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DEEP DIVING SERVICE SUBMARINES

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Service submarines have been developed for support duties in offshore operations in deep waters. Three submarine concepts have been designed for water depths ranging from 400 to 1500 m.

The operation philosophy is to use an autonomous manned submarine as a carrier for components, tools and work modules and as a base for IMR operations on subsea installations. The design principles are similar to that of the Space Shuttle incorporating a payload bay, energy supply and a closed environment for the crew and operators.

The operation profile of an offshore submarine demands capabilities above those of naval submarines: deep diving, long endurance underwater, dynamic positioning. New technology had to be developed: air-independent energy system, regenerative life support, dynamic positioning, integrated control system.

This paper covers the special design aspects of the three submarine concepts and reports on the development work done on the new submarine systems.

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INTRODUCTION

As offshore activities move into deeper waters, platform based oil and gas production systems are being displaced by subsea seabed based systems. Most of the field developments in water depths greater than 300 m incorporate subsea completions to a great extent.

The use of divers at such water depths is not practicable, so that installation and maintenance work procedures have been developed to be done from surface vessels using guide line techniques and remote controlled vehicles (RCV/ROV) with umbilicals. Such systems have limited capability and availability due to the great distance between operator and work spot and due to weather conditions. The operating costs are therefore relatively high.

Inspection, maintenance and repair (IMR) procedures with a submarine are much simpler with practically no down time due to rough weather. Three concepts for service submarines have been developed for operation in water depths ranging from 400 to 1500 m.

DESIGN PARAMETERS

Two of the three submarine concepts were designed for operation in the North Sea in water depths up to 450 m. The third was conceived for operation in the Gulf of Mexico or Offshore Brazil in water depths up to 1500 m.

The following performance data were defined:

450 m Submarines

- Maximum service depth	450 m
- Action radius	200 naut. miles
- Payload	25 tons
- Endurance submerged	21 days
- Speed submerged	10 knots
- Water current near sea floor	2 knots

The submarine should be able to be dynamically positioned over a subsea structure within a radius of less than 0.5 m.

1500 m Submarine

- Maximum service depth	1500 m
- Action radius	150 km
- Payload	20 tons
- Endurance submerged	5 days
- Speed submerged	8 knots

In order keep the size of the submarine small it was decided to minimize the energy storage which resulted in reduced action radius, submerged endurance and DP capability. The submarine would rest on the protection structure of the subsea installation while performing work tasks.

All three submarine concepts have been designed to be fully autonomous with no surface support. The submarine operation is to be highly automatized with a crew of only 2 persons per watch.

SUBMARINE CONCEPTS

Offshore Service Submarine (OSS)

The first submarine concept to be developed was the Offshore Service Submarine (OSS). The submarine is designed as a transport vehicle for personnel, components and work tools and as a base for IMR operations on subsea installations (Fig. 1).

The submarine is 47.0 m long, 8.5 m wide and has a submerged displacement of 1600 t. The submarine has a cylindrical pressure hull and a wet cargohold forward of the pressure hull which is subject to ambient conditions. The pressure hull contains the energy system, the accommodation and the control room. Oxygen for combustion is stored outside the pressure hull as LOX in insulated pressure tanks.

The cargohold is L 10.0 m x B 7.0 m x H 8.0 m and can accommodate six 6' API guide post structures. It is serviced by a hydraulic crane with a capacity of 25 tons. The crane handles a work module fitted with a swivelling hook, two manipulator arms, TV cameras and lights.

The OSS has DP capability and can maintain position in a head current up to 2 kn. While performing tasks the submarine can either hover over the installtion, be anchored to the structure by tension cables or rest on the protection structure.

The submarine is provided with a 2.5 m diameter garage for a large work ROV. The garage is within the pressure hull and the ROV can be sluiced into an 1 atm. dry chamber for servicing and tool changes.

Super Subsea Submarine (SSS)

The second concept is a submarine designed within the EUREKA project Super Subsea. Super Subsea is a modularized subsea oil and gas production system developed by Kvaerner, Norway (Ref. 1).

The SSS ist designed as a carrier for modules which are attached to the submarine bottom or sides by special connectors (Fig. 2). The modules are streamlined containers for production equipment or service units. The submarine also serves as a work station for IMR operators and as a power source for underwater work.

The submarine is 42.0 m long, 7.1 m wide and displaces 870 t submerged. The pressure hull is divided into 2 compartments by a pressure tight bulkhead. The forward compartment contains the accommodation and the control room, the aft compartment encloses the engine room and oxygen (LOX) storage. This area would normally not be manned during the mission.

All installation components and work systems are carried in dedicated modules. The modules can be entered from the submarine through hatches in the connectors. Hydraulic and electric power is supplied to the modules from the submarine.

The SSS can operate, just as the OSS, in the hovering mode, being anchored by tension cables or while resting on the structure. Further, it can dock to a subsea structure or a 1 atm. chamber fitted with the special connectors.

Deep Diving Submarine (OSS 1500)

The third concept is a deep diving version of the OSS, called the OSS 1500, designed for operation in water depths up to 1500 m (Fig. 3).

The OSS 1500 is conceived as a fully autonomous vehicle to transport personnel, material and tools to the subsea site and as a base for IMR operations on wellhead installations in deep waters. It would operate from a shore base or an offshore platform within a range of 150 km from the subsea location.

The submarine is 28.6 m long, 6.85 m wide and displaces 320 t when submerged. It has two spherical pressure hulls with a wet cargohold in between. The forward pressure hull is made of high tensile steel and contains the accommodation and control station. The aft pressure hull is made of carbon reinforced plastic (CRP) and encloses the power plant and other machinery.

The submarine carries its payload in the wet cargohold which can accommodate two standard 6' API guide post frames. A hydraulic crane with a capacity of 20 t immersed is provided for handling equipment and tools.

A ROV is carried in a wet garage in the sail behind the cargohold.

The OSS 1500 normally transits submerged to the location. At the subsea site the submarine approaches the structure with positive buoyancy and manoeuvres with the DP thrusters. The submarine would rest on the protection structure of the installation during IMR operations.

SUBMARINE SYSTEMS

The operation profile of an offshore submarine requires capabilities beyond those of conventional naval submarines: deep diving, long endurance, dynamic positioning, high level of automation. New technology had to be developed to meet these requirements.

Energy System

All submarine concepts have an air-independent energy system based on the closed cycle diesel engine developed by Cosworth Engineering and the University of New Castle (Ref. 2). This system uses sea water to scrub the exhaust gases.

The Cosworth system uses conventional unmodified off-the-shelf diesel engines. The working gas is conditioned to have the same properties as in the diesel running turbocharged with ambient air.

The exhaust gas is passed through an absorber where the water vapour and the excess CO_2 in the cycle gas are dissolved in sea water. All other gas components, in particular the unused oxygen, do not dissolve easily in water and are recycled to the diesel.

The cycle gas leaving the absorber is enriched with oxygen and doped with a small quantity of argon before being fed back to the engine. With argon the gas has the same properties as normal air and the diesel runs under its design conditions. Fig. 4 shows a diagram of the closed cycle diesel engine system.

The seawater needed to absorb the exhaust gas is supplied by the so called water management system (WMS). The WMS reduces the ambient water pressure to closed cycle pressure and after absorption, brings it back to ambient pressure. A system of valves effects the pressure changes with no loss or consumption of power. Only friction losses in the circuits have to be compensated for by differential pressure pumps.

A full scale (120 kW) test rig of the closed cycle diesel engine has been built to test the performance and reliability of the system. Ambient pressure at diving depth is simulated by a "slave" WMS working in the reverse manner.The test rig has been commissioned and has run on closed cycle for 300 hours so far.

Propulsion and DP System

The propulsion and DP-system has to be optimized with respect to space requirements and energy efficiency. The specific weight should also be as low as possible. A further requirement is that the thruster systems should react quickly to the signals received for safety reasons and to save energy.

Besides performance and space requirements, safety, reliability and serviceability of the system are important for the overall economy of the project and have to be given due consideration in the design.

These considerations led to the choice of a pressure balanced hydraulic system with secondary controlled propulsion motors to drive to the main propeller and the DP thrusters. The motors can thus be arranged close to the propellers outside the pressure hull.

The secondary controlled hydraulic system works at constant pressure and variable flow. The self controlling pumps regulate the fluid flow according to the demand of the drive motors. Thus the throttling losses of a pressure controlled system are avoided.

The main propulsion unit is a single propeller aft. The DP system consists of a number of thrusters in tunnels or in nozzles arranged on the vessel hull in a manner to give the submarine a 3-dimensional DP capability.

A key component of the DP system of the OSS and SSS submarines is a rotatable, retractable azimuth thruster. A full scale prototype of a 20 kW azimuth thruster complete with control and pressure balance systems has been built and successfully tested in a hyperbaric tank at 60 bar. The purpose was to verify the performance of the secondary controlled pressure balanced thruster under simulated subsea conditions.

Life Support System

The life support system is designed to monitor and control all toxic and inflammable gases which could be present in inadmissible quantities. Based on experience, following gases have been defined for control:

- Oxygen
- Carbon dioxide
- Carbon monoxide
- Hydrogen
- Argon
- Halon
- Freon

Carbon dioxide is the main contaminant in the submarine atmosphere produced principally by human metabolism.

Considering the requirements that the submarine should be able to operate submerged for several days, it was decided to base the concept of the life support system on the regenerative adsorption principle for CO2 control. Thus it would not be necessary to carry large amounts of CO2 absorbing chemicals on board.

The CO2 control system uses regenerative solid amine for CO2 absorption. It consists of 2 amine beds one of which works in the CO2 adsorption mode while the second bed is being regenerated by steam. After completion of the absorption/regeneration cycle, the beds are switched over. Fig. 5 shows a schema of the solid amine CO2 absorption system.

Integrated Control System

The integrated control system MICOS (Mission Control System) is a computer aided general control system which governs all systems, functions and operations of the submarine and the work module. Operation and manoeuvring of the submarine and the control and monitoring of its systems are on a high level of automation. The crew is relieved from routine tasks and assistance is provided for decision making in emergency situations. The crew strength can be reduced considerably; it is planned to have two persons per watch.

MICOS has two central stations from where the whole submarine can be monitored and controlled. These stations are the interfaces between operator and MICOS. Each station has a separate computer and is connected to all other stations over a ring bus. The optic fibre ring bus is duplicated, one being redundant. Both computers are identical; all submarine systems can be controlled and monitored from either operator console.

An individual substation is provided for each major submarine system. The substation receives its instructions and target values from the central computer but performs its tasks independently. Real values, status reports and alarms will be transmitted back to the main computer for presentation at the pilots' consoles. Each substation has two computers one of which is redundant. Both computers are active and have the same information status.

CONCLUSIONS

The development work done has established the technical feasibility of using submarines for underwater work.

A number of work procedures for inspection, maintenance and repair (IMR) operations on subsea offshore installations have been investigated. The study showed that the submarine has many advantages over the surface vessel as a base for subsea operations:

- Weather independent; less down time.

- o Stable platform; no motions due to seaway and wind.

- o On the spot; direct visual observation of operations.

- o Short distance to work spot; shorter tool running times, short umbilicals for ROVs and robots.

Besides offshore work, the submarine can be used for a variety of underwater tasks such as oceanographic research, seismic survey, wreck salvage, underwater rescue.

Economic analyses have indicated appreciable cost savings resuting from higher availability, reduced down time and shorter job performance times.

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2. Fowler, A., Boyes, A.: "The Argo-Diesel Enhanced Underwater Power Source", Underwater Technology Conference "Intervention '88", Bergen April 1988.

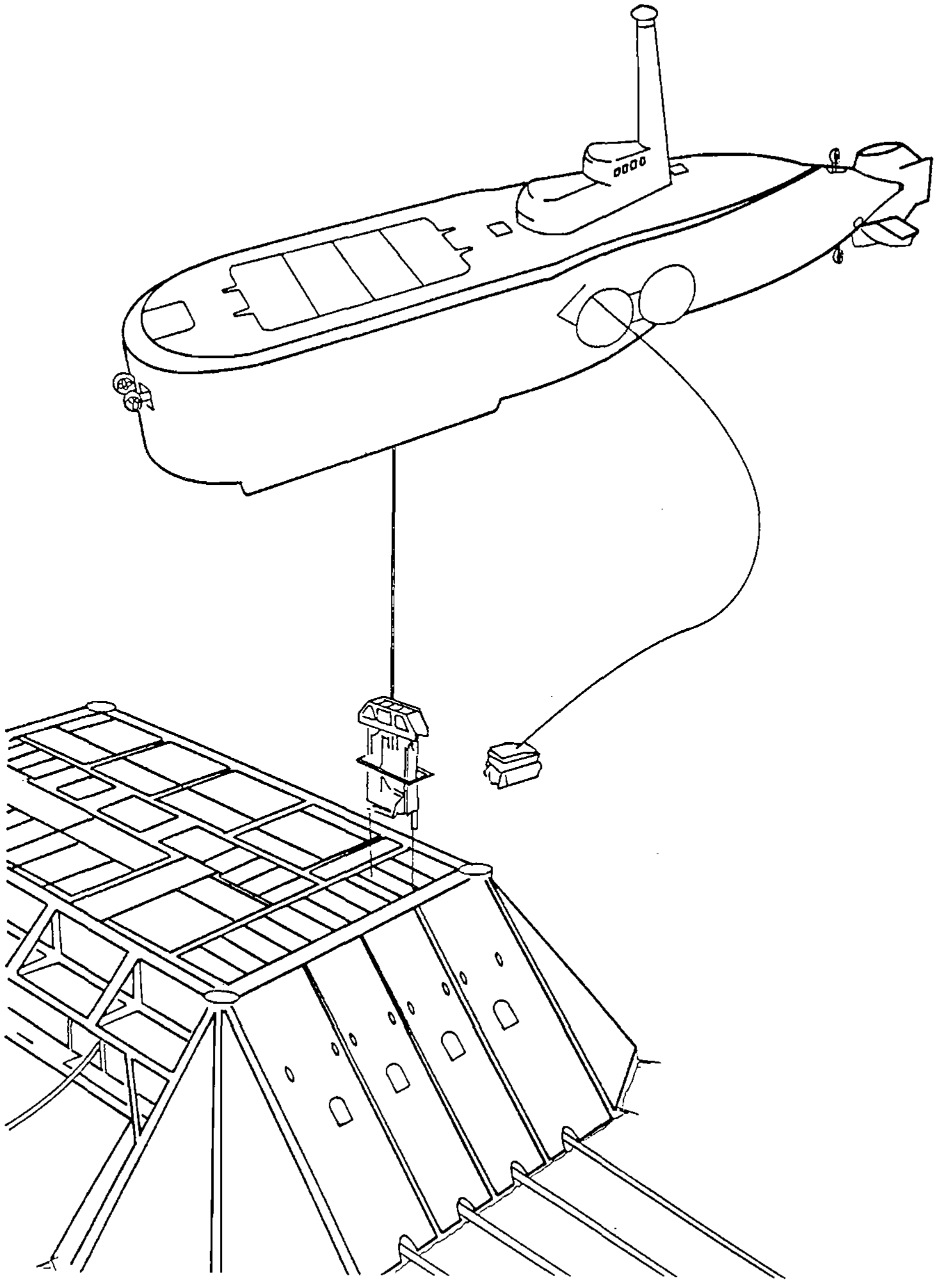

Fig. 1: OFFSHORE SERVICE SUBMARINE (OSS)

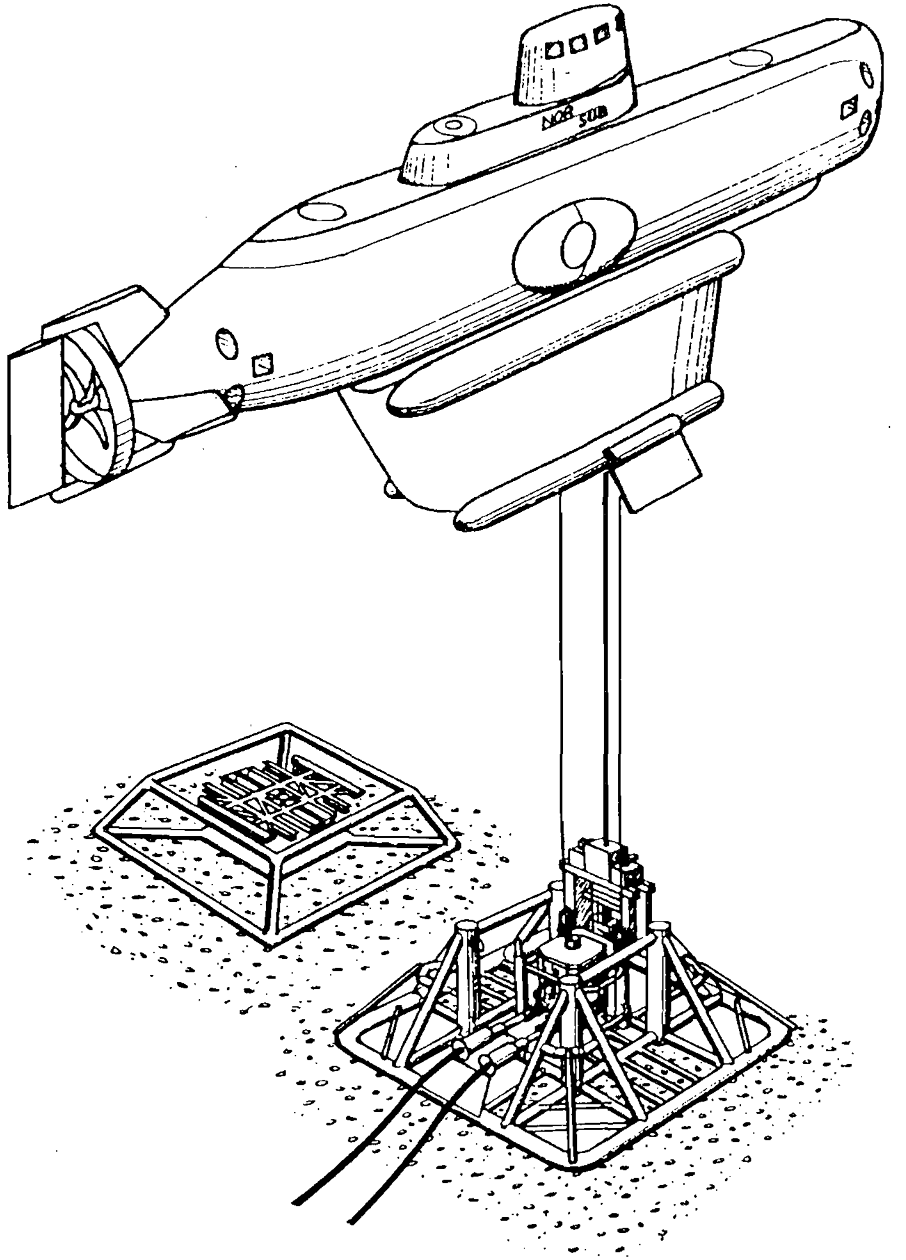

Fig. 2: SUPER SUBSEA SUBMARINE (SSS)

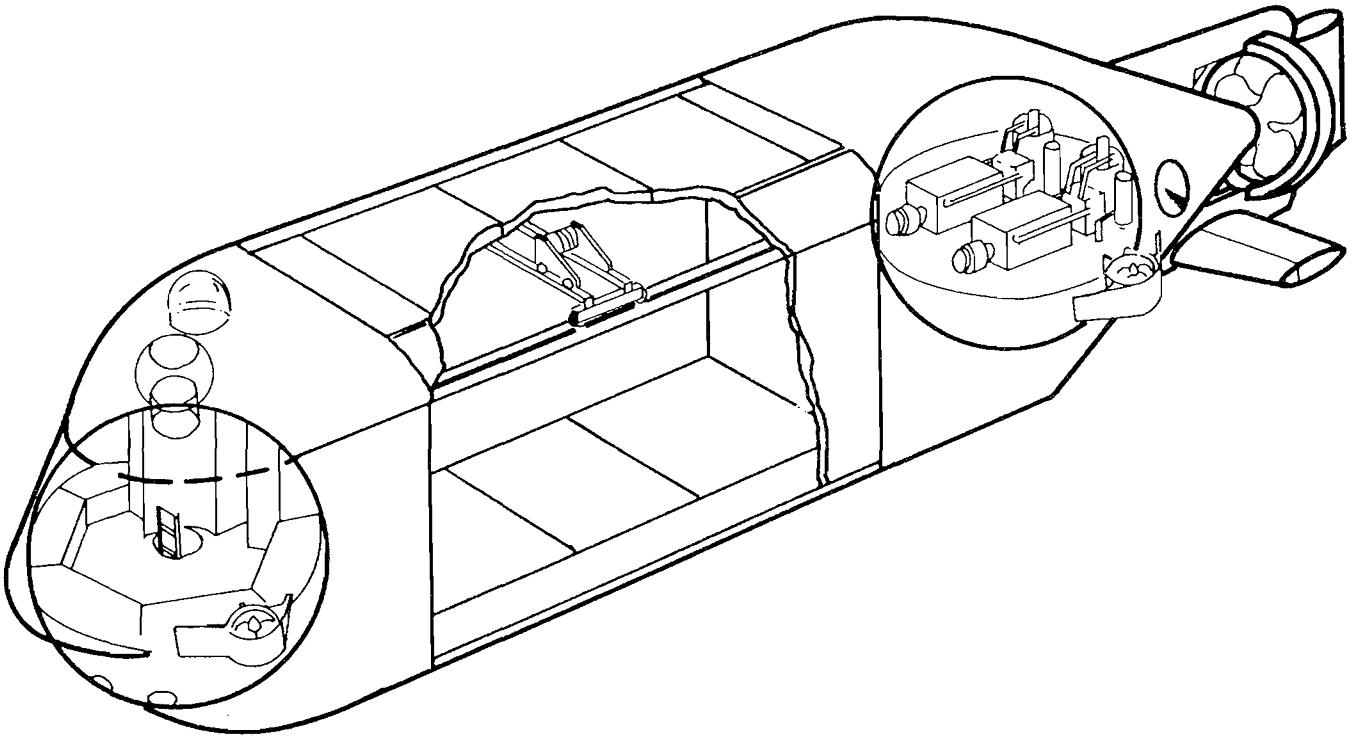

Fig. 3: DEEP DIVING SUBMARINE OSS 1500

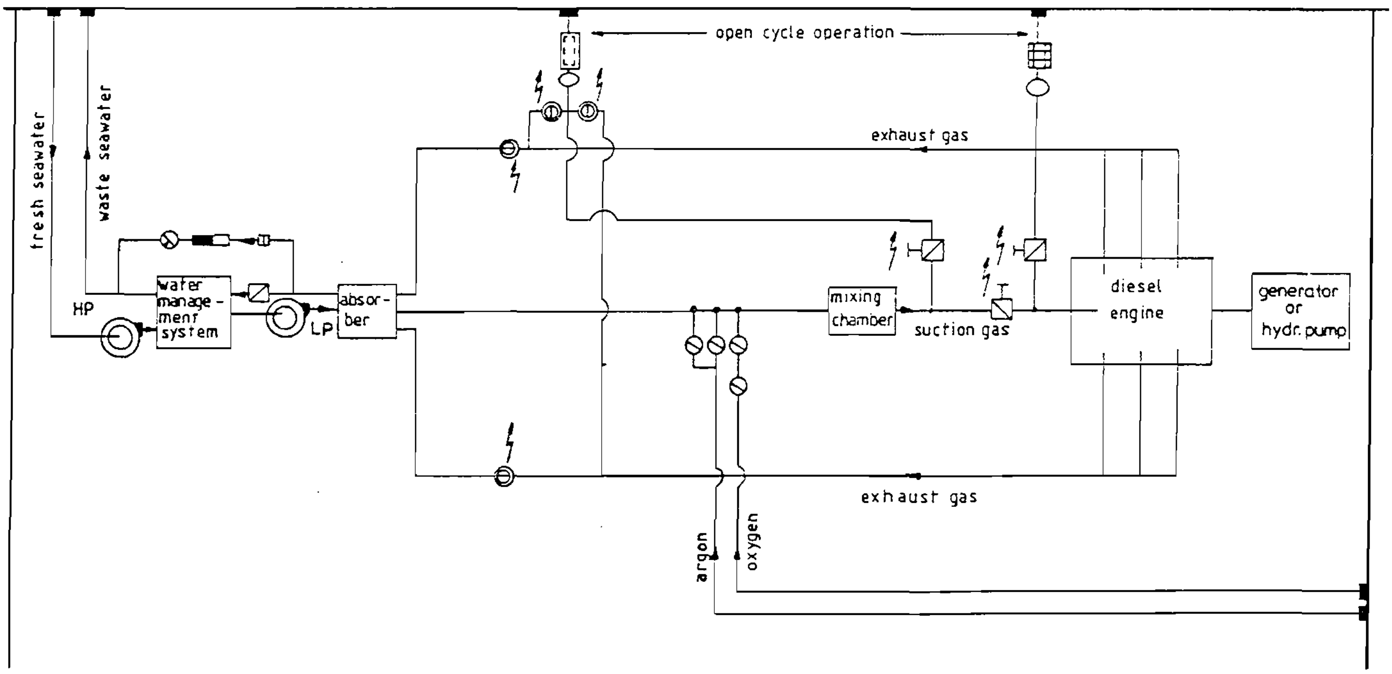

Fig. 4: SCHEMA CLOSED CYCLE DIESEL ENGINE

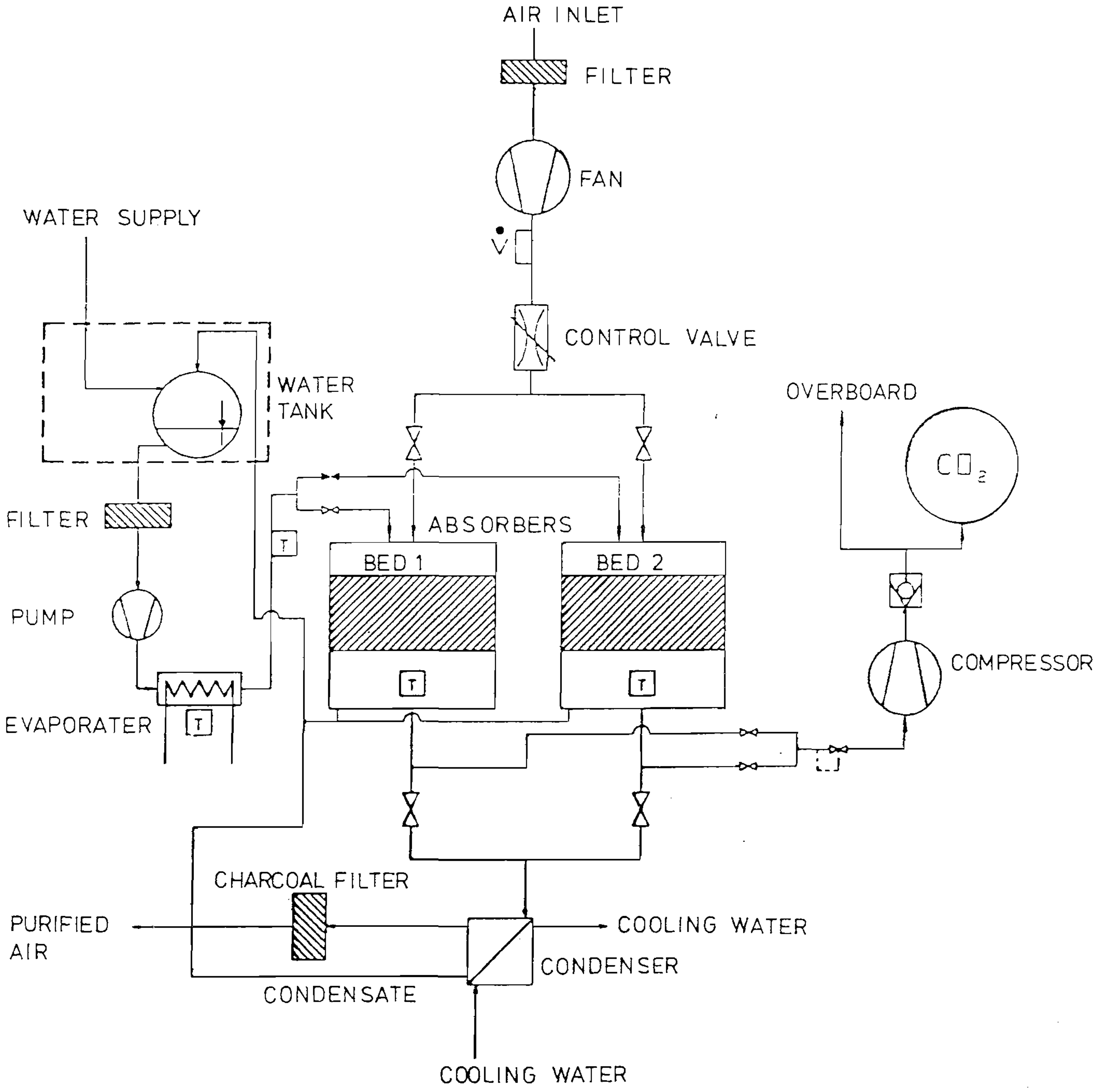

Fig. 5: CO_2 ADSORPTION SYSTEM