AUXILIARY ENERGY

WHAT PRICE TO PAY?

BY

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Introduction

Fuel use is a relatively small proportion of the through-life cost of a frigate or destroyer size warship (FIG. 1), but it is a more significant portion of the day-to-day running expense. It is an element in the design calculations for a ship, whether featuring as endurance or specific fuel consumption (s.f.c.), and is one aspect over which the engineer has some control. Not suprisingly, efficient use of fuel has been a theme for three recent articles, on hull and propulsion efficiency[1], on waste heat recovery for propulsion[2], and energy for auxiliary systems[3].

This article takes up the discussion on auxiliary energy, by looking at the present pattern of use, and seeks to give a pointer for future ship auxiliary systems.

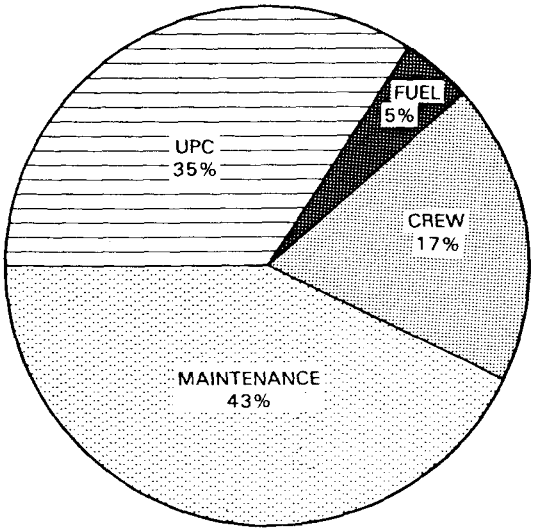

FIG. 1—THROUGH-LIFE COST OF A FRIGATE.

Present Auxiliary Energy Use

Up to 25% of the fuel used in a warship is consumed in the auxiliaries—the diesel generators, auxiliary boilers, and incinerator—and costs around £400 000 per year. Such figures are obviously subjective, depending as they do on the ship's duty, environment and the prevailing price of oil, but they serve to given an indication of the magnitude of the subject.

A recent study using the Type 22 as a basis sought to examine quantitatively the use of energy by ship services, and to consider alternative routes for the provision of that energy. FIG. 2 shows the major consumers of energy, as typified for cruising in a tropic, temperate or sub-arctic environment. Of note is the significant consumption for fresh water production in the distillers, for the HP seawater (HPSW) system and for chilled water, and the limited use of heating which is mainly for intake air to directly ventilated compartments.

Almost half the electricity is used in a multiplicity of small consumers throughout the ship, significant among which are galleys, cooling machinery, forced lubrication pumps and air compressors. Some equipments with high installed power, such as the main hydraulic system, stabilizers and CPP system, do not rate high in the list of consumers because of their low load factor; this is also true of the weapon systems.

Where does this energy come from, and can we make more effective use of these sources?

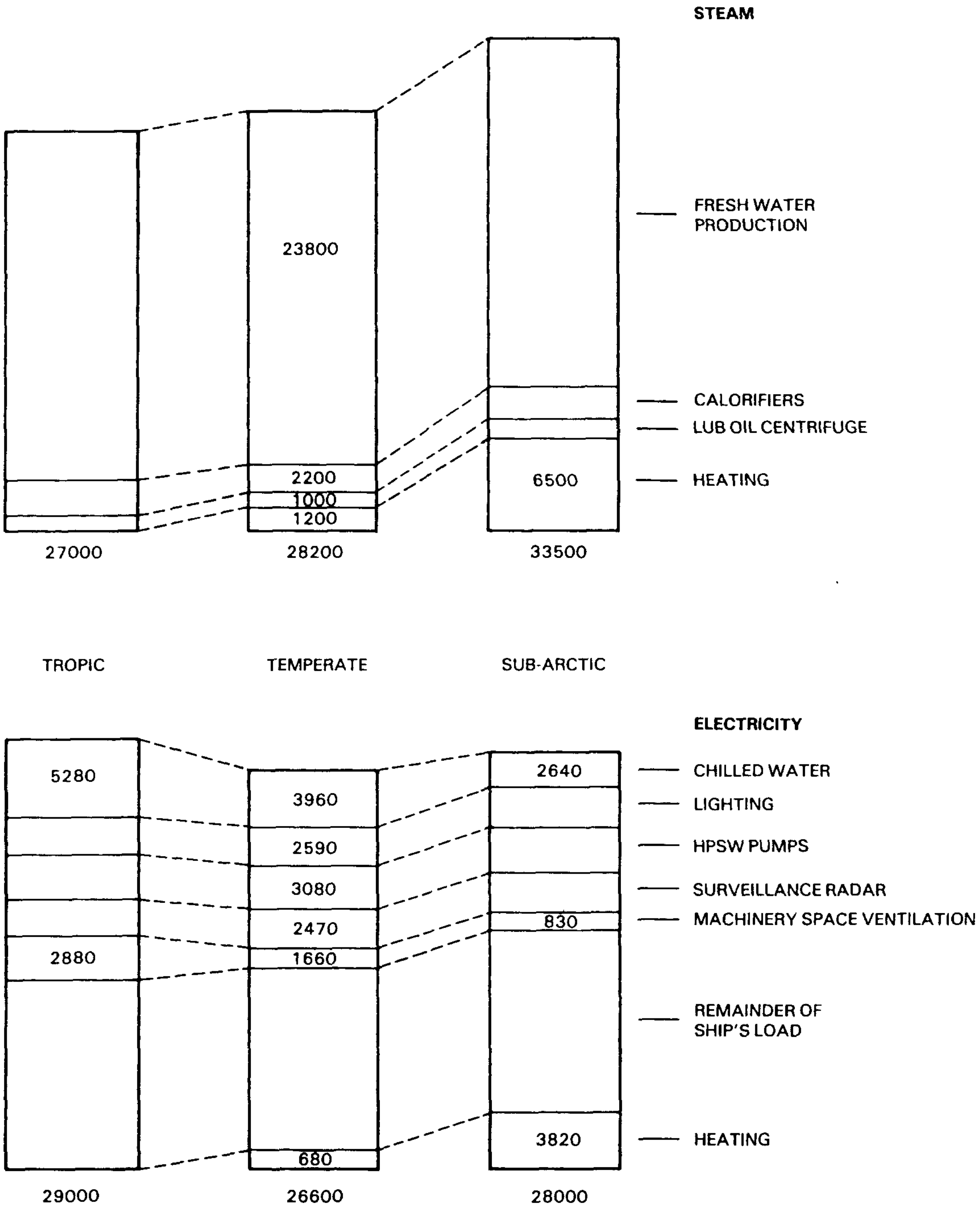

FIG. 2—AUXILIARY ENERGY CONSUMPTION IN THE TYPE 22 (KW.H/DAY, CRUISING)
Where the loads are the same in all columns the figures are not repeated

Shipboard Energy Sources

Diesel Engines

FIG. 3 gives an indication of the relative conversion efficiency of diesels, gas turbines and boilers, but this bold picture hides a number of other considerations. For instance, heat can be derived from a diesel, from the jacket water and from the exhaust gas, to the scale shown for a high speed engine in FIG. 4. In this case, most of the heat is recovered at low temperature, around 80° to 90°C; low pressure steam can be generated, but with a less effective recovery. Because of the low temperature, fouling of the uptake

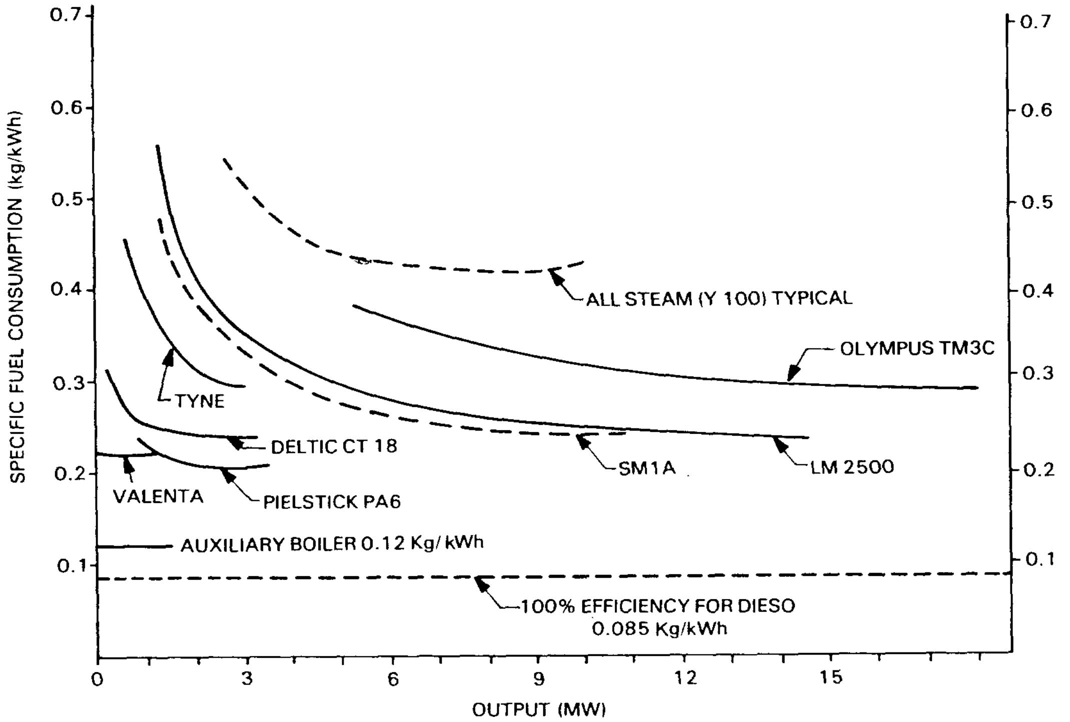

FIG. 3—SPECIFIC FUEL CONSUMPTIONS OF ENERGY SOURCES

boiler is inevitable and will lead to reduced efficiency and an increased maintenance load. Those engineers with MCMV experience are well aware of the joys of a dirty exhaust pipe.

Gas Turbines

Gas turbines can be an economic source of additional power. Although the specific fuel consumption of simple cycle gas turbines is considerably higher than that of diesels, the marginal s.f.c. can be attractively low (FIG. 5).

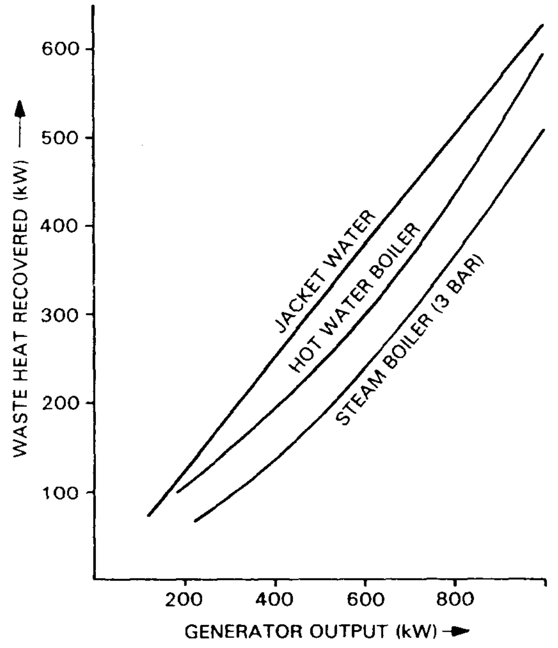

FIG. 4—WASTE HEAT RECOVERY FROM 1000 KW PAXMAN DIESEL

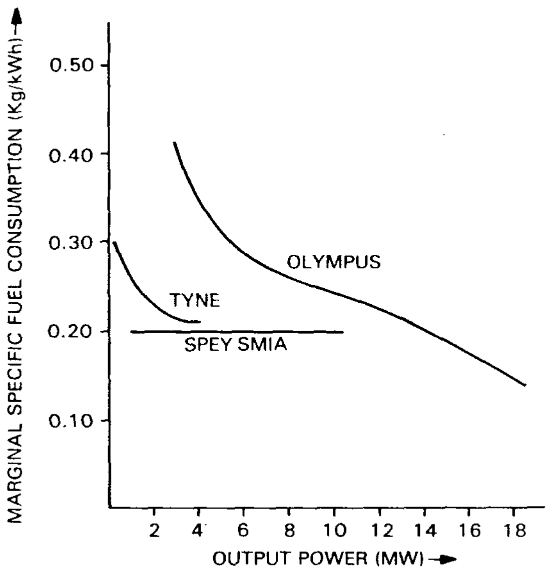

FIG. 5—MARGINAL SPECIFIC FUEL CONSUMPTION OF GAS TURBINES

'Marginal' means the additional fuel consumed for each extra kW of shaft output power

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Heat recovery from gas turbines is common industrial and naval practice, as evidenced by installations generating steam from gas turbine alternator exhausts in the Canadian DDH280 and the U.S. DD963 and CG47 classes, and also the proposals for RACER on the LM2500 propulsion engines[2]. The potential of this route is attractive, but operating experience has shown that there are severe penalties to be paid unless the quality of engineering makes a system that is both flexible and reliable. Such were the problems that the U.S.N. now has a programme to remove steam systems from the DD963 class and convert to all electric operation, despite the increased fuel consumption.

Boilers

Boilers are effective providers of heat, but the conversion of that heat into mechanical power is limited to a percentage of the theoretical Carnot cycle efficiency.

In a warship, steam propulsion plant or auxiliary drives are considerably less efficient than diesel or gas turbine arrangements, as FIG. 3 shows.

Apart from basic efficiency, what other factors drive the design of systems in which these energy sources are used?

Considerations in Auxiliary System Design

On what basis should we judge proposals for platform systems? The list of desirable attributes is long and often contradictory, so, rather than repeat this, a number of cardinal principles are advanced here. It must always be borne in mind that the product of the design process is a warship, and all other considerations are subordinate to the objectives of 'float, move, fight.'

(*a*) Simplicity is sought. Simplicity promotes accuracy of operation, reliability, comprehension by operator and maintainer, and a lower maintenance workload.

(*b*) Autonomy is attractive. A system should rely on as few others as possible, to maximize availability and reliability, and to limit the consequences of failure.

(*c*) Big is bad, (or at least, not good.) Weight and space are at a premium in warships, so a system that is intrinsically smaller and lighter than another, for the same function, is to be preferred. As an illustration, FIG. 6 shows the weight and space of systems to transmit 200 kW of heat. For lower powers, pipe systems are at an even worse disadvantage when compared with electric cabling, because thickness of lagging and mechanical strength become significant determinants of the weight and volume.

(*d*) Flexibility is favoured. The ability readily to reconfigure a system to isolate damage or to maintain equipment is an attraction, as is the ability to react quickly to changes in duty.

These principles may seem self-evident, and this is a proof of their validity, but they cover only those aspects as they affect a system in isolation. The range of environments, from extreme tropical to arctic, and the activity states of the ship define the boundaries of the system design, but into the consideration also must be added the proportion of time which it is expected will be spent in that state or environment. It therefore becomes debatable whether a system should be optimized for a condition in which the ship will spend only a small proportion of its time.

By way of an example, it is often suggested that to reduce the load on the chilled water plant, a direct fresh water/sea water heat exchanger be installed in the chilled water system for use when the sea temperature is sufficiently low. But adequately low temperatures are not found in the Atlantic except north of the Faroes in winter and south of the Falklands.

So, what practical changes are open to the auxiliary systems designer, to reduce their energy consumptions?

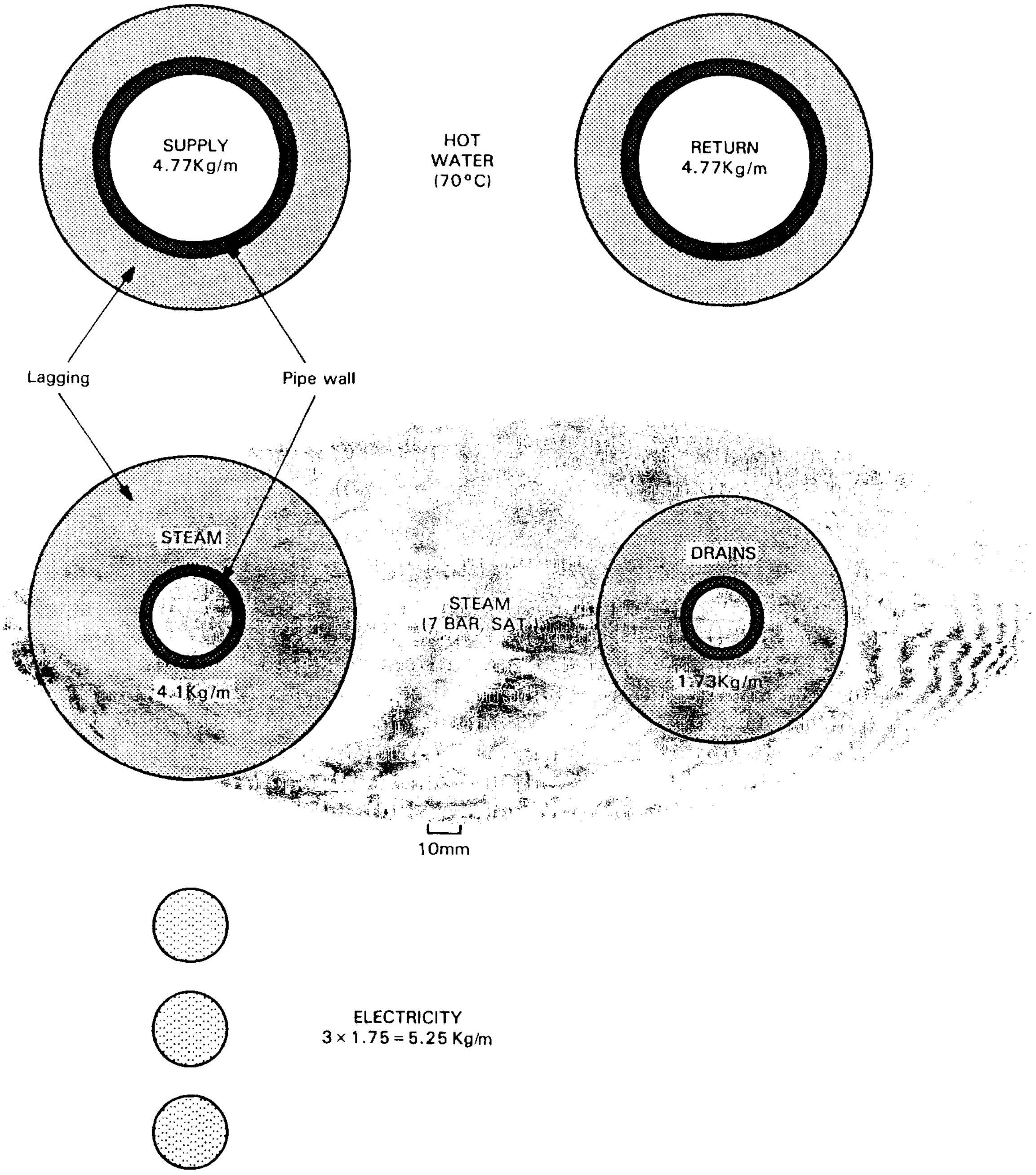

Fig. 6—Comparisons of 2000 kW heat transmission by hot water, steam, and electricity

Note: 1. Weights include contents and lagging

2. Heating surface area for water is 3 times that for steam

Reduction in Energy Consumption—What Could Be Done?

Fresh Water Production

Owen[4] showed the marked reduction in energy consumption that was possible by adopting Reverse Osmosis (RO) or waste heat distillation. FIG. 7 shows the relative additional fuel consumption for a variety of methods of fresh water production. RO is the chosen route for the Type 23 frigate and the Type 2400 submarine, and is under consideration to provide the initial desalination treatment for feedwater for steam plants.

An alternative for the Type 23 would be waste heat distillers, fed from the diesel generator water jackets, but this poses an interesting problem. The total energy consumption of the waste heat plant is similar to a conventional single stage distiller, and this energy must be able to be derived from any two out of the four diesels when running on 'hotel' load only. A typical load of 1200 kW (electrical) would give 700 kW of waste heat, but 850 kW is required for the 1 tonne/hr duty. This mismatch can be overcome at a penalty; either by supplementary electrical heating giving an increase in fuel consumption, or by the additional complexity of recovering some of the diesel exhaust heat.

The potential complexity of waste heat systems for desalination, due to their need to tap a number of heat sources, becomes obvious. There is an unavoidable minimum of plumbing, and either the heat must be transported through the ship (study again FIG. 6.) or each diesel generator has its dedicated distiller.

A 'middle-of-the-road' alternative is the vapour compression distiller, favoured by the U.S. Navy but which has proven less than ideal in R.N. service. In the absence of any advantage over RO, this technology is unlikely to be developed further.

Chilled Water

Total abolition of the system is not possible. Direct air cooling is precluded by the NBCD requirement, and in addition there is a need for air conditioning for comfort and effectiveness in the tropics or Mediterranean or even in the temperate summer. Having accepted the principle of a closed circuit system, a central cooling plant would require an impracticable volume of air to transport the heat loads from even just the weapons systems. So some circulating liquid system is necessary to bring the unwanted heat to the cooling plant.

The obvious coolant is sea water, which could be tapped off the firemain and dumped overboard after passing through heat exchangers. Unfortunately, the range of sea water temperatures that can be met make cooling in this way impractical; it would be ineffective in achieving comfort levels in the tropics and too severe in the sub-arctic, so some form of regulation and heat pumps are necessary. The complications grow!

If each equipment and Air Treatment Unit (ATU) has its own heat pump, there is a significant implication for reliability and maintenance from the multiplicity of small machines. The nature of the heat pump employed, whether refrigerant, air cycle or thermo-electric, is immaterial to the complexity of the problem; these different technologies do tend to trade reliability for energy consumption, though. We are drawn towards a centralized chiller plant, circulating cold water through simple heat exchangers in the equipment. Note also that a sea water cooling system (for cooling individual heat pumps) will be just as vulnerable to damage as a chilled water system; the palliative for this is zoning and provision of thermal capacity (e.g. large capacity coolant tanks) close to vital equipment to allow them to operate for a period after supplies have been interrupted.

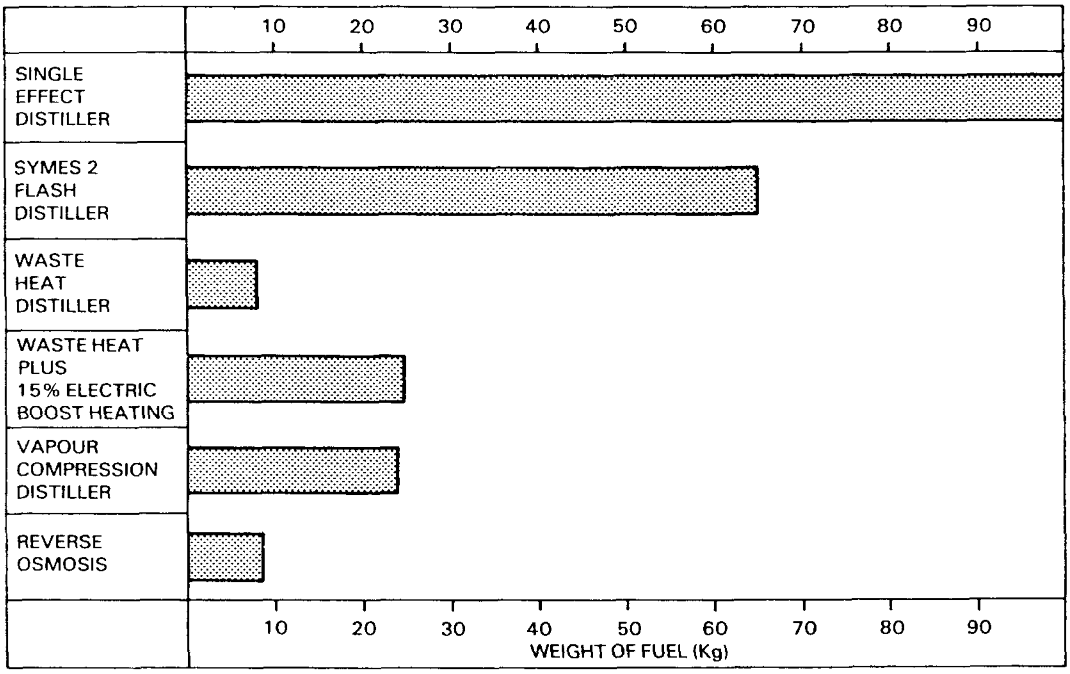

FIG. 7—WEIGHT OF ADDITIONAL FUEL TO MAKE ONE TONNE OF WATER

from Owen[4]

If the chilled water system is here to stay, can it be made more efficient? Sessions[3] has identified the temperature of the sea water that cools the chilled water plant condenser as a significant factor in the efficiency of the plant. If the plant can accept sea water at the ambient temperature, significant energy savings can be made in temperature or sub-arctic conditions. The installed capacity of the plant cannot be changed, however, because this is governed by the tropical requirement.

Heating

The principal uses of heat are for ventilation intake air, tempering air from ATUs for individual compartments, for domestic water (washing and laundry), and for lubricating oil centrifuges. A possible future use is to heat fuel before the treatment system to help separate insoluble degradation products.

Heating of intake air can and will be reduced to a minimum by the move towards 'Total Air Conditioned' (TAC) ships, a philosophy which simplifies the transition to Closed Down conditions. The design of the Type 23 ventilation system has followed this trend by including heads and bathrooms within the citadel. The energy required for this could be taken from the diesel generators, but similar considerations of diversity of sources and weight and space apply as already discussed for desalination.

Lubricating oil centrifuges now incorporate heat exchangers which reduce the energy consumption to reasonable levels,[3] but require heat at over 90°C, higher than that available from diesel generator (DG) jacket water. The major practical use for waste heat would appear to be the domestic hot fresh water system, provided a simple and reliable system can be designed. This application has the advantage that only a relatively minor change is required to bring the hot water system to the DG rather than extending the DG cooling system outside the machinery spaces.

Fuel preheating is not yet a requirement; for the Type 23 the demand would be about 90 kW when on gas turbine drive. It is for consideration that this heat is provided by an additional heat exchanger in the gearbox lubricating oil circuit, with due account taken of duty cycles and the hazards of cross-contamination.

Pumps and Fans

The provision of mechanical power to pumps and fans and the like throughout the ship is normally accomplished by electric motors, although hydraulic motors and steam or air turbines have their place. It is also possible to make use of the excellent marginal fuel consumption of the propulsion engines at high power, as described above. This is already done in gear-driven CPP pumps, LP sea water pumps, and lubricating oil pumps where the duty is directly related to the shaft line, although the motivation here is operational and not economic. There is little scope beyond these examples, because of the need to cope with disparate duty cycles, power transmission to remote equipments, and shaft reversal (even with CPPs). Shaft-driven generators are a commercial exploitation of favourable main engine s.f.c.

Variable speed drives can reduce energy consumption markedly, especially when substituted for throttling control. The penalty that must be paid is increased complexity, cost, weight and space. An electronic speed control system also is liable to cause waveform distortion of the electrical supply. As can be seen from FIG. 2, the HPSW system is one of the most significant users of mechanical power, and could benefit from a variable speed system. The major drawback is the introduction of further complexity into this vital service.

Trends and Prospects

Should there be a radical change in auxiliary systems in future ship designs? If the motivation for change is solely energy conservation, the answer must be no; the great leap forward has already occurred in the Type 23 by the introduction of RO plant for desalination, and the abolition of auxiliary steam systems. A useful limited development would be the tapping of diesel water jacket waste heat for domestic hot water, but further extension to circulating hot water systems for space heating is difficult to justify, especially in the light of the reduced heating demand expected in a TAC ship design. Chilled water may remain the prime cooling system, but the plants will become more efficient; one study has predicted that relaxing the control of seawater temperature could save up to £30 000 per ship per year.

The concept of zoning will have a significant impact on the disposition of equipment in ships and in system layouts, but will not materially change their function or power requirements. There is little pressure from new weapon systems for change, because progress in electronic technology offsets the power growth that would be expected from the increase in capability. A further factor is the tendency to passive, and thus low power, surveillance systems.

Although the diesel is more efficient than the gas turbine, the pressures of signature reduction may lead to diesels being discounted for propulsion systems, and perhaps even for electricity generation. This could close the door on any waste heat recovery from prime movers, in the absence of reliable uptake heat exchangers.

Conclusions

For future surface warship designs, the difficulty of reconciling the role of the ship with the necessary complexity of energy-efficient auxiliary systems make it unlikely that radical changes will be made. Some minor beneficial changes in equipments are probable, but generally energy economy can be expected to take second place to operational effectiveness. Only in conventional submarines, where energy consumption is a major determinant of underwater endurance, is it likely that economy will be a critical factor in system design and equipment selection.

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