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MONTHLY REPORT

CONFIDENTIAL SECRET

Physical-Chemical and Chemical Engineering Problems
Summary of Progress July 15 to August 15, 1942.

Subsection B-7-B: Oxygen Problems - E. P. Stevenson, Chairman

Problem NL-B-42: Development of Chemicals and Apparatus for Regenerative Production of Oxygen.

Problem AC-12: Manufacture of Oxygen while in Flight for Use of the Combat Crew.

Problem NA-111: Portable Unit for Supplying Oxygen.

Problem NS-116: Portable Unit for Producting Oxygen for Welding and Cutting, and for Breathing Oxygen Aboard Aircraft.

Problem NS-117: Oxygen Producing Apparatus for Repair Ship Installation.

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SALCOMINE

Preparation and Equivalents

A study of the preparation and properties of the parent material Salcomine is continuing in order to improve the capacity, rate of reaction and stability. In addition research is being continued for new materials having improved properties over the parent material.

Research for new materials has included preparation of intermediate materials and the combining of these materials into chelate compounds. Substitutes for salicyaldehyde, the preparation of cyclopentandione-1,2, and its dioxime have been completed. Progress is being made towards the preparation of salicylaldehydes carrying carboxylic acid groups to confer water-solubility on the complex. One of these, salicyaldehyde-5-carboxylic acid, has been prepared. Work is being started on the preparation of 6-substituted salicylaldehydes and 3-alkyl salicylaldehyde. Further work on the -diketones, represented by those of the cyclopentanone and cyclohexanone series already prepared, has been suspended in view of the lack of encouraging behavior of these substances when converted into complexes. In addition to the above a number of other aldehydes have been prepared and incorporated into the chelate compounds.

Substitutes for the amine radical, incorporating properties of complexes containing bis-trimethylene triamine has lead to concentrated efforts on the preparation of further amines of the general type NH_2-X-NH_2 where X is a basic atom or group capable of filling one of the coordinating positions of the metal atom.

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A number of the new chelate compounds have been prepared, both at the University of California and at Iowa State College, some of which having an oxygen capacity of 4 to 6%. However in most cases considerable work needs to be done to increase the speed of absorption or lower the pressure of absorption. In general this will involve a more precise, detailed knowledge of the structural factors influencing both capacity and speed, and a study should be made of the physical and chemical methods available; for example, in addition to the ones being pursued at present the oxidation-reduction potentials might be measured, the chelate-oxygen equilibrium in solution, the absorption spectra, and a number of other chemical studies might be made in an attempt to discover some parallelism between the desired properties whose origins are still obscure in the already more or less well understood properties of these substances.

Some studies were continued on di-(2-hydroxy-3-methoxybenzal)-ethylenediimine cobalt (Co-Ox M). A new and much better activating machine was designed, constructed, and placed in operation. This machine is essentially a rotating drum, vacuum drier and differs from the earlier models in having a large gas exit tube which does not become plugged by the tar which distills from Co-oX M during the activation process. Study has been made of the rate of absorption of water as compared to the rate of absorption of oxygen on this material and the conditions under which water and oxygen are absorbed. It was found that water is absorbed about half as fast as oxygen under the conditions of operation. However, it will be remembered that with the methoxy compound water is removed, and the material thereby activated only at a temperature of 170°C. or higher. Furthermore there is some indication of acceleration of oxygen absorption by the presence of traces of water vapor, but these are largely masked or overcome by the detrimental effects of any great quantity of water vapor.

A study of the preparation of 2,3-dihydroxybenzaldehyde was continued. An entirely satisfactory method of preparing the material was not obtained. Seven attempts were made to ethylate 2,3-di-hydroxybenzaldehyde without success; it appears to be impossible to obtain the homologues of 2-hydroxy-3-methoxy-benzaldehyde from 2,3-dihydroxybenzaldehyde. For this reason work has been continued on the synthesis of 2-hydroxy-3-ethoxybenzaldehyde from pyrocatechol through its mono-ethyl ether and the hexamethylenetetramine-boric acid-plycerol (Duff) synthesis. Although the yields are almost microscopic, sufficient ethoxy compound has been prepared so that the study of its properties, begun last month, can be carried out properly.

The 3-ethoxy derivative of Salcomine has been shown to oxygenate about as rapidly as the methoxy derivative and to be conveniently deoxygenated at a temperature of approximately 85°C. Dehydration of the material also takes place at 85°C. so that it is contemplated that moist air may be used for the absorption inasmuch as any deleterious hydration will be overcome during the process of

deoxygenation; this last feature has not yet been demonstrated, but should it prove feasible, then the advantages of the methoxy compound for speed of absorption without the attendant disadvantages of sensitivity to moisture may be realized.

The rate of oxygenation of di-(3-chlorosalicylaldehyde) dipropylenetriamine cobalt at 5,11, and 32° at 25 pounds pressure and at 5° at 113 pounds oxygen pressure was determined using the differential manometric apparatus. This material was found to be unusual in that it absorbed oxygen rapidly at temperatures much lower than any previously known compound. At room temperature at atmospheric pressure it released its oxygen rapidly. The amount of oxygen carried by the material varied markedly with the temperature being about 0.7 of a percent at 32° and 35 pounds pressure, 3.75 per cent at 11° and 35 pounds, 5.75 per cent at 5° and 35 pounds pressure, and 6.3 per cent at 5° and 113 pounds oxygen pressure.

Further work has been done on the preparation and study of transannular peroxides, particularly the 9,10-diphenylanthracene. Further studies of the effect of solvents on the photooxidation of the hydrocarbon has substantiated previous reports that carbon disulfide is not necessary as a solvent, and it appears from recent experiments that it is not the best. The highest rate of oxidation so far observed has been with mixtures of acetonitrile and benzene as solvents. The photo-oxide may be decomposed with the liberation 90% of the theoretical amount of oxygen by boiling in nitrob enzene for 5 minutes; a clean, clear solution of the parent hydrocarbon is left. Other solutions, such as glacial acetic acid, pyridine, etc., are also being studied inasmuch as the rate of photo-oxidation in nitrobenzene is slow.

It has been suggested on the part of the Rumford Company in the past that 2% of vanadium pentoxide mixed with Salcomine would increase the rate of absorption by as much as 25%. In an attempt to check this at the University of California no such increase in rate was observed in air at atmospheric pressure and 25°C., although possibly the original work was done at much higher pressures and may be obtained under the conditions of higher pressures. It would seem, however, that the effect is largely one of heat transfer rather than a chemical catalytic effect.

An analytical study is continuing of the deteriorated Salcomine. It is quite evident that the deterioration is due to a burning of irreversible oxidation of the molecule, and an effort has been made to take apart the deteriorated material and study the separate components. Hydrolysis of active Salcomine with dilute acid results in the recovery of 96 to 97% of the calculated amount of salicylaldehyde. In a series of runs on the deteriorated material the recovery of salicylaldehyde was 22-25%. In the decomposition of the active material only an insignificant amount of solid residue remained. The residue remaining after the decomposition of the deteriorated material amounted to 25-29%. There is indication that the salicylaldehyde present in the deteriorated

complex is still in combination with the diamine.

The deterioration appears to be a deep-seated oxidation in which a large part of the organic material of the complex has been converted into polymeric material of a higher state of oxidation. Some of the nitrogen has been oxidized to the level of HCN, and some of the carbon is probably lost as CO (known) and CO_2.

Life Tests

A major protion of the experimental work has been directed to a study of the deterioration of the Salcomine material in the 1/2 inch tube units. A large number of tests have been carried out and in a qualitative way they confirm previous indications, although there are some notable differences. However, it has been noted that the experimental results have not been very duplicatable. In other words, runs made in the past month do not check the runs carried out about two months ago. A similar lack of reproducibility had been noted in the single tube unit several months ago. Therefore any comparisons or conclusions are very questionable. The present tests indicate considerably higher rates of deterioration than had previously been obtained. The tests are being carefully checked and further comparisons are being deferred until check results can be obtained in a given test cycle.

A number of runs have been carried out using the methoxy compound supplied by Prof. Diehl and the Rumford Chemical Co. These runs were carried out in the cold room and various types of tubes were employed. These results indicated that with a 1" o.d. tube it was possible to obtain saturations of about 2.0% in 15 minutes with atmospheric pressure air when employing a cold air blast on the tubes at 0 to -20°C. The compound was found to be very sensitive to water as had been previously reported by Prof. Diehl and careful drying of the inlet air was necessary to prevent loss of activity. A larger unit employing a multiplicity of the 1" aluminum tubes is being constructed by Arthur D. Little, Inc. and will be tested in the cold room as soon as it is available.

The methoxy derivative of Salcomine was put through the life cycle test and found to have a life extremely short of the order of 150 to 250 cycles. However, the material after testing was found to contain large amounts of water and on reactivation to have it initial oxygen-carrying capacity of 3.9%. A second study employing the rotating drum apparatus at the Iowa State College indicated that the activity of the compound decreased from 3.9% to 2.5% during the first 1130 cycles of the run.

Equipment has been designed and constructed by duPont for life tests on Salcomine-oil suspensions. It operated between 20° and 105° at two complete cycles per hour. At stated intervals samples are removed, the Salcomine separated from the oil by centrifuging and the solid washed with cyclohexane. The dried Salcomine is then given a standard test for capacity and activity. In

the first test the capacity* after 333 cycles had dropped about 9% and the activity** somewhat more. These figures are preliminary. Improvements in design are being incorporated in two new units now under construction. These units will be operated in parellel at atmospheric pressure, one with dry oxygen, the other with oxygen saturated with water at room temperature. Thus simultaneously information will be obtained as to absorbent life and the effect of water vapor on absorbent life and activity.

A somewhat different test made at the University of California by shaking a 10% suspension of Salcomine in white oil in one atmosphere of oxygen at 100° C indicated that after 7 hours a residual activity of 94% remained; after 15 hours, 87% with no further loss in activity at the end of 30 hours.

Magnetic and X-Ray Measurements

The study of magnetic susceptibilities is going forward, and while the results are not definitive, the observations so far may be interpreted in the following manner. In the solid the cobalt atoms are so arranged that an oxygen molecule cannot be shared between a pair of them. Since, however, they each have three unpaired electrons each one is capable of holding an oxygen molecule albeith not very strongly, hence the relatively high oxygen pressures required. In solution, however, the molecules are free to move about and hence two cobalt atoms can come to share an oxygen atom between them and hold it much more strongly, hence the lower pressures. An attempt to establish this suggestion as fact is being made by all the means at our disposal. Further--a definite knowledge of the effect of substituents and changes in structure on the strength of the cobalt-oxygen bond should make it possible to design a compound in which the oxygen partial pressure over the one-to-one compound in the solid state is not too high.

The X-ray work at the California Institute of Technology continues and it is hoped that a detailed analysis of both the inactive and active forms of the parent compound will aid materially in determining some of the factors which influence the capacity and especially the speed of the absorption, thus enabling a more intelligent design of new compounds to be accomplished. In addition, a study of the lattice as a function of the absorbed oxygen will throw much light on the mechanism of the process. Further, the examination of at least powder photographs of the large group

* Capacity is defined as the total oxygen absorbed to complete saturation, expressed as a percentage weight gain.

** Activity is defined as the per cent weight gain per minute during the period to half saturation.

of compounds now available having varying capacities and speeds should aid very considerably in the recognition of the important structural factors required to produce the desired properties.

Toxicity Tests

The Mine Safety Appliance standard CO analyzer was used in the determination of carbon monoxide in oxygen produced from Salcomine in white oil suspension. The instrument is sensitive to 10 parts/million of CO and probably precise to 2 parts/million. It was found that the CO content from the semi-works oil suspension unit of duPont was less than 40 parts/million, when the absorption temperature is around 20° C. If the absorption temperature be raised to 45°, the CO content of the oxygen rises to 260 parts/million. These are preliminary analyses and the significance of the values is still open to conjecture.

Oil Suspension

Two sets of experiments on the production of oxygen by the use of oil suspensions of Salcomine are in progress, one at duPont and the other at the University of California.

duPont has started work on the design and assembly of a unit larger than heretofore used (about 70 cu.ft. of oxygen per hour) for operation with 30% Salcomine oil suspension. To guide the work on this unit a number of experiments were completed aimed at determining the properties and feasibility of handling 30% Salcomine suspensions. Stirred autoclave tests, although difficult to carry out on a small scale, indicated that the 30% suspensions of Salcomine were not too viscous to be handled in a stirred autoclave, due to higher back pressures of the 30% suspensions in the lines originally designed for handling more dilute material, made measurement of efficiency factors unreliable and made comparison with 20% suspensions on this scale impossible.

Pumping tests through a tower filled with glass Raschig rings (ca. 3/8" O.D.) indicated that the 30% suspension could probably be used in a tower type absorber without running into serious difficulty. Suspensions of the 30% material did not settle measurably on the bottom of a drum on standing several days.

Heat transfer data was obtained which indicated that the effective viscosity for heat transfer was much lower than the apparent viscosity based on measurements with a Parlin cup. Pressure drop data for the 30% oil suspension was also obtained.

In order to obtain oxygen of a purity of 99.5% it is necessary to strip out the nitrogen dissolved in the oil before desorption of oxygen. The nitrogen present in the oil would constitute about 2.5% of the gas volume. In order to avoid serious oxygen losses

the nitrogen was stripped from the oil at low temperatures under vacuum. Tests showed that 80% of the dissolved nitrogen could be removed in 3 minutes at 80 mm. pressure to produce 99.5% oxygen. If the nitrogen were stripped at 1 mm. pressure for 8 minutes 99.8% oxygen night be produced.

Typical dispersion agents were tested to increase the rate of oxygen absorption in the oil-Salcomine suspension, but no detectible effects on the oxygen absorption rate were observed. Some of the dispersing agents caused the precipitation or settling of Salcomine from its oil suspension.

Preliminary tests at the University of California with a 9% suspension of Salcomine in white oil have shown little difference in absorption rates for air pressures of 83 and 117 psi. With an 8 minute absorption time yields of about 4.5 cu.ft. of oxygen per hour per cu.ft. of absorption column were obtained. This may be compared with a figure of approximately 10-12 cu.ft. of oxygen per hour per cu.ft. of column obtained in the duPont apparatus. Very likely an increase from 9 to 30% in the suspension used at the University of California would introduce a considerable increase in the yield of oxygen per cu.ft. of absorption column. The apparatus in use at the University of California differs considerably from the duPont apparatus in the type of absorption equipment used. In the former case a plate column is used, whereas in the latter a stirred autoclave or simple column is employed.

Oxygen Producing Units

Tests upon the 300 cu.ft./hour unit at the Engineering Experiment Station at Annapolis are continuing satisfactorily. The oxygen produced by this unit has been used for the cutting of steel plates of considerable thickness with entire satisfaction. The oxygen used in these cutting tests was at a gauge pressure of 20 psi. and thickness of plate cut was suitable for this pressure; in order to go to greater thicknesses an oxygen pump will have to be supplied and this is not yet available.

Due to some difficulty in manufacture it appears that the first reactor for the 1000 cu.ft./hour shipboard unit will not be ready on schedule so that the unit as a whole will not be ready for preliminary testing before September 1st.

The 1000 cu.ft./hour truck unit employing pancake-type reactors and in which absorption-desorption heat is supplied through a water system will, it is now estimated, be ready for testing around November 15th instead of October 15th as originally thought.

The second portable truck-mounted chemical unit employing tubular reactors will be ready for testing around December 1st. Because of inherent difficulties in the contamination of the Freon with lubricating oil it is now believed that the system employed for this unit will be identical with that of the preceding units.

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namely water for heating and cooling. There is some possibility that a modification of the Freon system might be worked out, but the elimination of contaminating oil with any such system will nullify the saving in power originally contemplated for the use of Freon.

A small unit for producing oxygen on board bombers, utilizing the methoxy derivative of Salcomine, low temperature air at high altitudes for cooling, and engine exhaust gases for heating has been constructed and is on the way out to Wright Field for testing.

Some further estimates have been made on the characteristics of the unit for producing oxygen by the use of oil suspensions of Salcomine which have lead to a guess of 25,000 to 30,000 lbs. for the weight of a unit producing 1000 cu.ft./hour, exclusive of the trailer mount, the required trailer being approximately 30 ft. long and 7 ft. in height above the trailer frame. However, the estimated size and weight are based on the use of readily available, standard equipment and may be reduced somewhat by specially engineered, light-weight equipment. The design and construction of any of the portable units employing oil suspension will be postponed for the moment pending calculation of further engineering data from the pilot plant tests now underway.

OXYGEN PRODUCTION BY MECHANICAL METHODS

Problem No. Ac-12:	The Manufacture of Oxygen while in Flight for use of a Combat Crew.
Problem NA-111:	Portable Unit for Supplying Oxygen.
Problem NS-115:	The Development of Equipment for the Production of Liquid Oxygen Aboard a Submarine.
Problem NS-116:	Portable Unit for Producing Oxygen for Welding and Cutting, and for Breathing Oxygen Aboard Aircraft.
Progress Report:	Final Report, Serial No. 315, OSRD No. 780 on "Analysis of Liquid Air Rectification Cycles" by The Linde Air Products Company.

Rectification Studies

The differential heats of vaporization from oxygen-nitrogen mixtures from 20% to 80% oxygen to yield vapor of an equilibrium composition have been measured.

An integral heat of vaporization corresponding to the process:-

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$$1 \text{ gm. air (liq., } 20.9\% \ O_2, 78.7^\circ K., 1 \text{ atm.}) + q = 1 \text{ gm. air (gas, } 20.9\% \ O_2, 78.7^\circ K., 1 \text{ atm.})$$

was measured. The value obtained in this manner was 48.96 cal./gm. as compared to 49.03 cal./gm. obtained by Dana.

Two heat capacities of liquid air (20.9% O_2) were measured at 75.70°K. and 77.42°K. The values obtained were 0.4331 cal./gm. and 0.4284 cal./gm. respectively.

Apparatus Study

Small laboratory tests have continued on packed columns for the liquification of air, which indicate that Haydite packings are equivalent to Stedman packings and that they are not as good as Berl saddles. In some of the tests a short column of 1/4 inch saddles was used above the Haydite packings to give a distribution of liquid, which distribution is a serious problem in all of these packings.

Two short preliminary runs of 5 hrs. and 12 hrs. respectively have been made upon the 8 inch column packed with 1/4 inch Berl saddle, having vapor velocities of about 0.3 ft. per sec. under total reflux. These data gave a H.T.P. of 10 inches.

One Mond-Ricardo liquifier unit has been received from England and after study and setting up is being tested in Cambridge.

Specimens of the Collins type heat interchangers are in the process of being completed.

Exhaustive tests on regenerative heat exchanges are under way. Many mechanical difficulties have arisen in the operation of the regenerators, such as the breaking of thermocouples, excessive heat leak, plugging of lines with carbon dioxide, scoring of valves, etc. Runs have been made with the entering air saturated at temperatures as high as 100°F. These runs definitely establish the fact that water vapor is removed in a very satisfactory manner and without causing any appreciable increase in pressure drop. There is also evidence, although not conclusive, that carbon dioxide is removed when the temperature is low enough.

Much work still remains to be done on the testing of air drying equipment especially that employing dessicants such as activated alumina, but this program has been held up pending the tests on regenerators.

Oxygen Producing Units

The portable low pressure mechanical unit to produce 1000 cu.ft. of oxygen per hour is going along on schedule with a completion date somewhere in the middle of October. Practically all the

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material has been ordered for this unit. Likewise, a corresponding high pressure unit will, it is hoped, be ready for testing by November 1st. Some modifications have been made in the cooling and refrigerating equipment, but most of the material has been ordered.

Work is still in progress on the 380 C.F.H. portable mechanical unit with all major pieces of equipment on order except the oxygen compressor. It is expected that the oxygen compressor will be completed about October 1st when the air compressor becomes available.

Work is under way in the construction of a small lightweight unit for production of oxygen aboard bombers. The main item in the schedule of this program is the construction of the engine-compressor by the Clark Bros. as noted below.

Work is still in progress on the design and construction on the trailer unit to produce 85 lbs. of liquid oxygen per hour. This is the only small portable unit on our list for the production of liquid oxygen, although other mechanical units may be converted for this production should the necessary extra power be installed.

Submarine Units

The detailing and contracting for the two submarine pilot plants has been put in the hands of the J. F. Pritchard Co., who will work in close cooperation with the Kellogg Company, and at present, heat exchanges are being designed for the medium pressure unit. It is contemplated that a delay of about two months will occur in the delivery of the air compressor for this unit, and certain changes in the plans for the air compressor as described below will hold up the design of some of the heat exchange equipment.

As a preliminary to the testing pilot plants, a study is being made of the removal of carbon dioxide snow by filters of the Cuno type which comprises plates spaced about 0.008 inches apart. Preliminary results indicate that such a filter might be satisfactory although the present spacing of plates is not sufficiently close to remove all carbon dioxide snow formed. In a large scale apparatus with proper design there is a good possibility of operating with no filter except on the final product and no chemical removal of carbon dioxide.

With respect to the unit for conditioning air on submarines, it was originally contemplated to use the Mond-Ricardo equipment in conjunction with the compressor already available upon the submarines, but it is now believed that this liquifying equipment is too small and unsuited for the production of liquid oxygen. Therefore, it is now contemplated to design a unit which will take all of the air from one of the submarine compressors which will be ample for a production of approximately 16 lbs. liquified oxygen per hour with no forecooling. If a compact Freon refrigerating unit is used to provide air precooling at -40° C., oxygen

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production can be raised to about 32 lbs. per hour. Such a small refrigerating unit is readily available from the Servel Company, and it is only a question as to whether the Navy wishes to use space for this unit plus any added inconveniences of operation.

ENGINES AND COMPRESSORS

Problem Nos.: NL-B-42; AC-12; NA-111; NS-115; NS-116; NS-117.

Material is being assembled for the three 200 CFM, 0 to 100 PSI compressors, and these should be assembled and ready for testing early in September.

The detailed drawings on the 0 to 3000 PSI, 100 CFM air compressors for the high pressure truck units (both liquid and gas) have been completed and construction is underway. A tentative delivery date of about the 1st of November appears possible.

The design and construction of two compressors of about 40 CFM capacity and 100 PSI output is underway. These compressors will be adaptations of a four cylinder air cooled airplane engine. One is destined for the oxygen producing bomber unit and the other for the oil suspension salcomine unit. A second low pressure compressor unit for airplane use is now under construction in Cambridge.

The final layout on the 200 CFM turbo compressor has been checked and parts, tools and materials ordered. The exact delivery date has not yet been ascertained.

Present plans with respect to the low pressure submarine pilot plant air compressor is for the use of a first stage 10,000 CFM turbine supplying air at a pressure of 40 PSI and a second stage separately driven rotary compressor handling 2,000 CFM of free air taking a portion of the output of the first stage compressor and delivering this at 105 PSI. This arrangement is proposed to speed the tests at Annapolis of the pilot plant by utilizing a first stage compressor in construction for the Navy without impairing production schedule at the Elliott Company. It is further contemplated that by the time the initial tests of the oxygen producing unit are completed at Annapolis, the first stage compressor for 2,000 CFM will have been completed by the Elliott Company and combined with the second stage now under construction.

A preliminary outline drawing and tentative layouts have been made on the 0 to 600 PSI, 1000 CFM vertical compressor for use with the high pressure submarine pilot plant. This compressor will be a double acting vertical unit having four low stage, one intermediate and one high stage compressor cylinders. The unit has a 12 inch stroke and will operate at 600 RPM.

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Experimental tests on carbon liners for the last two stages of oxygen compressors are underway. The most recent liner is fabricated from an extremely dense carbon and impregnated with silver; to date the results on this arrangement are not yet available.

The first of three reciprocating expansion engines should be assembled and ready for testing by the end of August.

The two expansion engines for the high pressure submarine pilot plant are still in the calculation stage.

Preliminary calculations on a double acting high speed expansion engine unit using air lubricated pistons and piston valves has been completed and the possibilities appear attractive. No immediate steps are being taken toward the actual design and construction of such an engine pending the completion of the low pressure engine compressor now in construction in Cambridge.

Work is progressing on the two rotary expansion engines for the low pressure submarine pilot plant. The efficiency of the Rateau machine for this service is estimated at 72 1/2%, wherein all but very minor losses have been deducted. The efficiency for the Kapitza wheel is estimated at 87%. This latter figure does not include seal loss and turbulence loss in the wheel and minor losses such as slippage and shock losses; the sum of all these losses could be less than 10%. The final design for the Kapitza wheel indicates a diameter of 7 inches running at 21,000 RPM. The final designs on the Kapitza wheel have been checked, and it is estimated that a test machine will be available by the end of September.

UNDERWATER PROPULSION

Problem No.: NL-B-6 - Operations of Diesel Engines on Recycled Fuel and Exhaust Gases.

Tests are still underway on scrubbing carbon dioxide from exhaust gases of Diesel engines and recycling of the scrubbed gas. There appears to be no difference in indicated horsepower or specific fuel consumption when using 100% oxygen with or without water scrubbing. However, when using 95% oxygen and 5% argon with water scrubbing, gains of approximately 10% in both indicated horsepower and specific fuel consumption were obtained. These gains are in line with what would theoretically be expected and are due to the higher C_p/C_v ratio of the recycle gas because of the nitrogen and argon present. From the study made thus far, considering engine performance and oxygen loss only, it would be highly desirable to employ water scrubbing of the recycle gas. Approximately 55 cu.ft. of water per lb. of fuel is the minimum which should be employed in the scrubbing operation.

Preliminary tests are now underway under the direction of the Standard Oil Development Company on the operation on oxygen and fuel with recirculation of exhaust gases of an engine designed by the Von Seggern Brothers somewhat related to the Diesel operation but employing a puddle of fuel in the combustion chamber rather than continuous injection of fuel.

With respect to the disposal of exhaust gases from submarines, the study of orifice sizes has been continued. The total theoretical horsepower and the water rate required for complete absorption of 3800 lbs. per hour of the 85% CO_2-15% O_2 mixture increases as the outlet area increases. The increase is small going to an orifice of 1/8 inches to 1/4 inches, but an increase to 3/8 inches requires an increase of 50% in water rate compared with that necessary for the 1/8 inch orifice, and horsepower is more than doubled. In general the bubble size depends on the diameter of the outlet hole as well as the mass velocity of gas through the hole, and the volumetric ratio of water to gas. Since the bubble size for any fixed gas mass velocity and fixed ratio of water to gas seems to increase as the area of the nozzle outlet increases, it is indicated that the scale should be increased by using a multiplicity of small holes rather than a single large hole. However, where small injector orifices are used, some means of straining the water will be necessary to prevent clogging. This difficulty of clogging may also be overcome by using one 3/8 inch diameter water injector in series with ten orifices, each 1/8 inch diameter. A full scale unit of this description will comprise 55 injectors and 550 orifices and will require a water rate of 1150 gal. per minute for a total theoretical horsepower of 130.

MISCELLANEOUS

Problem NLB-1 (Item f)	Development of an Instrument for the Measurement of Oxygen Partial Pressures.
Problem NA-106:	Development of Oxygen Breathing Equipment and Associated Apparatus.
Item 1:	Development of Oxygen Breathing Apparatus for use with Liquid Oxygen.
Item 4:	Development of Means for Automatically Eliminating Nitrogen in Oxygen Rebreathing Equipment
Progress Report:	Final Report, Serial No. 314, OSRD No. 779 on "Improvements in Instrument for Measuring the Partial Pressure of Oxygen" by Linus Pauling et al.

An adaptation of the Pauling oxygen meter for submarine use has been shipped to the Naval Research Laboratory for testing. It

is designed to indicate the oxygen content of the ambient atmosphere, and will operate even when tilted steeply. A method has been developed for measuring and classifying strung quartz fibers for use in these oxygen meters on a basis of their torsion constants rather than on measured diameters. The new method is to be preferred inasmuch as it is based directly upon the property of interest.

Models of two different types of instruments for converting liquid oxygen to gaseous oxygen at constant pressure upon demand are under construction and testing. These instruments give a very satisfactory supply of oxygen at any rate up to about 300 times the normal evaporation rate from the insulated container. Both instruments are designed to operate in any position (any degree of inversion) and are specifically adapted to operation on board airplanes for supplying oxygen to breathing equipment. Further work and tests are required to fully adapt these instruments to operation in all positions.

No progress has been made upon the development of means for automatically eliminating nitrogen in oxygen breathing equipment.

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