15 November 1935 NRL Report No. P-1216.

NAVY DEPARTMENT

BUREAU OF ENGINEERING

First Partial Report on

Submarine Propulsion Systems

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON DC

Number of Pages: Text - 9 Tables - 2 Plates - 5

Authorization: Bureau of Engineering letter NP14(5-6-W8) of 12 July 1935.

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ABSTRACT

This report considers several possible methods of driving submarines submerged. Of the considered methods, many are of no value, while engineering analysis of others shows that systems can be developed which would make possible the design and construction of submarines having military characteristics greatly superior to the present storage battery submarines. It is concluded that two systems, in addition to the electrolytic gas system now being studied at this Laboratory, warrant development; these are:

(a) The heat-storage system; in this, heat is stored in hot substances and used to generate steam for submerged propulsion;

(b) The Diesel-liquid oxygen system; in this, liquid oxygen is generated and stored for use in driving the Diesel engines submerged.

AUTHORIZATION

1. This study was authorized by Bureau of Engineering letter NP14 (5-6-W8) of 12 July 1935. Pertinent references are listed from (a) to (d).

Reference: (a) Bu.Eng.let.NP14(5-6-Ds) of 18 June 1935.
(b) Mechanical Engineering, 57 469 (1935).
(c) "Dampfspeicheranlagen" (Steam Accumulators) by Walter Goldstern, Berlin: Julius Springer: 1933.
(d) American Society of Naval Engineers, Journal, 42 536 (1930).

STATEMENT OF PROBLEM

2. The military limitations inherent in the present type storage battery propulsion system for driving submarines submerged are widely recognized. Most serious of these limitations are the limited submerged cruising radius and low submerged speed. With the storage battery propulsion system, improvement in the cruising radius must depend upon increasing the capacity in watt-hours and ampere-hours per unit of weight and of space of the battery. Consideration of available information on the possibility of future research developments in storage batteries indicates that only a limited improvement in capacities can be foreseen in the next few years -- too small an improvement to increase materially the military value of submarines. Possible increases in battery capacity of perhaps 20 to 50 per cent can be anticipated, but improvements of the order of 100 per cent in the submerged cruising radius of submarines should be sought. It is therefore desirable to examine the merits of other systems for propelling submerged submarines in the hope of finding a practicable system which would give a greater cruising radius and, if possible, obviate some of the other disadvantages of the storage battery system.

3. In this report a number of systems for submerged propulsion of submarines will be examined. Many of these are at present not feasible, but may become so in the future; others can be dismissed at once as impracticable; but some are considered worthy of further study.

POSSIBLE SYSTEMS OF SUBMARINE PROPULSION

4. The following systems have been suggested:

(a) The del Proposto System. In this the Diesel engine for surface propulsion is used submerged as a compressed air engine operating from compressed air stored in high-pressure tanks. (Plate 1(a)).

(b) The Neff System. In this, too, the surface Diesel engines are used, being fed with Diesel oil and with air from high-pressure compressed air storage tanks. In the early form of the Neff system the exhaust from the engine was forced overboard near the propellers with a resultant wake. In the later modification, exhaust gases were compressed and returned to high-pressure tanks within the submarine. The compressed air tanks were recharged on the surface with Diesel-driven air compressors. (Plate 1(b) and Appendix A).

(c) The Electrolytic Gas System. Internal combustion engines are driven by burning compressed hydrogen and oxygen stored in high-pressure storage cylinders. These cylinders are recharged on the surface by electrolysis of water in high-pressure electrolyzers using current from Diesel-driven generators. The hydrogen and oxygen gases may be stored separately or generated and stored as a mixture. (Plate 2(c))

(d) The Steam Accumulator System. Steam turbines are fed with high-pressure steam from a steam storage tank (steam accumulator). This accumulator is recharged on the surface from an oil-fired boiler (which, of course, also drives the submarine on the surface with the same turbines). (Plate 2(d)).

(e) The Solution Cycle System. This is a modification of the steam accumulator system in which the exhaust steam from the turbine while operating submerged is caught in a "solution transformer", that is, in a concentrated solution of sodium hydroxide (whence the name "soda-boiler").

The high temperature soda boiler is then used to generate steam to drive the turbine. The system is recharged on the surface by refilling the accumulator from an oil-fired boiler and at the same time concentrating the soda solution by evaporation. (Plate 3 and Appendix B)

(f) Fused Solid Storage System. A turbine is driven with steam generated by a heat-storage boiler, the heat being stored in molten salt mixtures or in molten organic substances such as diphenyl oxide. The system is recharged on the surface by remelting the salt mixture (or reheating the organic liquid) with oil heat. (Plate 4(f) and Appendix C)

(g) Hot Solid Heat Storage System. A turbine is driven with steam (or other working fluid) generated by a heat-storage boiler, the heat being stored in hot solid substances. (Plate 4(g))

(h) Liquid Oxygen Diesel System. In this a Diesel engine (or other internal combustion engine) is used, Diesel oil being burned with oxygen stored as liquid oxygen. The exhaust gases -- containing steam, nitrogen, carbon dioxide and carbon monoxide -- are run through a condenser to condense the steam, through a cooler to remove the carbon dioxide, and then to a regenerator in which oxygen from the liquid oxygen storage is added. This regenerated "air" is fed again to the engine. The system is recharged by means of a liquid oxygen plant with Diesel-driven air compressors. (Plate 5 and Appendix D).

DISCUSSION OF POSSIBLE SYSTEMS

5. Some features of these several systems may now be considered, in particular their chief advantages and disadvantages.

(a) The del Proposto System. The outstanding deficiencies of this system are the wake formed by the exhaust air and the very small energy content of compressed air; these make this system valueless.

(b) The Neff System. A submarine using this system was actually built privately and put through trials about 1920. It is said to have shown greatly increased submerged speed and submerged cruising radius over contemporary submarines. This system has the advantage of using the identical power plant for surface and for submerged propulsion. The chief deficiency of the early Neff system was the formation of a wake by the nitrogen and carbon dioxide gases in the exhaust. With modern airplane scouting, this disadvantage is, of course, so serious as to rule out this system. The later Neff system, in which the exhaust gases are stored within the submarine, has the serious drawback of poor weight efficiency -- heavy steel cylinders being required to store the compressed air and the exhaust gases.

(c) The Electrolytic Gas System. It has been stated in the public press that the German Navy has actually built a submarine employing this system. The component parts have been developed intensively in Germany and elsewhere in the last few years. The use of hydrogen in internal combustion engines has been studied by Erren, while the high-pressure electrolyzers have been developed by Noeggarath and others. This system is now being investigated at this Laboratory under authority of reference (a).

(d) The Steam Accumulator System. An elementary form of this system has been used on submarines. It dates back to 1887 when Nordenfelt built a steam submarine. Since then the components of this system have been widely developed and used ashore in Germany. Steam accumulators are used extensively for stand-by and peak-load power production, and turbines having suitable characteristics to give good efficiency from stored steam have been developed. There appear to be no insurmountable obstacles to adapting these components for submarine use.

The advantages and disadvantages of steam for submarine propulsion are well known, largely as a result of British and French experience with their K-class and Dupuy de Lome and Gustave Zédé submarines respectively. Among the disadvantages are the difficulty of insulating the high temperature parts of the system, the difficulty in designing and constructing satisfactory watertight smoke overboard discharges such that they could be secured rapidly and not increase the diving time of the boat, and the dangers inherent in having large quantities of high-pressure steam, especially in a ship subject to machine gun attack. It is believed that the purely engineering difficulties can be overcome.

(e) The Solution Cycle System. The soda-boiler system of submarine propulsion was suggested by D'Equevilley-Montjustin a few years before the World War. It was tested by the German Navy, but the tests were stopped by the outbreak of the war and, so far as is known, have not since been continued.

This system has all of the disadvantages of the plain steam accumulator system with the added disadvantages of the complexity of the soda-boiler. Its advantages are chiefly the increased thermodynamic efficiency, but this increased efficiency becomes less and less as the steam accumulator pressure is increased; with modern steam accumulators the use of the soda-boiler addition is probably not justified.

(f) Fused Solid Storage System. The use of steam accumulators as a means of storing heat requires the use of high-pressure storage vessels which are heavy and dangerous. Several engineers have suggested that it would be better to store heat in molten solid substances at high temperature but at low pressure. In this case the heat is stored as latent heat of fusion (in contrast to the latent heat of evaporation storage with liquids), and as the heat capacity of the material heated to a high temperature. Paralleling the development of steam accumulators for stand-by and peak-load power production in Germany, German engineers have developed fused-salt mixtures for heat storage for emergency power production. The salt mixtures are melted in off-peak-load periods, and then used to generate steam on demand. Suitable salt mixtures having the requisite properties of non-corrosiveness, high latent heat of fusion, non-expansion and solidification, etc., have been developed. The chief disadvantages of this system are the high temperatures used and the difficulty of insulating against them, and the heavy weight of fused salt required. In the United States, organic chemical materials, such as diphenyl oxide, have been widely used.

(g) Hot Solid Heat Storage System. This method was suggested informally to the Bureau of (Steam) Engineering about 1920 by an engineer of the General Electric Company. He contemplated using a large body of refractory material, such as fire brick, which would be heated to a high temperature and, being well insulated, would serve as a heat-reservoir, this stored heat being used to generate steam for submerged propulsion. As the heat capacity of solids is small compared with the latent heats of evaporation and fusion of the substances considered above, high temperatures with the consequent heat insulation difficulty would be required to obtain the requisite weight and space characteristics. The weight and space characteristics would compare favorably with the diphenyl oxide and fused salt storage systems if solids of a maximum heat capacity were used.

(h) Liquid Oxygen Diesel System. This system has the advantage that the same Diesel engine would be used for submerged as for surface propulsion. Further, most of the component parts have been developed to a high degree and are widely used ashore. The production of liquid oxygen aboard ship offers some difficulties, but these are not insuperable, as is indicated by the fact that the U.S. Army has developed portable liquefiers for use in producing liquid oxygen for the Air Corps in high altitude flying. These Army liquid air plants are mounted on motor trucks whose engines supply the power. All of the component parts of this suggested system make use of equipment familiar to chemical engineering unit processes.

It is not known whether this system has ever been tried aboard submarines, but the patent (Appendix D) by the eminent German engineer, the late Fritz von Opel, proves that it is being considered in Germany. The care and detail with which this patent has been drawn up indicate that Von Opel has developed this system to a high degree.

ENGINEERING ANALYSIS OF FEASIBLE SYSTEMS

6. From the above discussion it appears that of the several schemes considered only the following warrant further analysis:

Electrolytic Gas
Steam Accumulator
Fused Solid
Liquid Oxygen-Diesel

Pending completion of the development of the first at this Laboratory, no final decision as to its value can be given. To indicate the possibilities of the other three systems, a sketchy engineering-weight analysis may be made. To do this the engineering weights for propulsion plants for the U.S.S. SHARK will be drawn up. The weights for the Diesel battery system of the SHARK are as follows:

(Generators	~~177,200~~ lbs.	44,200
(Motors	~~130,000~~ "	40,000
Main Engines (and Auxiliaries) (4 engines, 1300 H.P. each)	105,800 "	
Storage Batteries	356,600 "	

Steam Accumulator, U.S.S. SHARK

7. In this, it is assumed that the electric-drive is retained, so that the motor and generator weights remain unchanged. Next, it is assumed that the total weight of the Diesel engines and storage batteries

Diesel engines	105,800 lbs.
Storage Batteries	356,600 "
	462,400 "

is to be used for installation of steam turbines, a steam boiler and a steam accumulator. It appears that a steam-driven submarine would only be feasible if a Velox boiler were used. Taking the best estimates (reference (b)) of weight for such a boiler as 10 pounds per H.P. (complete with auxiliaries) gives a boiler weight for a 5000 H.P. plant:

Velox Boiler 50,000 pounds.

Weight estimates for turbines suitable for use with steam accumulators are not available, although many such have been built. Estimating the turbines to weigh 20 pounds per H.P. gives

Turbines 100,000 pounds.

8. There remains a weight of 300,000 pounds to invest in a steam accumulator. From data given in reference (c), it is estimated that a steam accumulator (300 pounds per square inch initial pressure) of this weight would have a storage capacity of 4500 H.P. hours (assuming no mechanical losses), or an estimated effective storage of 3600 H.P. hours. This is a greater energy storage than the best storage battery at high rates, but is less than a good storage battery at low rates.

9. An outstanding drawback to the steam accumulator is that some 6 tons of hot water must be carried to generate 1 ton of steam. If the remaining 5 tons of water is a charge against the engineering weight of the whole ship, then the steam accumulator does not compare favorably with other storage systems. But if, in a Treaty-limited design, this weight were not counted, the comparison would be less unfavorable. Decision as to suitability of the steam accumulator propulsion system therefore depends in part upon interpretation of the provisions of the London Naval Limitations Treaty.

10. Apart from weight and space considerations, there is no doubt that a steam-accumulator submarine could be designed and built. All of the component parts of the system are in wide use ashore.

11. It may be considered that the figures taken for the weight characteristics of a small steam surface propulsion plant are unduly optimistic. As illustrative of what has been attained in the development of such small plants, the characteristics of a 1600 B.H.P. plant for a German patrol boat may be given (reference (d)). The weight of the complete system, including boilers, auxiliaries, engines, shafting and propellers is about 20 pounds per B.H.P. and the fuel consumption is less than 0.78 pound per B.H.P. Also, the above discussion assumes the use of electric-drive; geared-drive would considerably reduce the estimated weight required.

Fused Solid Heat Storage, U.S.S. SHARK

12. In this, too, it is assumed that the electric-drive is retained and that the Diesel engines and storage battery weights are to be used to install a steam system, the steam for submerged operation being generated in a fused-solid boiler. With the Velox boiler and suitable turbines, there remains a weight of 300,000 pounds to invest in the fused-solid boiler. Thermodynamic data for the fused salts are not available, so the high-boiling organic chemicals so extensively used in heat-transfer operations in the United States will be assumed. Of these, Dowtherm C, a product of the Dow Chemical Company, appears to be most suitable. If this is stored at 800°F, a 300,000 pound boiler would have an ideal storage capacity of about 27,000 H.P. hours, far superior to any storage battery. The heat thus stored could be used at high efficiency in a steam turbine.

13. The oustanding difficulty of this system is that of insulating against the high temperature required for maximum efficiency. With modern Naval heat insulators, this difficulty is not insuperable. Even were lower temperatures accepted, the system would still give a submarine of superior military characteristics. Inherent in all steam plants is, of course, the lower efficiency compared to a Diesel plant. Presumably, therefore, some of the 300,000 pounds weight would be used to increase the fuel supply to compensate for the increased surface fuel consumption.

14. The development of a steam-driven heat-storage submarine propulsion system would make possible the construction of high-surface-speed submarines having long underwater cruising radius. The heat-storage tank could be recharged on the surface in a short time while the submarine was underway at full speed.

15. In this discussion the use of organic materials for heat storage is assumed. It is of interest to note that if 300,000 pounds of metallic aluminum were used for heat storage at 800°F, the ideal storage capacity would be about 15,000 H.P. hours.

Diesel-Liquid Oxygen Drive, U.S.S. SHARK

16. In computing the engineering weights for this system, it is assumed that the present Diesel-electric drive is retained unchanged and that the weight of the storage batteries is available for replacement by a liquid oxygen generating and storage system. It is further assumed that

two main engines totaling 2000 H.P. at a maximum will be used submerged and that the liquid oxygen plant will be of sufficient capacity to recharge a one-hour's full-speed drain in 7 hours.

17. Oxygen Consumption. Assuming .4 pound of oil per H.P. hour, the oxygen consumption at 2000 H.P. would be about 2700 pounds per hour.

18. Oxygen Plant. To recharge a one-hour's drain of 2700 pounds in 7 hours would require a liquid oxygen plant of 200 liters per hour capacity. The estimated weight of such a plant is 170,000 pounds.

19. Oxygen Storage. Liquid oxygen sufficient to run submerged at full speed for 10 hours could be stored in all-metal "thermos-bottle" storage tanks.

Oxygen weight	27,000	pounds
Storage Tank	23,000	"
Total	50,000	"

Of the total (storage battery) weight of 357,000 pounds, there remains a weight of 137,000 pounds for the condensers, heat interchangers, etc. Since these all operate at low pressures, their weights should be low in spite of the large quantities of gas dealt with.

20. This liquid-oxygen system has apparently been developed in Germany. The patent disclosure (Appendix D) by the famous German automotive engineer, the late Fritz von Opel, shows that he had such a full appreciation of the principles and operations involved as could only have been obtained from experimental development.

21. The entire propulsion system is made up of components which are in extensive use ashore and are common in chemical engineering practice. Thus the development work necessary to adapt this system to shipboard use would not be extensive.

22. It may be seen that the liquid-oxygen-Diesel drive makes possible a submarine having a very large submerged cruising radius at high speed, together with the large surface cruising radius which characterizes Diesel plants.

23. The outstanding deficiencies of the system are the long time necessary to recharge the oxygen storage (with oxygen plants in their present stage of development), the possible excessive noise in submerged operation, and the large space required for apparatus to handle the large volumes of exhaust and intake gases (assuming that air and not pure oxygen were used in the engine).

24. To diminish these deficiencies of the oxygen system, it might prove advantageous not to use the Diesels for submerged operation, but to use instead simple gas turbines modeled after the Mark VIII torpedo power plant but burning pure oxygen. It is estimated that a complete engine for 2000 H.P. could be constructed with 2 pounds per H.P., or with 4000 pounds total (the weight of the complete afterbodies of 10 torpedoes, each of which can develop 100 H.P. with air, is 4860 pounds).

Such a power system would use pure oxygen (plus water for cooling the excessively hot combustion gases) and the exhaust would have only about one-fifth the volume of the exhaust from air-operated Diesels.

25. The types of power systems here considered are becoming of increasing interest and importance to engineers. Developments in this field will therefore doubtless be rapid in the future, and will probably be more rapid than will be the improvements in storage batteries. If this proves to be true, then the superiority of these systems for submarine propulsion should be even greater in the future than at present.

26. It appears probable that the submarine of, say, 20 years hence will be driven on the surface and submerged alike by gas turbines which are fed with air on the surface and with oxygen from liquid-oxygen storage submerged. Such a submarine would have an enormous surface and very large submerged cruising radius.

CONCLUSIONS

27. From the above study, it is concluded that there are at least two systems of submarine submerged propulsion the development of which would make possible the construction of submarines having greatly improved military characteristics. The first of these, the heat-storage boiler (probably employing an organic chemical substance for the heat storage medium), would require the use of steam propulsion; the second, the liquid-oxygen system, would require modification of the present Diesel system. The development of both of these systems is feasible and could be done by the present personnel of this Laboratory; in the development of the latter system, the experience of this Laboratory uniquely fits it to undertake the work. It is considered that the engineering development of these systems could best be done by developing pilot plants of, say, 100 H.P. which could be exhaustively tested.

28. The conclusions from the above studies are summarized in Tables 1 and 2. In Table 1 the energy storage for a given space and weight of the several systems is compared, while in Table 2 a rough comparison is given of the characteristics, military and engineering, of the several systems.

29. It is considered that the new systems discussed are not alone superior in military characteristics to the storage battery at present, but that they hold greater promise for future improvement.

30. The liquid-oxygen system is considered of possible importance to the Bureau of Aeronautics. Stratosphere flights, for example, may eventually require the carrying of liquid oxygen for the engine. Presumably the development of power plants for stratosphere flying will tend toward use of gas turbines energized by fuel oil and oxygen stored as liquid oxygen.

RECOMMENDATIONS

31. It is therefore recommended that:

(a) The development of the electrolytic gas storage system (reference (a)) be continued.

(b) The development of a liquid-oxygen power system for a 100 H.P. Diesel engine be undertaken.

(c) Detailed study of the possibilities of heat-storage systems be undertaken in consultation with the Dow Chemical Company (which has developed shore installations of this character).

(d) The development of a heat storage system of 100 H.P. be started.

TABLE 1.

Comparison of Energy Storage Systems

Energy storage for 100,000 lbs. weight

System		Horsepower Hours for 100,000 lbs. weight	Notes
Storage Battery	1 Hr. Rate	950	These figures are for the highest capacity cell tested by the Material Lab., Navy Yard, N.Y. Weight is for bare cells.
	10 " "	1800	
	20 " "	2000	
Steam Accumulator, High Rate		1800	Ideal, no thermal or turbine losses included.
Dowtherm C Boiler 800°F		9000	Ideal.
Aluminum Boiler 800°F		5000	Ideal.
Fuel Oil-Liquid Oxygen		57000	.4 lb. oil per B.H.P. Hr. assumed.

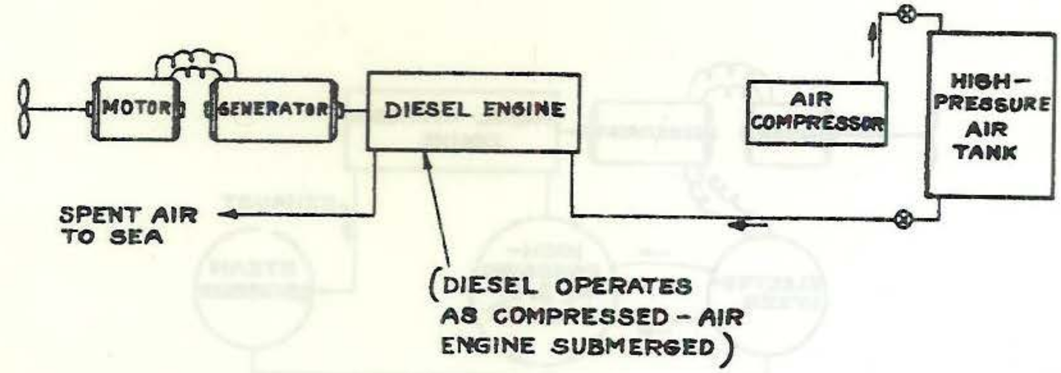
Energy storage for 1000 cubic feet space

System		Horsepower Hours	Notes
Storage Battery	1 Hr. Rate	1500	High capacity cell. Bare cell.
	10 " "	2900	
	20 " "	3200	
Steam Accumulator		1000	Ideal. No losses.
Dowtherm C Boiler 800°F		4500	Ideal. No losses.
Aluminum Boiler 800°F		8100	Ideal. No losses.
Fuel Oil-Liquid Oxygen		38000	Assuming .4 lb. Diesel oil per B.H.P. Hr.

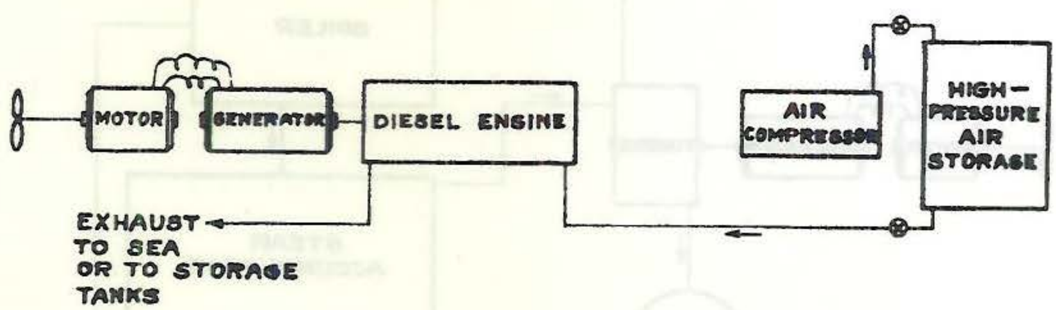
TABLE 2.

Comparison of Characteristics, Propulsion Systems.

	Diesel-Storage Battery	Steam Accumulator	Fused-Solid Steam	Diesel-Liquid-Oxygen
Military Characteristics				
Surface cruising radius	Large	Medium	Medium	Large
Submerged cruising radius	Small	Small	Large	Very large
Time to recharge	Medium	Small	Small	Medium or large
Diving time	Small	Medium to small	Medium to small	Medium to small
Other Characteristics				
Danger to operating personnel	Medium	Large	Small	Medium
Skill required of operating personnel.	Medium	Small	Small	Medium
Ease of detection from noise generation.	Small	Small	Small	Medium to large
Expense - Initial and upkeep	Large	Small	Medium	Medium

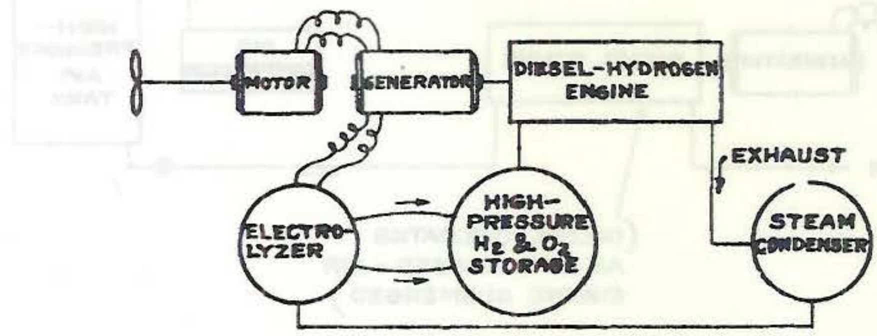

MOTOR
GENERATOR
DIESEL ENGINE
AIR
COMPRESSOR
HIGH-
PRESSURE
AIR
TANK
SPENT AIR
TO SEA
(DIESEL OPERATES
AS COMPRESSED - AIR
ENGINE SUBMERGED)

(a)

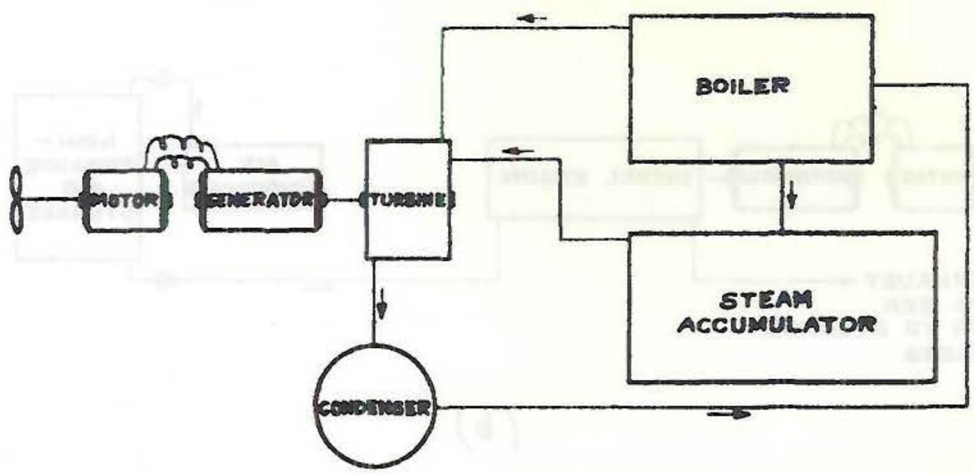

MOTOR
GENERATOR
DIESEL ENGINE
AIR
COMPRESSOR
HIGH-
PRESSURE
AIR
STORAGE
EXHAUST
TO SEA
OR TO STORAGE
TANKS

(b)

PLATE 1

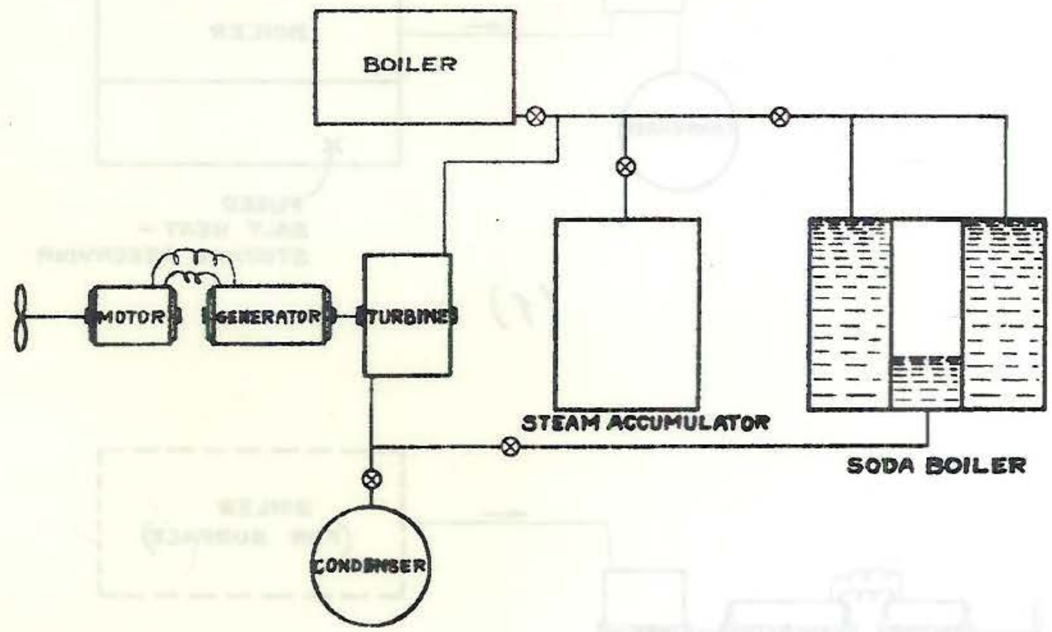

MOTOR
GENERATOR
DIESEL-HYDROGEN ENGINE
EXHAUST
ELECTROLYZER
HIGH-PRESSURE H_2 & O_2 STORAGE
STEAM CONDENSER

(c)


BOILER
MOTOR
GENERATOR
TURBINE
STEAM ACCUMULATOR
CONDENSER

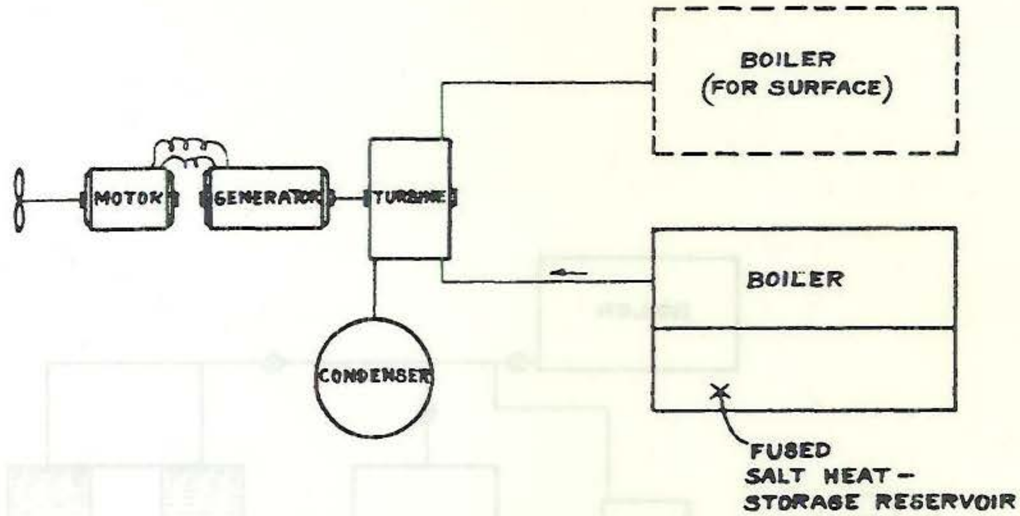
(d)

PLATE 2

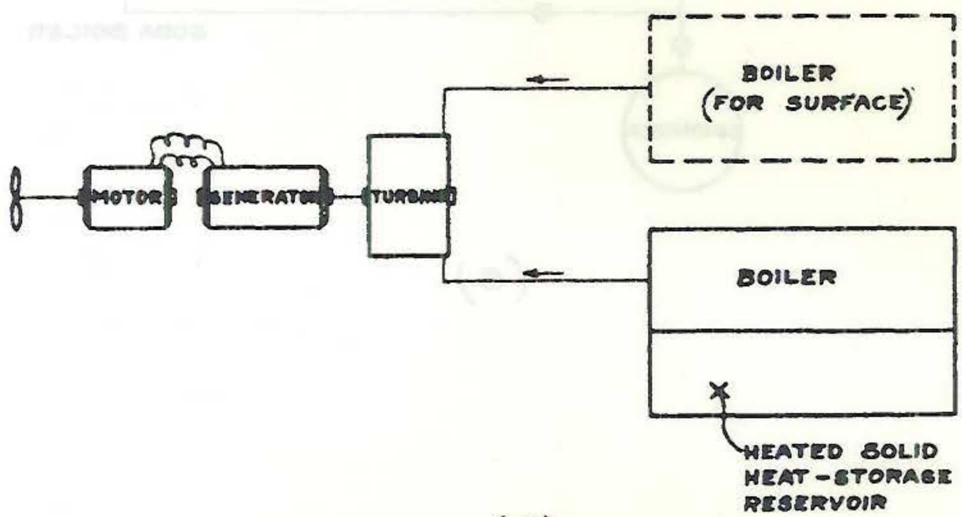

BOILER
MOTOR
GENERATOR
TURBINES
STEAM ACCUMULATOR
SODA BOILER
CONDENSER

(e)

PLATE 3

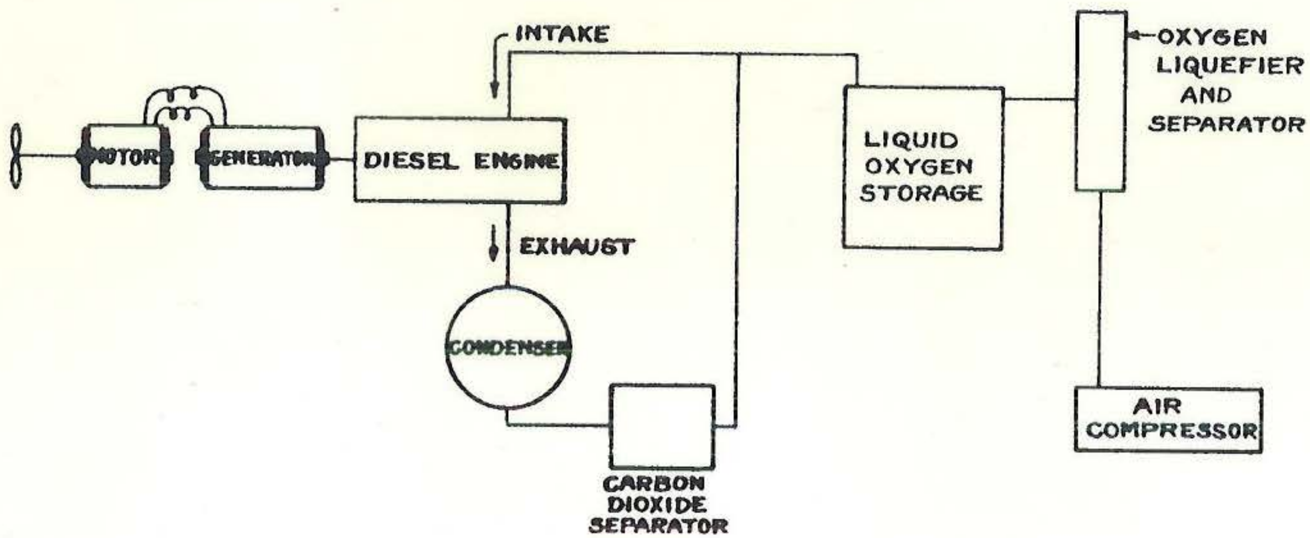

BOILER
(FOR SURFACE)
MOTOR
GENERATOR
TURBINE
BOILER
CONDENSER
FUSED
SALT HEAT-
STORAGE RESERVOIR

(f)


BOILER
(FOR SURFACE)
MOTOR
GENERATOR
TURBINE
BOILER
HEATED SOLID
HEAT-STORAGE
RESERVOIR

(g)

PLATE 4


INTAKE
OXYGEN LIQUEFIER AND SEPARATOR
MOTOR
GENERATOR
DIESEL ENGINE
LIQUID OXYGEN STORAGE
EXHAUST
CONDENSER
CARBON DIOXIDE SEPARATOR
AIR COMPRESSOR

(h)

PLATE 5

APPENDIX A

Aug. 9, 1932. A R NEFF 1,870,263

SUBMARINE

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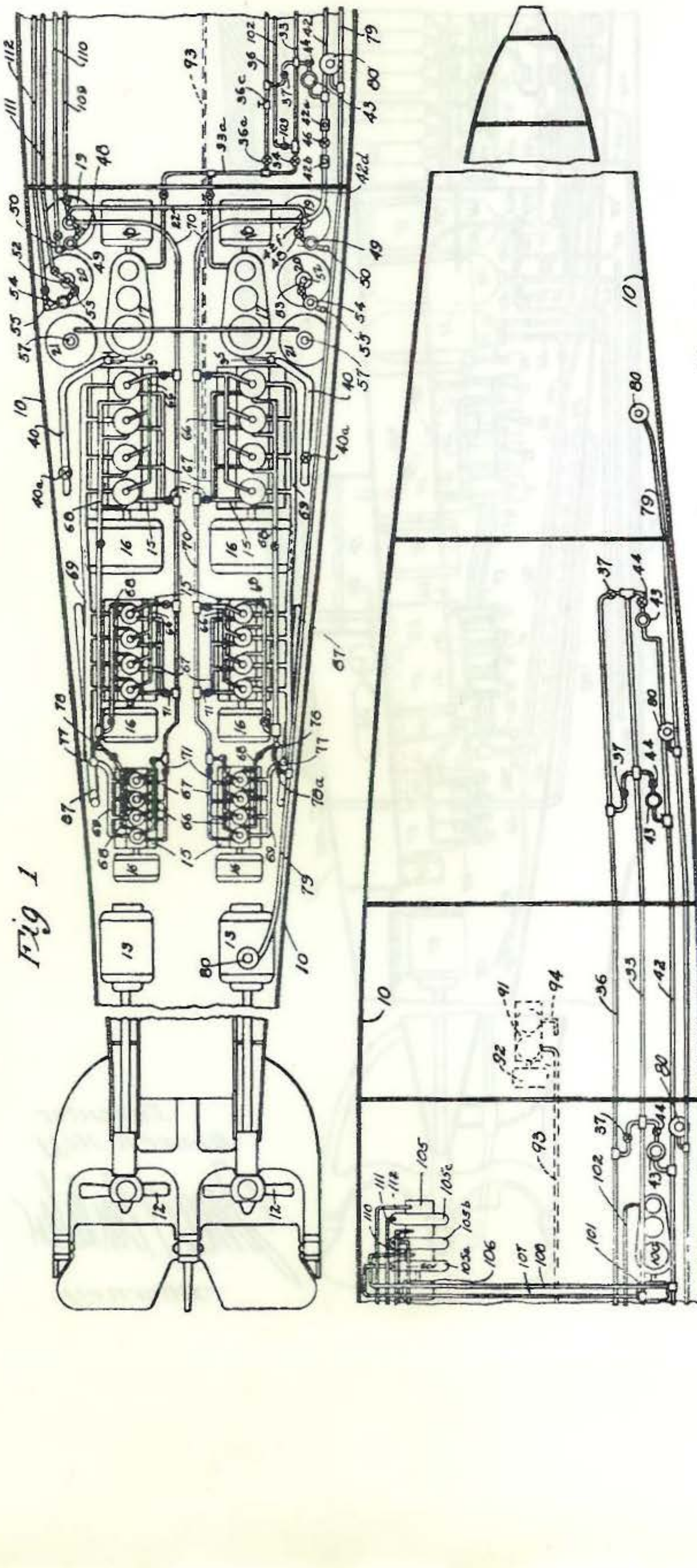

Fig 1

Fig 1a

Inventor
Abner R Neff.

Attorney.

Aug. 9, 1932. A. R. NEFF 1,870,263

SUBMARINE

Filed March 18, 1930 5 Sheets-Sheet 2

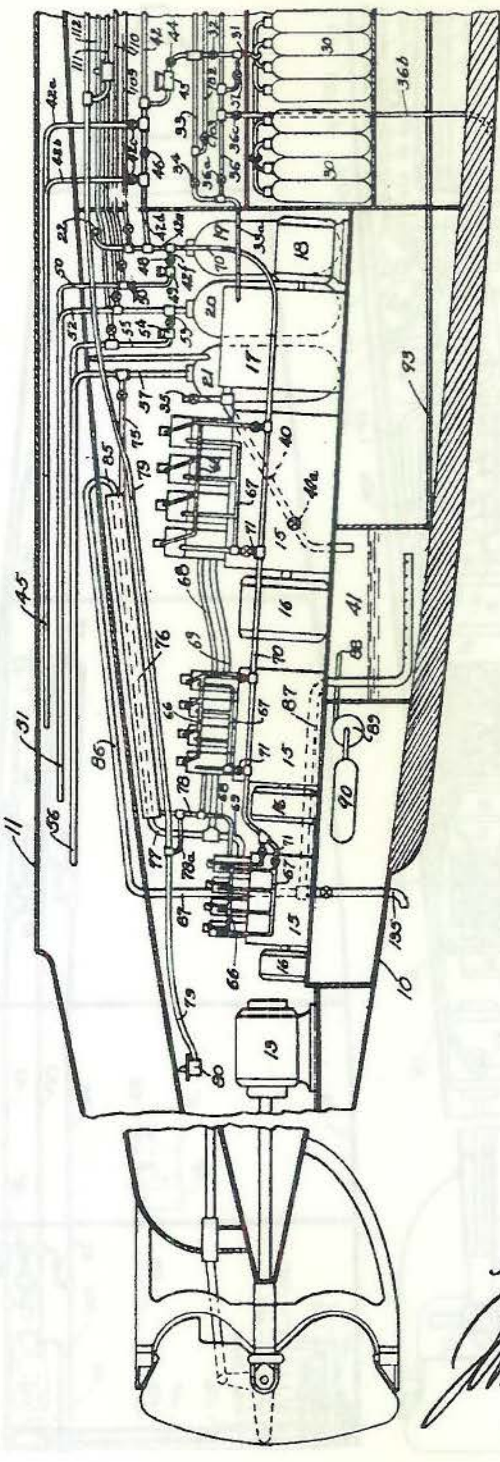

Fig. 2.

Inventor.
Abner R. Neff.

James T. Barkelew

Attorney.

Aug. 9, 1932. A. R. NEFF 1,870,263

SUBMARINE

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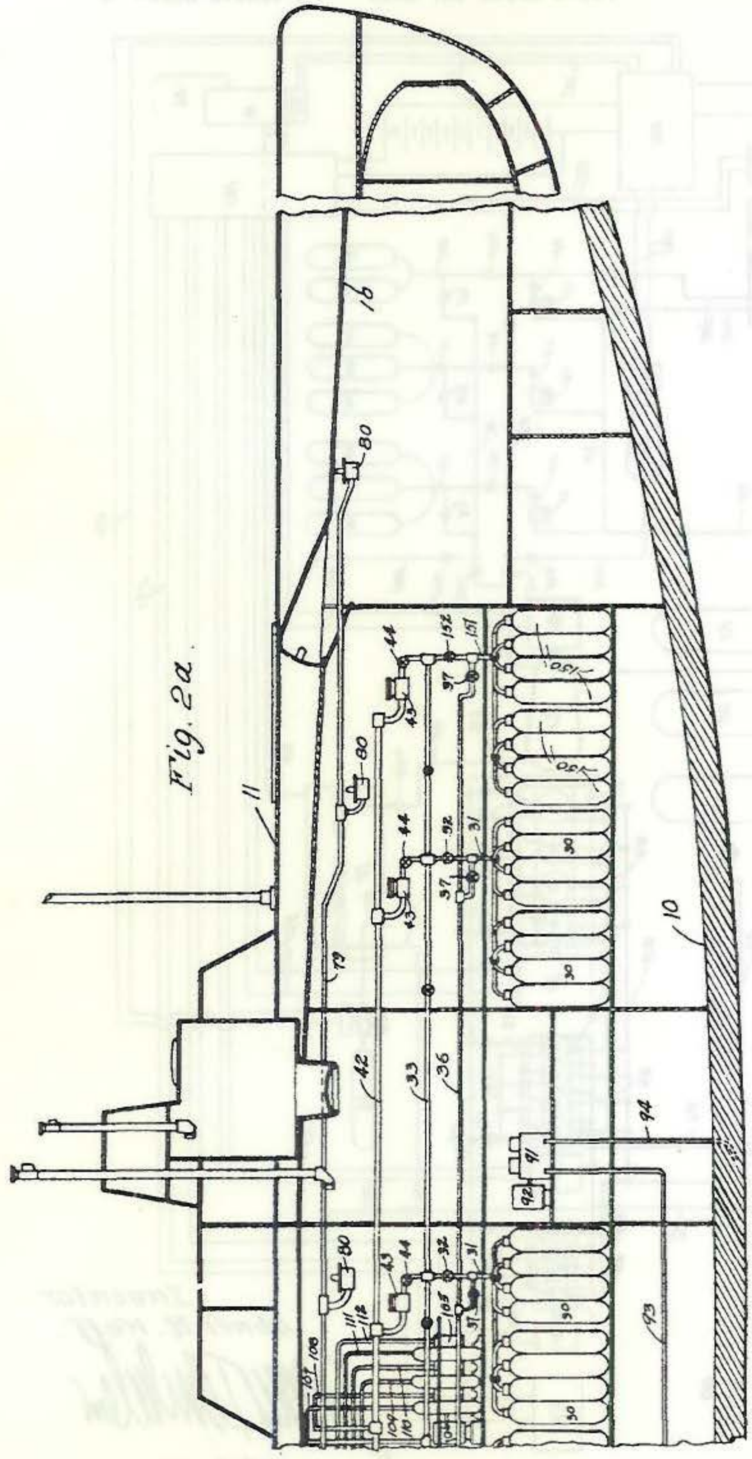

Fig. 2a

Inventor
Abner R. Neff.

[signature]

Attorney.

Aug. 9, 1932. A. R. NEFF 1,870,263

SUBMARINE

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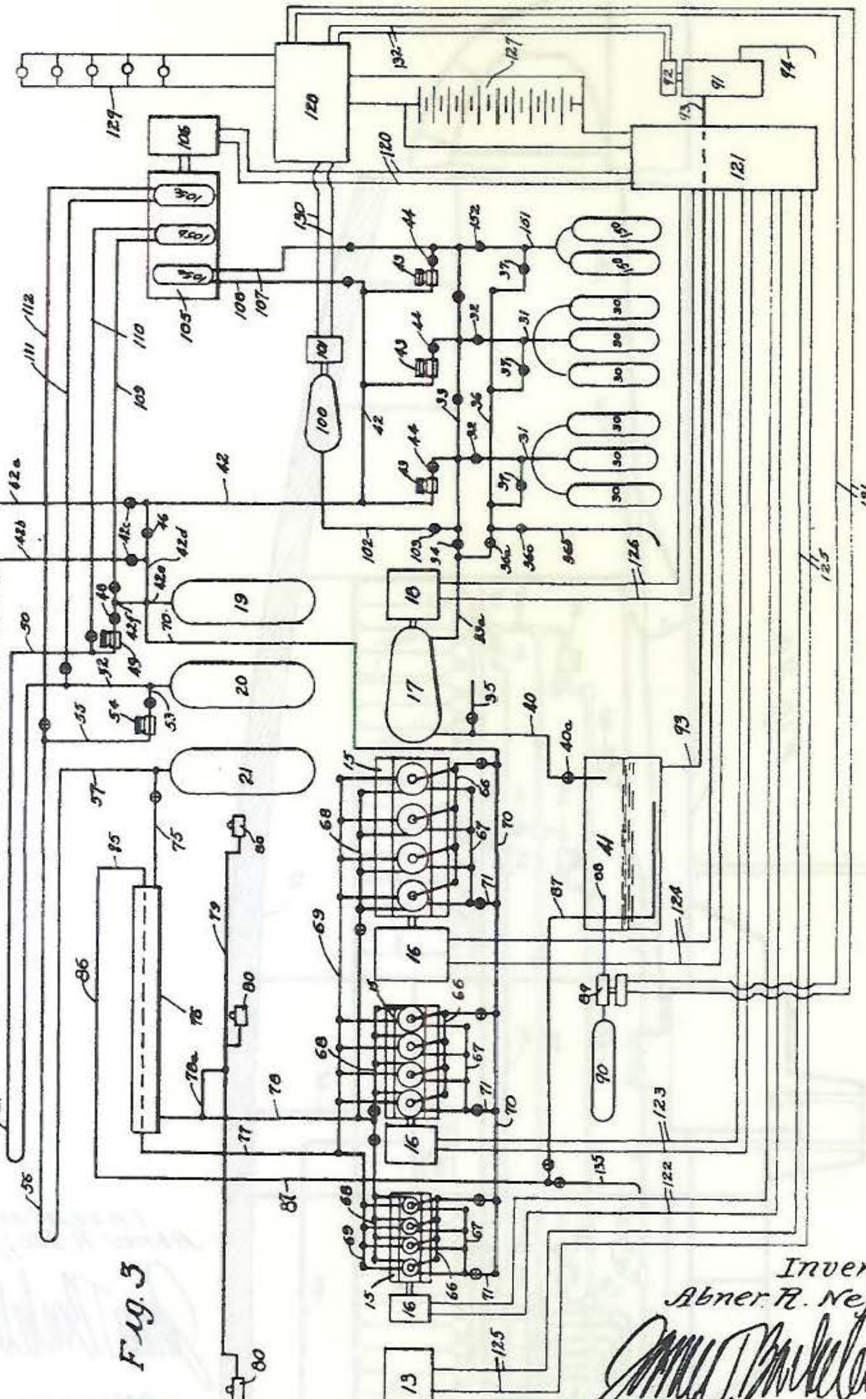


FIG. 3

Inventor

Abner R. Neff.

Attorney.

Aug. 9, 1932. A. R. NEFF 1,870,263

SUBMARINE

Filed March 18, 1930 5 Sheets-Sheet 5

Fig. 4.

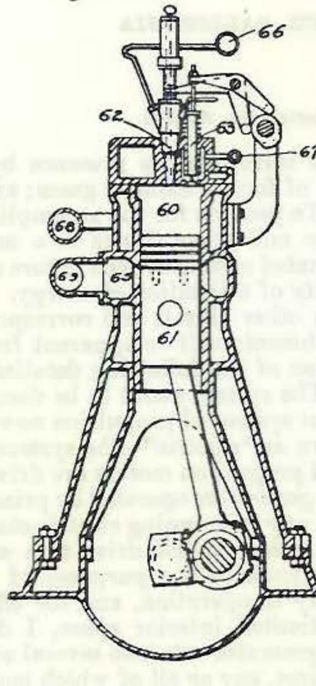
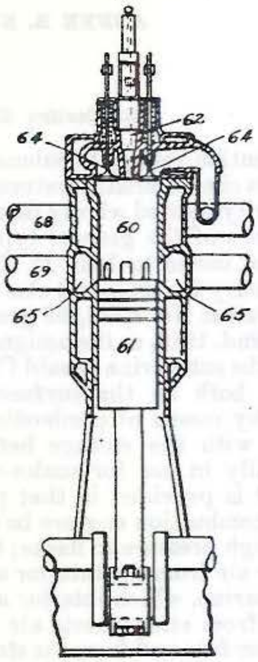


Fig. 5.



Inventor
Abner R. Neff

Attorney

Patented Aug. 9, 1932 1,870,263

UNITED STATES PATENT OFFICE

ABNER R. NEFF, OF LONG BEACH, CALIFORNIA

SUBMARINE

Application filed March 18, 1930. Serial No. 436,705.

This invention relates to submarines, and, in some of its characteristic features, although not necessarily limited wholly thereto, relates to submarines of the general type disclosed in the patent issued to John M. Cage, 1,126,-616, on January 25, 1916, and also of the type set out in Patent No. 1,172,992 granted to me February 22nd, 1916, as the assignee of Allen Hoar. In the submarine of said Cage patent, propulsion, both on the surface and submerged, is by means of combustion engines, dispensing with the storage battery drive now generally in use for under-water propulsion. It is provided in that patent that air for the combustion engines be stored and carried at high pressure in flasks; the engines taking their air from the interior atmosphere of the submarine, which interior atmosphere is supplied from atmospheric air while running at the surface and from the storage while running submerged. The exhaust gases, in the Cage patent, are compressed and expelled overboard by an exhaust compressor operated by the engine.

In the Hoar patent the propulsion is by combustion engines, both at the surface and submerged, as in the Cage submarine. In the Hoar system, however, the exhaust gases, after being cooled and somewhat condensed, are compressed and expelled overboard by using the energy of expansion of the stored air.

In the submarine in accordance with my present invention I utilize both these prior ideas and, among other things, my present invention provides improvements upon those former systems. The present invention, however, contains other improvements in submarines, as will be set out later. Generally speaking, the object of the present invention may be briefly summarized under the following heads:

(1) To improve the efficiency and range of action of submarines which are driven exclusively by combustion engines;

(2) To improve the flexibility of operation and control of such a submarine;

(3) To provide such a system of operation that the submarine can either travel or lie under water for comparatively long periods without betraying its presence by any expulsion of foul or exhaust gases; and

(4) To provide for the accomplishment of all these and other things in a unified and co-ordinated system of such nature as to allow flexibility of utilization of energy.

Many other objects and corresponding accomplishments will be apparent from a consideration of the following detailed description. The system about to be described utilizes that system of propulsion now commonly known as "electric"—the system in which the final propulsion motors are driven directly from generators operated by prime movers, without any intervening electric storage. In adapting this electric drive to a submarine, and particularly for purposes of increased flexibility in operation, and for efficient use of the limited interior space, I divide the engine-generator sets into several sets of different sizes, any or all of which may be used for driving the propulsion motors.

Such division leads both to efficieny and flexibility of operation. For instance it enables very slow speed propulsion of a submarine without the usual very low engine efficiency. It also makes for better propelling efficiency as the propellers are designed for operation only by the propulsion motors, instead of being designed as a compromise for efficiency between operation by propulsion engines and propulsion motors. And at the same time, this division of the power plant into units of different sizes enables the units to be located with high space-using efficiency in the tapering hull of the boat.

In thus utilizing combustion engines exclusively for propulsion power, the present system provides for efficient air storage and for efficient use of the stored air and also of its energy of compression; and also for efficient use of the heat of combustion which otherwise would go to waste from combustion engines. The air is initially compressed to storage by compressor units driven by the combustion engines. On coming out of storage the air is reduced in pressure by stages and is heated by heat exchange with sea water or heat exchange with the engines, at each stage of expansion. The maximum amount of energy of compression is thus kept in the stored air. The air pressure at the several stages may very conveniently be used for Diesel engine operation, such engines being the preferred type of prime mover selected for submarines. Utilizing thus the several stages of air pressure, the necessity of compressor units on the engines themselves is eliminated. In other words, a single compressor unit or compressor plant serves for all purposes in a complete unified submarine system.

To utilize the energy of compression of the air, I prefer to provide an air pressure motor such as an air pressure turbine which drives an electric generator which in turn delivers its output into the common electrical system which feeds not only the final propulsion motors but also all other electrically operated appurtenances of the boat, such, for instance, as the lighting system and the small pumps necessary for ventilation when the submarine is at rest. Thus, by making such arrangement for utilizing the energy of compression, that energy is utilized under any and all circumstances of the submarine.

With this general idea of the system in mind, the invention as a whole, and many other objects and accomplishments, will be best understood from the following detailed description wherein I set forth, in more or less specific details, the preferred and illustrative form of the invention, reference for this purpose being had to the accompanying drawings, in which:

Fig. 1—1*a* is a more or less diagrammatic plan of a submarine equipped with my system; the complete figure being divided into two parts for convenience of illustration;

Fig. 2—2*a* is a similar section elevation;

Fig. 3 is a diagram illustrating the interrelations and interconnections of the various elements in my system. In this diagram piping interconnections are shown in heavy lines and electrical interconnections in light lines; and

Figs. 4 and 5 are vertical sections of a typical Diesel engine unit as may be used in my system.

As the description proceeds it will be noted at various points and as regards various features of the described system, that the invention is not necessarily limited to the particulars described. It may, however, be noted at the outset that the system is not at all necessarily limited to the use of Diesel engines, except in some particulars wherein the system is especially adapted to Diesel engine operation. On the other hand, broadly speaking, any type of combustion prime mover may be utilized.

In the drawings a typical hull is indicated at 10 and a typical super-structure at 11. The hull is divided into several various compartments and, in general, will contain all those compartments, tanks, etc., usual or desirable in a submarine. Such things need no particular description here. The propellers 12 are directly coupled with and driven by the propulsion motors 13, which motors may conveniently be located in the stern of the hull close to the propellers, or, if the propellers be arranged forwardly in the hull, then the motors will in that case be arranged in the forward part of the hull close to the propellers.

In the stern portion of the hull I place the several engine generator units, each of which comprises a Diesel engine 15 and a generator 16. In the present instance, I have shown three such units at each side, with the larger units of each set forward and the small units aft; so as to utilize to fullest advantage the space within the tapering hull. Just forward of the engine units are shown two compressor units 17, each of which may be of any suitable number of stages; and each driven by a motor 18. Alongside these compressor units the air expansion flasks or reservoirs 19, 20, 21, may be situated. These are shown as three in number as I show the air as being expanded in three stages. Of course any suitable number of stages may be used for air expansion; I merely indicated here three as being typical and suitable.

The propulsion motors, engine generator sets and compressor units, so far described, as well as the air expansion flasks, are arranged in duplicate sets for purpose of symmetry and utilization of space. But an explanation of operation of a single set suffices for both, and so only a single set is shown in the diagram of Figure 3. To combine the two oppositely arranged sets of expansion flasks into a single operating unit, the two flasks 19 may be cross connected by the pipe shown at 22 in Figures 1 and 2.

In any suitable location in the hull, the several banks of air storage flasks may be located. For instance, these flasks are shown at 30 in Figures 2 and 2*a*; and they are shown as interconnected in groups or banks, each bank being connected by a pipe 31, controlled by valve 32, with the high pressure air line 33. This high pressure air line has a branch 33*a* leading to the high pressure outlet of compressor 17, and is controlled by a valve 34. Through this connection air may be compressed at suitable high pressure (say 3000 or more pounds per square inch) into the flasks. The compressor units take the air for this purpose from the interior atmosphere of the submarine, the valve controlled inlet of the compressor being shown at 35 in Figures 2 and 3.

It will be noted that the high pressure air line 33 is so connected to the several banks of air flasks that any one or more of the banks may be put into communication with the high pressure line either for compressing air into the flasks or for releasing air from any selected set of flasks. Paralleling the high pressure air line 33 is a high pressure exhaust gas line 36; and a valve controlled connection is made at 37 between this high pressure exhaust gas line 36 and each of the connections 31 to the several banks of flasks; and thereby this high pressure exhaust gas line may be put into communication with any selected one or more of the banks of flasks. This high pressure exhaust gas line, controlled by a valve 36*a* connects into the high pressure air line extension 33*a*; so that, by proper manipulation of the high pressure air control valve 34 and the high pressure exhaust control valve 36*a*, compressor 17 may be connected so as to compress air or exhaust gas into either the high pressure air line 33 or the high pressure exhaust line 36. The high pressure exhaust line 36 has a branch 36*b*, controlled by a valve 36*c*, leading overboard. And the inlet of compressor 17 not only comprises the atmospheric valve 35 but also a connection pipe 40, controlled by valve 40*a*, and which communicates with the exhaust tank 41 for the purpose of taking up the condensed residue of exhaust gases when it is desired to compress them into any of the air flasks.

Paralleling the high pressure air line 33 is a first reduction air line 42, which line is in communication with high pressure line 33 through communications which include reducing valves 43 and shut-off valves 44. There may be one such reducing valve communication from the high pressure to the first reduction line for each bank of air flasks. The reducing valves will reduce the pressure typically from the high pressure to a first stage pressure of say 800 pounds per square inch.

The first stage air line 42 has branches 42*a* and 42*b*, controlled by valves 42*c*, leading to an outboard coil 45 in which the expanded air is heated by heat exchange with sea water, the outboard coil being located exterior of the hull and within the super-structure. A valve 46 is located in the air line 42 and between the branches 42*a* and 42*b* so that, by proper manipulation of the valve 46 and the valves 42*c*, air may be passed through the outboard coil, or not, as desired.

After passing the outboard coil 45, the first stage air line extends on, as at 42*d* and has a connection at 42*e* with the first reduction tank 19 which acts as a reservoir for the first stage air. Then this first stage air line 42 also has a connection 42*f*, controlled by the valve 48, to a reducing valve 49. From the reducing valve a connection 50 leads to an outboard heating coil 51, and from this coil 51 a connection 52 leads to the second stage tank 20.

From the connection 52 a valve controlled branch 53 leads to the reducing valve 54 which has connection at 55 with the third outboard heating coil 56; and from this third coil a connection 57 leads to the third stage air tank 21.

The pressure in the second stage tank 20 may typically be 200 pounds per square inch and the pressure in the third stage tank 21 may be typically about 5 pounds per square inch. The air in each of these three stage tanks and their interconnected pipe systems will have been at least to some extent warmed by heat exchange with sea water; so that the energy of compression at each stage is kept as high as possible or practicable.

As I have indicated before, the several stages of expansion may preferably be selected so as to suit the operation of a Diesel engine, and to do away with the necessity of having special compressor units on the engine. Though this system is particularly adapted to and is described with a 2 cycle engine, it will be appreciated that it may be adapted, by making minor changes, to a 4 cycle engine, as well as any type of combustion engine, and still be within the spirit of my invention.

For instance in Figures 4 and 5 I show a unit of a Diesel engine wherein the cylinder is shown at 60, the piston at 61, the injector valve at 62, the starting valve at 63, the scavenge valves at 64 and the exhaust at 65. The injection air manifold is indicated at 66, the starting air manifold at 67, the scavenge air manifold at 68 and the exhaust manifold at 69; and the piping connections are correspondingly indicated in the diagram of Figure 3. The fuel injection air will be operated at the first stage pressure of say 800 pounds; and so a branch line 70 leads from the first stage line at 42*e* to feed air at that pressure to the injector system of the several engine cylinders. Air at this same pressure is used for starting operations, and so branch connections are indicated in the diagram of Figure 3 at 71 to communicate air from the fuel injection air line 70.

Air from the third stage at approximately 5 pounds pressure is used to feed the engine scavenge. For this purpose the air is led from the pipe line 57 through pipe 75 and then through a heat exchanger 76 through which the exhaust from the several engines is passed by exhaust communicating pipes 77 as indicated in Fig. 2. And the low pressure air, leaving the heat exchanger via line 78 communicates with the scavenge air manifolds 68 of each engine. Also in communication with this low pressure air line 78 at 78*a* is a line 79 which leads to reducing valves 80 to discharge air into the interior of the hull to keep up the proper atmospheric pressure there.

The exhaust gases, after leaving the heat exchanger 76 by way of pipe 85, first pass through the outboard cooling coil 86 which acts as an exhaust condenser to cool and condense the exhaust gases as far as is practicable by cooling with sea water. As a result of this condensation a considerable amount of liquid (mostly water) is produced, and the exhaust gas residue is also reduced in volume. The condensed and contracted exhaust then passes by pipe 87 into the exhaust tank 41, where the pipe leads under the level of the liquid which may be maintained in the tank, so that the gases are washed. Also to wash the gases and carry down any suspended liquids or solids, a spray may be introduced into the tank at 88. A small motor operated spray pump is shown at 89 which takes its liquid from a small tank 90. The tank may contain water or any other liquid, or any chemical which by reaction with the exhaust gases tends to condense or liquefy them. The accumulated liquid in the exhaust tank may be pumped out by the bilge pump 91 operated by a motor 92, a piping connection from the tank to the pump being shown at 93, and a line leading overboard from the pump at 94.

Under ordinary running conditions the exhaust gas residue is taken from the exhaust tank 41 through the line 40 to compressor 17, and is forced out at the requisite high pressure from the compressor through the high pressure exhaust line 36 through exhaust line 36*b* overboard. If at any time it is desired not to pass any exhaust gases overboard, for purposes of concealment, the valves 36*c* in exhaust line 36*b* may be closed and the exhaust then compressed into the high pressure exhaust line 36 and, by proper manipulation of the valves 37 compressed at high pressure into any selected bank or banks of the air flasks which at that time do not contain air. It will be readily understood that, in order to provide for storage of exhaust at any time during the submarine operation, at least one bank of the air flasks must be at all times empty of the air and ready to take the exhaust. To take additional exhaust storage while running submerged, other banks of air flasks will be emptied of their contained air fast enough to be ready to take exhaust storage as banks are filled up with exhaust.

When the wide range of rates at which the compressor 17 will handle exhaust gases is considered, the importance of being able to operate the compressor over a wide range of speed independently of the engine speed becomes apparent, especially since the maximum speed required will undoubtedly be greater than the speed at which fresh air is compressed and this variable speed of compressor operation not only has reference to compressing exhaust, but also to forcing it directly overboard as elsewhere explained. In such case exhaust condensation may be partially or wholly disregarded and the compressors operated at high speed to expel the gases.

When it is subsequently desired to release the stored exhaust gases, that can readily be done by simply connecting the proper air flask banks with the high pressure exhaust line 36, and connecting that line with the exhaust line 36*b*, when the exhaust will be expelled overboard under the pressure of storage in the flasks. The relatively small residue of exhaust left in the flasks at the low final pressure may be cleaned out by subsequently pumping air into the flasks and then discharging. The flasks are thus cleaned for subsequent reception of their compressed air charge.

Interior ventilation of the submarine is, of course, effected by the compressor 17 when air is being compressed into the air flasks; because the compressor takes its air from the submarine interior. The compressor, however, is only operated to compress air when the vessel is on the surface and atmospheric air is entering. It is, however, used to compress exhaust, at least at certain times, when the boat is submerged; and during those periods the compressor 17 may be used for drawing foul air from the interior and compressing it along with the exhaust gases by somewhat opening the air intake 35 of the compressor so that a proportion of air from the interior will be taken in for compression along with the exhaust from tank 41. This is true also whenever the compressor 17 is compressing exhaust gases overboard. So that, whenever the vessel is running submerged, and the exhaust gases are being compressed either into the flasks or overboard, the compressor 17 may be used to draw off interior air and thus cause ventilation.

At times when the vessel is at rest submerged, and the engines are not being operated and it is thus not desirable to operate the air compressor or compressors 17, ventilation may be effected by a smaller compressor 100 operated by a motor 101. This compressor has its intake from the submarine interior and compresses through a high pressure line 102, controlled by valve 103 to the high pressure air line 33, and thus to the flasks. Seeing that compressor 17 and compressor 100 need not at any time be operated simultaneously, the high pressure air line and its distribution system to the flask banks may thus be utilized to compress and store the foul air from the compressor 100 in any selected bank or banks; to be subsequently released just as exhaust may be released. Or, if so desired, this compressed foul air may be subsequently released back through the high pressure air line and through the reduction systems, to be used, along with other air, in the engines and thus go into the engine exhaust which is ultimately stored or pumped overboard. The thorough ventilation of the submarine interior is thus provided at all times.

Just as the compressed foul air may be fed back to the engines, so compressed exhaust may be selectively fed back to the engines with a proportionate amount of pure air, or with a proportioned amount of oxygen which may be supplied from a special oxygen storage 150 which is shown connected into high pressure line 33 by pipe 151 controlled by valve 152. In average Diesel engine operation the oxygen content of the air is not completely consumed; and re-use of such once used air, either mixed with other air or oxygen, makes it possible in emergencies to maintain engine operation longer than can be otherwise.

In order to utilize the expansion energy of the stored air or other pressure stored gases, I may employ a turbine 105 which may preferably comprise three steps 105*a*, 105*b* and 105*c* (as many steps as there are in reduction of air pressure), and this turbine may conveniently drive a generator 106 which is connected into the general electrical system of the submarine. It is preferred to utilize a turbine of multiple stages in order that as nearly as possible the full expansive energy of the air or gases may be utilized. Thus the first turbine stage 105*a* may be connected by a line 107 to the high pressure air line 33, and its exhaust may go by line 108 to the first stage air line 42. Similarly the second turbine stage 105*b* will be connected by lines 109 and 110 between the first stage air line 42 (through the lines 22) and the second stage connection 50; and the third turbine stage 105*c* be connected by lines 111 and 112 between the second stage air line 52 and the third stage connection 55.

Suitable valvular arrangements are included whereby the air in its several stages of expansion may be passed in any proportion desired either through the turbine stages or through the several stage reducing valves; and in each case the exhaust connections of the turbine stages are made so that the expanded exhaust gases will pass through the several outboard heater coils 45, 51 and 56; so that, so far as the expansion of the air is concerned, the turbine stages perform exactly the same functions as are performed by the pressure reducing valves.

The turbine operated generator 106 has its output line 120 connected into the main electrical system so that this generator output may be flexibly utilized for any power purpose. For instance, in the diagram of Figure 3 the switchboard represented at 121 takes the output of all the generators 16, through their output lines 122, 123 and 124, and the output of generator 106 through its output line 120; and from this switchboard run the feed lines 125 to propulsion motor 13, and 126 to compressor motor 18. Also from the switchboard a small storage battery 127 may be fed; and another switchboard 128 is illustrated as being fed from the storage battery lines, which last mentioned switchboard controls the smaller electrically operated elements and those which may want to be operated at times when none of the generators are necessarily in operation. This, for instance, includes the lighting circuits 129, the compressor motor 101 which is fed by line 130, the spray pump motor 89 which is fed by line 131 and the bilge pump motor 92 which is fed by line 132. The storage battery for these purposes need not be very large—in fact it may be quite small as compared with the storage battery size necessary for storage battery propulsion of a submarine.

When the submarine is being propelled, one or more of the prime mover engines is, of course, being operated, with the propulsion motors directly energized from the generator or generators then in operation. For normal propulsion on the surface the engines simply exhaust overboard, either by operation of compressor 17 to raise the low pressure required for that purpose, or by direct exhaust overboard. For direct exhaust overboard a valve controlled branch 135 may lead from exhaust line 87. Accordingly, while running on the surface none of the auxiliary machinery need be operated unless it is desired to charge the air flasks, when compressor 17 will be operated.

Normally all of the air flasks will be preferably kept charged with air in readiness for submergence, excepting a single bank of flasks. If the boat is submerged and there is no immediate necessity for concealment, the engine exhaust is simply forced overboard by operation of compressors 17. Air from the flasks is released for interior ventilation and for engine operation; and foul air from the interior may be removed also by compressors 17 as long as the propulsion engines are operated.

Then if it becomes necessary to conceal the exhaust, that may be compressed at high pressure into any empty flask bank and, as has been before indicated, such storage of exhaust may continue as long as the vessel is capable of running submerged, because there are always air flasks available for exhaust storage as they are emptied of their air charge for engine operation.

In case the vessel is at rest submerged, then ventilation compressor 100 is utilized as hereinbefore described to remove foul air and compress either overboard or into empty air flasks, replenishing air being released from the air flasks.

Whenever, in any of these operations air is released from the high pressure storage, the air pressure turbine 105 may, of course, be operated. When the submarine is being propelled in submergence, the turbine opermay be selectively directed overboard or to the pressure storage means.

10. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a Diesel type internal combustion engine utilizing air at two different pressures for its operation, air storage means, a compressor energized from the engine and adapted to compress air into the storage means, and means for discharging air from the storage at reduced pressures and feeding the air at such reduced pressures to the engine.

11. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a Diesel type internal combustion engine utilizing air at two different pressures, a plurality of air storage units, a selective piping system selectively connectible with the storage units, a compressor adapted selectively to take air or engine exhaust and compress into the selective piping system, and means for discharging air and exhaust from the piping system at reduced pressures and feeding the air at such reduced pressures to the engine.

12. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a Diesel type internal combustion engine utilizing air at two different pressures, a plurality of air storage units, a selective piping system selectively connectible with the storage units, a compressor adapted selectively to take air or engine exhaust and compress into the selective piping system, and means for discharging air and exhaust from the piping system at reduced pressures and feeding the air at such reduced pressures to the engine, and oxygen storage selectively connectible with the selective piping system.

In witness that I claim the foregoing I have hereunto subscribed my name this 17th day of February 1930.

ABNER R. NEFF.

ated generator 106 adds a considerable amount of electrical energy for propulsion purposes, or for compression of exhaust, or for any of the various other purposes for which power is required. Such utilization of the pressure energy is thus very flexible and is not confined to any one particular purpose. For instance, although thus the compression energy may be utilized for exhaust compression, it is not necessarily utilized for that purpose but may be utilized for propulsion or for any other power purpose. And one particularly advantageous result flowing from this flexibility of power use is in this; that even when the submarine is at rest submerged, and only a small amount of stored air is being released for ventilation, the corresponding small amount of energy, utilized through turbine 105 and generator 106 will be sufficient to supply a large proportion of the power required by compression motor 101 even if the foul air is being stored in flasks at high pressure. By compressing the foul air overboard, or by storing it in the flasks at something less than the high pressure of original air storage, the turbine generator set 105, 106 may be made to supply substantially all the power necessary for lighting and small power purposes and for the compressor motor 101; so that in such manner the submarine may lie concealed as long as its stored air will suffice for ventilation.

I claim:

1. In a submarine, the combination of a hull and a propeller therefor, a propulsion power plant including a combustion engine, air storage units, a compressor, intake means for the compressor whereby it may take either air or engine exhaust for compression, and a piping system connecting with the air storage units and whereby the compressor may compress either air or exhaust into any selected storage unit.

2. In a submarine, the combination of a hull and a propeller therefor, a propulsion power plant including a combustion engine, air storage units, a compressor, intake means for the compressor whereby it may take either air or engine exhaust for compression, and a piping system connecting with the air storage units and whereby stored air may be released from any selected storage unit for feeding the combustion engine.

3. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a combustion engine, a compressor adapted to take either air or engine exhaust for compression, air storage units, a piping system selectively connectible with any of the air storage units and with the compressor, an air discharge piping system leading from the selective piping system to the combustion engine and to the hull interior, and a second compressor adapted to compress air from the hull interior into the selective piping system and thereby into any selected storage unit.

4. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a combustion engine, means for cooling and condensing the exhaust from said engine, and means for compressing and storing said exhaust under pressure.

5. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a combustion engine, means for cooling and condensing the exhaust from the said engine, a compressor having intake arrangements to take either air or the condensed exhaust for compression, air storage units, a selective piping system capable of being selectively connected with any of the air storage units and with the compressor, whereby either air or condensed exhaust may be compressed or stored in any selected storage unit, and means for feeding air to the combustion engine from the selective piping system.

6. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a combustion engine, means for cooling and condensing the engine exhaust by heat exchange with sea water, and means for compressing and storing the condensed engine exhaust under pressure.

7. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a combustion engine, means for cooling and condensing the engine exhaust by heat exchange with sea water, a compressor, a plurality of air storage units, a selective piping system selectively connectible with any of the storage units and with the compressor, whereby condensed exhaust may be stored under pressure in any selected storage unit, and means for feeding air from the selective piping system to the combustion engine.

8. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a combustion engine, a compressor energized from the combustion engine and having an intake adapted selectively to take either air from the hull interior or the engine exhaust, pressure storage means, and means connecting the compression side of said compressor either to the exterior of the submarine or to pressure storage means.

9. In a submarine, the combination of a hull and a propeller therefor, a propulsion plant including a combustion engine, a compressor energized from the combustion engine and having an intake adapted selectively to take either air from the hull interior or the engine exhaust, pressure storage means, the second compressor energized from the combustion engine and having its intake from the hull interior, and means whereby the compression side of both said compressors

APPENDIX B

R. D'EQUEVILLEY-MONTJUSTIN.

METHOD OF GENERATING STEAM FOR SUBMARINE BOATS.

APPLICATION FILED MAY 12, 1909.

986,373. Patented Mar. 7, 1911.

2 SHEETS—SHEET 1.

Fig. 1.

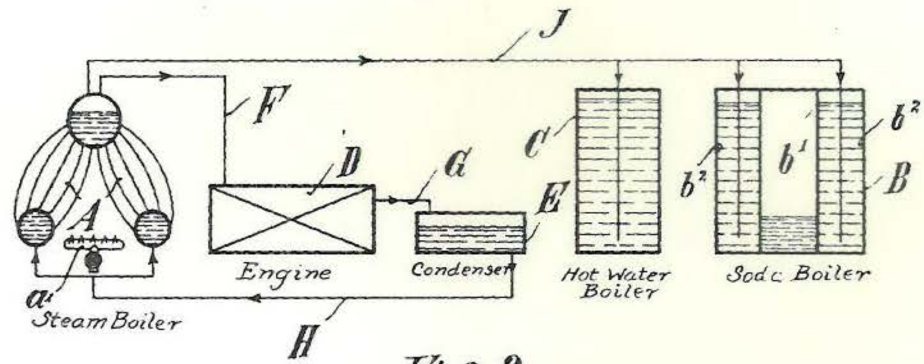


Fig. 2.

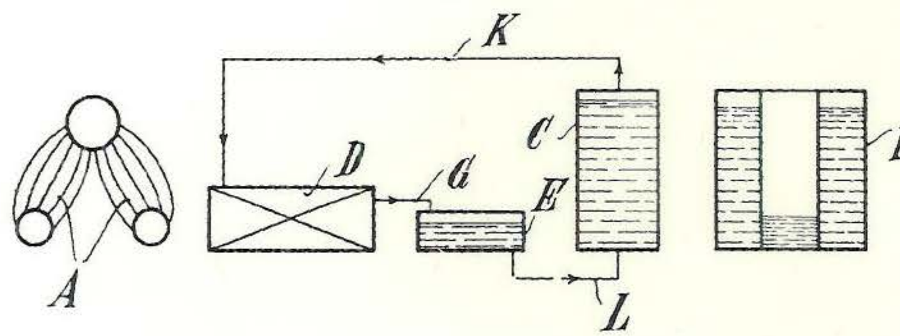
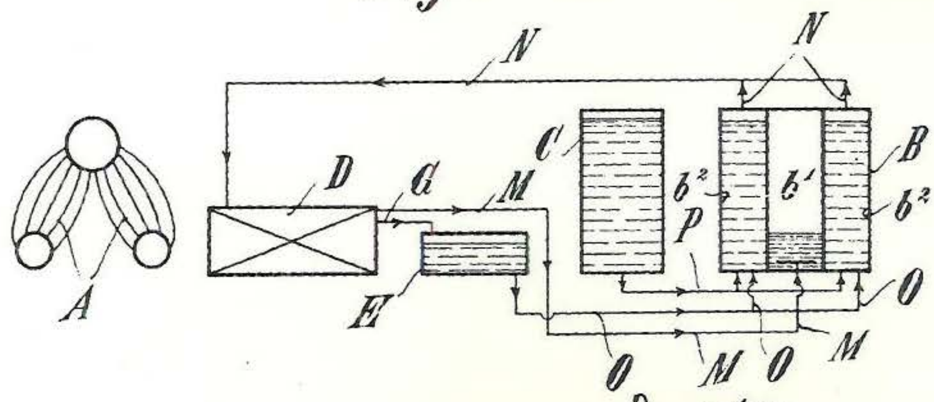


Fig. 3.



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R. D'EQUEVILLEY-MONTJUSTIN.

METHOD OF GENERATING STEAM FOR SUBMARINE BOATS.

APPLICATION FILED MAY 12, 1909.

986,373. Patented Mar. 7, 1911

2 SHEETS—SHEET 2.

Fig. 4.

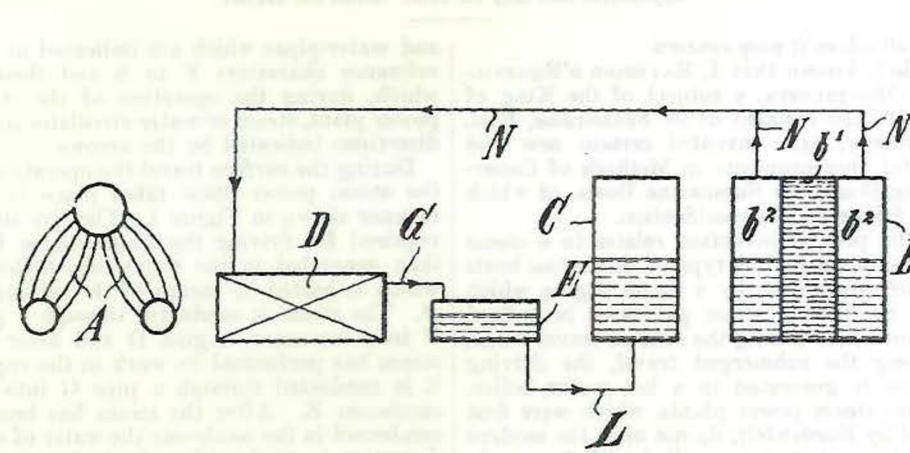
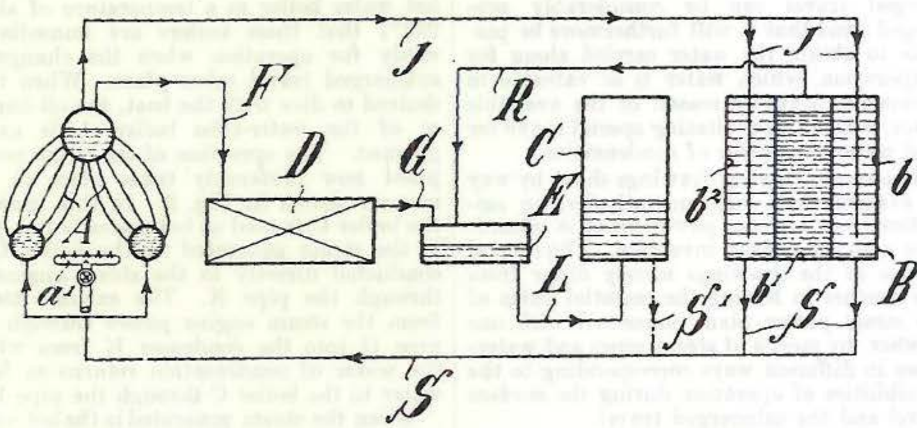


Fig. 5.



Witnesses
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UNITED STATES PATENT OFFICE.

RAYMOND D'EQUEVILLEY-MONTJUSTIN, OF KIEL, GERMANY.

METHOD OF GENERATING STEAM FOR SUBMARINE BOATS.

986,373. Specification of Letters Patent. Patented Mar. 7, 1911.

Application filed May 12, 1909. Serial No. 495,491.

To all whom it may concern:

Be it known that I, RAYMOND D'EQUEVILLEY-MONTJUSTIN, a subject of the King of Spain, and resident of 94 Feldstrasse, Kiel, Germany, have invented certain new and useful Improvements in Methods of Generating Steam for Submarine Boats, of which the following is a specification.

The present invention relates to a steam power plant for the type of submarine boats which are driven by a steam engine which has its driving steam generated in a fired steam boiler during the surface travel while, during the submerged travel, the driving steam is generated in a hot water boiler. These steam power plants, which were first used by Nordenfelt, do not meet the modern requirements to be complied with for a submarine boat in as far as the hot water boiler alone can only give off steam for a comparatively short time so that travel under water can only take place for a short time.

The object of the present invention is to improve this type of steam power plants and the process of operating the same in such a manner that the duration of the submerged travel can be considerably prolonged; and that it will furthermore be possible to obtain the water carried along for evaporation, which water is so valuable in submarine boats by reason of the available space, without necessitating special tanks for feed water and water of condensation.

The accompanying drawings show, by way of example and diagrammatically, an embodiment of a steam power plant in accordance with the present invention. The several figures of the drawings merely differ from one another in having the essential parts of the steam power plant connected with one another by means of steam-pipes and water-pipes in different ways corresponding to the possibilities of operation during the surface travel and the submerged travel.

The steam power plant mainly consists of the following parts: a water-tube boiler A which can be heated by means of an oil-burner a^1; a soda-boiler B which is divided into a compartment b^1 for a solution of caustic-soda and two compartments b^2 for water to be evaporated; a hot water boiler C; a steam engine D and a condenser E. These parts of the steam power plant are connected with one another in the manner shown in the several figures by means of steam-pipes and water-pipes which are indicated by the reference characters F to S and through which, during the operation of the steam power plant, steam or water circulates in the directions indicated by the arrows.

During the surface travel the operation of the steam power plant takes place in the manner shown in Figure 1. The live steam required for driving the steam engine D is then generated in the water-tube boiler A which is heated by means of the oil-burner a^1. The steam is conducted through a pipe F into the steam engine D and after the steam has performed its work in the engine it is conducted through a pipe G into the condenser E. After the steam has become condensed in the condenser the water of condensation is conducted as feed-water to the water-tube boiler A through the pipe H.

Prior to the change to submerged travel a part of the live steam generated is conducted through the pipe J into the hot water boiler C and into the water-compartments b^2 of the soda-boiler, whereby the contents of the hot water boiler and of the soda-boiler is brought to such a temperature (the hot water boiler to a temperature of about 200°) that these boilers are immediately ready for operation when the change to submerged travel takes place. When it is desired to dive with the boat, the oil-burner a^1 of the water-tube boiler A is extinguished. The operation of the steam power plant now preferably takes place in the manner shown in Fig. 2. In this instance the boiler C is used as hot water boiler, that is the steam generated in the boiler C is conducted directly to the steam engine D through the pipe K. The exhaust steam from the steam engine passes through the pipe G into the condenser E from which the water of condensation returns as feed-water to the boiler C through the pipe L.

When the steam generated in the hot water boiler C is not any longer of sufficient tension I proceed to the operation of the soda-boiler as illustrated in Fig. 3. The exhaust steam from the engine is not any longer conducted exclusively to the condenser E but a part of the exhaust steam is conducted through the pipe M into the soda-solution in the compartment b^1 and is absorbed by the solution. The solution is thereby heated and gives off its heat to the water in the compartments b^2 and generates live steam in these compartments. This live steam is then conducted through the steam-pipe N into the steam engine D.

As experience has demonstrated that the heat in the soda-boiler, especially at the start of the operation, increases to a considerable extent and as the capability of absorption of the soda-solution decreases with the increasing temperature, the water of condensation, which is formed from the part of the exhaust steam of the machine conducted to the condenser, is, especially at the start of the operation, conducted through the pipe O into the water compartments b^2 of the soda-boiler. This fact enables the operator to regulate the temperature of the water to be evaporated and therefore also the temperature of the soda-solution in such a manner that the capability of absorption of the soda-solution remains approximately the same. During the operation the feed to the water-compartments b^2 takes place from the boiler C through the pipe P and in this instance the boiler C is used in its second capacity, viz. as feed water receptacle for the soda-boiler B. The provision of special feed water tanks is therefore made unnecessary.

If, after a protracted submarine travel, the dilution of the solution caused by the absorption of the exhaust steam from the engine has caused the level of the soda-solution to become so high that the solution completely fills the compartment b^1, or if before that time the dilution of the solution has reached such an extent that the soda-solution is not any longer capable of absorbing any steam, the duration of the submerged travel of the boat can be further prolonged by using the method of operation illustrated in Fig. 4. This method consists in the further utilization, to the greatest practicable extent, of the heat present in the soda-solution for the generation of live steam in the water compartments b^2. The live steam is conducted to the engine D through the pipe N as in the mode of operation shown in Fig. 3. However in the method according to Fig. 4 the exhaust steam from the engine D is not any longer conducted into the soda-solution, but it is conducted exclusively into the condenser E. The water of condensation is now conducted through the pipe L into the boiler C and is stored therein. The boiler C then serves in a third capacity, viz. as a receptacle for the water of condensation so that the provision of special tanks for the water of condensation is made unnecessary.

On the change to surface travel the burner a^1 is again put into operation. The method of operation shown in Fig. 5 is then first made use of and serves to once more put the soda-boiler B and the hot water boiler C in condition for operation. The live steam required for driving the steam engine D is in this instance again taken from the water-tube boiler A and is conducted through the pipe F to the engine D whence the total exhaust steam passes through the pipe G into the condenser E. Simultaneously herewith another part of the generated live steam is conducted from the water-tube boiler A through the pipe J into the water compartments b^2 of the soda-boiler B, whereby the diluted soda-solution is evaporated, and in order to facilitate the evaporation the compartment b^1 for the soda-solution is placed in communication with the condenser E through the steam-pipe R. The water of condensation which is formed in the condenser E from the exhaust steam of the steam engine D and from the steam arriving from the compartment b^1 is conducted to the boiler C which serves as tank for the water of condensation and which in that manner becomes gradually refilled, the amount of the water in the boiler C having become greatly decreased during the operation according to Fig. 3. The surplus of hot water resulting from the introduction of live steam through the pipe J into the water compartments b^2 is conducted as feed water through the pipe S into the water-tube boiler A or in the opposite direction through the pipe P (Fig. 3) into the boiler C (Fig. 3); when the boiler C is sufficiently refilled the water-tube boiler A may be supplied with water therefrom through the pipe S^1. When the soda-solution has become sufficiently concentrated by the evaporation and when the boiler C has become sufficiently refilled I once more revert to the method of operation shown in Fig. 1 (the cycle A D E A).

Having thus described my invention and what I claim as new therein and desire to secure by Letters Patent is:

1. In the method herein described for propelling vessels of the submarine type which consists in using a fired steam boiler to propel the vessel during surface travel, using a hot water boiler to generate steam during submerged travel, and using a soda boiler in connection with the fired steam boiler to supply the necessary steam generating power upon the exhaustion of the hot water boiler, and in conducting the heated water remaining in the hot water boiler to the soda boiler as feed water, whereby to prolong the submerged travel.

2. In the method herein described for propelling vessels of the submarine type which consists; first, in using a fired steam boiler to propel the vessel during surface travel; second, in conveying steam therefrom into a hot water boiler for generating steam to be utilized during submerged travel; and third, in the utilization of a soda-boiler wherein a part of the exhaust

steam from the engine is conducted into the soda solution for generating live steam, while the remaining portion of the exhaust steam after condensation, and after reduction to a lower temperature than the water in soda boiler, is introduced therein for keeping within permissible limits the undesirable increase of heat in the soda boiler, whereby to prolong the duration of operation of the soda boiler.

3. In the method herein described for propelling vessels of the submarine type which consists; first, in using a fired steam boiler to propel the vessel during surface travel; second, in conveying steam therefrom into a hot water boiler for generating steam to be utilized during submerged travel; third, in the employment of a soda boiler having its soda compartment connected with the exhaust of the engine and adapted to generate the necessary steam power upon the exhaustion of said hot water boiler generating means; fourth, in discontinuing the use of the soda boiler means when the increasing dilution causes the soda solution to completely fill its receptacle or makes it incapable of further absorption; fifth, in then conducting the exhaust steam aforesaid into a condenser and thence storing the same in the hot water boiler aforesaid; and sixth, in utilizing the heat remaining in the soda solution for generating live steam in the water compartment of the soda boiler until the heat of the soda boiler is practically exhausted.

4. In the method herein described for propelling vessels of the submarine type which consists; first, in using a fired steam boiler to propel the vessel during surface travel; second, in conveying steam therefrom into a hot water boiler for generating steam to be utilized during submerged travel; third, in the employment of a soda boiler connected with the aforesaid means and adapted to supply the necessary steam generating power upon the exhaustion of said hot water boiler generating means; fourth, in conducting the heated water remaining in said hot water boiler to the soda boiler as feed water, whereby to prolong the submerged travel; and fifth, in conveying the water of condensation from the fired steam boiler during the next surface travel, to the hot water boiler for utilization during the next submerged travel.

5. In the method herein described for propelling vessels of the submarine type which consists in using a fired steam boiler to propel the vessel during surface travel, supplying a hot water boiler with live steam direct from the fired steam boiler to quickly generate steam therein for submerged travel, using a soda boiler in connection with the fired steam boiler to supply the necessary steam generating power upon the exhaustion of the hot water boiler, and in conducting the heated water remaining in the hot water boiler to the soda boiler as feed water whereby to prolong the submerged travel.

The foregoing specification signed at Paris, France, this 21st day of April, 1909.

RAYMOND D'EQUEVILLEY-MONTJUSTIN.

In presence of—

DEAN B. MASON,
JOHN BAKER.

Patented Dec. 18, 1934 **1,984,369**

UNITED STATES PATENT OFFICE

1,984,369

HEAT CARRIER FOR HIGH TEMPERATURES

Karl Gensch, Berlin, Germany, assignor to Gesellschaft für Drucktransformatoren (Koenemann-Transformatoren) G. m. b. H., Berlin, Germany, a corporation of Germany

No Drawing. Application May 24, 1933, Serial No. 672,734. In Austria May 30, 1932

8 Claims. (Cl. 252—5)

The invention relates to a heat carrier for high temperatures for indirectly heated plants. While I prefer the illustrative salt melt embodiments disclosed herein, which are particularly desirable because of their cheapness and effectiveness, my invention contemplates, and my preferred embodiments are illustrative of, such like substances as will be suggested to the skilled chemist by my present specification. A salt melt consisting of zinc chloride and several other metal chlorides which form double salts with zinc chloride, was found to suit very well the aforesaid purpose.

Chiefly a melt is used which contains approximately 75% zinc chloride, 10% sodium chloride, and 15% potassium chloride. This melt has all properties which are required from such a heat carrier, e. g. low melting point, high boiling point, good heat transfer, low viscosity, high specific heat, low specific weight; and last but not least it is very cheap. Besides it does not attack iron, is not combustible, not explosive, and does not form any explosive mixtures with other substances. The composition being as stated above, the melting point ranges approximately at 180° centigrade. If the melting point is desired to be lower, it can be reduced to approximately 140° centigrade by adding other salts such as lithium chloride and ferric chloride. Compared to other heat carriers known so far, the above heat carrier offers the following advantages.

It is much cheaper than any metal melt. Metals with low melting point, such as mercury or bismuth alloys, cost approximately from ten to twenty Reichsmarks per kilogram. Their specific weight amounts approximately from 10 to 13. The chloride melt can be supplied at a price of one half Reichsmark per kilogram and has a specific weight of approximately 2. The metallic filling of an apparatus would cost approximately 100–260 times as much. Even if comparatively cheap metals, such as lead and zinc, are used, the filling still would cost approximately four times as much. Now, the melting point of these metals ranges above 300 centigrade, and this fact renders operation conditions so difficult that these metals can not be used. Also the high coefficient of expansion and the good conduction of heat of the metals in the solid state are of disadvantage. When the solid metals are heated they expand very much before getting liquid; consequently, the apparatuses are stressed to such an extent that they are liable to burst. Furthermore, the high specific weight of the metals has the disadvantage that if a high apparatus is used the lower parts of it are subjected to a considerably high hydrostatic pressure. Finally, several metal melts, e. g. molten zinc, attack iron very much.

Oils having high boiling points, and other organic liquids, e. g. diphenyl oxide, can not be used at temperatures over 400° centigrade. Up to the present no organic liquids are known which are stable above this temperature. They decompose, incrust the heating surface, especially in the highly loaded tubes, and then these tubes burn through.

Compared to other salt melts, the above heat carrier has the special advantage that it is very cheap. Zinc chloride, sodium chloride, and potassium chloride are by-products of very low price. Further the above heat carrier has such a low melting point that it can be melted by heating it by steam of customary pressure, e. g. 15 atmospheres. Besides it contains neither water nor oxygen; therefore it does not attack iron even at high temperatures and cannot form any explosive mixtures with other substances, e. g. with coal, as is the case with nitrate melts.

The above heat carrier can be used especially in the chemical industry and in the oil industry, in other words everywhere where heating at high temperatures is involved, and where the products, e. g. oil or other substances very sensitive to high temperatures, have to be treated as gently as possible.

In the field of generation of high pressure steam, indirect heating by means of the above heat carrier offers great advantages. Under these conditions, the feed water treatment is not such an important factor because scale incrustations can only result in reducing the heat transfer, in other words in a decrease of efficiency; but never can they result in boiler explosions.

I claim:

1. An indirect heating system employing as the heat carrying medium a molten mixture of metal chlorides, predominantly consisting of chloride of zinc, and including substantial quantities of metal chlorides of the class consisting of alkali metal chlorides and chlorides having similar effect in the molten mixture, the medium thus constituted having a melting point substantially below that of chloride of zinc.

2. An indirect heating system employing as the heat carrying medium a molten mixture of chloride of zinc and other metal chlorides forming with chloride of zinc double salts existing in the molten mixture, the medium thus constituted having a melting point substantially below that of chloride of zinc.

APPENDIX C

3. An indirect heating system employing as the heat carrying medium a molten mixture approximately 75% chloride of zinc, 15% chloride of potassium and 10% chloride of sodium.

4. An indirect heating system employing as the heat carrying medium a molten mixture of approximately 75% chloride of zinc, 12% chloride of potassium, 8% chloride of sodium, 5% chloride of lithium and 5% chloride of iron.

5. An indirect heating system employing as the heat carrying medium a molten mixture preponderantly chloride of zinc, and containing sufficient alkali metal chloride to impart to the mixture a melting point materially below that of chloride of zinc.

6. An indirect heating system employing as the heat carrying medium a molten mixture comprising preponderantly chloride of zinc, and containing sufficient metal halide of the class consisting of potassium-, sodium-, lithium-, and iron-chloride to impart to the mixture a melting point materially below that of the preponderant metal halide.

7. An indirect heating system employing as the heat carrying medium a molten mixture comprising preponderantly chloride of zinc, which is a halide of a weak negative, acid forming metal, and sufficient halides of the class consisting of NaCl, KCl and LiCl, which are halides of strong positive, base forming metals, to impart to the mixture a melting point materially below that of the preponderant metal halide.

8. An indirect heating system employing as the heat carrying medium a molten mixture comprising preponderantly chloride of zinc, which is a halide of a weak negative, acid forming metal, having incorporated therewith at least one of the halides of the class consisting of NaCl, KCl or LiCl, which are halides of strong positive base forming metals, characterized in that one or more of the incorporated latter halides forms with the preponderant halide a double salt existing in the molten state, and further characterized in that the quantity of these latter halides present is sufficient to impart to the mixture a melting point materially below that of the preponderant metal halide.

KARL GENSCH.

PATENT SPECIFICATION

Application Date: Nov. 22, 1932. No. 33,012/32.

398,367

Complete Accepted: Sept. 14, 1933.

COMPLETE SPECIFICATION

Improvements in and relating to Internal Combustion Engines and Methods of Operating the same.

I, FRITZ VON OPEL, of 33, Bismarckstrasse, Berlin-Charlottenburg, Germany, a German Citizen, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The invention relates to an internal combustion engine in which the exhaust gases after purification, cooling and enrichment with oxygen and fuel are again introduced to the engine, i.e., an internal combustion engine which can be regarded as operating with a circulated medium; the invention also relates to the requisite arrangements for this purpose.

Existing internal combustion engines are practically all dependent on the pressure and composition of the surrounding air and cannot maintain their performance with falling pressure or falling oxygen content of the air. In this connection, it is immaterial whether they operate as two-stroke or four-stroke engines or as diesel engines or as gas turbines. Thus, such engines are unsuitable for high altitude aircraft, particularly at such altitudes where the pressure drop can no longer be compensated for by means of pre-compressors.

Particularly for the purpose of driving submarine craft, it is known to employ engines operating with a circulated medium in which the combustion gases are not blown out into the open but after purification, cooling and re-generation are again fed to the engine. The oxygen which is newly introduced for each combustion in the closed cycle process can be carried in gaseous or liquid form. In aircraft, however, the use of liquid oxygen is absolutely essential in view of the weight of the containing vessels. Liquid oxygen can be carried in very light heat insulated containers whereas gaseous oxygen must be kept in steel pressure vessels under high pressure. The use of liquid oxygen has, however, the drawback that the heat of vaporisation of the oxygen must be derived from the heat content of the fuel. This heat of vaporisation is very important and the efficiency of the motor will be very poor if this quantity of heat can not in part be used again in the motor.

Now it is customary to spray the liquid oxygen into the cylinder at the end of the compression stroke with the fuel or subsequently thereto. The liquid oxygen which has been injected vaporises and extracts its heat of vaporisation from the compressed gas which serves as heat carrier. The temperature of the gas falls whereas the heat content of the mixture obtained remains the same. Owing to the vaporisation which takes place the pressure of the mixture in the cylinder rises so that in this manner a part of the heat energy is recovered as pressure energy. This, however, applies only to a part of the heat consumed since the heat of the liquid and by far the largest part of the heat of vaporisation is lost.

According to the present invention the heat of the exhaust gases, the cooling of which has hitherto been effected by special arrangements, is used for the vaporisation of the oxygen and for this purpose, immediately or a short time after the working stroke, the liquid oxygen is brought into direct contact with the hot exhaust gases.

The cooling action itself can be effected in the most diverse ways, for instance, by spraying the liquid oxygen into the combustion chamber or by bringing the exhaust gases into direct contact with the oxygen by blowing the gases therethrough. Particularly in the latter case it is possible, by intensive cooling, to cool the exhaust gas wholly or in part to such an extent that the carbon di-oxide and water vapour contained in the exhaust gas freeze out.

It has been found that considerable difficulties are encountered in spraying in the oxygen by means of pumps, as the liquid oxygen vaporises prematurely and gas formation occurs in the pumps. The invention proposes, therefore, to dispose the pumps within the oxygen container and preferably beneath the liquid level.

Further, the spraying in can be attained without the use of pumps by supplying heat to the oxygen container and utilising the vapour pressure arising

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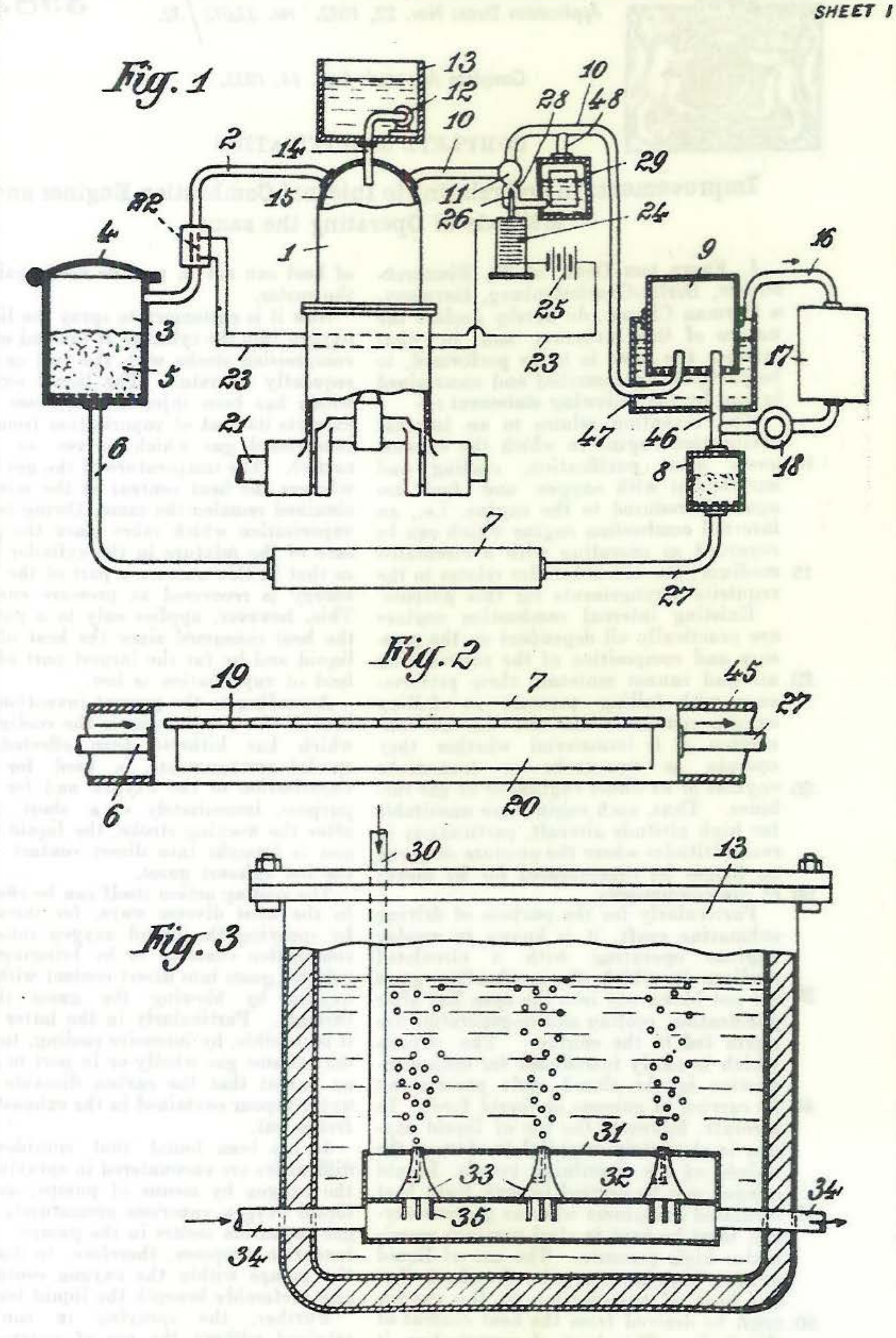

Fig. 4

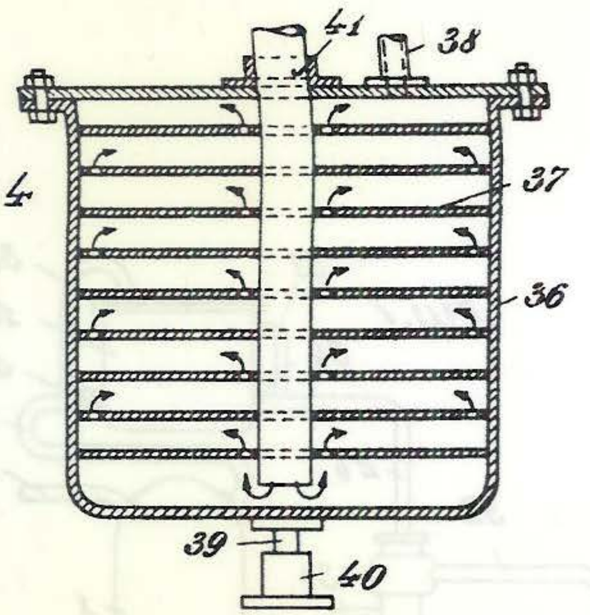

Fig. 5

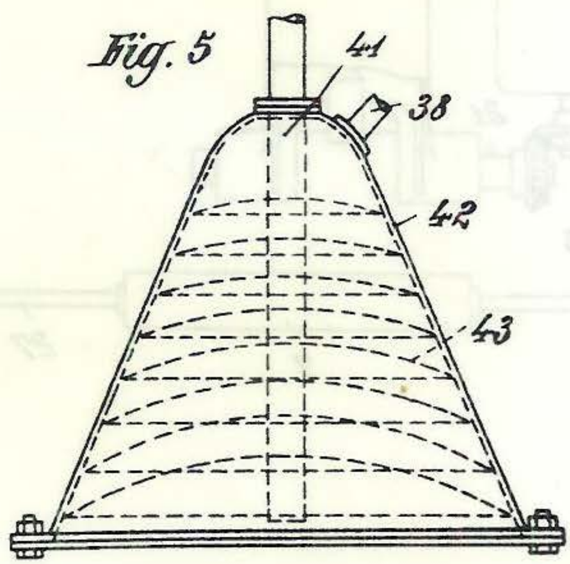

Fig. 6

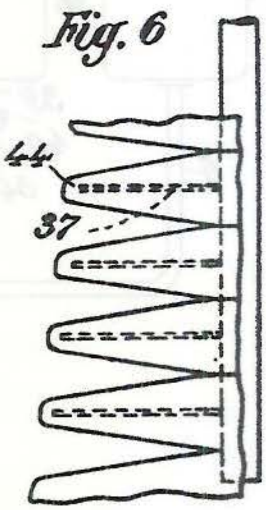

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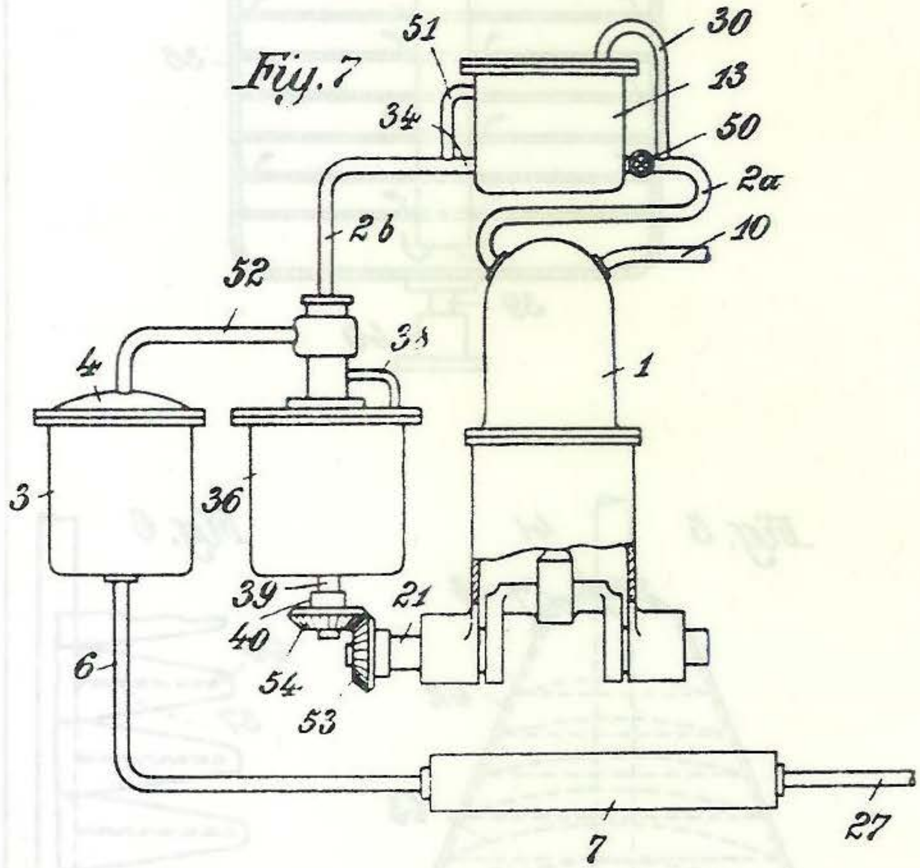
Fig. 7



Malby & Sons, Photo-Litho

for conveying and spraying in the oxygen.

The extensive cooling of the exhaust gas makes it necessary to make special provision for the separation of the condensate which occurs in part in large quantities because this condensate on the one hand would interfere with the circulation and destroy the desired increase in performance and on the other hand many condensates, for example, precipitates of oil and fuel vapours, form explosive mixtures with liquid oxygen. The usual methods of separation have not been found to be suitable because filtering processes of all kinds occasion resistances of too great a magnitude and simple, slightly curved deflection of the gas stream provides no absolute security for a complete separation. A further difficulty is presented in that the removal of the condensate must be effected without interrupting the operation.

According to a further feature of the invention, therefore, is provided in the circulation a condensate separator which consists of an externally cooled vessel which, if desired, may rotate at high speed, and in the interior of which the gas stream is directed to and fro by a system of correspondingly apertured discs arranged in tiers, the individual plates being suspended in an insulated manner and charged electrically for assisting the separating action if desired.

In order to alter the composition of the circulating mixture, the oxygen and fuel supply must be regulated. It is desirable to effect all such regulations not by hand, but automatically. The invention proposes, therefore, to effect the oxygen and fuel supply in dependence upon the state of the exhaust gas (temperature, composition, pressure), e.g., by means of a thermo element which controls the inflowing quantities by way of an electromagnet, the control being independent of the nature of the cooling effected by the oxygen.

The invention is illustrated by way of example in the accompanying drawings, in which:

Fig. 1 shows schematically the engine and other components in the system.

Fig. 2 shows the cooler for the exhaust gas on a larger scale,

Fig. 3 shows the container for the liquid oxygen in partial section and on a larger scale,

Fig. 4 is a section through a condensate separator,

Figs. 5 and 6 show views of modified constructions of the condensate separator.

Fig. 7 shows the inclusion of the vaporisation vessel of Fig. 3 and the separator of Fig. 4 in the system of Fig. 1.

In Figs. 1 and 2, 1 is the cylinder, or one of the cylinders, of the engine, the piston of which drives the crank shaft 21. The inlet 10 and the exhaust 2 are connected to the combustion space 15 of the cylinder 1. The exhaust conduit 2 leads to a safety vessel 3 which, for reasons of safety, has a loose or movable cover 4, which, in the event of an explosion, can yield upwardly. The container 3 is filled with chemicals 5 for absorbing those detrimental components of the combustion gases which are to be removed from the circulation. Through the pipe 6 the exhaust gases pass into the cooler 7 and from thence through the conduit 27 into a chamber 8, which is also filled with chemicals, and thence into a pressure equalisation vessel 47 provided with a gasometer bell 9. From thence the gases are directed through the pipe 10 and the carburettor 11 into the combustion chamber 15. The float housing 29 of the carburettor 11 is connected with the conduit 10 by way of a conduit 48. The pressure equalisation vessel 47 is connected by way of a conduit 16 with a separate gas storage vessel 17, the interior of which is connected by way of the pump 18 with the conduit 46 which leads to beneath the gasometer bell 9 of the pressure equalisation vessel 47. An oxygen supply container 13 is arranged above the cylinder 1 of the engine or at any other suitable position. On the base of the container 13 within the liquid is mounted a motor-driven pump 12 which introduces the liquid oxygen into the combustion chamber through a conduit 14. In the exhaust pipe 2 is provided a temperature sensitive resistance 22, which is connected in circuit by a conductor 23 with an electromagnet 24 and a battery 25. The armature 26 of the magnet 24 is connected with the needle of the carburettor 11.

The surface cooler 7 (Fig. 2) is provided with a flap 20 which can be rotated lengthwise about a shaft 19 and, in normal conditions, is held closed by means of spring pressure, but in the case of an explosion can open against the action of the spring and the pressure of the outer air passing over it.

The mode of operation of the motor is as follows:

The neutral gas, such as nitrogen, constitutes a charge in the conduits and chambers 1 to 11, and the combustion space 15. If now the motor is set in motion by starting means, then, by means of the pump 12, more and more oxygen is injected to the circulating nitrogen. When the desired percentage content of oxygen is attained, the fuel aperture of the carburettor is opened and the motor commences to operate in the normal way. After an explosion has occurred a new quantum of oxygen is injected, whereby the temperature of the exhaust gas is lowered and its volume is reduced. The exhaust gas is now directed through the exhaust pipe 2 to the safety vessel 3 filled with the chemicals 5 where detrimental combustion residues such as carbon-monoxide and carbon-dioxide, for example, are absorbed. It is advantageous to employ chemicals similar to those customary in submarine craft in which oxygen is released corresponding to the absorbed carbon-dioxide. If necessary, alkali lyes can also be used satisfactorily for precipitating detrimental waste gases. If hydrogen fuels are burnt instead of carbon fuels, then, in an analogous manner, hygroscopic chemicals are used for absorbing the water or the water is removed by water separators and is directed to the cooling water circulation or is used for other purposes. When employing alcohol as fuel, it is advisable, by adding alkalies or in any other way, to neutralise the acetic acid which, in some circumstances, may be produced. The container 3 in which this process is effected is preferably provided with extensible walls (loose cover and the like) so that explosions in the exhaust pipe can be taken up without detriment. For the purpose of cooling and reduction in volume the gas which is purified and enriched with oxygen is directed to the cooler 7, which, for use in high altitude aircraft, is preferably disposed within the wings and along the leading edges thereof. It may itself constitute a part of the wing. By the cold outer air passing over the wings an effective cooling of the gas is attained whereas the latter in turn effects a warming of the wings which is desirable at high altitudes in view of the danger of ice deposition. It is advisable, for reasons of safety, to provide this surface cooler with a kind of expansion arrangement for releasing sudden pressure increases without involving danger.

After complete cooling, the gas mixture is directed to the container 8, the chemicals (e.g. barium oxide) of which have the function of a "chemical accumulator," i.e., should the gas passing through them be too strongly enriched with oxygen, they become oxidised and withdraw oxygen therefrom and yield the oxygen which is only loosely bound as soon as the oxygen content of the gas passing through them drops. This arrangement has the purpose of balancing out, to a limited extent, irregularities in the injection of oxygen. The gas, which in this way has been normalised, as if were, now flows into an air chamber 47, in which a supply of gas is collected for equalising pressure and volume. Even at constant temperature, this gas supply does not remain constant, but is reduced due to the conduit losses, particularly leaks at the piston, and due to partial combustion of the gas mixture, whereas, on the other hand, it is increased due to the combustion products which are continuously arising. In the latter case, the gasometer bell 9 rises to such an extent that gas can escape from beneath its lower edge. This gas is collected and fed to the separate supply container 17 by means of the conduit 16. Also, the gases escaping into the housing of the motor may by suitable construction of the latter be drawn off and fed into this container. If, for any reasons the supply of gas or the pressure in the conduit falls, then for example by means of a pressure membrane known per se the electric contact of the feed pump 18 is closed or a conduit is opened so that gas flows from the supply container into the gasometer and into the circulation. The total quantum of gas now flows to the carburettor 11, vaporises the fuel emerging in known manner from the jets and passes into the motor, where the cycle recommences.

The carburettor is substantially of normal construction, except that the interior of the float housing 29 is connected with the interior of the gas conduit 10 by means of the conduit 48 in order that no variation in the fuel level occurs on fluctuating pressure in the gas conduit.

The injection of mixtures containing liquid oxygen or cold fuel is best effected by means of piston pumps known per se, but it is desirable, in order to avoid vaporisation of the liquids in the exposed pipe leading to and from the pumps, that the liquids are stored in insulated containers and that the pumps are disposed within the liquid preferably on the bottom of the container, as shown in Fig. 1. As shown by experience, this is also the only possibility of avoiding stresses in the material of the pump in pumping very cold media.

If, for example, a pump is used for the fuel and a pump for the oxygen, then, in view of the different quantities of liquid which have to be conveyed, the diameters of the feed pumps are chosen of different size, the speeds of operation being normally equal. However, by varying these speeds the composition of the mixture can be altered. The same effect can be attained by making the stroke of the pistons adjustable. It is also possible to employ a pump and a carburettor and to vary the cross section of the jet of the carburettor in known manner by moving a needle to and fro.

It is desirable to effect all such adjustments not manually, but automatically, by making the normal position of the regulating means dependent upon a normal condition of the motor, for example, its speed of rotation, its temperature, the pressure of the exhaust, and so on. In Fig. 1, such an arrangement is shown in which the temperature of the exhaust gas affects the resistance 22 included in the exhaust pipe 2 and, in turn, controls the electromagnet 24 by way of the conductor 23. A spring, not shown, in the interior of the coil 24 tends to urge the armature 26 upwards and to close the fuel nozzle by means of the conical end and the magnetic field of the coil 25 operates against this. The effect of this coil, however, is dependent upon the magnitude of the electric current which is determined substantially by the magnitude of the resistance 22. If this resistance alters, for example increases with temperature, then the current decreases and the spring can move the core of the magnet a certain distance upwardly. When the highest permissible temperature of the exhaust gas is attained there is a complete throttling of the fuel. In a similar way, pressure fluctuations in the conduit can be utilised for controlling the jet, while the quantities forwarded by the pumps can be altered in a similar manner. Also for example the variations in the chemical composition of the gas can be established in manner known per se by means of exhaust gas analysers and can be utilised to regulate the pumps or carburettors.

If desired the loose cover 4 could be provided on the cooler 7 or on the container 8, it being only necessary that it be provided at some point in the cycle.

As initially mentioned, the cooling of the exhaust gas or of the gas which is again utilised if the whole of the exhaust gas is not returned to the cylinder can be effected in a very efficient manner by bringing it into direct contact with the liquid oxygen by blowing it into the latter. In this way, it is possible to cool the exhaust gas to such an extent that unwanted admixtures such as carbon-dioxide and water vapour can be trapped by freezing them and thus excluded from the circulation. Preferably, the same vessel is used for vaporising the liquid oxygen and for freezing the above mentioned admixtures so that the quantities of ice formed can be removed from the vaporiser vessel which is at a pressure less than atmospheric pressure through a trap arrangement. The ice is conveniently advanced into the trap chamber by means of a dredger arrangement or a tilting rake.

It has been found that the exhaust gas has to be blown into the oxygen for the above mentioned purpose through a large number of very fine apertures or nozzles disposed along the length of a container, but that in consequence difficulties caused by deposition of ice are increased thereby. For this reason, the vessel in which the gas is introduced is provided with an excess pressure valve which automatically opens should the nozzles become blocked with ice so that the nozzles are warmed due to the passing gas current and thus the deposition of ice is overcome. Further, it is necessary to construct a special form of nozzle which has as small as possible a surface exposed to the oxygen, but as large a surface as possible within the vessel, i.e., in the direction in which heat is supplied. Preferably, such a nozzle has a conical shape and the conical nozzle is disposed with the apertured point towards the oxygen and with the broad base against the wall of the container which is separately heated. The walls of the container are preferably heated by means of a further container which is attached thereto and through which preferably the hot exhaust gas is directed. For the purpose of taking up more heat the nozzles may be equipped with ribs which project into the heating container. In addition, the nozzles can be directly heated. For this purpose, either electric heating bodies of any suitable kind are used or each nozzle itself is used as bridge member in a resistance heating arrangement. The heating can also be effected by means of heating wires which are either passed about the nozzles or are directed through the apertures of the nozzles themselves.

A preferred construction of the oxygen container is shown in Fig. 3 of the drawings.

The oxygen container 13 of Fig. 1 is constructed as a double-walled vacuum vaporisation vessel. Within this vessel is a container 31, which is connected to the exhaust of the machine by means of the pipe 30. In the container 31 are provided a number of nozzles 33, the apertures of which extend angularly so that the exhaust gases pass into the cone through the lateral part of the aperture and emerge through the point of the cone into the oxygen. A further container 32 is attached to the container 31 and is connected with the exhaust pipe by means of a pipe 34. On the bottom of the conical nozzles are provided ribs 35 which project into the container 32 for increasing the quantity of heat absorbed. Instead of the two containers 31, 32, it would also be possible to use, in a corresponding way, a container with a partition.

The embodiment of the oxygen container 13 in the system of Fig. 1 is shown in Fig. 7 and the closed cycle process then operates as follows:

After combustion the waste gases are passed by way of the outlet pipe 2*a* through the conduit 30 to the container 13, through the nozzles 33, through the liquid oxygen and leave the vessel through the conduit 51 which discharges into the conduit 2*b*. The gas then passes from the conduit 2*b* to a separator 36, to be described, and after separation of the liquid or solid condensates present in the gases leaves the separator by way of a conduit 38, from which it passes to the vessel 3, already referred to, by way of the conduit 52. The separator 36 is constructed to be rotatable and can be driven through toothed wheels 53, 54, the conduit 52 having an enlarged portion embracing as shown the portion of the separator remaining stationary and the pipe 38 rotating with the separator, suitable connecting means for the passage of the gas being provided. From the vessel 3 the mixture of gaseous oxygen and purified exhaust gas then traverses the rest of the system and enters the cylinder after injection with fuel by way of the pipe 10.

A conduit 34 also shown in Fig. 3 branches from the conduit 2*b*, but, however, is usually closed by the excess pressure valve 50. The valve 50 only opens when the nozzles 33 become frozen on account of the excess pressure then arising and the heated gases pass into the container 32 until the nozzles are cleared by a heating of the ribs 35.

It has been found that the performance of a motor operating on the circulation system can be further increased if the circulating nitrogen is separated out and replaced by corresponding quantities of water vapour and carbon-dioxide. For this purpose, a portion of the combustion gases is blown into the open and the freezing correspondingly reduced so that, in this way, the nitrogen content is reduced step by step. Then on each subsequent cycle only the excess water vapour or carbon-dioxide added in each working stroke is removed from the system.

Further, as mentioned initially, the considerable cooling of the exhaust gas in the internal combustion engine operating on the circulation system makes it necessary to effect very careful extraction of the condensate which is contained in large quantities in the exhaust gas.

The methods of separation hitherto used have been found to be inadequate because filtration processes of all kinds occasion resistances of too great a magnitude and simple deflection of the gas stream along gentle curves affords no absolute security for a complete separation. A further difficulty is involved in that the operation must be continuous so that the removal of the condensate has to be effected without interrupting the operation.

The invention avoids the disadvantages of the known methods of separation by means of a condenser arrangement which preferably operates on a so-called alternate system which is included in the circulation at a suitable point and consists essentially of a container which is externally cooled and if necessary rotated at high speed, in the interior of which the gas stream is directed to and fro by means of a system of correspondingly perforated discs arranged in tiers, an insulated suspension and electric charging of the individual plates being provided if desired for assisting the separating action. To facilitate the discharge of the condensate, the discs of the separator may slope downwardly outwardly from the centre. The "alternate" operation is effected in such a way that the greater part of the exhaust gases is first directed through the separator and when the latter has been filled a definite amount with solid condensate is then directed through a second separator. Simultaneously a small part of the exhaust gases is passed through the filled container so as to convert the solid condensate into the liquid form when it can then be run out of the separator. The small portion of the exhaust gases used for this purpose is not used again and is lost from the system.

In order to assist the precipitation the walls of the container are cooled preferably by the use of liquid gases or low external temperatures. The liquid oxygen used as working medium can also be used for the cooling. The cooling action can be further increased in that the container is constituted of a number of superimposed individual chambers, in which the deflecting discs are disposed so that a large surface comes in contact with the cooling means.

Embodiments of the separator according to the invention are shown by way of example in Figs. 4—6. In Fig. 4 the container 36 is provided with a centrally disposed inlet tube 41, which terminates in the vicinity of the base. 38 is the outlet pipe. The container 36 is preferably included in the outlet pipe 2 (Fig. 1) of the motor. It can, however, be disposed at any other suitable point in the cycle. Annular discs 37 are arranged in tiers between the inlet tube and the walls of the container, openings being disposed alternately on the outside of the wall of the container and on the inside adjacent the tube, so that the current of gas introduced through the pipe is forced to reverse its direction a number of times within the container. The entire container can be rotated at a high speed about the axis of the tube by driving a shaft 39 connected with the container by means of a clutch 40, so that the particles of condensate have the greatest speed at the outer wall, where a sharp reversal in motion occurs and the centrifugal force is greatest.

The container can be of cylindrical or conical form and in the latter case with the base of the cone lowermost an auxiliary centrifugal action occurs on the wall. A container constructed in this way is shown in Fig. 5. 41 and 38 are again the inlet and outlet pipes. 42 is the conical container. The deflecting discs 43 are arched so that they run downwards in the outward direction. This container is precisely the same as that according to Fig. 4 with the exception that the discs 37 are curved.

In Fig. 6 a condensate separator is shown which consists of individual superimposed chambers 44 in which the deflecting discs 37 are arranged. The separator is again very similar to the construction according to Fig. 4, the inlet and outlet pipes 41 and 38 being provided as before, but differs therefrom in that it is built up of individual hollow portions as shown. The cooling action can be materially increased in this construction of the container in view of the great surface which is obtained.

In order to drive the various constructions of container the gas introduced can be directed into a turbine arrangement connected with the container. In aircraft it is advisable to effect the drive by the air current due to motion through the medium of a propellor or the like.

In order to make it possible to introduce and withdraw the gas readily, the shaft around which the separator rotates is made hollow and is used as conduit, in which case, for instance, the hollow shaft of the container is mounted concentric within the stationary inlet pipe.

The condensate can emerge from the container through an excess pressure valve not shown disposed in the wall of the container, this valve being automatically opened, for instance, under the influence of centrifugal force or due to deliberate increase of pressure within the container for example by obstructing the outflowing gas. The condensate can also be removed by means of pumps which are driven preferably by utilising the relative motion between the container and the stationary outer parts, for example, by rolling a rotating cam over a stationary cam disc.

The constructions of separator described effect a rapid and efficient separation of the condensate occurring as a result of the novel process and protection thereon is envisaged only in combination with the cyclic motor.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:—

1. An internal combustion engine operating on the closed cycle process with the use of liquid oxygen of the kind in which the exhaust gases after purification, cooling and enrichment with oxygen and fuel are returned to the motor, in which the liquid oxygen is brought into direct contact with the exhaust gases immediately or a short time after the working stroke in order that the heat necessary for the vaporisation of the oxygen shall be directly derived from the waste gases.

2. An internal combustion engine as claimed in claim 1, in which liquid oxygen is directly injected into the working cylinder or cylinders.

3. An internal combustion engine as claimed in claim 2, in which the injection pump together with feed and discharge pipes is arranged within an oxygen container and preferably below the liquid surface.

4. An internal combustion engine as claimed in claim 1, in which the exhaust gas is blown through liquid oxygen.

5. An internal combustion engine as claimed in claim 2 or 4 in which the pressure arising on heating the liquid oxygen is utilised for conveying and injecting the liquid oxygen.

6. An internal combustion engine as claimed in claim 4, in which the introduction of the exhaust gas into the oxygen is effected by means of a container which preferably is equipped with an excess pressure valve and is provided with a plurality of nozzles.

7. A vaporiser vessel as claimed in claim 6, in which the nozzles or their discharge apertures are electrically

heated.

8. A vaporiser vessel as claimed in claim 7, in which the nozzles themselves are constructed as bridge members between two electrodes.

9. A vaporiser vessel as claimed in claim 6, in which the nozzles are conical, or substantially conical, and are disposed with the apex towards the liquid oxygen and the base against walls at a higher temperature.

10. A vaporiser vessel as claimed in claim 9, in which the base surfaces of the nozzles are provided with projections or ribs for the purpose of better absorption of heat.

11. An internal combustion engine as claimed in claim 4, in which the exhaust gas is cooled to such an extent by the liquid oxygen that water vapour and carbon-dioxide freeze out.

12. A vaporiser vessel for an internal combustion engine as claimed in claim 11, in which the carbon-dioxide ice and aqueous ice is removed mechanically preferably by means of a lock system (chamber system).

13. An internal combustion engine as claimed in claim 1, in which a " chemical accumulator " is included in the circulation by means of which excess quantities of oxygen are removed and are yielded up to the circulating volume of gas when there is a deficiency of oxygen.

14. An internal combustion engine as claimed in claim 1, in which for maintaining the pressure and volume of the circulating gas constant an equalisation vessel to which a separate container is connected by means of a by-pass conduit is included in the circulation, said container taking up excessive quantities of gas and yielding them again when the pressure in equalisation vessel falls.

15. An internal combustion engine as claimed in claim 1, in which an expansion vessel is included in the exhaust pipe for taking up impulses due to explosions.

16. An internal combustion engine as claimed in claim 15, in which the expansion vessel is combined with the purifier or cooler, or both.

17. An internal combustion engine for high altitude aircraft as claimed in claim 1, in which the cooler for the exhaust gas is disposed in the wing of the aircraft.

18. An internal combustion engine as claimed in claim 1, in which the gas escaping to the crank case or escaping from other apertures is collected and reintroduced into the circulation.

19. An internal combustion engine as claimed in claim 1, in which by allowing partial escape of the gas the nitrogen content of the circulating mixture is reduced and is replaced by water vapour and carbon-dioxide which is continuously produced.

20. An internal combustion engine as claimed in claim 1, in which a condensate separator for excluding the condensate content in the exhaust gas is provided with a system of deflector discs due to which the gas current is subjected to a complete reversal of motion on each deflection.

21. A condensate separator for internal combustion engines as claimed in claim 20, in which for the purpose of attaining a centrifugal effect the container is adapted to be rotated.

22. A condensate separator as claimed in claim 21, in which the rotation of the container is effected by means of a turbine-like arrangement against which the inflowing gas impacts.

23. A condensate separator as claimed in claim 21, in which the rotation of the container is effected by means of an auxiliary propeller or the like on the craft.

24. A condensate separator as claimed in claim 20, in which the wall of the container is cooled.

25. A condensate separator as claimed in claim 24 in which the cooling of the container is effected by liquid oxygen.

26. A condensate separator as claimed in claim 20, in which for the purpose of facilitating the drainage of the condensate the deflecting discs are inclined downwardly, umbrella fashion.

27. A condensate separator as claimed in claim 20, in which for the purpose of enlarging the surface of contact with the cooling means the container consists of superimposed individual chambers in which the deflecting discs are arranged.

28. A condensate separator as claimed in claim 20, in which the deflecting discs are insulated and are adapted to be charged electrically for assisting the separating process.

29. A condensate separator as claimed in claim 20, in which the removal or the conveyance of the condensate obtained is effected by means of the pressure of the gas or centrifugal force.

30. A condensate separator as claimed in claim 20, in which the condensate emerges through an excess pressure valve disposed in the wall of the container, the excess pressure valve being opened automatically if desired under the influence of centrifugal force or by deliberate increase of pressure in the container (e.g., by obstructing the outflowing gas).

31. A condensate separator as claimed in claim 20, in which the condensate is conveyed by means of pumps.

32. A condensate separator as claimed in claim 31, in which the drive of the pump is effected by using the relative motion between the container and stationary outer members, for example, by rolling a rotating cam over a stationary cam disc.

33. An internal combustion engine as claimed in claim 1, in which the oxygen supply and fuel supply is controlled in dependence upon the condition of the exhaust gas (temperature, composition, pressure), e.g., by means of a thermo element and an electromagnet controlled thereby.

34. The internal combustion engine substantially as described with reference to the accompanying drawings.

Dated this 22nd day of November, 1932.

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Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1933

PATENT SPECIFICATION

Application Date: Nov. 22, 1932. No. 33,012/32.

398,367

Complete Accepted: Sept. 14, 1933.

COMPLETE SPECIFICATION

Improvements in and relating to Internal Combustion Engines and Methods of Operating the same.

I, FRITZ VON OPEL, of 33, Bismarckstrasse, Berlin-Charlottenburg, Germany, a German Citizen, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The invention relates to an internal combustion engine in which the exhaust gases after purification, cooling and enrichment with oxygen and fuel are again introduced to the engine, i.e., an internal combustion engine which can be regarded as operating with a circulated medium; the invention also relates to the requisite arrangements for this purpose.

Existing internal combustion engines are practically all dependent on the pressure and composition of the surrounding air and cannot maintain their performance with falling pressure or falling oxygen content of the air. In this connection, it is immaterial whether they operate as two-stroke or four-stroke engines or as diesel engines or as gas turbines. Thus, such engines are unsuitable for high altitude aircraft, particularly at such altitudes where the pressure drop can no longer be compensated for by means of pre-compressors.

Particularly for the purpose of driving submarine craft, it is known to employ engines operating with a circulated medium in which the combustion gases are not blown out into the open but after purification, cooling and re-generation are again fed to the engine. The oxygen which is newly introduced for each combustion in the closed cycle process can be carried in gaseous or liquid form. In aircraft, however, the use of liquid oxygen is absolutely essential in view of the weight of the containing vessels. Liquid oxygen can be carried in very light heat insulated containers whereas gaseous oxygen must be kept in steel pressure vessels under high pressure. The use of liquid oxygen has, however, the drawback that the heat of vaporisation of the oxygen must be derived from the heat content of the fuel. This heat of vaporisation is very important and the efficiency of the motor will be very poor if this quantity of heat can not in part be used again in the motor.

Now it is customary to spray the liquid oxygen into the cylinder at the end of the compression stroke with the fuel or subsequently thereto. The liquid oxygen which has been injected vaporises and extracts its heat of vaporisation from the compressed gas which serves as heat carrier. The temperature of the gas falls whereas the heat content of the mixture obtained remains the same. Owing to the vaporisation which takes place the pressure of the mixture in the cylinder rises so that in this manner a part of the heat energy is recovered as pressure energy. This, however, applies only to a part of the heat consumed since the heat of the liquid and by far the largest part of the heat of vaporisation is lost.

According to the present invention the heat of the exhaust gases, the cooling of which has hitherto been effected by special arrangements, is used for the vaporisation of the oxygen and for this purpose, immediately or a short time after the working stroke, the liquid oxygen is brought into direct contact with the hot exhaust gases.

The cooling action itself can be effected in the most diverse ways, for instance, by spraying the liquid oxygen into the combustion chamber or by bringing the exhaust gases into direct contact with the oxygen by blowing the gases therethrough. Particularly in the latter case it is possible, by intensive cooling, to cool the exhaust gas wholly or in part to such an extent that the carbon di-oxide and water vapour contained in the exhaust gas freeze out.

It has been found that considerable difficulties are encountered in spraying in the oxygen by means of pumps, as the liquid oxygen vaporises prematurely and gas formation occurs in the pumps. The invention proposes, therefore, to dispose the pumps within the oxygen container and preferably beneath the liquid level.

Further, the spraying in can be attained without the use of pumps by supplying heat to the oxygen container and utilising the vapour pressure arising

APPENDIX D