force in horizontal sections of the plume. They characterized each such section by a horizontal length scale b, proportional to the plume radius at the height being considered. They also state that these assumptions are probably satisfied in the lower regions of a plume, but not in the upper regions. The latter regions may be of some importance in the hydrogen plume work. Another factor not considered by these authors is molecular diffusion, which may be important in the hydrogen plume case.[6] Morton, Taylor and Turner also assumed that the velocity and buoyancy profiles are normally distributed about

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5/ Turner, J. S. The Starting Plume in Neutral Surroundings. Journal of Fluid Mechanics, v. 13 (1962), pp. 356-368.

6/ A thick layer of pure hydrogen will diffuse into an air layer below it so that at a distance of 10 cm from the original boundary the concentration of hydrogen will be 4 percent (the lower flammability limit) within about 18 seconds. Further dilution of the plume will depend strongly on molecular diffusion. While the plume density increases with height because of entrainment, the ambient air density decreases with height. A hydrogen plume at the point of the lower flammability limit will have a specific gravity of about 0.964 with respect to air. This corresponds to the specific gravity of air itself at a temperature of about 10° C above that of the plume. Such a temperature differential may exist under a high ceiling. Thus, a plume which has been diluted to the lower flammable limit of hydrogen will not, as a result of buoyancy, penetrate a layer of air whose temperature is 10° C or more above that of the plume.

the axis of symmetry. Under this assumption, the horizontal scale b is the distance from the axis of symmetry to points at which the buoyancy and velocity amplitudes are 1/e of those on the axis. This length is proportional to the radius to be observed in plume experiments. An entrainment constant α is selected so that the rate of entrainment of volume at any height is $2\pi b\alpha u(x)$,[7] where α is the ratio of the horizontal velocity at the edge of the plume to the vertical axial velocity at that height, and u(x) is the axial vertical velocity depending only on the height x. The authors reduced the resulting equations to non-dimensional form and tabulated numerical solutions. Two heights were found, that at which the buoyancy first vanishes and that at which vertical velocity first vanishes. The bulk of the fluid in the plume will rise almost to the greater of these heights and then in spreading horizontally will fall back again somewhat.

The foregoing brief discussion of plume theory contains much that is applicable to the problems involved with the turbulent diffusion of hydrogen released into either the open atmosphere or into the confines of a reasonably large room. For optimum location of sensors, one of the requirements will be an ability to predict hydrogen concentrations based on known parameters.

As an example of such prediction, new numerical solutions to the non-dimensional equation for a steady plume in a constant density environment were calculated. These solutions, based on the work of Morton, Taylor and Turner are presented in figure 1. It may be seen that the radius of the plume varies linearly with height while the buoyancy and the vertical velocity first decrease rapidly and then slowly with height. Assuming that the assumptions of Morton, Taylor and Turner are correct, these curves may be used to predict the buoyancy, radius and vertical axial velocity under given experimental conditions with only a few actual measurements. For example, if the buoyancy is determined at two adjacent points along the axis--and this can be done by measuring hydrogen concentrations and calculating the resulting buoyancy--a point on the curve of total buoyancy versus height can be found where the slope will equal that calculated from the experimental data. This will relate the non-dimensional curve to the given experimental conditions and further points may be found directly from the curve. In order to test this concept, data have been used from figures 10 and 11 of Report No. 4. These are the only suitable data presently available for hydrogen. The experimental data depicted by these figures involved measurement of hydrogen in air at various levels above a 10 ft^3/min leak. Figure 11 indicates that in about 10 seconds, the hydrogen concentration reached 0.8 volume percent 10.5 feet above the leak and 0.65 volume percent at the 14 ft level. Figure 10 shows that the concentration reached somewhat below 1 percent at the 7 foot level in 4.5 seconds. From the data of

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7/ Both α and u(x) are empirical parameters. By using certain approximations, values of u(x) can be predicted.

figure 11 of Report No. 4 and the non-dimensional curve of buoyancy versus height (fig. 1) calculated from the new numerical solution to the non-dimensional equation for a steady plume in a constant density environment, it is possible to calculate the concentration at the 7 foot level which would be reached in the same time (10 seconds). This calculation indicates that a hydrogen concentration of 1.8 percent will exist at 7 feet in 10 seconds. The actual value of somewhat less than 1 percent in 4.5 seconds which was found experimentally is not in disagreement with this calculated value. Further confirming data are necessary to show the validity of this approach for determining theoretically the concentrations, velocities and spread to be expected when the surrounding air is at constant density or when the density of air decreases uniformly with height.

Experimental work is being planned to verify the validity of these concepts for predicting the concentrations to be expected upon release of hydrogen. A large room, whose volume is about 18,000 cubic feet, is being modified so that it will be safe for the release of hydrogen. Ventilation of the room is being modified and a light steel barricade is being built to protect personnel in the event of an ignition. While this facility is being constructed, preliminary studies are being conducted with helium.

One of the problems of this study of hydrogen plumes is the detection and measurement of small concentrations of hydrogen or helium. Previously this has been done by grab sampling methods. It would be better to develop means of continuously monitoring the concentration. Rosensweig et al.[8/] have developed an optical method for measurement of concentration fluctuations in a jet of smoky air discharged into ambient air. The important consideration in the present study is whether the injected smoke particles can follow the flow of hydrogen. The criterion adopted by these authors was the ratio of particle maximum velocity to fluid maximum velocity for a steady sinusoidal fluctuation. They calculated that this ratio was 0.997 at 5,000 cps for the one-micron diameter smoke that they used. Using the density and viscosity of hydrogen instead of corresponding values for air, calculations show that this ratio will be about the same for hydrogen as for air. By this criterion, therefore, it will be feasible to follow concentrations of hydrogen in the plume. A fiber optic probe and miniature photocell are being used in exploratory work with helium to adapt this method to our plume studies.

During the coming quarter, further work on the plume studies will be conducted with helium, pending the completion of the hydrogen facility.

8/ Rosensweig, Ronald E., Hoyt C. Hottel, and Glenn C. Williams. Smoke Scattered Light Measurement of Turbulent Concentration Fluctuations. Chemical and Engineering Sciences, v. 15 (1961), pp. 111-129.

Plans on this phase of the work include:

(1) Further development of the fiber optic probe to determine its feasibility as a precision method of determining concentrations.

(2) Measurement of concentration, velocity and plume spread from a jet, and correlation of these measurements by means of the previously discussed model.

(3) Following the work on a simple plume model, it will be desirable to consider the effect of such variables as the presence of baffles or other obstacles to the free flow of plumes.

Hydrogen Detectors

Four hydrogen gas detector units were evaluated. Two of the units are portable, one of these sampled the air by diffusion and convection while the other sampled by aspiration. Of the two non-portable units, one sampled by diffusion while the other sampled by aspiration. The detectors were subjected to a series of tests which were designed to evaluate them under likely operation conditions.

Evaluating Hydrogen Detectors

Unit HD-9

This is a portable unit utilizing a sensing head connected to the analyzer system by a coiled cable several feet long. The surrounding atmosphere is sampled by diffusion and convection through a porous cylindrical element which acts as a flame arrester. Two heated filaments within the porous element are balanced in resistance when the gas sample is air. However, since one of the elements is coated with a catalyst, the presence of hydrogen causes a rise in its temperature which results in an unbalance in the circuit, resulting in a read out proportional to the amount of hydrogen in the sample.

As may be seen from figure 2, this detector gave consistently low readings on the 0-5 percent scale, which varied between 10 percent and 26 percent below the actual composition as determined by gas chromatographic analysis. On the 0-1 percent scale the instument was more erratic in that both high and low readings were obtained. It was found that battery failure in the instrument occurred in about eight hours of intermittent use. Characteristically, the readings were lower as the batteries declined. When new batteries were installed, the instrument reading did not recover to its previous value. However, when the instrument was exposed to enough hydrogen to cause full scale deflection, and subsequently retested, the readings were found to be higher than before, but still considerably lower than they should have been on the basis of the actual hydrogen concentration. It is concluded,

therefore, that this instrument will satisfactorily indicate the presence or absence of hydrogen; however, it should not be relied on to give accurate readings within its nominal capability unless it is calibrated before each use. Since the condition of the batteries is critical, comparisons within a series of calibrations will indicate whether the batteries have to be replaced.

Unit HD-10

In this portable instrument, the sensing element is an integral part of the complete assembly and the gas samples are drawn through a probe by aspiration.

Accuracy of this instrument is indicated by the data in figure 3, which shows that at low concentrations of hydrogen, the instrument reading agreed with the actual hydrogen concentration as determined by gas chromatography. As the concentration approached 100 percent of the lower explosive limit, the readings were low by about 13 percent. The instrument was checked for reproducibility of meter readings at six different hydrogen concentration levels. The meter reading was least reproducible near the 4.0 percent hydrogen level, where the second reading was 4.4 percent lower than the original. These same concentrations were again checked one, two and five days later. Readings were generally lower after the first day, at concentrations less than 1 percent. Readings made with 1 percent hydrogen varied from a difference of 3.7 percent when checked the same day to 16.7 percent on the fifth day. However, meter readings at 1.6 percent, 2.1 percent and 2.9 percent hydrogen were identical on the second, third and fifth day.

Unit HD-11

This is a console unit with a diffusion head, similar in operating principle to Unit HD-9. This unit is designed to operate at a number of stations utilizing a number of modules with one sensing head connected to each module. The units under test consisted of three sensing heads, three modules and three sensing elements. Measurement of the output of the instrument was made on a Ballantine A.C. Vacuum Tube Voltmeter.

It was found that the sensing heads and modules were interchangeable, provided appropriate adjustments were made. The three sensing elements designated as Nos. 10015, 777 and 10120 were quite different. No. 777 produced an output which was on the average only about 60 percent as high as that produced by No. 10015. Readings of the latter sensing element were quite consistent within themselves; readings could be equalized by suitable adjustment of the amplifier gain. No. 10120, on the other hand, turned out to be inoperative. Further experiments were conducted with element No. 10015, with its filament at 14 volts.

The following observations were made on this unit:

(1) The voltage output in response to various known concentrations of hydrogen-air was quite reproducible. A series of readings were made on the high scale of the instrument where full-scale reading equals 100 percent LEL. There was a single deviation among three trials of 8.6 percent when measuring a concentration of the order of 0.5 percent. In the concentration range of 1.0 percent to 4.0 percent hydrogen, the largest deviation from the average was 4.0 percent (see fig. 4). On the low scale, where full scale equals 25 percent LEL, the meter responds to aspirated air alone so that there was a tendency to read high when hydrogen was introduced. In the presence of 0.10 percent hydrogen, this instrument indicated 75 percent more hydrogen than was actually present. When 0.80 percent hydrogen was present, the indication was 11 percent high. These figures, indicating a slight zero shift upwards on the low scale, should caution the user that calibration of this instrument is desirable before use if accuracy is desired.

(2) When the hydrogen-air mixture was bubbled through water to produce a highly humid mixture, the voltage output was approximately 10 percent lower than corresponding voltages for dry samples (see fig. 5).

(3) Exposure of the detector element to moist air has a detrimental effect on the reliability of the instrument. The voltage output was lowered by two-thirds of the original value for a given concentration of H_2-air when the detector head remained inactive in static air of high humidity over a weekend. This effect is reversible by operating the head at its maximum voltage output for about 1/2 hour. The heat generated is apparently sufficient to dry out the element and thus reactivate it.

(4) The detector head is position sensitive, the voltage output readings being about 8 percent higher with the detector in the horizontal position than when it was used in the vertical position (see fig. 6).

(5) When the instrument was subjected to low temperature (-21° C) the output voltage dropped to values from 18 percent to 50 percent below the corresponding output at room temperature. After exposure to cold, the instrument would perform erratically, but after about an hour at room temperature the output was again normal (see fig. 7).

(6) At a somewhat elevated temperature (45° C), the instrument responds normally to hydrogen concentrations up to about 1.0 percent at which it reaches a maximum value which will not be exceeded irrespective of increased hydrogen concentration (see fig. 8).

(7) Both response and recovery times are dependent on hydrogen concentration. Response time was measured by covering the element with sheet rubber (part of a rubber glove) and measuring the time from the slitting of the protective cover to 2/3 normal reading. Recovery time was determined by removing the detector element from the given concentration of H_2-air and measuring the time for the instrument to return to zero. Results were as follows.

Table 1. - Unit HD-11 Response and Recovery Times

Hydrogen concentration, volume percent	Response time, seconds	Recovery time, seconds
50	--	10.1
15	1.4	--
4	2.2	6.4
3	2.1	5.4
2	2.1	4.4
1	3.4	2.9

(8) The effect of inert gases was examined too. The voltage output of Unit HD-11 was determined when the sensing element was exposed to mixtures of hydrogen with nitrogen, helium and carbon dioxide. Curves of the voltage output as a function of hydrogen concentration are given in figure 9. It is noteworthy that for 100 percent helium, the output was 1.30 volts, which is the same as that for 1.5 percent hydrogen in air.

(9) The effect of high concentrations of hydrogen in air is indicated in figure 10. The voltage output of Unit HD-11 rises to a maximum of 3.6 volts at 50 percent hydrogen in air and then drops to 1.6 volts at 100 percent. This latter value corresponds to that for 2 percent hydrogen concentration on the high scale.

Unit HD-12

This is a console type instrument that samples by aspiration. The sensing element, containing catalytic filaments is remote from the rest of the assembly and is enclosed in an explosion-proof container designed for Class 1, Group B atmospheres. Samples of air are drawn through this unit which is fitted with flame arresters both at the inlet and outlet ends. The amplifier and control unit is to be located in a safe area and is designed to indicate percent LEL of hydrogen. Suitable relays are incorporated to set alarms and indicate malfunctions.

(1) Voltage across the filaments should be from 1.18 to 1.20 volts for optimum performance of this instrument. As the filaments get older, the voltage has to be raised in order that the instrument

continue operating. However, this leads to even more rapid deterioration of filaments. According to the manufacturer, filaments in this instrument should last about six months to two years under normal operating conditions.

(2) When the instrument was received it was found that the filament voltage had been raised to an excessive level. Some tests were made under this condition, but the filaments soon deteriorated and new ones were obtained from the manufacturer.

(3) Since the instrument is designed to operate with a set flow rate of 14 c.f.h., it was decided to determine how a variation in flow rate would affect the readings. To this end, a series of runs was made with flows of 7 c.f.h., 14 c.f.h. and 28 c.f.h. with the following results.

Table 2. - Unit HD-12. Effect of Sample Flow Rates.

Hydrogen concentration, volume percent	Meter reading, percent LEL		
	7 c.f.h	14 c.f.h.	28 c.f.h.
1	18	24	30
2	50	50	60
3	68	70	72
4	84	100	96

Figure 11 shows these results graphically. It is apparent that the flow should be kept reasonably close to the design value of 14 c.f.h., since the higher flow generally made the instrument read high.

(4) The effect of temperature is indicated in figure 12. Both high and low gas temperatures affected the response of this unit.

(5) The effect of humidity is shown in figure 13. High humidity lowers the response of the instrument by about 20 percent. It would seem that precautions to dry the air flowing through the unit are warranted.

(6) The effect of high concentrations of hydrogen-air was determined. The instrument was subjected to progressively higher concentrations of H_2-air, up to 100 percent hydrogen. The reading remained over 100 percent LEL until the hydrogen content reached 30-35 percent, when response became very erratic, with the reading fluctuating between 0 and 100. This erratic action continued until the 90 percent hydrogen level was reached. At this concentration a steady reading of 92 percent LEL was obtained. Further increase of concentration to 100 percent H_2 sent the reading up to 100 and then down to 0 where it remained. After the instrument was subjected to high hydrogen concentrations, the zero shifted so that even after adjustment a mixture of 4 percent hydrogen in air gave a reading of 84 percent LEL.

At this point, it was noted that when 100 percent hydrogen was displaced from the instrument by passing dry air through it, the flame arrester in the exhaust port of the instrument failed in its function. A bright flame was emitted down the exhaust tubing, some parts of which were translucent rubber. The flashback of flame was photographed. Figure 14 shows first the configuration of the tubing in conjunction with the sampling unit, and second, the bright flame as it travels down this tubing. On exchanging the inlet and outlet flame arresters, the arrester on the outlet side failed too. Examination of the flame arresters did not indicate any obvious breaks in either flame arrester.

Hydrogen Explosion Hazards (J. N. Murphy and E. L. Litchfield)

Combustion of gradient mixtures of hydrogen and oxygen was investigated in the 24 × 24 × 2-1/4 inch chamber described in the last quarterly report (Hydrogen Safety Progress Report No. 5, January 1 to March 31, 1965). The chamber was designed to observe the effect of adding a second dimension to the essentially one-dimensional configuration presented by the combustion tubes used in our initial investigations of combustion behavior in gradient hydrogen-oxygen mixtures. The results paralleled those obtained with the tubes.

With the draw-plate inserted, the lower half of the chamber was filled with oxygen and the upper half with hydrogen. The plate was then withdrawn and mixing by diffusion was allowed to proceed for 300 seconds at which time ignition was effected by discharge of an electric spark at the plane of composition desired. Composition-distance values after 300 seconds of diffusive mixing are indicated in figure 3 of the last quarterly report.

When ignition took place in the chamber at the composition plane of 32 percent hydrogen: 68 percent oxygen, flame trajectory records indicated that flame moved relatively slowly for about 10 msec after which maximum velocities of about 6,200 ft/sec (1.9 mm/μsec) and 2,300 ft/sec (0.7 mm/μsec) were reached in the hydrogen-rich and hydrogen-lean portions of the chamber, respectively. For ignition of a similar gradient mixture in a tube, flame had developed slowly for about 8 msec after which maxima of approximately 6,000 and 2,300 ft/sec, respectively, were observed.

When ignition took place in the chamber at the composition plane of 70 percent hydrogen: 30 percent oxygen, an essentially constant velocity of about 2,900 ft/sec (0.9 mm/μsec) was reached in the upper, hydrogen-rich portion. For a similar run in a combustion tube, the same nearly constant velocity of about 2,900 ft/sec was reached in the hydrogen-rich end. Ignitions in the chamber at points in planes of other composition produced results essentially the same as those observed with the combustion tube, as well.

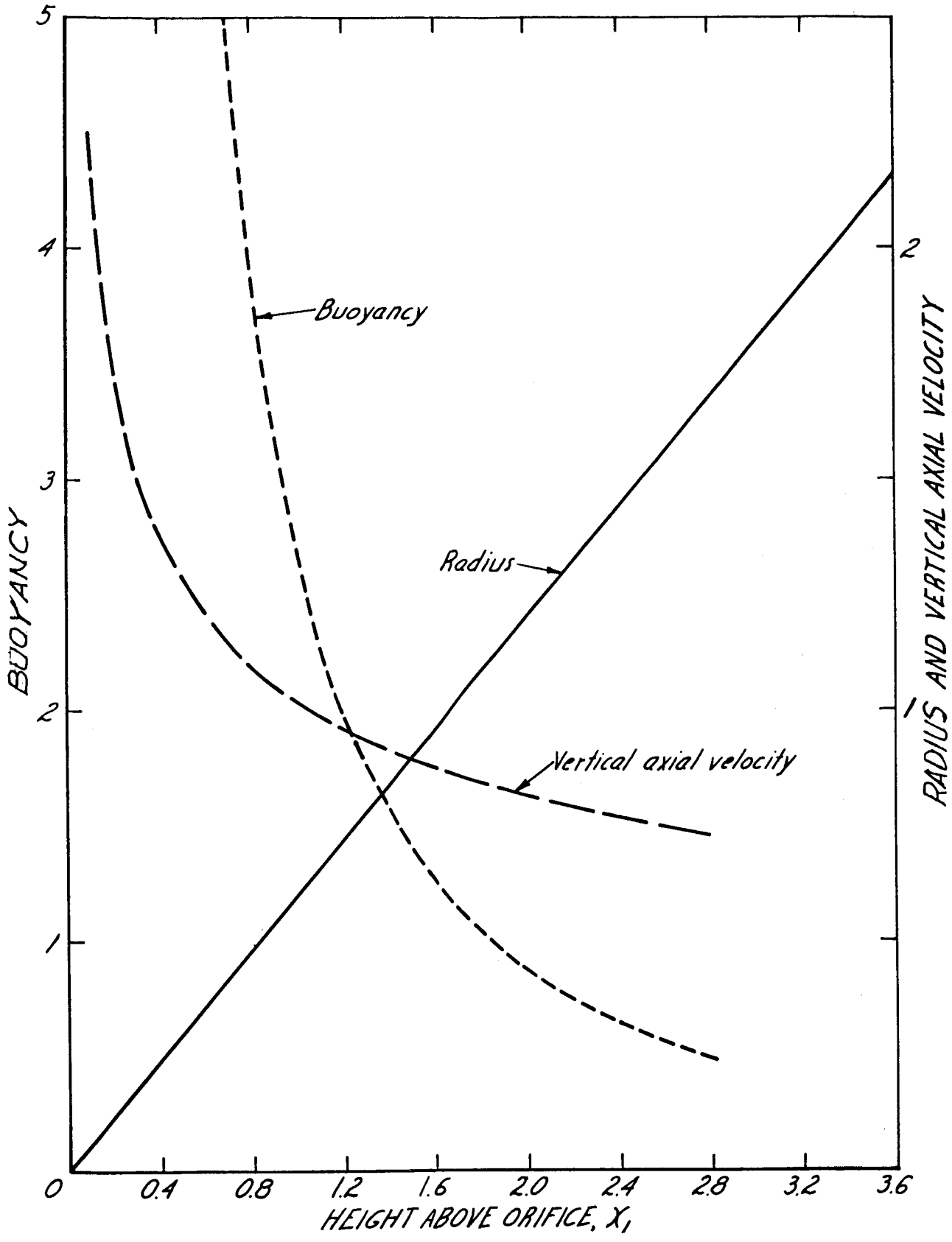

Figure 1. - Solution to the Non-Dimensional Equation (Reference 3) for a Plume in a Constant Density Environment.

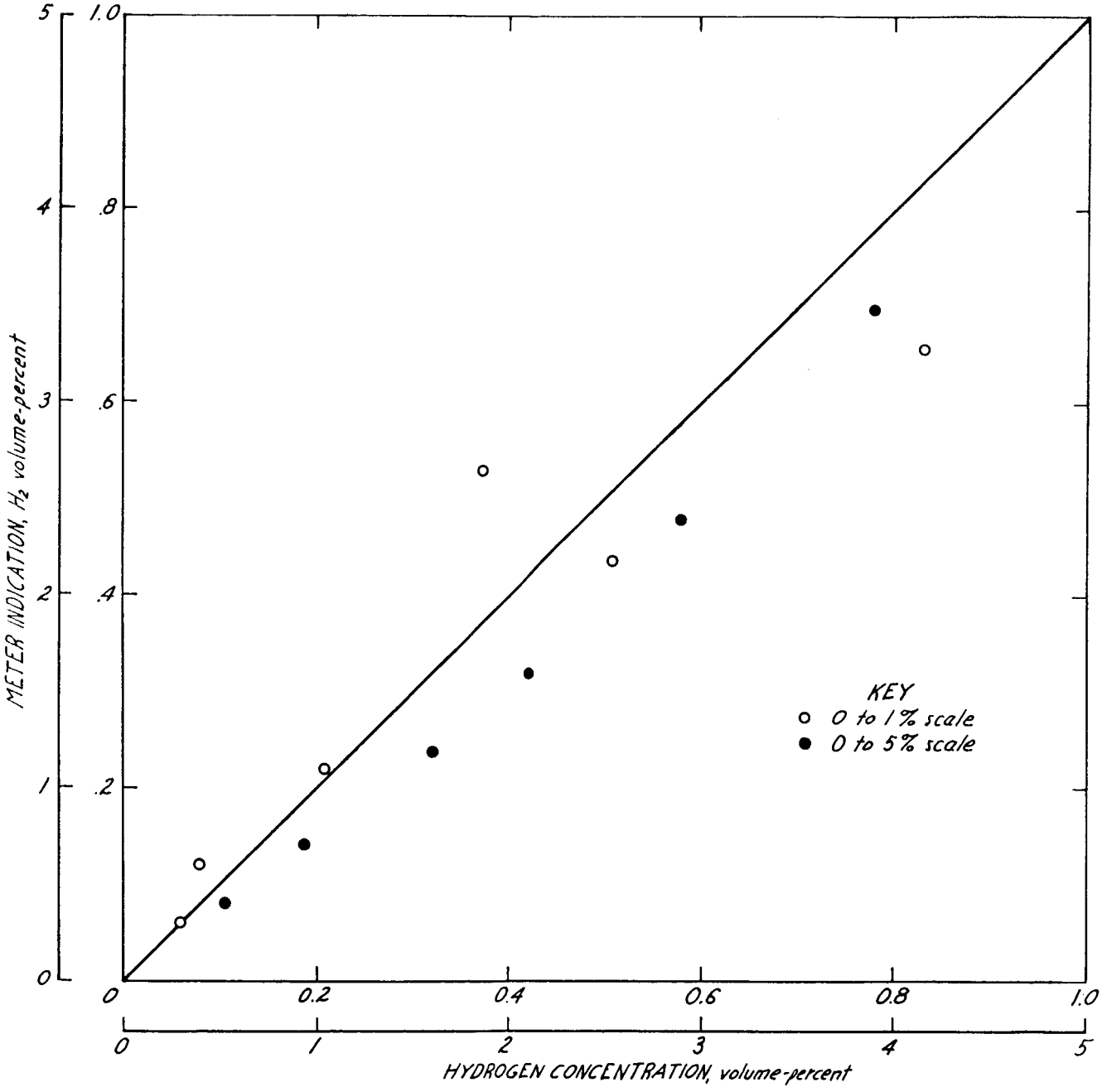

Figure 2. - Response of Portable Detector Unit HD-9 to Hydrogen-Air Mixtures.

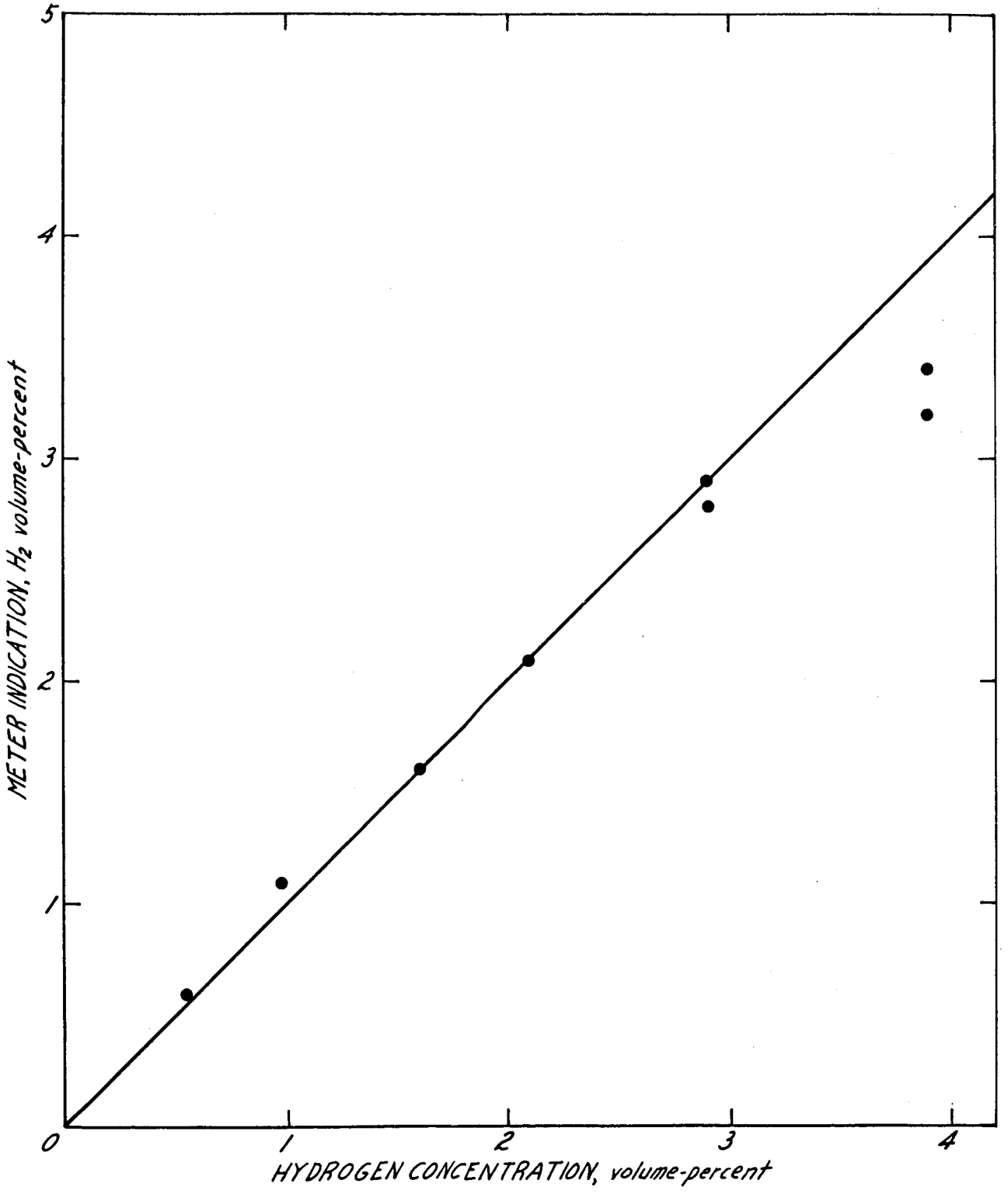

Figure 3. - Response of Portable Detector Unit HD-10 to Hydrogen-Air Mixtures.

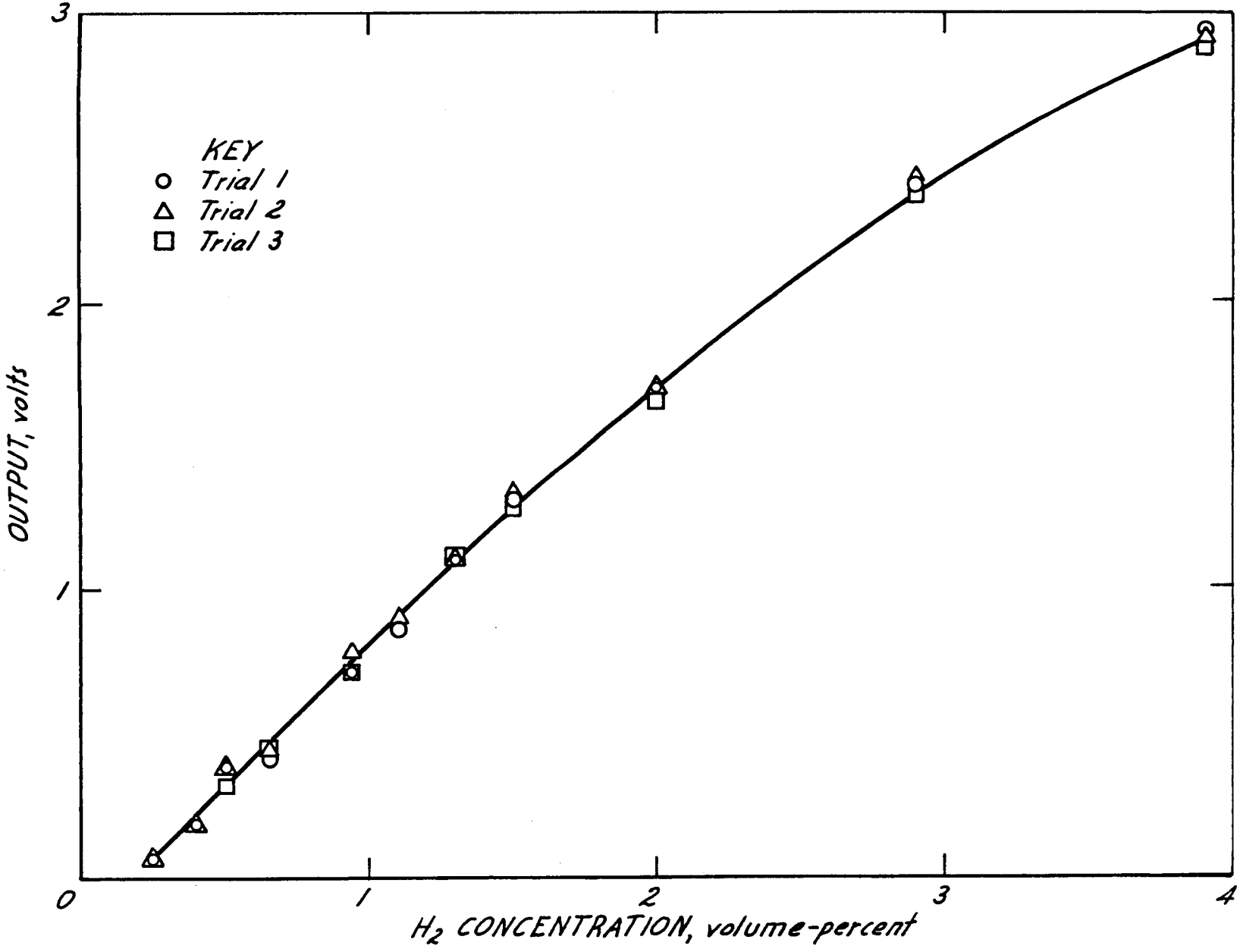

Figure 4. - Response of Detector Unit HD-11 to Hydrogen-Air Mixtures.

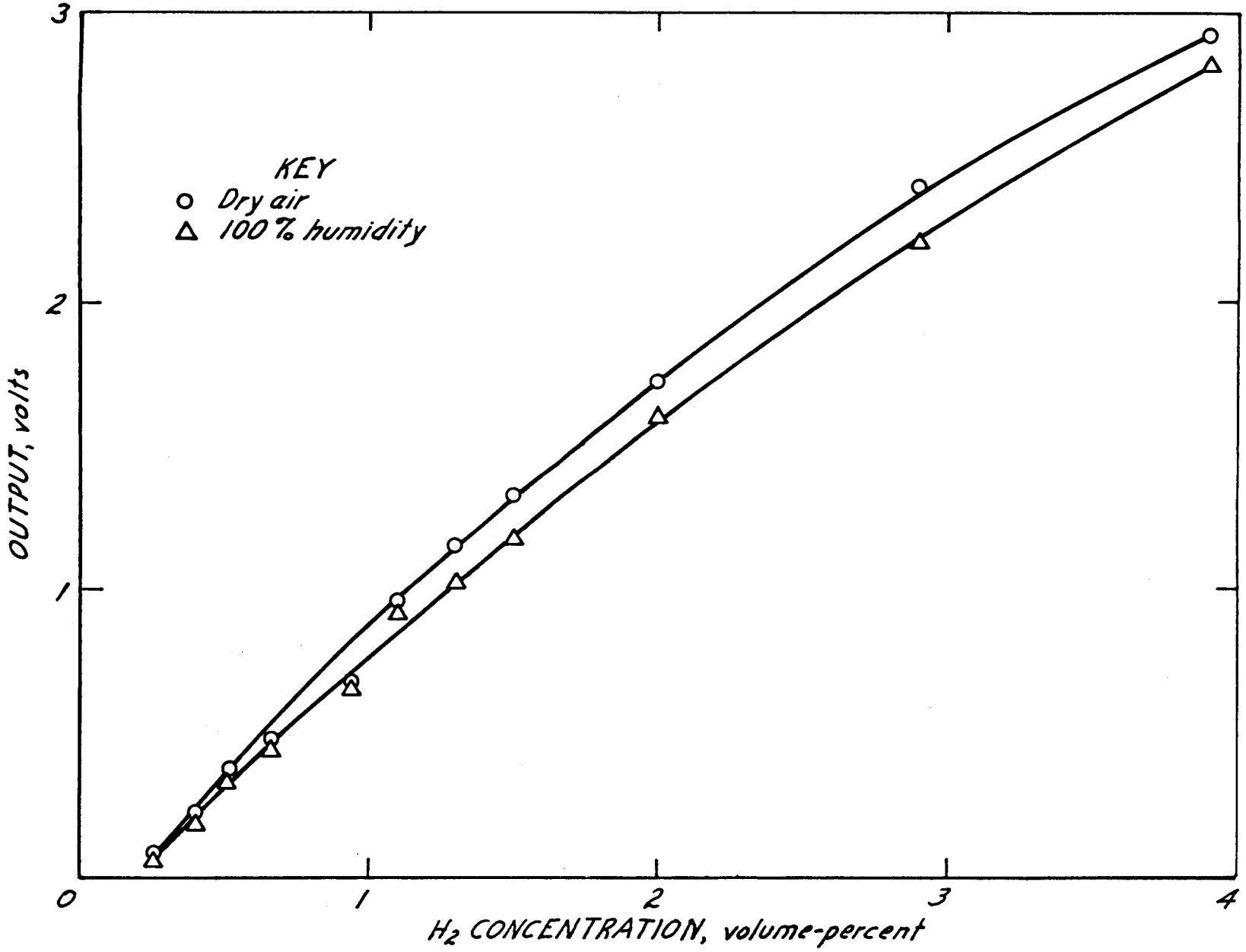

Figure 5. - Effect of Humidity on Response of Unit HD-11.

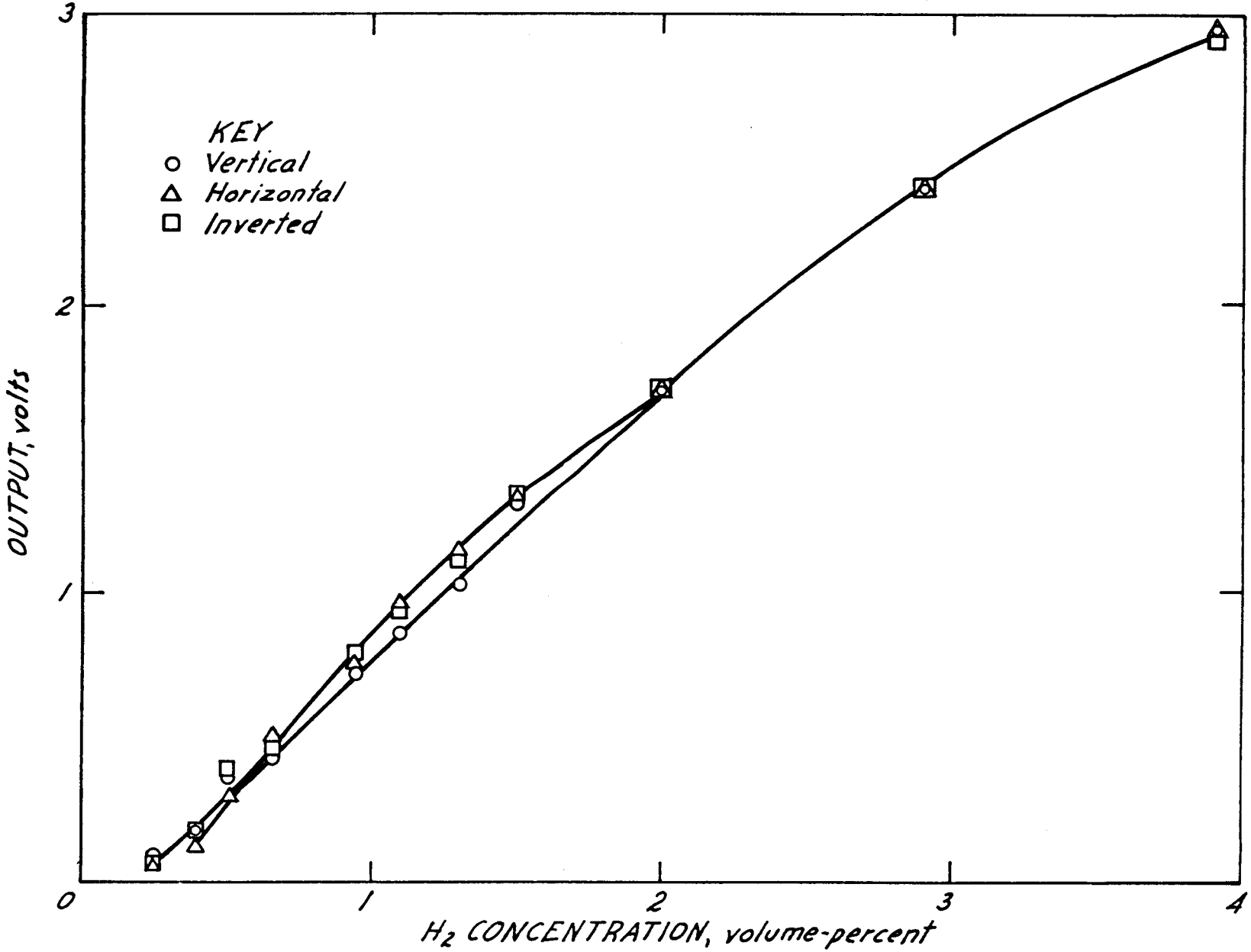

Figure 6. - Effect of Orientation on Response of Unit HD-11.

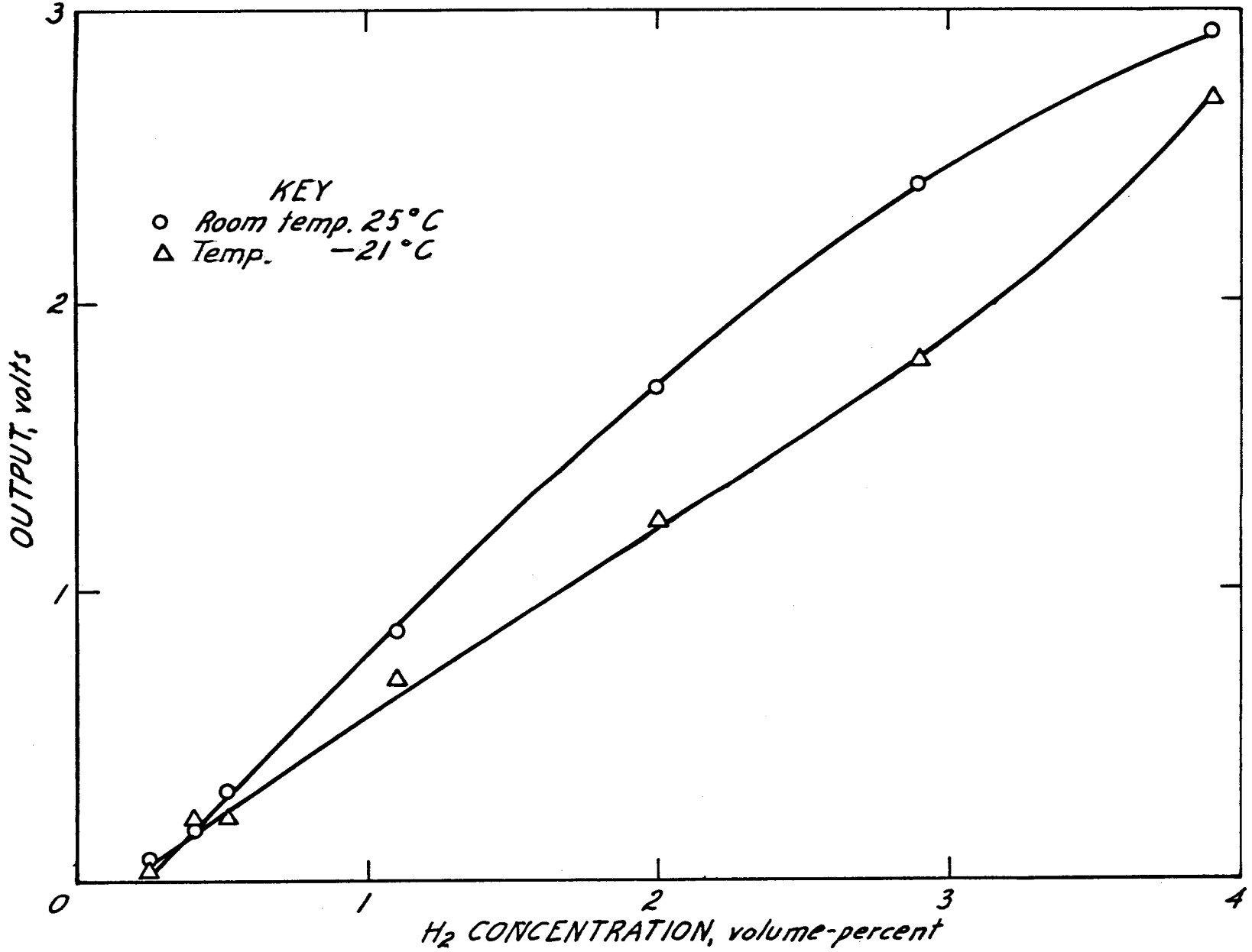

Figure 7. - Effect of Lowered Temperature on Response of Unit HD-11.

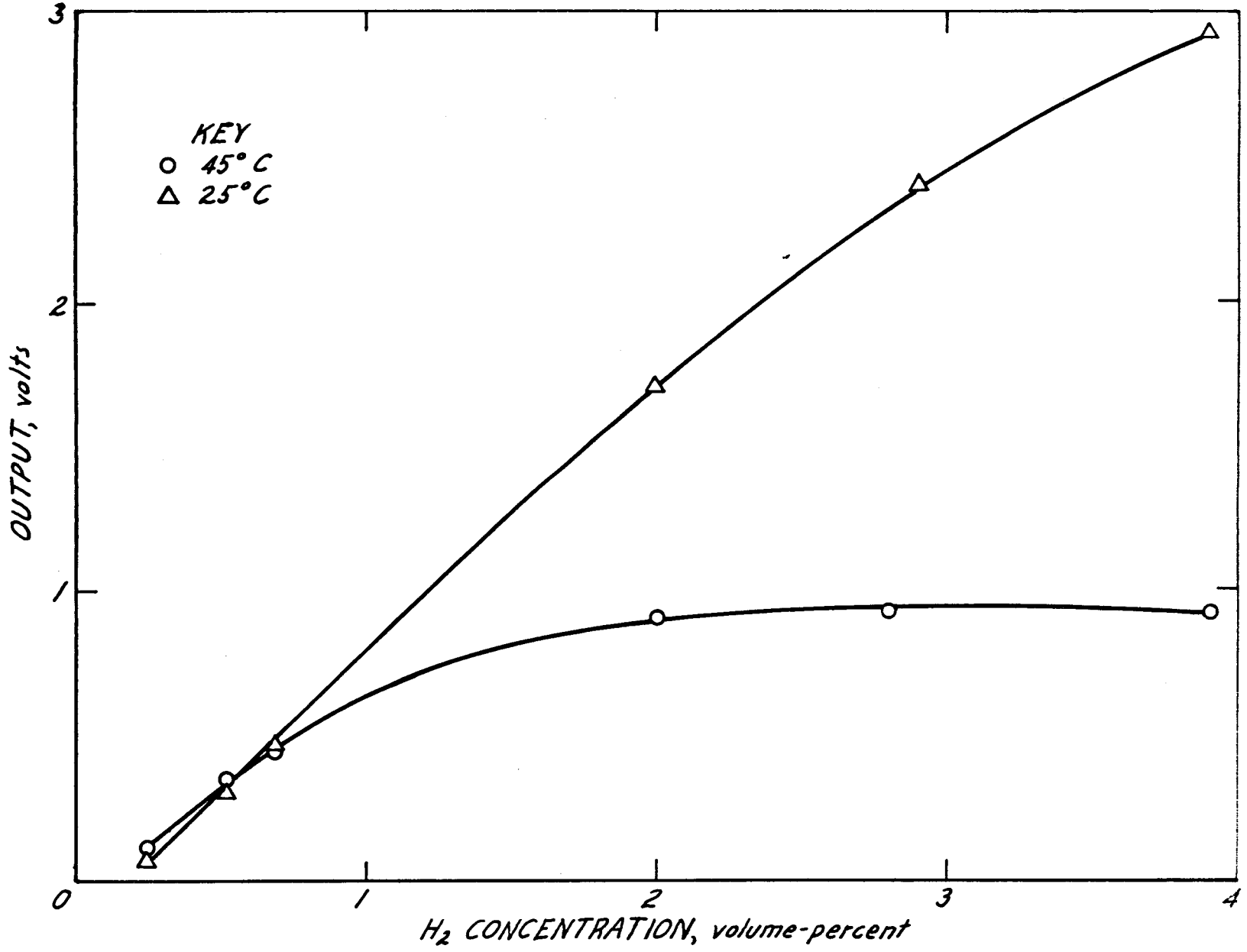

Figure 8. - Effect of Elevated Temperature on Response of Unit HD-11.

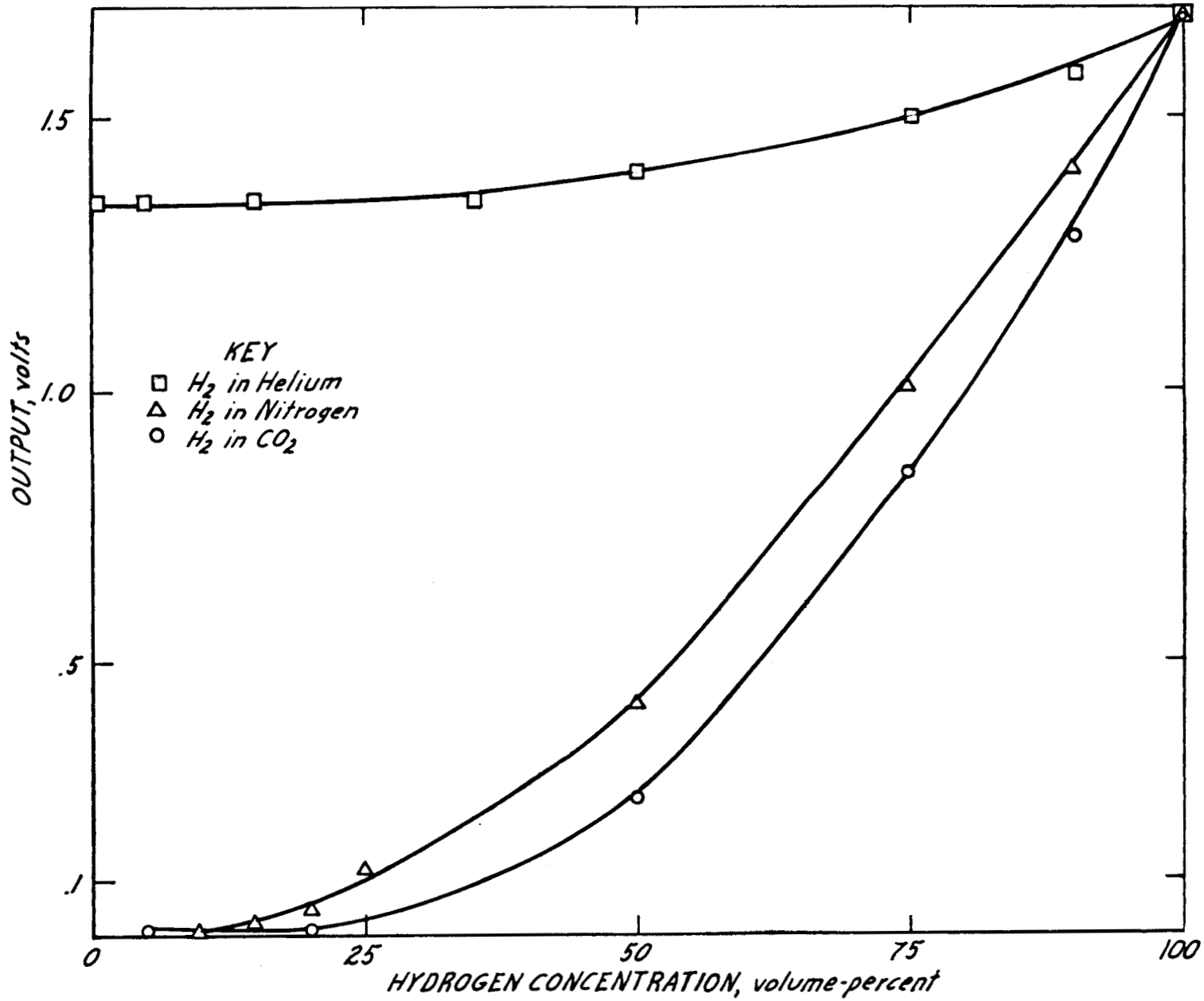

Figure 9. - Response of Unit HD-11 to Hydrogen-Inert Gas Mixtures.

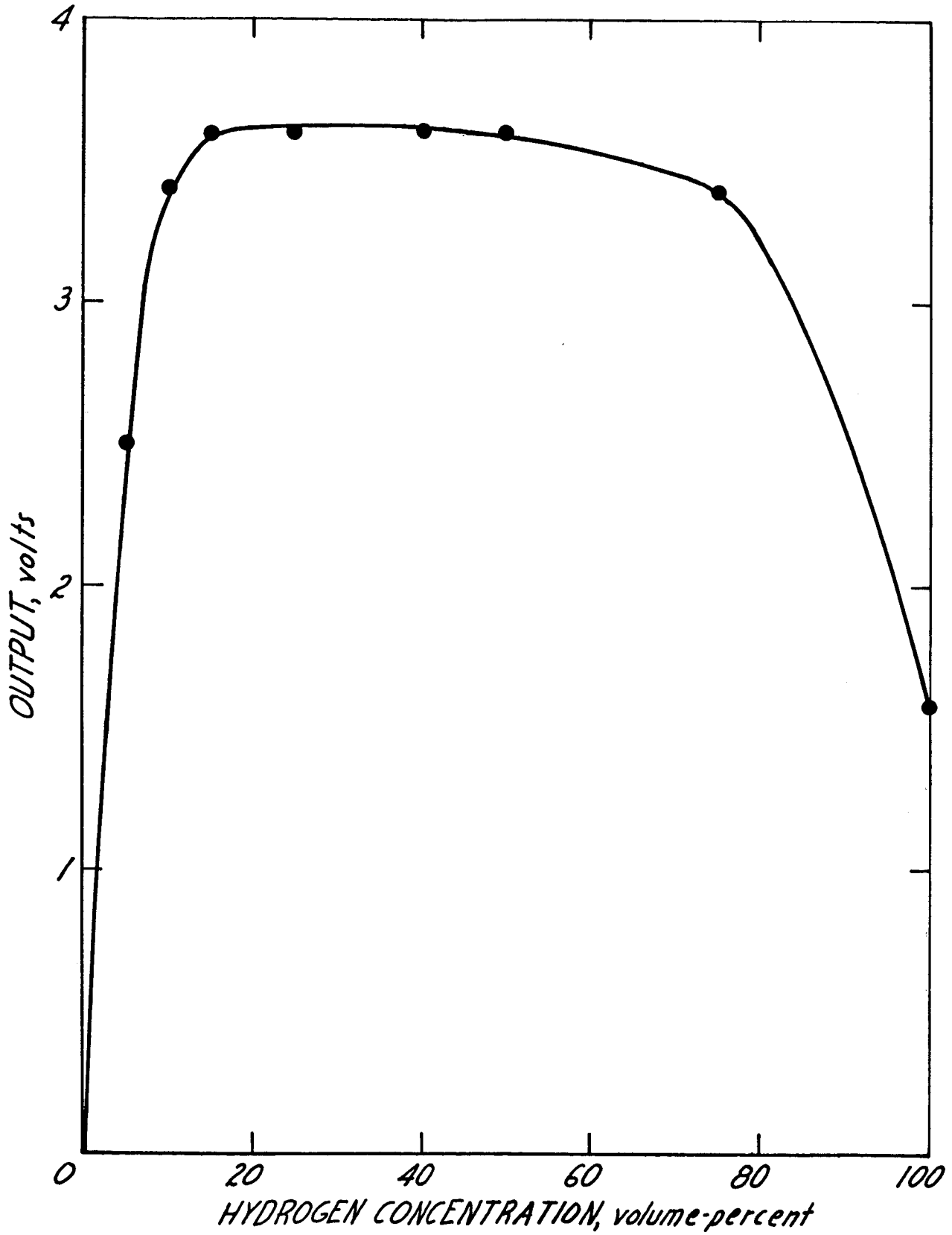

Figure 10. - Response of Unit HD-11 to High Concentrations of Hydrogen in Air.

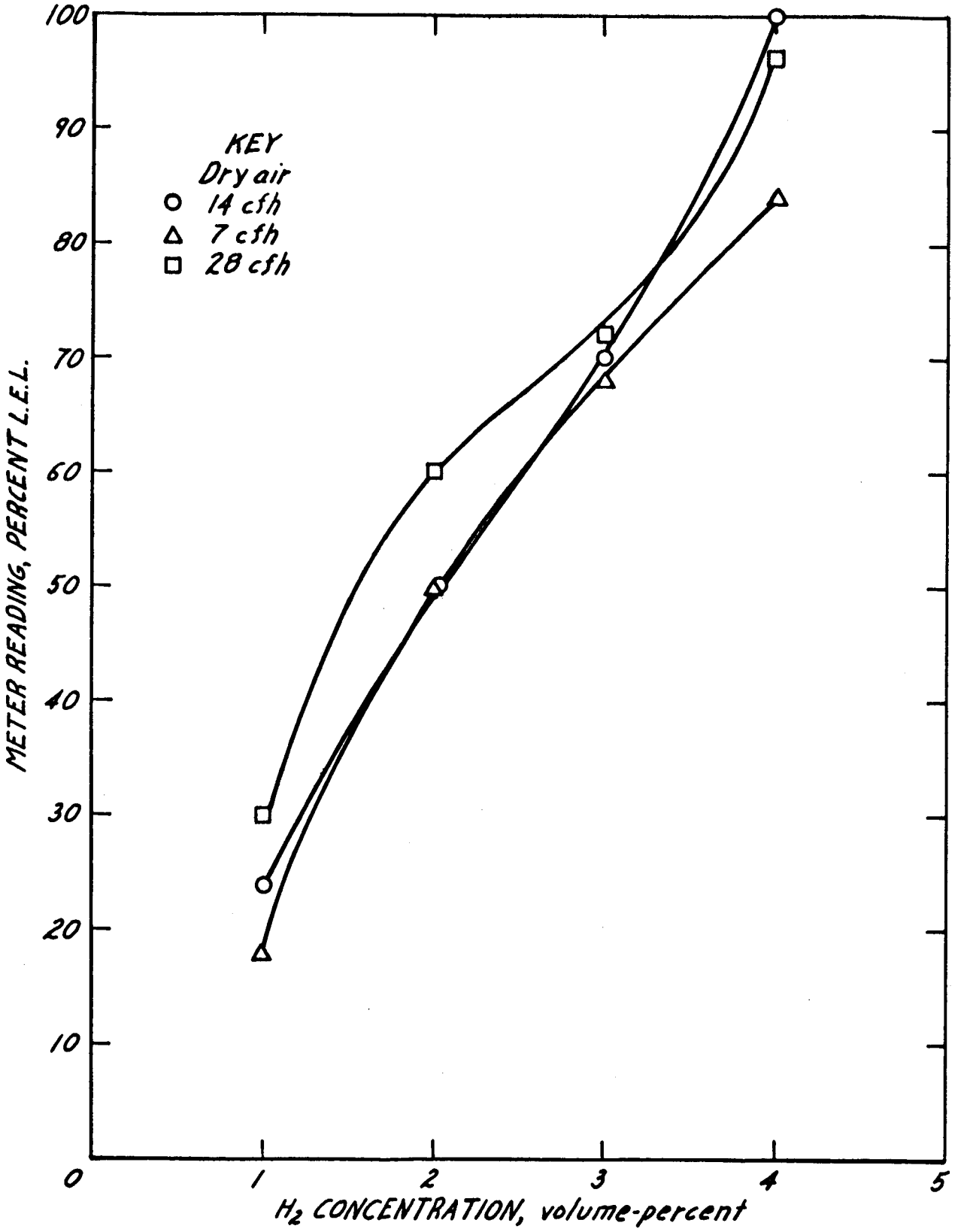

Figure 11. - Effect of Variation in Flow Rate on Response of Unit HD-12.

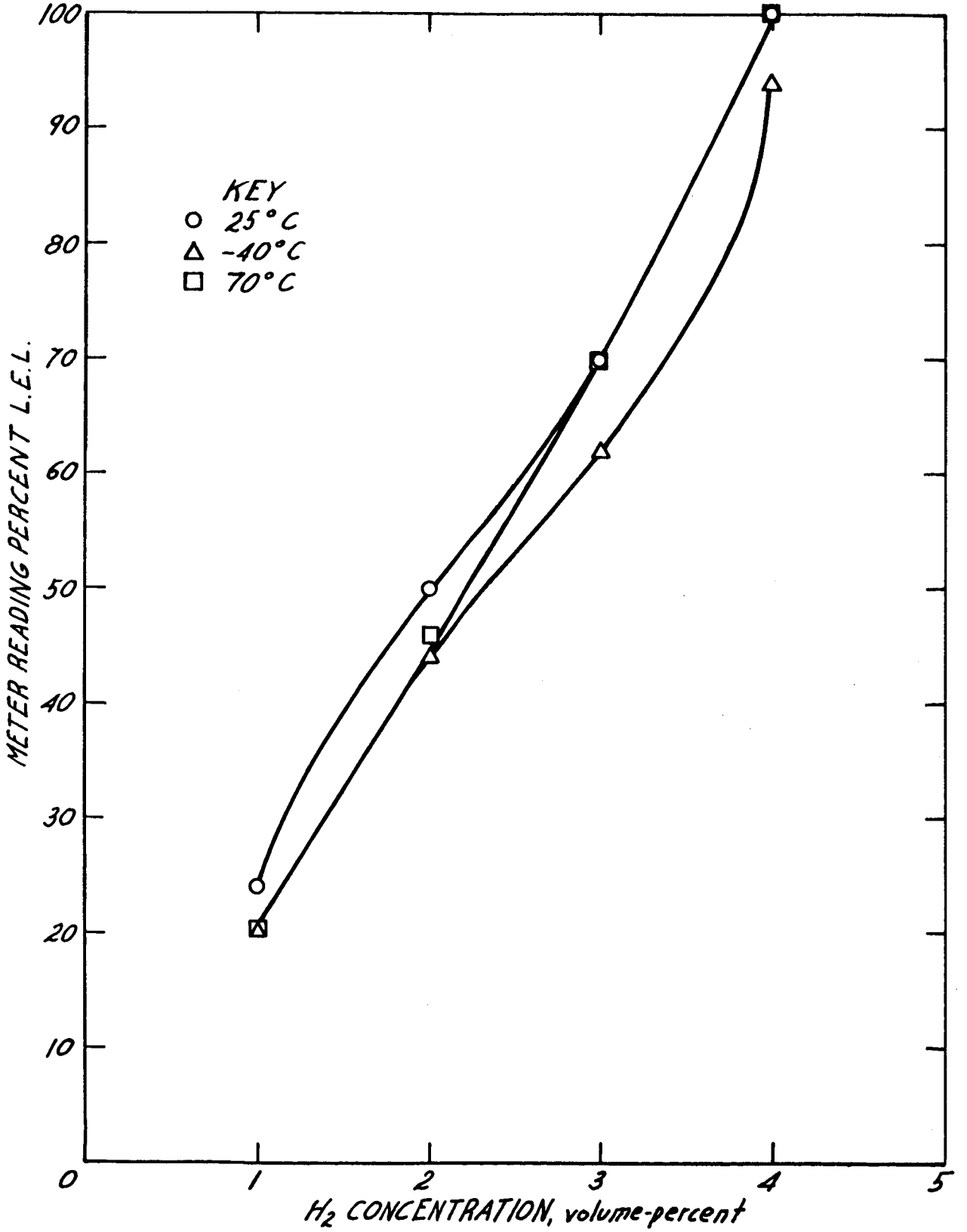

Figure 12. - Effect of Temperature on Response of Unit HD-12.

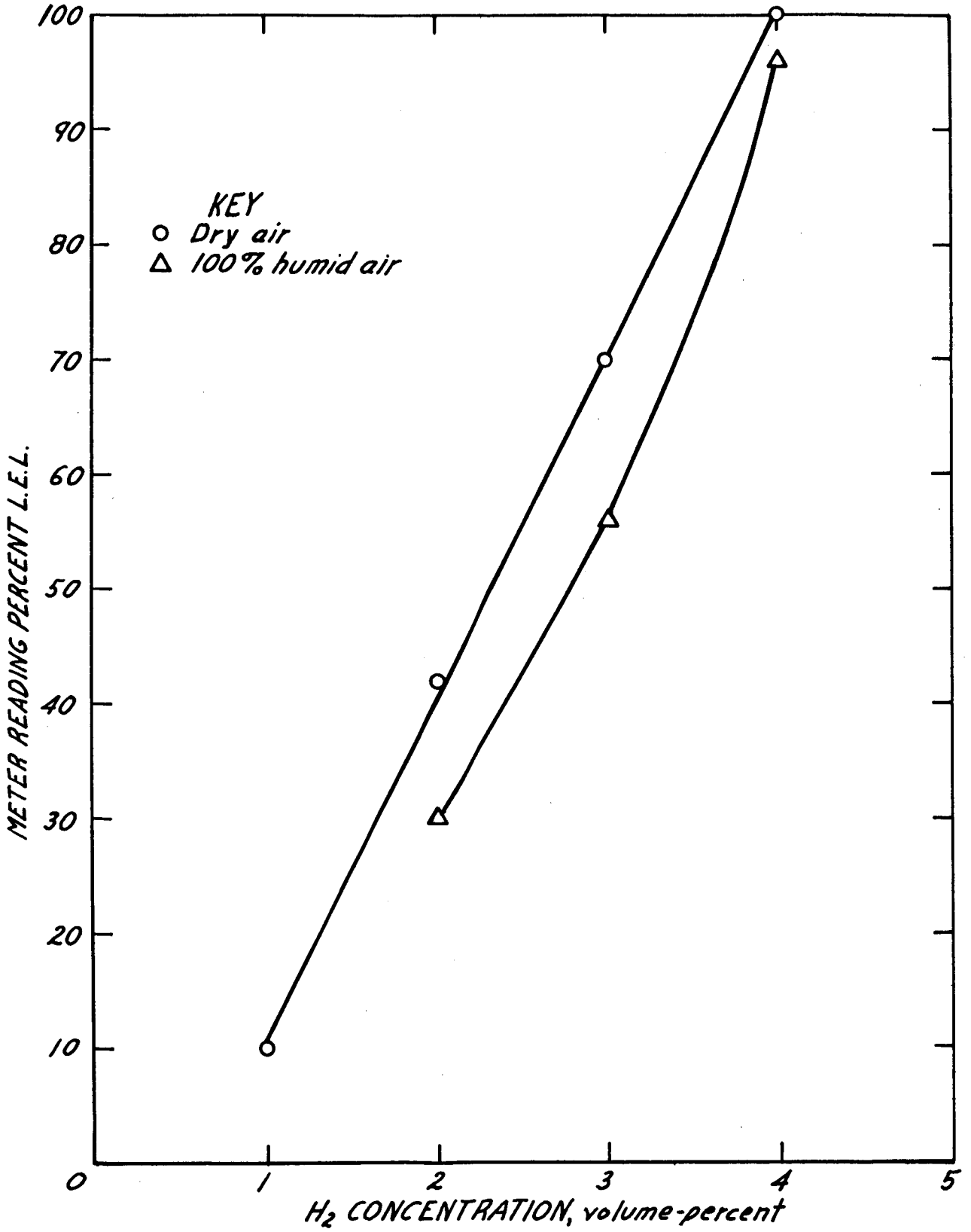

Figure 13. - Effect of Humidity on Response of Unit HD-12.

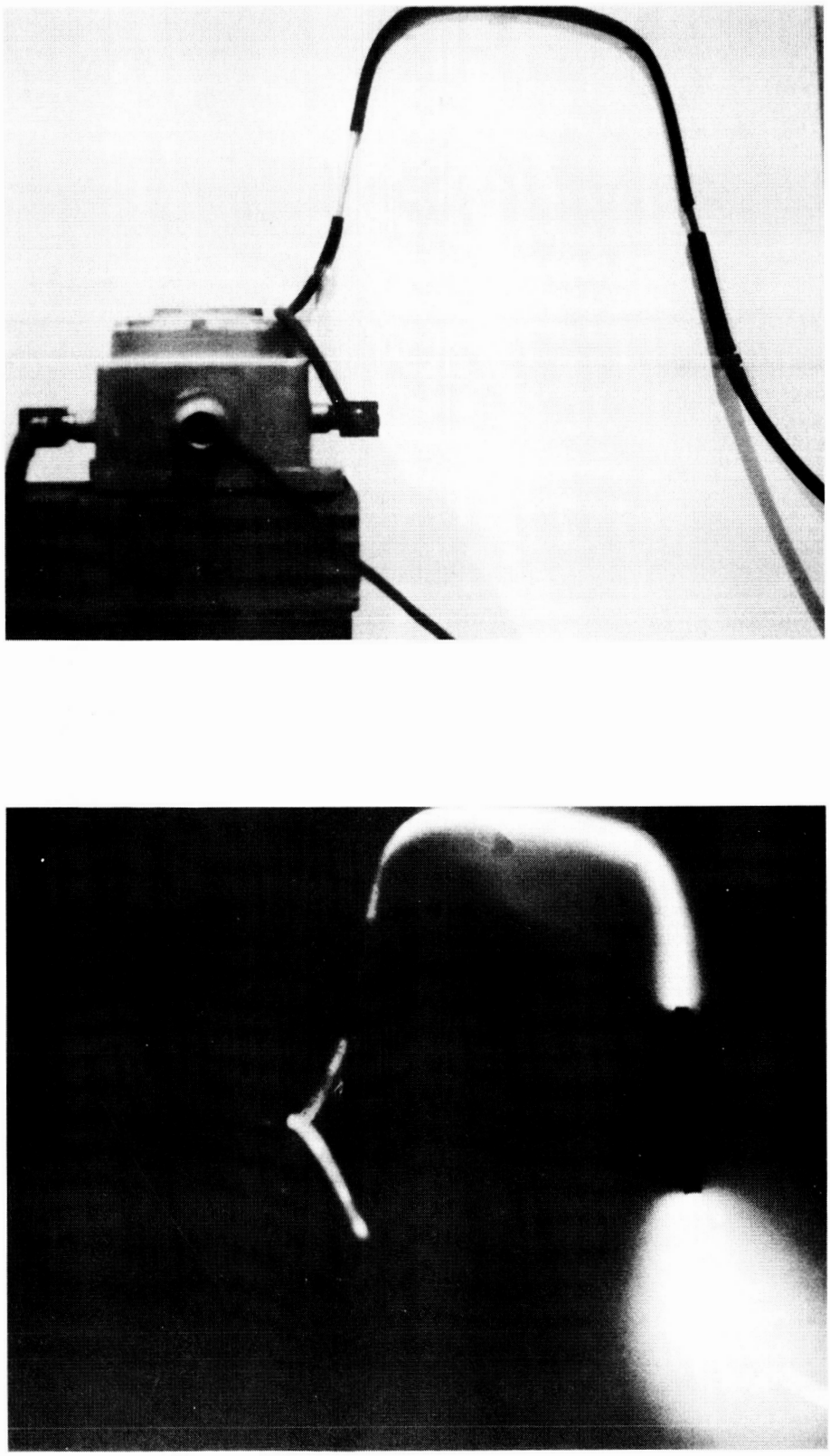

FIGURE 14. - Failure of Flame Arrestor in Unit HD-12.

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