REPORT NO. 6

DETERMINATION OF TOTAL RECIRCULATION, VACUUM, HIGH PRESSURE NOZZLE DISCHARGE AND OTHER GENERAL CHARACTERISTICS OF THE RECIRCULATING SYSTEM OF THE STANDARD U.S. NAVY HELIUM OXYGEN DEEP SEA DIVING HELMET UNDER VARIOUS CONDITIONS OF DEPTH AND VENTURI SUPPLY PRESSURES, WITH AIR AND HeO_2 MIXTURES

22 APRIL 1948

REPORT NO. 6

DETERMINATION OF TOTAL RECIRCULATION, VACUUM, HIGH PRESSURE NOZZLE DISCHARGE AND OTHER GENERAL CHARACTERISTICS OF THE RECIRCULATING SYSTEM OF THE STANDARD U.S. NAVY HELIUM OXYGEN DEEP SEA DIVING HELMET UNDER VARIOUS CONDITIONS OF DEPTH AND VENTURI SUPPLY PRESSURES, WITH AIR AND HeO_2 MIXTURES

22 APRIL 1948

AD 728-260

22 April 1948

U. S. NAVY EXPERIMENTAL DIVING UNIT

NAVAL GUN FACTORY

WASHINGTON, D. C.

PROJECT NUMBER - SRD 235/46

TITLE - Determination of Total Recirculation, Vacuum, High Pressure Nossle Discharge and Other General Characteristics of the Recirculating System of the Stan-ard U.S. Navy Helium Oxygen Deep Sea Diving Helmet Under Various Conditions of Depth and Venturi Supply Pressures, with Air and HeO_2 Mixtures.

G.G. MOLUMPHY
Commander, USN
Officer in Charge

OBJECT

The object of this experiment is to test the recirculating device of the standard U.S. Navy helium-oxygen deep sea diving helmet and to determine the vacuum, high pressure nozzle flow, total recirculation and pressure drop of air, oxygen and HeO_2 mixture of about 19.5% O_2 in a HeO_2 recirculating system under various depths with the supply pressure of these gases to the high pressure nozzle at 25, 50, 75 and 100 lbs/in^2 over bottom pressure. It is desired to compare the above data of the venturi system when the tip of the high pressure nozzle is flush and 1/4 inch away from the mouth of the Venturi discharge nozzle respectively. It is also desired to compare air with HeO_2 mixtures with respect to high pressure nozzle flow, recirculation and other characteristics.

METHOD

The method and apparatus used, was as shown on page 4 of the data sheet. This apparatus was used in all tests subsequent to number 2. The first two tests were of a preliminary nature. Two types of aspirator bodies, Plate 97, page 229, Navy Department Diving Manual, 1943, differing only in the vertical face to face dimensions are currently in use. In one type, the dimension is 2 inches, in the other 2 1/4 inches. The 2 inch aspirator body placed the high pressure nozzle at the mouth of the Venturi discharge nozzle, whereas the 2 1/4 inch body placed the high pressure nozzle 1/4 inch away from the mouth of the Venturi discharge nozzle. The same high pressure nozzle and Venturi discharge nozzle were used throughout the experiment with intermittent checks made with a number 74 drill to assure a clean orifice.

The air used came from the high pressure 2500 lbs/in^2 banks. It was reduced in pressure twice. The first reduction was to 250 lbs/in^2. The second reduction was to the various pressures desired over bottom. The moisture content was not ascertained. The cannister was filled with fresh Shell Natron except in some of the preliminary runs.

The meter used was manufactured by the American Meter Co., Albany, New York. It is similar to the gas meter used in reaidential installations. Its capacity is 5 to 150 cubic feet per hour. It was checked for accuracy with a spirometer and it read 1.637 liters high in 100 liters. The correction factor is 0.984. The number of the meter is 4500830. This meter was calibrated in liters.

The capacity tank used, was a can with a capacity of 0.66 ft^3. It is felt that this tank together with the hose, meter and cannister approached the volume of the average hat and the accompanying spaces. A one inch pipe ran from the tank to a 13 1/2 inch water seal which is equivalent to a pressure of 1/2 lb/in^2.

All tubing was 3/4 inch inside diameter except that portion of the system running from the valve to the cannister. This was 1 inch pipe with a 1 inch gate valve. The total length of the piping and tubing was about 8 feet. Four manometer taps were in the piping system as shown in sketch on page 4 of data sheet.

The system was "open" when tap number 3 was open to the ambient pressure. When the system was "closed", it operated in a closed cycle at constant pressure which was controlled by the water seal. When the vacuum and high pressure nozzle flows were taken, the 1 inch valve (diagram on page 4 of data sheet), was closed. The latter were taken when the system was both "open" and "closed". The vacuum was taken when the system was "open" at tap number one. Except as stated above, the apparatus operated 1/2 lb lbs/in^2 over ambient pressure.

The vacuum readings and pressure drops across points were taken in centimeters of water. The high pressure nozzle flows and total recirculation were taken in liters per minute. All other data are in English units. All lbs/in^2 are gauge readings.

When gases other than air were used, the system was flushed for 5 minutes with a pressure of 25 lbs/in^2 over bottom pressure supplied to the high pressure nozzle.

Attention is invited to the fact that the tests as arranged are not in chronological order. The data sheets were relocated in logical order to the position of the high pressure nozzle with respect to the Venturi and pressure increments. The actual order of the experiments can be seen by noting the experiment number. Before each test, the system was checked for leaks by means of a water column. When the system reached equilibrium conditions, the gas was shut off and the water column observed. Most of the volume readings were taken by the minute.

Tests of the Venturi system when the high pressure nozzle was flush and 1/4 inch away from the Venturi discharge nozzle mouth, were made with air and HeO_2 mixtures at atmospheric, 75 feet, 150 feet, and 225 feet depths, with supply pressures of 25, 50 75 and 100 lbs/in^2 over bottom to the high pressure nozzle at each depth. Oxygen was not used in the experiments under pressure. The results of air and oxygen tests at atmospheric were almost identical. Thus, the results of air tests could be applied to oxygen without any appreciable error. This is as anticipated, since the molecular weights of oxygen and air are almost the same.

The Navy standard Venturi discharge nozzle and high pressure nozzle are as indicated by Plate 97, page 229, in the Bureau of Ships Diving Manual, 1943. The high pressure nozzle orifice diameter is 0.0225 inches with a throat diameter in the Venturi of 0.40. The high pressure nozzle is shown flush with the mouth of the Venturi discharge nozzle.

It is important to note that the high pressure nozzle has been called a "jot" in the data sheets and graphs to save space. The Venturi discharge nozzle is called a "Venturi" or a "Venturi tube".

DISCUSSION OF RESULTS

The apparatus set up simulates an actual diving dress as close as possible. There are certain factors that can be only estimated. One of them is that of the actual volume of air present in a diving dress. The volume of a hat is about 0.3 ft^3. This does not take into account the deduction of the volume occupied by the diver's head. However, the breast plate and the upper partially inflated part of the diving dress occupy considerable space. This, too, varies with the size of the diver and the conditions of inflation that he habitually uses. It is felt that the capacity tank of 0.66 ft^3 does not deviate very much from the volume of free space in the average diving suit.

Another unknown factor is that of dead gas in the diving dress. In a HeO_2 dive, the gas is expelled intermittently and some of the gas in the dead spaces is replaced. Even an approximate apparaisal of recirculation in these spaces is difficult.

For analysis, the system is divided into two parts, the recirculation and the high pressure nozzle. The recirculation will be discussed first.

There is more frictional resistance in the test apparatus than in an actual diving helmet. The frictional resistance of the tubing and meter reduces the recirculation somewhat. Since the results are comparative, little error is introduced into the results. This resistance increases approximately as the square of the velocity. It would be impractical to measure the recirculation directly because of the difficulty of the introduction of a flow measuring device between the cannister and the helmet. It is conceivable that a pitot tube might be used, but the non-uniformity of the entrance into the hat would also produce errors.

The moisture content of the gases used did not affect the flows appreciably. This is true of both the HeO_2 mixture and the air. The air was reduced twice from a pressure of 2500 lbs/in^2. Since the absolute humidity of gases is dependent almost entirely on temperature, the relative humidity of air at the average temperature of our experiments is fairly low. The temperature of the gases used in these experiments was about 70°F. It was slightly higher in the tests under pressure because the temperature of the chamber under pressure was higher and the pressure drop of the gases was not as great. Both factors would tend to raise the temperature of the gases in the closed circuit. The excellent condition of the Shell Natron after the experiments would also indicate a low relative humidity of the gases.

The recirculation flow can always be considered as turbulent since Reynold's number is always over 2000. This is especially true in parts of the system that have small cross-sectional areas with respect to the rest of the system such as the throat of the venturi discharge nozzle and areas around the Shell Natron. Therefore no increase in recirculation can ever be expected by the acquisition of streamlined flow.

The recirculatory system of the helmet can best be compared to the flow of gases in pipes at constant temperature in terms of pressure drops.

$$P_1^2 - P_2^2 = \frac{f\, l\, V^2\, P_1}{d\, g\, v}$$

where:

P_1 = absolute pressure at pipe entrance

P_2 = absolute pressure at pipe exit

l = length of pipe

d = diameter of pipe

V = velocity at entrance ft/sec

v = specific volume at entrance cu.ft/lb

g = gravitational acceleration ft/sec/sec

f = pipe friction factor which is dependent on Reynold's number. It can be considered constant in our range of experiments.

It is seen from the data sheet that the pressure drop across taps 1 and 2 is equal to the sum of the pressure drops in the entire system. Only four factors change in this system. They are V, P_1, P_2, and v. A venturi is capable of circulating air because the high velocity of the jet carried with it other molecules. This produces a rarefaction in the vicinity back of the jet which in turn causes a flow to this point. This is actually the conversion of a pressure or heat energy of the gas into kinetic energy of the issuing stream. The purposes of the venturi discharge nozzle is to channel this energy to obtain the most efficient conversion into velocity. The shape of it depends on the rates of velocity and specific volume increase. They are independent. Our type is the converging-diverging type where at first, the velocity increases faster than the specific volume. Past the throat, the converse is true.

The maximum work that can be done by the venturi recirculating system is the difference in heat content before and after the expansion of the gas passing through the high pressure nozzle. This available energy decreases with higher pressures when air is used. Thus, 50 lbs/in^2 over bottom pressure cannot do the same work at 225 feet as at 75 foot depths. However, more air measured at standard temperature and pressure, is provided by the same high pressure nozzle at the greater depths as shown in graph number 5. Since the work done is dependent on the heat content change per unit weight of gas discharged through the jet, the energy supply is continued at higher pressures by increased supply in terms of weight per minute. No helium enthalpy charts were available and it is assumed that the HeO_2 mixture acts somewhat like air.

The pressure drops in all tests above atmospheric are almost constant. An increase in ambient pressure on the system would produce changes in "V", "P_1" and "v". The increase in inlet pressure, "P_2", which is really the depth, would decrease the specific volume. By examination of the equation, it is seen that this will tend to increase the value of the friction loss. Since this was not appreciable, the velocity, "V", must be decreased. This in turn reduces the recirculation. This is illustrated in graph number 1. The dominant effect of the change in velocity will be at the throat of the venturi discharge nozzle because it has the smallest cross sectional area in the system. This would also incicate that the effect of the rest of the system of which the smallest cross sectional area is four times as great, would not cause the apparatus set up to deviate too much from an actual helmet. The throat diameter is 0.40 inches and the tubing was about 0.75 inch inside diameter.

With the use of different gases, the only factor changing in the equation is the specific volume, "v". The equivalent molecular weight of air is about 29. The molecular weight of a HeO_2 mixture, 20% O_2 is 9.6. This mixture would have a specific volume about three times as great. Therefore this would indicate an increase in "V" or recirculation to hold the friction loss constant. This is shown by observing the recirculation flows in graph number 1. It is to be noted that for friction less of one gas, the only independent variable over a range of pressures is "P_2" or the depth, "V", and "v" are dependent on "P_2". The change in "f" is slight.

The meter capacity of 150 cu.ft./hr. has been exceeded in some instances at lower depths. It is felt that this introduced little if any error. The correction factor of 0.984 was also ignored since this correction is not more than the probable error made in reading the meter. The manometer was also difficult to read in some instances, due to the surging effect.

Test number 3 showed erratic results and the data was discarded. It is quite certain that there was a leak in the system. The reason for running parallel tests with HeO_2 and air is to provide a basis for comparison. The results of air can be applied to oxygen with little error. The molecular weight of O_2 is 32 and air 29. The comparison of tests number 8 and 9, indicate very little difference in results between oxygen and air. Air is often used as a basis for comparison because of its availability.

One of the chief difficulties of accurate high pressure nozzle flow calculations lies in the fact that compressed gases while flowing through a pipe create friction which gradually decreases the pressure of the air. This loss of pressure is accompanied by a corresponding expansion of the air, that is, by an increase in volume. To transmit this increased volume requires increased velocity of flow resulting in a further increase of friction loss, and so on.

It is felt that the high pressure nozzle flow is best treated from a standpoint of gas flow through a pipe. It cannot be treated as an orifice or nozzle since the experimental data shows that it does not follow the thermodynamic laws applicable to either. It is actually a cross between a pipe and a nozzle. In this type, three diameters are used in a distance of 1.38 inches. Beginning at the tip, a portion 1/8 inch long has a diameter of 0.0225 inches. The following section is 0.793 inches long, with a diameter of 0.040 inches. The last section is 0.450 inches long with a diameter of 0.1875 inches.

The failure of the above high pressure nozzle to conform to laws for nozzles and orifices lies in that the maximum flow in pounds per minute is determined by the accustic velocity of the gas at the throat or narrowest construction. This is governed by the critical pressure in the throat. This pressure can never be less than a given ratio to the initial or entrance pressure.

The relation of throat pressure to initial pressure is given by this equation:

$$Pt = \left(\frac{2}{K+1}\right)^{\frac{K}{K-1}} P_1$$

where:

P_t = throat pressure

P_1 = initial pressure

K = the ratio of $\frac{cp}{cv}$ where

cp = specific heat of gas at constant pressure

cv = specific heat of gas at constant volume.

For air, K is 1.40. For helium, it is 1.659.

For air, the ratio of throat pressure to initial pressure, 0.528 or $P_t = 0.528\ P_1$. Thus, if we had two chambers "A" and "B", with a connecting nozzle with 100 lbs/in^2 absolute in each chamber, we would get no flow. If we kept the pressure constant in "A" and lowered the pressure in "B", we would get a greater and greater flow through the nozzle. This would occur until a pressure of 52.8 lbs/in^2 pressure in chamber "B" was reached. Lowering the pressure in "B" below 52.8 lbs/in^2 absolute, will not increase the weight of air passed. At this back pressure the stream is flowing at accustic velocity. Therefore, the adjacent point upstream would never receive notice nor be affected by disturbances originating downstream.

For helium, the relation for critical throat pressure is:

$$P_t = \left(\frac{2}{K+1}\right)^{\frac{K}{K-1}} P_1$$

$$= \left(\frac{2}{2.66}\right)^{\frac{1.66}{0.66}} P_1$$

$$= (.752)^{2.52} P_1$$

$$P_t = 0.488$$

The above shows there is little differnece between air and helium with regard to critical throat pressure.

In our experiments, the high pressure nozzle output continued to increase when the back pressure was dropped below the calculated critical pressure. This would indicate that the pressure inside it, just before the point of emergence must be above critical and P_1 is more than the critical value of $\frac{P_t}{0.488}$. This pressure drop could only be accomplished by friction inside the nozzle.

If we examine another equation for pressure drops in pipe lines, we will see why such a large loss is possible in so short a pipe.

$$P_1^2 - P_2^2 = \frac{V^2 L}{2000 D^5}$$

(Density is ignored in the above quation)

P_1 = initial pressure

P_2 = pressure at end of line

V = volume of free air in ft^3/min

L = length of pipe in feet

D = diameter of pipe in inches

It will be seen at once that the dominating effect is that of "D" diameter of the pipe. The small diameters used in our high pressure nozzle will cause a very high friction loss. This explains the apparent anomaly in our tests that show increases in the high pressure nozzle output although the back pressure had long since equalled the calculated critical back pressure. What actually occurred was that the pressure in the high pressure nozzle at the point of emergence has been dropped by friction to a value somewhat less than the back pressure divided by the critical pressure ratio.

The viscosity of gases does not have much effect on the high pressure nozzle flow. It is independent of pressure except for very high or very low pressures. It may be of interest to note that the viscosity of gases increases with temperature, which is the opposite of liquids.

The density of gases is affected by both temperature and pressure. The equation of density in gases is:

$D = \frac{P}{RT}$ where

D = density pounds per cubic foot

P = absolute pressure lbs/in ft^2

T = absolute temperature

R = gas constant

As shown before, "P" is actually the depth in our experiments and thus the independent variable and the dominant effect. This obviously centrols the density of gas in the high pressure nozzle since it is a certain value over the bottom pressure or depth. The effect of temperature "T" is negligible in most cases. It may havde a slight effect in the case of helium because of its high specific heat.

The gas constant "R" is dependent on the gas. For air, it is 53.3 and for helium, it is 386.5. For 20% HeO_2 mixture, it is 158. Thus, it is seen that the density will be considerably less when helium is used.

All graphs except number 5, are constructed at the actual conditions of the dive. Graph number 5 is reduced to terms of atmospheric pressure to show the HeO_2 used and total recirculation at various depths.

In graph number 1, the high pressure nozzle flows of air and HeO_2 mixtures increase with increase of pressure over bottom pressure. At higher pressures, some flow is gained by increasing the pressure over bottom, past 50 ft/in^2. The curve of the high pressure nozzle flow of the HeO_2 mixtures at a depth of 225 feet is almost a vertical line. It is felt that pressure over bottom should not be dropped much below 50 lbs/in^2 to provide a margin of safety. The saving of gas is almost negligible. This is also indicated in graph number 5. The entire family of curves showing the high pressure nozzle flows of air and HeO_2 mixture act very consistently. All flows decrease with depth and the shape of the curve, which is a straight line tends to approach a vertical line. All air flows are less at the same ambient pressure than the HeO_2 mixture because of the greater density of air.

The vacuum induced in the venturi discharge nozzle by the two gases is almost the same at lower depths. At higher depths the vacuum produced by the HeO_2 is slightly greater. The vacuum induced by both gases increases with depth. The shape of the vacuum curve is almost a straight line for both gases at all depths. The slope of the curve remains almost constant.

The total recirculation curves show a decrease in recirculation with depth as would be expected with the increased density of the gases. The volume of free gas at greater depths increases. It takes work to accomplish recirculation by means of high pressure nozzle flow. The latter does not increase in proportion as shown in graph number 5. The recirculation of air is always less than the helium oxygen mixture at the same depths. The curve tends toward vertical at greater depths. The effect of increasing pressure over bottom at depths normally used in helium diving (50 lbs/in^2) produces a significant increase in recirculation. All curves in the above graph were of the recirculating system where the high pressure nozzle is 1/4 inch away from the entrance to the venturi tube. The ratio of recirculation to jet flow in HeO_2 mixtures is about 7 or 8 to 1 over a large range of depths.

Graph number 2 illustrates the circulation of a HeO_2 mixture with respect to depth, and various pressures over bottom supplied to the high pressure nozzle. All the curves start to flatten out at 100 feet and are almost horizontal at 200 feet. It appears as if they tend to come together at higher pressures. 50 lbs/in^2 over bottom pressure seems to produce satisfactory recirculation.

Graph number 3 shows the superiority of one positioning of the high pressure nozzle over another with regard to vacuum and recirculation. There is very little difference between the recirculation at depths past 130 feet. The vacuum induced by the high pressure nozzle 1/4 inch away from the mouth is slightly higher. This does not produce a superiority of total recirculation.

Graph number 4 shows the ratio of the total recirculation to the high pressure nozzle flow. This ratio is shown as about 7 to 1 with HeO_2 and increases slightly with the depth. The curve reaches a maximum for each depth and then reverses at the point where the pressure over bottom is 50 lbs/in^2. At 75 lbs/in^2 the curve reverses again and at about 100 lbs/in^2, it exceeds the ratio obtained when 50 lbs/in^2 is supplied. The latter value would be an optimum pressure over bottom with regard to recirculation, if pressure ever bottom in the vicinity of 50 lbs/in^2 is supplied to the high pressure nozzle. The air recirculation ratio is also plotted for comparison. The air recirculation is important in that it is applicable to oxygen recirculation during decompresion.

Graph number 5 illustrates the volumes of gas used and recirculation at various pressures over bottom reduced to atmospheric pressures. The volumes of gas used and recirculation, both increase with depth in terms of atmospheric pressures. However, the actual volumes at these depths decrease with an increase in depth.

In the plotting of all graphs, only four points were used to determine the curve. This is the absolute minimum because a circle or any curve can be drawn through three points. Bad experimental data at any point would affect the general shape of the curve. This is especially true at the end of a curve where this would point to a probable result if the experiment were carried to greater depths. Despite the paucity of experimental points, the families of curves are quite consistent and the general characteristics of the gases at various conditions can be ascertained. All graphs except number 5 were plotted in terms of pressure and volumes as under actual conditions of the experiment. The volumes of graph number 5 were converted to atmospheric conditions.

Graph number 6 shows the vacuum, high pressure nozzle flow, and total recirculation plotted against depth of a HeO_2 system with 50 lbs/in^2 over bottom supplied.

The primary purpose of this experiment is to determine the volume of recirculation and high pressure nozzle flow at various depths. The recirculation is especially vital because it is so necessary in the CO_2 absorption by the Shell Natron.

At a depth of 225 feet and a pressure over bottom of 50 lbs/in^2 supplied to the high pressure nozzle, a total volume of 1.78 cubic feet of gas was recirculated per minute. The high pressure nozzle flow was 6.6 liters per minute. Both of these values will decrease with depth.

Whether or not this is enough recirculation to maintain the effective CO_2 level below the danger point, is to be determined by subsequent experiments. The volume of recirculation may not be an absolute criterion of this. A finite time is necessary for the gas to react with the shell natron for CO_2 absorption. An increase in recirculation with an attendant velocity of flow may not increase the CO_2 absorption proportionately.

A proper distribution of the tas after absorption is desirable to prevent stagnation of the CO_2. It is felt that ducts discharging at a point in the helmet diametrically opposite to the intake would be most effective. This would also afford protection to the diver should a leak in the cannister cause an irritating solution to be formed with the shell natron and water. This solution may be ejected into the helmet with resultant burns.

The use of parallel tests with air serve a convenient basis for comparison. If it is desired to compare the recirculation and jet flow of a venturi system, this can be accomplished with air by comparison with data obtained in this experiment.

The data obtained with air can also be applied to oxygen because the molecular weight and density are almost identical. The coefficient of viscosity of both gases is similar also. For air it is 173×10^{-6} poise, and for oxygen it is 189×10^{-6} poise. Both values are at 0° Centigrade.

It is to be expected that slightly more recirculation should occur in the helmet than shown by the experiment because the resistance to flow such as produced by the tubing and the meter, are not present.

All gear used in this experiment was in good order, and the Shell Natron never turned soggy from absorbing water vapor. Thus, the test conditions are probably superior to actual conditions. The effect of CO_2 with regard to recirculation in the system is insignificant. The same is true of any water vapor because of its low viscosity.

The difference of viscosity between air and helium is not great. Air has a viscosity of 173×10^{-6} poise, and helium 186×10^{-6} poise at 0° Centigrade. The viscosity of a helium oxygen mixture would not change appreciably from that of helium because oxygen has a viscosity of 189×10^{-6} poise. Because of this similarity in viscosity, density will emerge as the controlling characteristic of these gases. This in turn is dependent on the depth.

The flow formulae used are meant for use with pipe and therefore are only approximate when used in relation to this experiment.

The recirculation of the system is about 10% less with dry Shell Natron in the cannister. This is shown by comparison of data on pages 13 and 14. This reduction may be considerably more with soggy shell natron as would be found at the end of a dive.

The discharge edge of the Venturi tube was thin and considerable care was taken so that it would not be damaged.

The examination of the graphs shows that the vacuum produced by either HeO_2 or air under identical conditions is almost the same. Therefore air may be supplied to the high pressure nozzle to measure the vacuum produced in a helmet. A vacuum of 9 to 12 cm of water with 50 lbs/in^2 supplied to the high pressure nozzle at atmospheric pressure would indicate a satisfactory HeO_2 recirculating system. With 100 lbs/in^2 supplied to the high pressure nozzle, a vacuum of 20 to 25 cm of water should be produced. The determination of vacuum at atmospheric pressure is a simple and reliable method of testing the operating condition of a helmet.

It is felt that graph number 4 is of particular importance. It indicates that the optimum pressure over bottom in the range of 0 to 75 lbs/in^2 is about 50 lbs/in^2. At about 100 lbs/in^2, this ratio is exceeded and the curve indicates a trend toward a higher recirculation to high pressure nozzle ratio. Hence a significant recirculation increase may be obtained by merely increasing the pressure over bottom. This graph also indicates the recirculation that may be expected when oxygen is used for decompression by reference to the data obtained for air.

High pressure nozzle flow may also be used as an indication of the recirculation since this ratio is at least 7 to 1. This must be made with the assumption that the system is in normal operating order. It would not reveal gross malfunctions caused by bad high pressure nozzle to venturi discharge nozzle mouth positioning, eccentricity of the stream with regard to the discharge nozzle venturi throat and obstructions in the circuit.

CONCLUSIONS

The ratio of total recirculation to high pressure nozzle flow for HeO_2 is about 7 to 1, and it increases somewhat with depth. The optimum ratio occurs in the 0 - 75 lbs/in^2 range, when a pressure of 50 lbs/in^2 over bottom is supplied. At about 100 lbs/in^2, this ratio is exceeded and the curve points to a higher ratio at greater pressures over bottom.

There is practically no difference between the performance of Venturi systems whether the high pressure nozzle is 1/4 inch away of flush with the mouth of the Venturi discharge nozzle with regard to recirculation. The vacuum is slightly higher when the high pressure nozzle is 1/4 inch away from the Venturi discharge nozzle mouth, but this has little influence on the recirculation.

All high pressure nozzle and recirculation flows decrease with depth. However, when these volumes are converted into terms of atmospheric pressure, they both increase with depth. All high pressure nozzle and recirculation flows for air are less than for HeO_2 mixtures at the same depth. The vacuum produced by both gases is almost the same. At greater depths, the HeO_2 mixture produces a slightly higher vacuum.

The viscosity of air, oxygen and the HeO_2 mixture, is similar. This quality is independent of pressures except at very high or very low pressures. The temperature can be considered constant. It may be of interest to note that viscosity of gases increases with temperature. This is the converse of liquids. For these reasons the viscosity can be considered constant in our experiments for all gases. Therefore density is the dominating influence in the behavior of the gases in these experiments. It increases with depth and molecular weight. Because of the similarity of molecular weights, the results of air data can be applied to oxygen with little error. This is important in indicating recirculation when oxygen is used in decompression.

The moisture content of gases should cause little change in recirculation because of the low viscosity of water vapor. No increase in recirculation can ever be expected by the acquisition of streamlined flow because Reynold's number will be always over 2000.

The decrease in recirculation is caused by an increase in depth which increases the density of the gas which in turn increases the weight of gas to be moved without a proportional increase of energy produced by the high pressure nozzle flow. The heat drop of the high pressure nozzle is not as great at higher pressures. This reduces the available energy convertible into the external work of imparting velocity to the emerging gas. This loss is partially compensated for by an increase of the weight of gas passed through the high pressure nozzle, assuming that the efficiency of the system remains constant.

In all tests above atmospheric, the pressure drops are almost the same with each gas. Since the specific volume (which is a function of density) decreases, the velocity must decrease to hold the equation constant. The reduction of velocity is really a reduction of recirculation.

The flow through the high pressure nozzle is analogous to gas flow in a pipe at constant temperatures. It does not follow the flow laws applicable to nozzles because the weight of gas emitted continues to increase although the back pressure had long since passed the calculated critical pressure. This would point to a considerable friction loss (which reduces the available energy) in the high pressure nozzle. It would indicate a velocity near the point of emergence somewhat below accustic. There is little difference between the critical pressure ratios of the HeO_2 mixture and air.

Slightly more recirculation is to be expected in a helmet than in this experimental apparatus because of less resistance to flow. However, the throat of the Venturi discharge nozzle has the smallest cross sectional area in the system and thus making it the biggest friction factor in recirculation. Flow discrepancies between the test and actual systems should not be significant.

The recirculation volume may not be an absolute criterion of CO_2 absorption since a finite time is required for reaction between it and the Shell Natron. Proper distribution of the HeO_2 mixture is desirable after CO_2 absorption. The location of discharge ducts diametrically opposite to the intake may help accomplish this.

The extreme thinness of the Venturi discharge edge makes damage to it inevitable. The sharpness of this edge also makes it a hazard for personnel dressing and undressing the diver. Increasing the wall thickness to about 1/16 inch at this point would eliminate the above disadvantages. Except for slight eddy currents, the flow characteristics of the system would not be altered.

The placing of Shell Natron in the cannister reduced the total recirculation about 10% when air was used at atmospheric pressure. This reduction in flow would probably be increased with soggy Shell Natron as would be found at the end of a dive.

Vacuum may be ascertained by supplying either air or HeO_2 to the high pressure nozzle without appreciable error. At 50 lbs/in^2 over bottom, a vacuum of about 9 to 12 cm of water should be produced. With 100 lbs/in^2 over bottom supplied, a vacuum of about 20 to 25 cm of water should be obtained.

It is felt that measuring the vacuum is the most reliable and simple method of checking the HeO_2 recirculation system. High pressure nozzle flow may also be used, but the assumption must be made that the system is in normal operating condition. By itself, it would not reveal gross malfunctions. The apparatus required to measure this flow is also more complex.

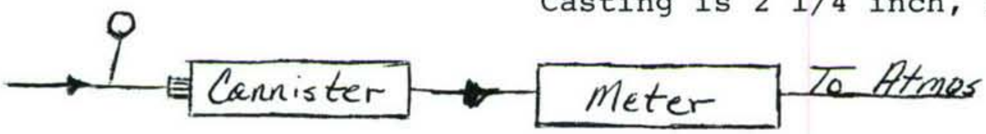
The grapth illustrating the ratio of recirculation to high pressure nozzle flow, number 4, is of considerable importance. It is fairly constant over a large range of depths with maximum ratios obtained when 50 lbs/in^2 or 100 lbs/in^2 over bottom is supplied to the jet. At greater pressures over bottom, the curves point to a greater ratio. Recirculation may be significantly increased by raising the pressure supplied to the high pressure nozzle. This raises the output which in turn increases total recirculation.

Only four points are used in plotting the graphs. This is the minimum because any curve or circle can be drawn through three. Therefore a bad point affects the entire curve. Nearly all graphs indicate good experimental data.

VENTURI TEST #1

19 November 1947

Gas Used	;	Air
Distance from jet to mouth of Venturi	:	1/4 inch
Pressure conditions	:	Atmospheric
Cannister	:	Filled with Shell Natron
Remarks	:	Navy Yard Drawing A-14294 (current type) Casting is 2 1/4 inch, face to face.



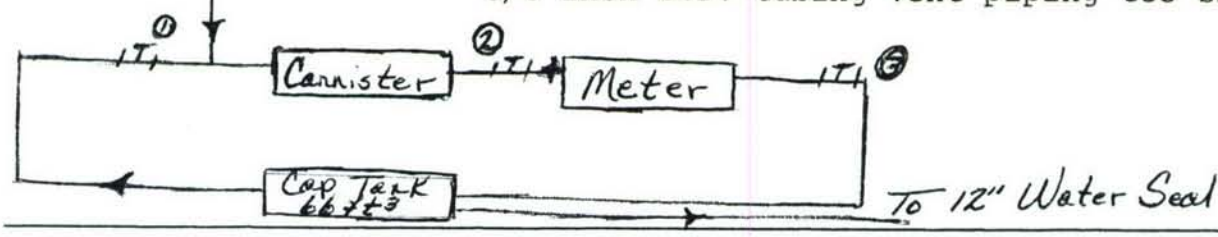
Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	5.2	17.8
Jet flow	6.4	17.5
Total recirculation	42.9	84.6

Pressure over botton	50 lbs/in^2	100 lbs/in^2
Vacuum	10.1	24.3
Jet flow	11.0	22.3
Total recirculation	61.9	101

VENTURI TEST #2

21 November 1947

Gas used	:	Air
Distance from jet to mouth of Venturi	:	1/4 inch
Cannister	:	Empty
Pressure conditions	:	Atmospheric, System under 1/2#/in^2 pressure
Remarks	:	All connections 3/4 inch rubber and glass tubing except from cannister to valve. 3/8 inch O.D. tubing vent piping too small



Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	6.1	18
Jet flow (open)	7.7	17.6
Total recirculation flow	68.5	114.5
Pressure at 1, 2, and 3 resp.	31.5 - 34 - 32	32.3 - 38.4 - 33.2
Pressure drop across 1 and 2	2.5	
Pressure drop across 2 and 3	2	
Pressure drop across 3 and 1	0.5	

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	12	25.8
Jet flow (open)	12.6	22.7
Total recirculation	95.5	137
Pressure at 1, 2, and 3 resp.	31.8 - 36.3 - 32.75	35 - 41.5 - 34.4
Pressure drop across 1 and 2	4.6	8.6
Pressure drop across 2 and 3	3.8	7.1
Pressure drop across 3 and 1	0.75	1.6

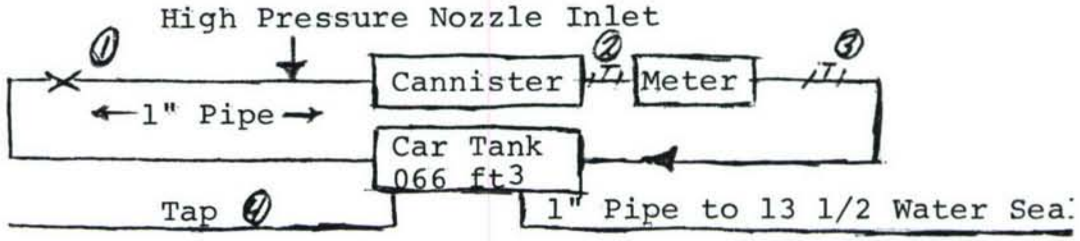
VENTURI TEST #4

26 November 1947

Gas used	:	Air
Distance from jet to mouth of Venturi	:	1/4 inch
Cannister	:	Filled with fresh Shell Natron
Pressure conditions	:	Atmospheric

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	6.3	17.4
Jet flow (open)	8.0	18.5
Jet flow (closed)	7.2	17.4
Total recirculation	70.5	119
Pressure at 1, 2, and 3 resp.	34.5 - 37.1 - 34.9	34 - 40.5 - 35.2
Pressure drop across 1 and 2	2.5	6.6
Pressure drop across 2 and 3	2.0	5.4
Pressure drop across 3 and 1	0.5	1.2

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	11.8	24.7
Jet flow (open)	13	23.6
Jet flow (closed)	12	22.4
Total recirculation	100	135
Pressure at 1, 2, and resp.	34.3 - 39 - 35.1	33.8 - 42.5 - 35.2
Pressure drop across 1 and 2	4.8	8.9
Pressure drop across 2 and 3	3.8	7.0
Pressure drop across 3 and 1	0.9	1.5



VENTURI TEST #5

26 November 1947

Gas used	:	Oxygen
Distance from jet to mouth of Venturi	:	1/4 inch
Cannister	:	Filled with Shell Natron
Pressure conditions	:	Atmospheric
Remarks	:	System was purged for 5 minutes before tests were taken with 25#/in^2 over bottom pressure being used. This procedure was followed in each test involving gases other than air.

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	6.5	17.5
Jet flow (open)	7.6	17.5
Jet flow (closed)	7.3	16.6
Total recirculation	67.5	113
Pressure at 1, 2, and 3 resp.	34.1 - 36.9 - 34.6	33.5 - 40.2 - 34.9
Pressure drop across 1 and 2	2.8	6.6
Pressure drop across 2 and 3	2.1	5.3
Pressure drop across 3 and 1	0.6	1.3

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	11.7 open	24.6 open
Jet flow (open)	12.2	22.3
Jet flow (closed)	11.7	21.4
Total recirculation	93	132
Pressure at 1, 2, and 3 resp.	33.9 - 38.7 - 35	33.3 - 41.8 - 35
Pressure drop across 1 and 2	4.9	8.6
Pressure drop across 2 and 3	3.9	7.4
Pressure drop across 3 and 1	1.0	1.6

VENTURI TEST #6

26 November 1947

Gas used	:	HeO_2
Distance from jet to mouth of Venturi	:	1/4 inch
Cannister	:	Filled with Shell Natron
Pressure conditions	:	Atmospheric
Remarks	:	The same shell natron was used in tests #4, 5, and 6. It was placed in cannister at 0830 and emptied at 1500. It was in very good shape after use.

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	6.5	17
Jet flow (open)	14.1	32.5
Jet flow (closed)	13.6	31.2
Total recirculation	118	204
Pressure at 1, 2, and 3 resp.	33.8 - 36.7 - 34.5	33.2 - 40.1 - 34.7
Pressure drop across 1 and 2	2.8	6.9
Pressure drop across 2 and 3	2.1	5.5
Pressure drop across 3 and 1	0.7	1.4

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	11.8	23
Jet flow (open)	23.3	41.4
Jet flow (closed)	22.5	40.2
Total recirculation	169	233
Pressure at 1, 2, and 3 resp.	33.4 - 38.5 - 34.6	33 - 41.5 - 34.7
Pressure drop across 1 and 2	5.2	8.8
Pressure drop across 2 and 3	4.0	6.9
Pressure drop across 3 and 1	1.1	1.8

VENTURI TEST #16

16 December 1947

Gas used : Air
Distance from jet to mouth of Venturi : 1/4 inch
Cannister : Filled with Shell Natron
Pressure conditions : 75 feet in chamber

Pressure above bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	6.6	20.7
Flow thru jet (open)	4.4	8.0
Flow thru jet (closed)	3.4	7.4
Total circulation	48.0	74.0
Drop across 1 and 2	2.5	6.7

Pressure above bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	14.0	27.1
Flow thru jet (open)	5.8	9.2
Flow thru jet (closed)	5.4	9.0
Total circulation	64.4	90.0
Drop across 1 and 2	5.0	10.5

VENTURI TEST #15

15 December 1947

Gas used	:	HeO_2 - O_2 19.5%
Distance from jet to mouth of Venturi	:	1/4 inch
Cannister	:	Filled with Shell Natron
Pressure conditions	:	75 feet in chamber
Remarks	:	Results are of second run since HeO_2 ran out on first run. Purged as before.

Pressure above bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	7.4	20.8
Jet flow (open)	7.8	14
Jet flow (closed)	7.8	13.6
Total circulation	58.0	120
Drop across 1 and 2	3	8.2

Pressure above bottom	50 lbs/in^2	100 lbs/in^2
Vacuum (open)	15.9	27.3
Jet flow (open)	11.4	17
Jet flow (closed)	10.8	16.8
Total circulation	89.0	152
Drop across 1 and 2	6.2	11.8

VENTURI TEST #13

11 December 1947

Gas used	:	Air
Distance from jet to mouth of Venturi	:	1/4 inch
Cannister	:	Filled with Shell Natron
Pressure conditions	:	150 feet in chamber

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	8.2	23.4
Flow thru jet (open)	4.2	6.3
Flow thru jet (closed)	3.2	6.2
Total recirculation	36	60.8
Pressure drop across 1 and 2	3.4	8.4

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	16	30.2
Flow thru jet (open)	5.6	7.0
Flow thru jet (closed)	4.8	7.0
Total recirculation	50.4	68.0
Pressure drop across 1 and 2	6.1	10.7

VENTURI TEST #14

15 December 1947

Gas used	:	HeO_2 - 19.35% O_2
Distance from jet to mouth of Venturi	:	1/4 inch
Cannister	:	Filled with Shell Natron
Pressure conditions	:	150 feet in chamber
Remarks	:	Meter recalibrated with a spirometer after mechanical failure. Read 1.637 liter high in 100 liter. Corr. factor = $\frac{100}{101.637}$ = 0.984

Pressure above bottom	25 lbs/in^2	75 lbs/in2
Vacuum	5.0	22
Flow thru jet (open)	5.7	10.5
Flow thru jet (closed)	5.4	9.3
Total recirculation	37.5	88.5
Pressure drop across 1 and 2	2.6	8.0

Pressure above bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	14.6	29.6
Flow thru jet (open)	8.7	11.4
Flow thru jet (closed)	7.8	11.1
Total recirculation	62.1	103.5
Pressure drop across 1 and 2	5.8	10.8

VENTURI TEST #21

22 December 1947

Gas used	:	Air
Distance from jet to mouth of Venturi	:	1/4 inch
Cannister	:	Filled with Shell Natron
Pressure conditions	:	225 feet in chamber

Pressure over bottom	25 lbs/in2	75 lbs/in^2
Vacuum (open)	10	24.6
Jet flow (open)	4.2	5.7
Jet flow (closed)	3.9	5.4
Total circulation	31.5	48.6
Drop acorss 1 and 2	3.2	8.1

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum (open)	17.2	32.7
Jet flow (open)	4.5	6.0
Jet flow (closed)	4.2	5.7
Total circulation	42	54
Drop across 1 and 2	5.3	9.2

VENTURI TEST #22

22 December 1947

Gas used	:	HeO_2 - O_2 19.5%
Distance from jet to mouth of Venturi	:	1/4 inch
Cannister	:	Filled with Shell Natron
Pressure conditions	:	225 feet in chamber

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum (open)	7.7	23.2
Jet flow (open)	6.6	9
Jet flow (closed)	63	8.7
Total circulation	33.3	63.6
Drop across 1 and 2	2.9	7.7

Pressure over bottom	50 lbs/in2	100 lbs/in^2
Vacuum (open)	16	30.8
Jet flow (open)	7.5	11.7
Jet flow (closed)	6.9	9.9
Total circulation	51	75.6
Drop across 1 and 2	5.8	9.9

VENTURI TEST #7

1 December 1947

Gas used	:	Air
Distance from jet to mouth of Venturi	:	Flush
Cannister	:	Empty
Pressure conditions	:	Atmospheric
Remarks	:	Jet is flush with mouth of Venturi. The same Venturi and jet were used in a different casting which was 2 inches face to face

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	5	14.1
Jet flow (open)	8	18.1
Jet flow (closed)	7.6	17.5
Total recirculation	69.5	118
Pressure at 1, 2, and 3	34.2 - 37 - 34.7	33.7 - 40.1 - 35
Pressure drop across 1 and 2	2.4	6.3
Pressure drop across 2 and 3	1.9	5.2
Pressure drop across 3 and 1	0.5	1.2

Pressure over bottom	50 lbs/in2	100 lbs/in^2
Vacuum	9.3	19.6
Jet flow (open)	13.1	23.4
Jet flow (closed)	12.6	22.3
Total recirculation	98.5	137
Pressure at 1, 2, and 3	34.1 - 38.7 - 35.1	33.7 - 41.2 - 35
Pressure drop across 1 and 2	4.7	8,7
Pressure drop across 2 and 3	3.9	7.2
Pressure drop across 3 and 1	0.8	1.4

VENTURI TEST #8

4 December 1947

Gas used	:	Air
Distance from jet to mouth of Venturi	:	Flush
Cannister	:	Filled with fresh Shell Natron
Prêssure conditions	:	Atmospheric

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	5	13.9
Jet flow (open)	7.7	18.2
Jet flow (closed)	8	17.8
Total recirculation	63	108.5
Pressure at 1, 2, and 3	33.8 - 35.8 - 34.2	33.4 - 39.1 - 34.5
Pressure drop across 1 and 2	2	5.5
Pressure drop across 2 and 3	2	4.5
Pressure drop across 3 and 1	0.4	1.0

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	9.7	18.6
Jet flow (open)	13.1	23.5
Jet flow (closed)	12.7	22.6
Total recirculation	89	123
Pressure at 1, 2, and 3	33.6 - 37.5 - 34.3	33.3 - 40.2 - 34.5
Pressure drop across 1 and 2	3.8	7.0
Pressure drop across 2 and 3	3.2	5.7
Pressure drop across 3 and 1	0.8	1.2

VENTURI TEST #9

4 December 1947

Gas used	:	Oxygen
Distance from jet to mouth of Venturi	:	Flush
Cannister	:	Filled with Shell Natron
Pressure conditions	:	Atmospheric
Remarks	:	System purged for 5 minutes with pressure $25\#/in^2$ over bottom

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	5	14.1
Jet flow (open)	7.7	17.3
Jet flow (closed)	7.2	16.5
Total recirculation	60	103
Pressure drop across 1 and 2	2.2	5.6
Pressure drop across 2 and 3	1.7	4.1
Pressure drop across 3 and 1	0.5	0.9

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	9.4	18.4
Jet flow (open)	12.3	22.2
Jet flow (closed)	11.8	21.5
Total recirculation	85.3	115.5
Pressure drop across 1 and 2	4	7
Pressure drop across 2 and 3	3.2	5.8
Pressure drop across 3 and 1	0.7	1.2

VENTURI TEST #17

16 December 1947

Gas used	:	Air
Distance from jet to mouth of Venturi	:	Flush
Cannister	:	Filled with Shell Natron
Pressure conditions	:	75 feet in chamber

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum (open)	5.6	17.4
Jet flow (open)	4.6	7.6
Jet flow (closed)	4.4	7.8
Total circulation	41	72
Drop across 1 and 2	2.4	8.1

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum (open)	11.2	22.6
Jet flow (open)	6.2	9.6
Jet flow (closed)	6.2	9.4
Total circulation	58.2	84.4
Drop across 1 and 2	5	10.3

VENTURI TEST #18

16 December 1947

Gas used	:	HeO_2 - O_2 19.5%
Distance from jet to mouth of Venturi	:	Flush
Cannister	:	Filled with Shell Natron
Pressure conditions	:	75 feet in chamber

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum (open)	6	17.1
Jet flow (open)	7.6	13.4
Jet flow (closed)	7.6	13
Total circulation	53	91.2
Drop across 1 and 2	2.8	6.8

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum (open)	12	21.1
Jet flow (open)	10.8	17.2
Jet flow (closed)	10.8	15.8
Total circulation	78	136
Drop across 1 and 2	5	9.3

VENTURI TEST #11

8 December 1947

Gas used	:	Air
Distance from jet to mouth of Venturi	:	Flush
Cannister	:	Filled with Shell Natron
Pressure conditions	:	150 feet in chamber

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	5.7	17.6
Jet flow (open)	3.8	5.6
Jet flow (closed)	3	5.2
Total recirculation	34.5	53
Pressure drop across 1 and 2	2.1	7.1
Pressure drop across 2 and 3	2	5.7
Pressure drop across 3 and 1	0.3	1.2

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum	12.2	26.1
Jet flow (open)	4.8	6.6
Jet flow (closed)	5.2	6.4
Total recirculation	45	61
Pressure drop across 1 and 2	4.2	8.1
Pressure drop across 2 and 3	4	6.3
Pressure drop across 3 and 1	0.7	1.6

VENTURI TEST #12

9 December 1947

Gas used	:	HeO_2 - 19.46% for 25 and 50 lb. runs; 19.28% for 75 and 100 lb. runs.
Distance from jet to mouth of Venturi	:	Flush
Cannister	:	Filled with Shell Natron
Pressure conditions	:	150 feet in chamber
Remarks	:	Pop valve went off at 50 lb. test. 75 and 100 lb. tests made on second run.

Pressure above bottom	25 lbs/in^2	75 lbs/in^2
Vacuum	6.8	17.7
Jet flow (open)	6.8	10.8
Jet flow (closed)	6.6	10.5
Total recirculation	41.2	70.8
Pressure drop across 1 and 2	3	7.3
Pressure drop across 2 and 3	2.7	5.9
Pressure drop across 3 and 1	0.5	1

Pressure above bottom	50 lbs/in2	100 lbs/in^2
Vacuum	11.7	23.3
Jet flow (open)	9.2	12.6
Jet flow (closed)	9	12.3
Total recirculation	63	98
Pressure drop across 1 and 2	4.9	8.8
Pressure drop across 2 and 3	4.3	6.9
Pressure drop across 3 and 1	0.9	1.5

VENTURI TEST #19

17 December 1947

Gas used	:	Air
Distance from jet to mouth of Venturi	:	Flush
Cannister	:	Filled with Shell Natron
Pressure conditions	:	225 feet in chamber

Pressure over bottom	25 lbs/in^2	75 lbs/in^2
Vacuum (open)	6.9	19.6
Jet flow (open)	3.3	5.4
Jet flow (closed)	3.3	5.1
Total circulation	30	51
Drop across 1 and 2	3.1	8.7

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum (open)	13.6	25
Jet flow (open)	3.9	5.7
Jet flow (closed)	3.6	5.7
Total circulation	42	58.5
Drop across 1 and 2	6.3	10.8

VENTURI TEST #20

18 December 1947

Gas used	: HeO_2 - 19.63% O_2
Distance from jet to mouth of Venturi	: Flush
Cannister	: Filled with Shell Natron
Pressure conditions	: 225 feet in chamber
Remarks	: Purged as before

Pressure over bottom	25 lbs/in^2	75 lbs/in2
Vacuum (open)	6.1	19.4
Jet flow (open)	5.4	9.3
Jet flow (closed)	4.5	8.7
Total circulation	33.3	63.5
Drop across 1 and 2	3.4	9.1

Pressure over bottom	50 lbs/in^2	100 lbs/in^2
Vacuum (open)	12.7	23.9
Jet flow (open)	6.6	10.8
Jet flow (closed)	6	10.2
Total circulation	50.4	73.5
Drop across 1 and 2	6.4	11.6

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Officer in Charge Navy Experimental Diving Unit Wash. Navy Yard, Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE DETERMINATION OF TOTAL RECIRCULATION, VACUUM HIGH PRESSURE NOZZLE DISCHARGE AND OTHER GENERAL CHARACTERISTICS OF THE RECIRCULATING SYSTEM OF THE STANDARD U.S. NAVY HELIUM OXYGEN DEEP SEA DIVING HELMET UNDER VARIOUS CONDITIONS OF DEPTH AND VENTURI SUPPLY PRESSURES WITH AIR AND HeO_2 MIXTURES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
FINAL

5. AUTHOR(S) (First name, middle initial, last name)
G. G. MOLUMPHY

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
22 April 1948	39	

8a. CONTRACT OR GRANT NO. b. PROJECT NO. SRD 235/46 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Project Number - SRD 235/46 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
U.S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through Office of Technical Services, Department of Commerce, Washington, D.C.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Navy Experimental Diving Unit Washington Navy Yard Washington, D,C, 20390

13. ABSTRACT