HYDRAULIC SYSTEMS

REDUCTION OF FIRE HAZARD

BY

H. J. JONES, C.ENG., M.I.MECH.E.
(Central Hydraulic Authority (R.N.))

The following article is an edited version of CHA(RN) Temporary Technical Memo No. 12, prepared with the help and assistance of fellow members of the CHA(RN) Working Party dealing with the Reduction of Fire Hazard in Hydraulic Systems.

The General Problem

Most naval hydraulic equipments employ mineral oil as the working fluid· OM33 is the commonly used hydraulic fluid in surface ship systems and OX 30 in submarines; OM15 is employed for the operation of many hydraulic mechanisms in aircraft. Details of these fluids are contained in Def St 01–5/2 (*BR 1336*). System pressures often exceed 200 bar and working temperatures are usually around 50°C. Provided these fluids are contained within their pipe systems and normal stowages, they do not constitute a significant fire risk; however, when ejected from a defective hydraulic component in the form of a spray, jet or droplet, ignition by flame, hot surface or spark may readily occur. FIG. 1 shows the flame intensity of different fluids when similar volumes are sprayed onto an ignition source.

Hydraulic equipments are used extensively both inboard and outboard of H.M. ships and submarines, e.g. steering gear, stabilizers, winches, hoists, davits, propeller pitch control, submarine control surface operation, gun mountings, and missile systems, etc. Pressure lines therefore traverse most areas of the modern warship, through bulkheads and across machinery spaces, galleys, accommodation areas, and storage bays. Considerable lengths of hydraulic pipe line are routed along the upper decks of warships, often in exposed and unprotected positions being particularly at risk under wartime conditions.

Mineral Oil Hydraulic Fluids

For use with heavily loaded, high-speed rotational hydraulic machinery, mineral oils have obvious advantages: they are internationally available, have been developed and improved over many years, and their lubrication properties are difficult to better. With correct mineral oil selection, hydraulic equipments perform well for very long periods with little evidence of wear or physical deterioration.

Fire-Resistant Hydraulic Fluids

Fluids less flammable than mineral oils are commercially available and fall generally into three categories:

(*a*) Oil/water emulsions
(*b*) Synthetic fluids
(*c*) Aqueous polyglycols

All of these fluids will burn given the right conditions. However, they are generally more difficult to ignite and much less self-sustaining than mineral oils in a fire situation.

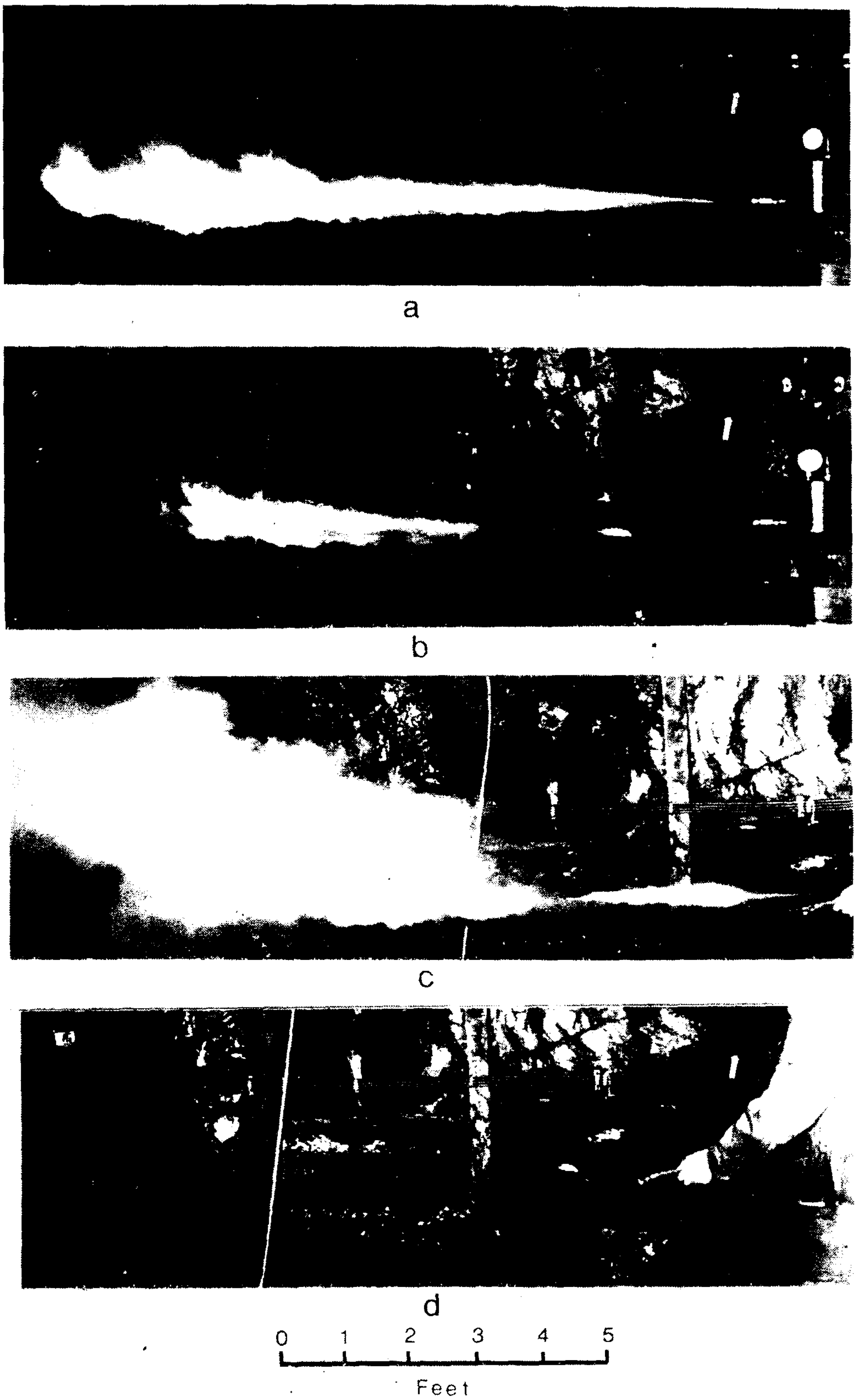


FIG. 1—SPRAY IGNITION CHARACTERISTICS

(*Courtesy: E.F.L. (H.S.E.)*)

(a) Mineral oil
(b) Water-oil emulsion
(c) Phosphate ester
(d) Aqueous polyglycol

Oil-Water Emulsions

The water content of these fluids ranges from 40 to 95 per cent. In general, the greater the proportion of water present the poorer the lubrication properties of the fluid and, therefore, the lower the reliability and life expectancy of components, particularly rolling bearings. Emulsions are widely used in the coal mining industry, pressures being usually maintained below 130 bar in order to achieve acceptable life and reliability. The requirement to operate under arctic conditions, at temperatures of −29°C, precludes the use of such fluids for naval hydraulic equipments fitted on the upper decks of ships.

Synthetic Fluids

Many different synthetic FR fluids are commercially available of which, perhaps, the phosphate esters are those most commonly encountered. In general they have excellent lubrication properties, but their use can introduce additional toxicity problems through handling and spillage. Although they are much less likely to ignite than mineral oils, fumes which are toxic can be given off when these fluids are subjected to heat. Phosphate ester fluids also have a solvent action upon many other materials with which they may be in close contact, e.g. paintwork, floor coverings, nitrile rubbers, etc. In the confined spaces of warships, the problems which these fluids present are obviously unacceptable, and outweigh possible fire-resistant considerations.

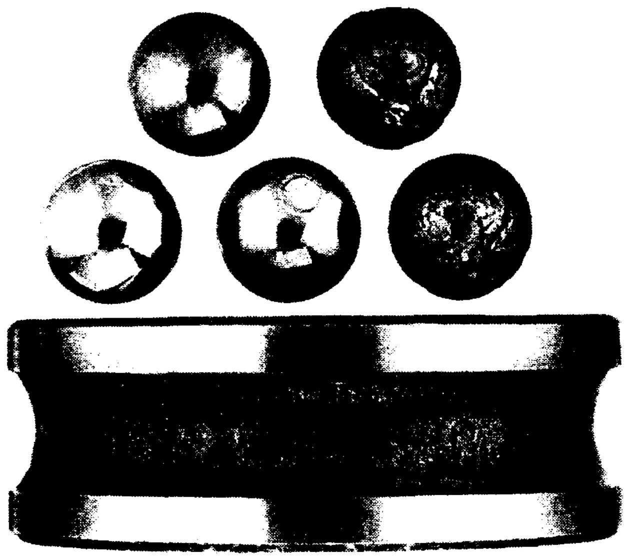


FIG. 2—BEARING FROM STABILIZER PUMP—AQUEOUS POLYGLYCOL

Aqueous Polyglycols

Houghtosafe 271 is a typical polyglycol fluid which was in service in hydraulic catapult and arrester gear systems of aircraft carriers for many years and has also been used for certain hydraulic system applications in submarines. Because polyglycols can be used at very low temperature and are much less aggressive than phosphate ester fluids, they are at present the most suitable fire-resistant fluids for use in naval hydraulic systems. However, in common with oil/water emulsions, tests have shown that a reduction in life and reliability of equipments must be accepted with the use of such fluids.

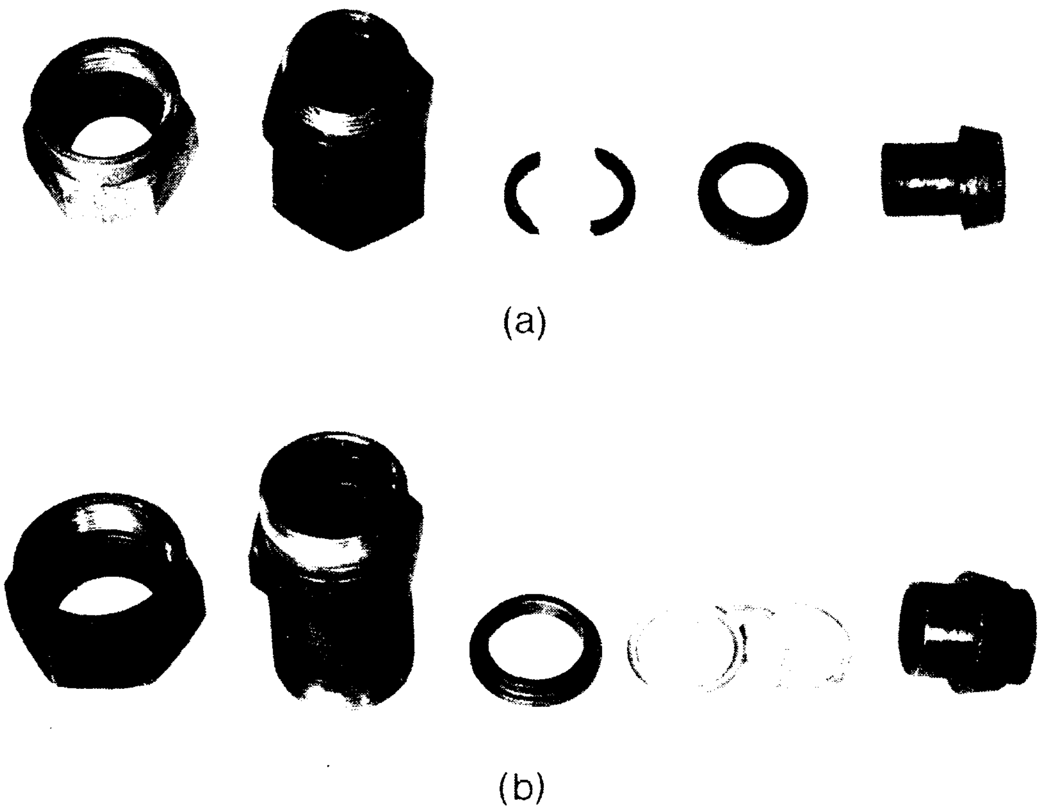
In a recent ship trial carried out on a stabilizer system of a DLG, the system operated successfully for around 3000 hours using HS 271 fluid in place of the original mineral oil. The system pump was a VSG Mk 3 Size 4, 1200 rev/min, maximum system pressure 2000 psi, and system cleanliness level Cl 15 000–21 000. Although the pump gave no trouble in service, post-trial strip revealed that one shaft bearing was severely pitted. FIG. 2 shows the damaged bearing components.

Improved polyglycol fluids are becoming available, and tests currently being conducted on these new fluids at NGTE (Cobham) and (West Drayton) are promising.

Pressure Considerations

The pump is usually the most heavily stressed component in a hydraulic system, and therefore the most likely to suffer from accelerated wear and fatigue through the use of aqueous FR fluid. It is apparent from work carried out by organizations such as the National Coal Board that a reduction in system operating pressure to around 130 bar (2000 psi) will allow certain hydraulic pumps to operate on aqueous FR fluids, with levels of reliability approaching those of mineral oil pumps operating at 207 bar (3000 psi).

Where particularly hazardous hydraulic equipment situations exist onboard R.N. ships, reduction in pressure may well justify the improvements in fire resistance made possible by the use of FR fluid as the working medium. Examples of equipment which could be considered in this category are: stabilizer systems, which are often of necessity sited in machinery compartments in close proximity to main engines and auxiliary machinery with associated hot surfaces, pipework and exhausts; and upper-deck hydraulic equipments which are exposed and particularly vulnerable during wartime.



(a)

(b)

FIG. 3—HYDRAULIC COUPLING FIRE TESTS

(a) Rubber 'O' seal (15 min at 400°C)
(b) Prototype metal seal ($2\frac{1}{2}$ hours at 500°C)

Pipework Considerations

Rigid metal pipework (steel, tungum and cupro-nickel) is used extensively for the transmission of hydraulic fluid in operational systems. In a typical warship many hundreds of mechanical couplings are employed for pipe junctions and equipment terminations; these couplings usually incorporate rubber sealing rings. To reduce the number of leakage paths, mechanical couplings should be kept to a minimum and pipe bends should be considered rather than a series of connectors and elbows, and the unnecessary use of intermediate adaptors should be discouraged.

Tests recently performed at NGTE (Haslar) showed that failure of a rubber sealing ring, incorporated into a typical pipe coupling, occurred within 10–15 minutes of being subjected to a flame. Similar tests conducted with a prototype all-metal seal gave no indication of failure after three hours endurance under the same flame application. FIG. 3 shows the effect of fire on these seals. D.G. Ships is pursuing, with the Keelaring Coupling manufacturer, the development of a fire-resistant metallic seal and tests are being conducted to ensure its satisfactory sealing properties under all operational conditions. Development work is also in hand by D.G. Ships to provide a fire resistant hydraulic stop valve.

Rubber 'O' rings also deteriorate with age, compression, environmental conditions, and, as a result, are prone to leakage after a period of service; new seals should therefore be provided whenever equipments are disturbed or refitted. The use of PTFE anti-extrusion washers in conjunction with rubber 'O' rings, when operating pressures are above 130 bar (2000 psi), will extend seal life and reduce leakage. Because of the sealing weaknesses outlined, pipe couplings should be sited as far as possible away from, and never directly over, heat generators, electrical machinery, lagged steam pipework, etc. Where this is not possible, consideration should be given to the use of either sleeve or butt-welded connections (pipe sizes being increased if necessary to meet welding requirements). High-integrity couplings of the CRYOFIT type (see *BR 3013 (2), Pt. 4*) are completely leak-proof and therefore ideal for use in areas where the fire hazard is significant.

In some hydraulic systems for submarines, couplings in hazardous areas are provided with metal cases and drainage systems to remove leakage fluid and glass fibre shrouds are fitted to break up sprays and jets emitted from couplings in the event of seal failure; modular construction methods are also employed to reduce the number of pipes and couplings.

Flexible Pipes

Rubber hoses are used on hydraulic systems for the connection of equipments that move or are resiliently mounted. The risk of hose failure is considerably reduced if the correct maintenance and upkeep procedures as given in S2022a C30268/2 are observed. As previously outlined for rigid pipe couplings, hoses should not be sited in close proximity to heat producing equipment, traffic, electrical machinery, etc. If technical considerations prevent reasonable separation, protection plates or covers which can be readily removed for hose inspection purposes should be employed. To improve fire resistance, glass fibre, woven asbestos (complying with Health and Safety requirements), or wound stainless steel strip sheaths are available from hose manufacturers. To prevent premature failure, hoses should be correctly installed so that they operate without constraint or distortion under all conditions. *BR 3038, Hydraulic Standards and Practices, Pt. 10* will provide detailed installation information.

Rubber hoses being used for system flushing routines are a particular source of risk. Flushing hoses must be routed well clear of operating machinery, heat generators and potentially hazardous repair or maintenance procedures, e.g. welding, testing of electrical equipment, temporary space heaters, etc. They should also be protected from chafing at hatch covers, doorways, etc. by the use of suitable padding material, and covers or protection plates should be provided in areas of heavy traffic.

Design Considerations

Because of the combustible nature of the material, rubber joints, seals and hoses are the components most likely to fail under fire conditions. The strength of ferrous and non-ferrous pipework is also significantly reduced by the application of heat: for example, the maximum design stress for Al.Ni.Si brass (Tungum) at 50°C is reduced by a factor of about three at temperatures of 300°C.

If it is not possible for operational reasons to isolate or to shut down completely a hydraulic system during a fire, arrangements should be made for reducing pressure in the pipework circuits concerned. Consideration may also need to be given to the venting of hydraulic accumulators. Current submarine practice is to provide hydraulically operated 'fire-isolation' valves (controlled by the system console operator) which serve to isolate completely the power plant from the distribution system.

As system reservoirs may contain many hundreds of gallons of hydraulic fluid, their situation relative to possible fire hazards is an obvious design consideration. Fluid-level sight gauges fitted to reservoirs should be of the heat-resisting glass type, fitted with a metal surround to protect the glass from damage. To prevent escape of fluid in the event of gauge glass failure, push-button operated, spring-loaded valves should be provided on the gauge. Consideration should also be given to the venting of reservoirs to the upper deck.

If the fire hazard is such that the use of an aqueous FR fluid is contemplated, in designing the system care must be taken to avoid material incompatibilities, e.g. the use of cadmium plating and calcium-based grease has contributed to defects in Polyglycol systems.

Certain designs of hydraulic pump are better suited to use with FR fluids than others. The designers advice, therefore, should be sought with regard to the proposed application, and recommendations obtained concerning pressure, speed, temperature, filtration, and viscosity requirements. Because only limited information is generally available on the performance of equipments with FR fluids, shore-based endurance trials should be conducted in the first instance.

Twin smaller bore pipes for hydraulic ring main systems may be worth considering, rather than a single large diameter main. An increase in the number of pipe joints, although undesirable, may be offset by certain advantages, for example:

(*a*) simpler coupling connections can be used i.e. welded flanges may be avoided;
(*b*) smaller pipework is easier to manipulate without heat application;
(*c*) more compact space arrangements are possible;
(*d*) alternative pipework routes between equipments may be possible, therefore improving damage control.

The significance of fire hazard should take into account selection of the type of power medium for the particular application, e.g. is hydraulic power the most practical if the fire risk is high?

The overall arrangement of a hydraulic system will influence any associated fire hazards. Provision of a number of dedicated power packs, rather than a large ring main system, may significantly reduce the fire risk in particular circumstances; similarly, there may be advantages in sub-dividing a ring main into smaller continuous circuits. Valves which close automatically at high flow rates are available commercially; these may be used to prevent discharge of fluid from a system in the event of pipe rupture. This is an important consideration in circuits containing accumulators or where hoses are sited in vulnerable areas. These valves are being further investigated by CHA(R.N.) and D.G. Ships. Pressures and flows in hydraulic systems can be kept low by the use of variable-displacement pumps controlled electrohydraulically from the terminal equipments.

Systems under Maintenance or Refit

Systems are particularly vulnerable during those periods when portable pumps, filters, test equipment, etc. are in use. At these times, equipments can be subjected to overload pressure conditions, and sections may be disconnected or partially stripped so that temporary equipment connections are necessary. Flushing equipment should be sited with care; warning notices should be prominently displayed; and prescribed safety precautions should be followed where a fire risk exists.

Summary

The fire resistance of all hydraulic systems can be greatly improved by attention to the routeing of rigid and flexible pipework and the selection and positioning of pipework couplings, by more enlightened upkeep of hydraulic hoses and seals, and by the siting of system components. In the longer term, much development work will be required on aqueous FR fluids and system components before unlimited use in R.N. hydraulic equipments is possible. However, where the fire hazard is great, selective application of FR fluids to hydraulic systems may be possible, provided component selection is made with care and reductions in operational requirements are accepted.