DEPARTMENT OF MARINE ENGINEERING

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"TECHNOLOGICAL DEVELOPMENT OF MACHINERIES IN TRANSPORTATION"

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Improving the efficiency of marine engines and reducing operating and maintenance costs while reducing emissions are among the most important goals of Marine Engineering. This paper dis
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KEYWORDS:- Six-stroke engine, Orimulsion

INTRODUCTION

Marine internal combustion engines have undergone steady improvements in their history of nearly one hundred years. Progress in the last few decades has been quite rapid and includes developments such as increase in power (now around 100,000 kW), reduction in specific fuel consumption, the use of gas and dual fuel engines and computer controlled ("intelligent") engines. Improvements in efficiency, reduction in operating and maintenance costs and reduction in harmful emissions are among the drivers of marine engine development. There are, however, many developments in engine technology in general which should be of interest to Marine Engineers and others associated with ship operation. Two such developments, described in this paper, are: six- stroke engines, an alternative fuel called Orimulsion.

SIX STROKE ENGINES

History

The introduction of six-stroke engines is a milestone in engine technology. The six-stroke engine is a type of internal combustion engine based on the four-stroke engine, but with some additional features to increase efficiency and reduce emissions. Different types of six-stroke engines have been developed since the 1990s. The Bajulaz six-stroke engine was developed in Switzerland, the Crower six-stroke engine in the U.S.A. and the Velozeta six-stroke engine in India at the College of Engineering, Thiruvananthapuram. Another type of six-stroke engine has opposed pistons. In the Velozeta engine, air is injected into the cylinder during the exhaust stroke to get a second power stroke, while in the Crower engine water is injected after the exhaust stroke. There are other types of six-stroke engines, and one such engine is described here.

This six-stroke engine is similar to a normal four-stroke engine but has two additional chambers of constant volume above each cylinder. In one of these chambers, fuel is burnt at constant volume to produce the first power stroke, while in the second chamber air is heated by the heat passing through the wall of the first chamber and this heated air is used to produce a second power stroke. This engine thus captures the heat lost from the four-stroke Otto cycle or Diesel cycle and uses it to power an additional power stroke followed by an exhaust stroke of the piston in the cylinder. The pistons in this type of six-stroke engine go up and down three times for each injection of fuel. There are two power strokes: one with fuel and the other with air.

The Working of a Six-Stroke Engine

Most internal combustion engines, operating on different cycles, have a common feature – combustion occurs in the cylinder after compression of air, and the expansion of gas acting directly on the piston (work) is limited to 180 degrees of the crankshaft angle.

In the six-stroke engine, the combustion occurs at constant volume in an enclosed chamber into which a charge of air compressed by the piston is admitted. The high pressure and temperature gas in the combustion chamber is then released into the cylinder to produce the first power stroke. The combustion chamber is surrounded by another chamber in which the temperature and pressure of the air are raised to a high level at constant volume by the heat passing through the walls of the combustion chamber. This air is then used to produce a second power stroke. A significant improvement in thermal efficiency is obtained, firstly by the combustion of the fuel at constant volume in the combustion chamber and secondly by using the heat that would be lost in the exhaust gases to produce a second power stroke.

In the six-stroke cycle engine, the two supplementary chambers function in parallel to produce a cycle of eight events, an internal combustion cycle of four events and an external combustion cycle of four events. Events three and six, which occur within closed chambers and have no direct action on the piston and the crankshaft, are called “static events” whereas the remaining six events are “dynamic events.”

The four events in the external combustion cycle are:

- ☐ Event 1: intake of air in the cylinder (dynamic event).
- ☐ Event 2: compression of the intake air in the heating chamber (dynamic event).
- ☐ Event 3: keeping this air in the closed chamber where a maximum heat exchange occurs with the combustion chambers walls, without direct action on the crankshaft (static event).
- ☐ Event 4: expansion of the compressed air in the cylinder, work (dynamic event).

During this cycle of four events, the air does not come into direct contact with the heating source, and in fact no combustion actually occurs.

The second cycle of four events is of internal combustion:

- ☐ Event 5: re-compression of heated air in the combustion chamber (dynamic event).
- ☐ Event 6: fuel injection and combustion in the closed combustion chamber, without direct action on the crankshaft (static event).
- ☐ Event 7: expansion of the combustion gases in the cylinder, work (dynamic event).
- ☐ Event 8: exhaust of the combustion gases (dynamic event).

During this cycle of four events, the air comes into direct contact with the heating source.

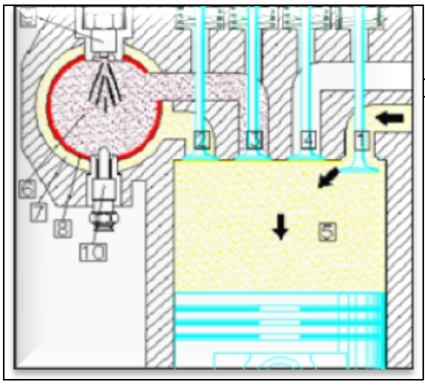
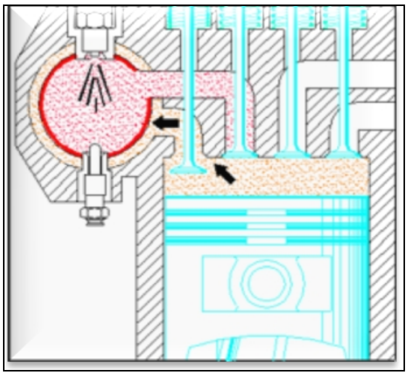


Fig. 1 shows the six stroke cycle. The different components in a cylinder are labelled as follows:

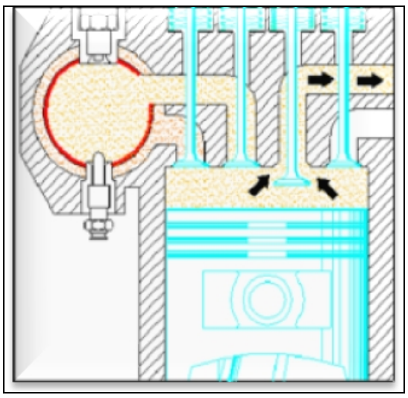


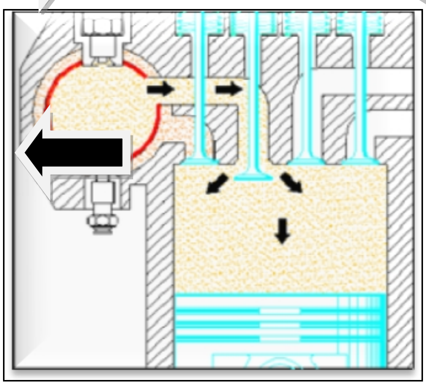
1. Intake valve. 2. Heating chamber valve. 3. Combustion chamber valve. 4. Exhaust valve. 5. Cylinder. 6. Combustion chamber. 7. Air heating chamber. 9. Fuel injector. 10. Heater plug

FIRST STROKE (SUCTION)

SECOND STROKE

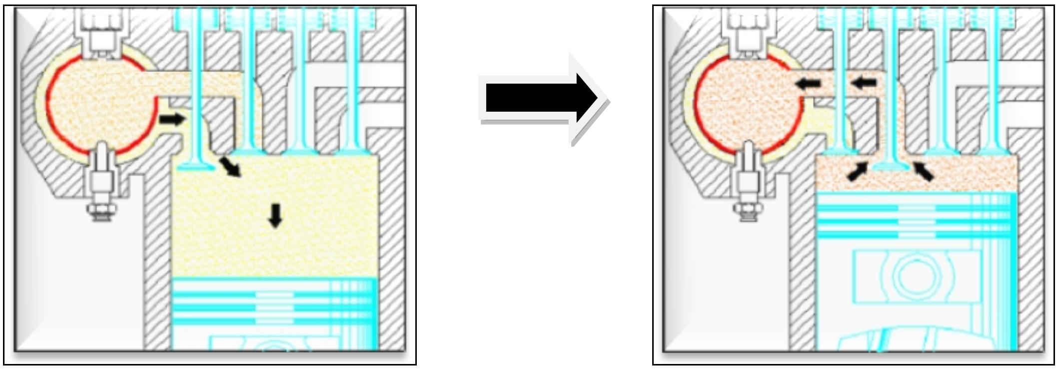
(COMPRESSION IN HEATING CHAMBER)





FOURTH STROKE (EXHAUST)

THIRD STROKE (POWER)



FIFTH STROKE (ADDITIONAL POWER) SIXTH STROKE (RE- COMPRESSION)

Fig. 1:- Six-Stroke Cycle

The figure shows the cylinder head with the air heating and combustion chambers and four valves of which two are the conventional intake and exhaust valves. The other two valves are made of heavy-duty heat-resisting material. During the combustion and the air heating processes, the valves could open under the pressure within the chambers. To avoid this, pistons are installed on both valve shafts, which compensate for this pressure. Being a six-stroke cycle, the camshaft speed is one-third the crankshaft speed. The wall of the combustion chamber glows red hot when the engine is running. The small thickness of the wall allows heat exchange with the air-heating chamber that surrounds the combustion chamber. The air-heating chamber is isolated from the cylinder head to reduce thermal loss.

Through heat transfer from the combustion chamber to the heating chamber, the work is distributed over two strokes, which results in less pressure on the piston and greater smoothness of operation. In addition, since the combustion chamber is isolated from the cylinder by its valves, the moving parts (especially the piston) are not subject to excessive stress from the very high temperatures and pressures. The moving parts are also protected from explosive combustion or auto-ignition, which is observed on the ignition of the air-fuel mixture in conventional gas or diesel engines.

The combustion and air-heating chambers have different compression ratios. The compression ratio is high for the heating chamber, which operates on an external cycle and is supplied solely with pure air. On the other hand, the compression ratio is low for the combustion chamber, which operates on an internal combustion cycle. The combustion of all injected fuel is insured first, by the supply of preheated pure air in the combustion chamber, and then by the glowing walls of the chamber, which act as multiple spark plugs. To facilitate cold starts, the combustion chamber is fitted with a heater plug (glow plug).

st to a diesel engine, which requires a heavy construction, the six-stroke ıade much lighter, especially all the moving parts. A six-stroke engine can nd gas fuels. Fuel injection may be split up for dual fuel by using the SNDF Dual Fuel) system.

Fig. 2 shows graphically the interconnection between the different events in the internal and external combustion cycles that take place in a six-stroke engine.

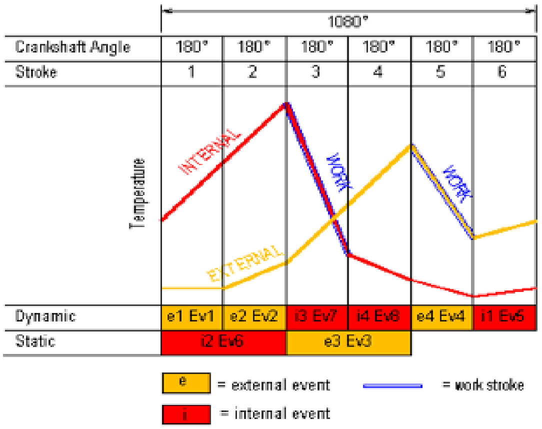


Fig.2:- Graphical Representation of a Six-Stroke Cycle

REDUCTION IN HARMFUL EMISSIONS

In a six-stroke engine, fuel injection and combustion tak combustion chamber and therefore at a constant volume over 360 angle. These features give sufficient time for the fuel to burn ideally an eliminating carbon monoxide in the exhaust. The glowing wall of the also calcines the residue that is deposited during fuel combustion. Tl pollution caused by the engine.

(f)

SI X T H S T R O

INCREASED THERMAL EFFICIENCY

Compared to a normal four-stroke engine, a six-stroke engine efficiency for the following reasons:

The heat that is lost during the cooling of the cylinders of a conventional engine is recovered in a six-stroke engine by the air-heating (chamber. After intake, air is compressed and heated degrees of crankshaft angle, 360 degrees of which combustion).The transfer of heat from the very thin w air heating chambers lowers the temperature and pre exhaust (internal combustion).Combustion and expa degrees of crankshaft rotation, 360 degrees of which a and 180 degrees during expansion.

This improves the combustion of the fuel. The the optimal burning of any fuel and calcines the residues. The useful work of the engine is distributed between two expansions or power strokes in six strokes of the cycle, which is a third more than in a four-stroke engine .The intake of air in the cylinder is better due to the lower temperature of the cylinder walls and the piston head. The mixing of exhaust gases with fresh air on intake is eliminated in the six-stroke engines, since intake takes place during the first stroke and exhaust during the fourth stroke, so that there is no overlapping period.

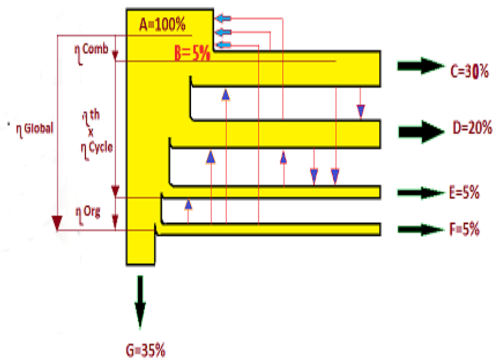
There is a large reduction in the power required for engine cooling. The cooling water pump and fan outputs are reduced and it may be possible to suppress the water cooler.

The inertia forces acting on the crankshaft are reduced because the moving parts can be made lighter since the combustion chamber is separated from cylinder. Moreover, since the combustion takes place outside the cylinder, the temperature of the lubricating oil inside the cylinder is lower and the risk of dilution is reduced, even in cold starts. Since the six-stroke engine has a third less intake and exhaust than a four-stroke engine, the reduced pressure in the cylinder during intake and the back pressure during exhaust are reduced by a third. The gain in efficiency due to this balances out the losses due to the passage of air through the combustion chamber and heating chamber valves during compression of fresh and heated air.

It has been claimed that the fuel consumption of a six-stroke engine is nearly 40 per cent less than that of a comparable four-stroke engine.

Fig. 3 shows the energy balance of a conventional internal combustion engine. It is seen that the cooling system and the exhaust heat are the two major heat losses. In a six-stroke engine, these losses are recovered to a large extent and converted to useful work.

The air flowing to the heating chamber acts as a coolant as well as the working fluid for the second power stroke. There may be a problem of cranking the engine in a cold state; this is tackled by placing a heater plug in the combustion chamber.



A - Energy in fuel

B – Energy in unburnt fuel

C - Energy in exhaust gases

D - Energy dissipated in cooling system

E - Energy dissipated by radiation

F - Friction losses

G - Useable work

Fig.3:- Energy Balance in an Internal Combustion Engine

COMPARISON BETWEEN CONVENTIONAL AND SIX-STROKE ENGINE

Some of the major differences and advantages of a six-stroke engine over a conventional two-stroke or four-stroke engine are:

- A two-stroke engine has one power stroke in every revolution and a four-stroke engine has one power stroke in every two revolutions, whereas a six-stroke engine has two power strokes in every three revolutions, the second power stroke using air.

- A conventional engine is a purely internal combustion engine whereas a six-stroke engine involves both internal combustion and external combustion.

- The thermal efficie[illegible] engine.

- The specific fuel consumption of a six-stroke engine is significantly less (by about [illegible] per cent according to some tests) than that of a conventional engine.

- The cylinder lubricating oil consumption in a six-stroke engine is lower than in a conventional engine because the combustion takes place in a separate chamber in the six-stroke engine whereas it takes place in the cylinder in a conventional engine.

- The jacket cooling water system, necessary in a conventional engine, is eliminated in the six-stroke engine, thereby allowing its weight to be greatly reduced.

- Air is the cooling medium in a six-stroke engine, and this air is also used to provide an additional power stroke. In a conventional engine, water is the cooling medium; this can cause high thermal gradients leading to cracked liners and leakage of cooling water.

- The pistons and liners in a conventional engine must withstand high thermal and gas loads, and must therefore be made of special alloys of complex composition. The pistons and liners in a six-stroke engine can be made of less sophisticated and expensive materials, leading to reduction in the cost of the engine.

- In a conventional engine there is an overlap period between exhaust and intake, leading to a reduction in efficiency. This overlap is eliminated in a six-stroke engine.

- The pollution caused by a six-stroke engine is far less (by as much as 65 per cent) than that caused by a conventional engine.

- The time between overhauls is longer in a six-stroke engine compared to a conventional engine.
- Chances of blow past, scavenge fire and crankcase explosion in a six-stroke engine are much less than in conventional engines.

- Incomplete combustion of fuel is a common problem in conventional engines, whereas complete combustion of the fuel almost always takes place in a six-stroke engine because the combustion chamber is always red-hot.
- The loads on the cams and crankshaft of a six-stroke engine are less than these loads in a conventional engine.

- The chances of contamination of crankcase oil are less in a six-stroke engine than in a conventional engine.

Compared to a conventional engine, a six-stroke engine may be said to have the following disadvantages:

- The thermodynamic properties of the working fluids in a six-stroke engine are further removed from the properties of an ideal gas than the working fluid in a conventional engine.
- The aerodynamic drag of the air moving to and from the cylinder to the combustion chamber and the heating chamber reduces efficiency.
- Water used in a conventional engine is a much better coolant than air used in a six-stroke engine.
- There are more moving parts in a six-stroke engine, and these cause additional frictional losses.

PRESENT STATUS

Six-stroke engines have been under development for about twenty years. Although there do not appear to have been any significant commercial applications of this type of engine so far, it is known that some automobile manufacturers are actively considering the use of these engines in the next generation of cars. Applications in the marine field would probably begin with six-stroke engines in motorboats and other small vessels. However, the pressing need for decreasing fuel consumption and reducing pollution should see the rapid introduction of these engines for the propulsion of large ocean going ships.

ORIMULSION

Orimulsion is a fuel derived from the bitumen that occurs in nature in large reserves in the 700 km long Orinoco oil belt in Venezuela.The Orinoco river basin has the world's largest bitumen deposits, currently estimated at more than 1.2 trillion million barrels (190 trillion m^3). This is an amount 50 per cent greater than the world's estimated oil reserves. It is extracted, processed and distributed by Bitumen's Orinoco SA (Bitor), a subsidiary of the Venezuelan state owned oil company. Raw bitumen has an extremely high viscosity, and a specific gravity ranging between 8 and 10 API degrees at ambient temperatures, and is unsuitable for direct use in conventional engines.

Orimulsion is made by mixing the bitumen with about 30 per cent fresh water and a small amount of surfactant. The resulting mixture has behaviour similar to fuel oil. It is transported in double hull tankers as a mixture (emulsion) of 70 per cent bitumen and 30 per cent water, with 0.2 per cent of surfactant (nonylphenol ethoxylate) to stop the mixture from separating. The fuel is currently being used or tested in a number of countries. The emulsion of Orinoco bitumen and water combines the select advantages of oil and coal. Orimulsion is now an attractive liquid fuel for low capital cost, highly efficient, and reliable production of power. The process for converting bitumen to Orimulsion is shown in Fig. 4.

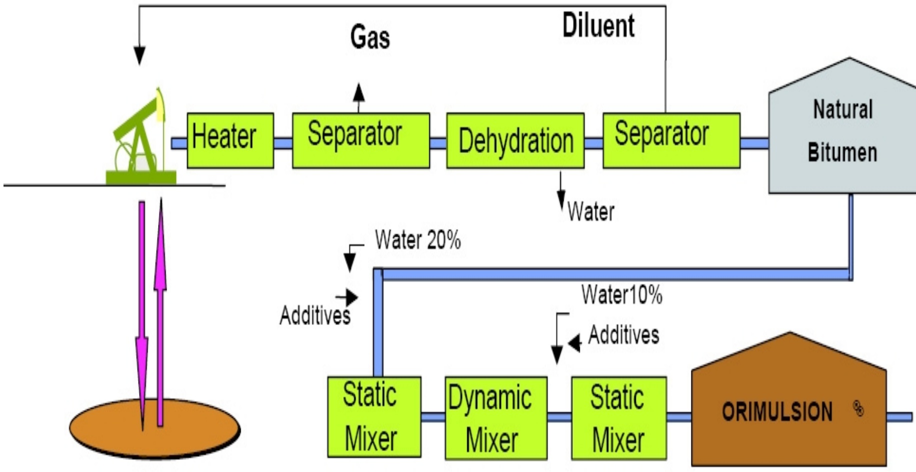


Fig.4:- Conversion of Bitumen to Orimulsion

ADVANTAGES OF ORIMULSION

As a fuel, Orimulsion has a number of attractive characteristics:

- The known reserves of bitumen are very large.
- Its current price makes it competitive with internationally traded coal.
- It is relatively easy and safe to produce, transport, handle and store.
- It is easy to ignite and has good combustion characteristics.
- With suitable modification of the power plant, it can be used for power generation and ship propulsion using plants that were earlier designed to run on coal or heavy fuel oil.
- It is possible to "upgrade" the fuel when signs of deterioration are noticed.
- The recommended storage time of 3 - 4 months can be prolonged to a year.
- Fuel treatment with centrifuges (separators) is possible.

CHARACTERISTICS OF ORIMUSION

Table 1:- Fuel Characteristics and shows the characteristics of Orimulsion as a fuel compared with heavy fuel oil. The flash point of Orimulsion is more than 65ºC, and its higher heating value is 29540 kJ/kg.

Particulars	Orimulsion	Heavy Fuel Oil
Water content, % w/w	28 – 30	1
Median droplet size, μm	13-15	-
Density (15ºC), kg/m^3	1010 – 1020	930 – 1010
Viscosity, CSt at 50ºC	420	380
Sulphur, % w/w	2.8 – 3.0	1.0-1.22
Ash, % w/w	< 0.1	< 0.1
Vanadium, ppm	320	100 - 300
Surfactant, % w/w	0.2	-

DISADVANTAGES

The burning of Orimulsion makes an unfavourable impact on the environment, and the emissions violate the MARPOL regulations. The four main areas of concern are:

- Once the fuel is ashore, environmental concerns shift to the burning of the fuel. When Orimulsion burns, it releases considerable amounts of sulphur dioxide (SO_2) and sulphur trioxide (SO_3).
- One of the major concerns of burning Orimulsion is that the process releases extremely tiny particles of heavy metals. These particles are so small that they appear more like gases than like solids.
- The final concern has to do with the phenols in Orimulsion. Released into the environment, either through improper burning or by spillage, phenols have serious "gender -bender" side effects all up and down the food chain.

However, these disadvantages can be overcome. The sulphur content in Orimulsion is below 4.5 per cent, the current limit for marine fuels. SOx emissions can be further reduced by fitting a flue gas desulphuriser. The removal of particulate matter can be carried out by electrostatic precipitators as shown in Fig. 5. The dangers of phenol in Orimulsion have already been eliminated by replacing the phenol based surfactant with an alcohol based one.

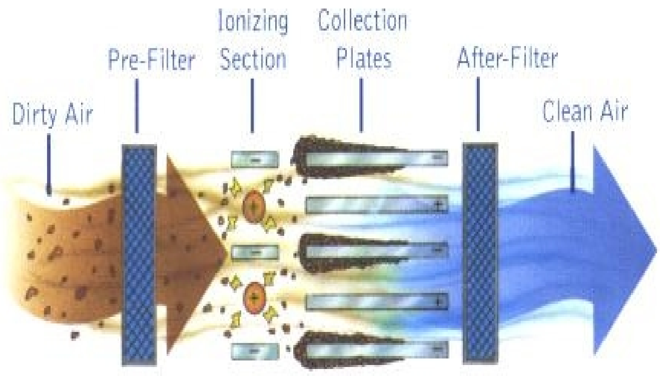


Fig.5:- Process for Removing Particles from Exhaust Gas

SHIP PROPULSION USING ORIMULSION- A FUTURE PROSPECT

Considering the advantages of Orimulsion as a fuel and noting that the disadvantages can be overcome quite easily, there is a prospect that Orimulsion will be used in future as a fuel in ships. This would necessitate certain modifications in marine engines. Some of the modifications necessary are shown in fig 6.

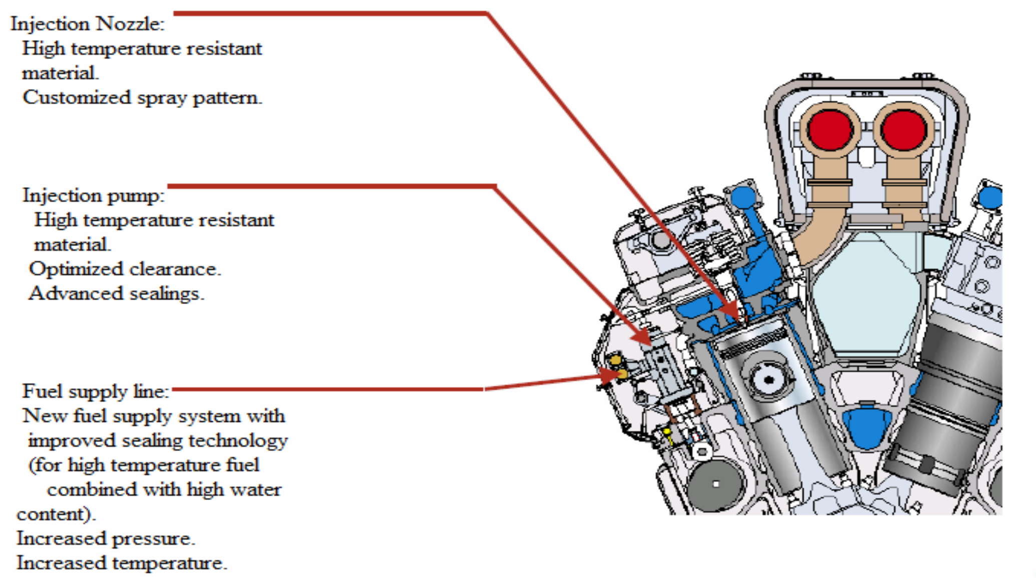


Fig.6:- Modifications for Using Orimulsion as a Fuel

CONCLUSION

The era of the internal combustion engine for ship propulsion is not about to end. The need to reduce fuel consumption and minimise pollution requires a reassessment of current technologies used in marine engines. The six-stroke engine, which offers the hope of reducing fuel consumption by up to 40 per cent and reducing pollution by more than 65 per cent compared to the marine engines of today, has the potential to revolutionise ship propulsion. Fuels become scarcer and more expensive; the need for alternative fuels will increase. An excellent alternative is Orimulsion, of which vast reserves are available, and which can provide high performance standards while meeting the most stringent environmental requirements. These two technologies six- stroke engines, and Orimulsion – should therefore be of interest to Marine Engineers for transportation.

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