WATER BALLASTING OF FURNACE FUEL OIL TANKS

This article was compiled by Lieutenant-Commander A. Richins, R.N. and Mr. L. F. Jaquest and describes the work carried out on this particular subject by their Section at the Admiralty, Bath.

In the post-war years it became increasingly evident that the armament weight/displacement ratio of H.M. ships was falling below acceptable limits. Furthermore, Staff Requirements for New Construction called for greater endurance than in pre-war design so that fuel became a greater proportion of the total weight. Radar equipment, which was of necessity placed high in the ship, was increasing and the advent of machinery of advanced design was also reducing the specific weight of main machinery. It was therefore essential that provision be made to avoid instability in the light condition, and the logical way to achieve this was by ballasting the fuel tanks as they were emptied, thereby maintaining stability as near constant as possible.

The need for ballasting of H.M. ships was established and Admiralty initiated action to fit trials systems in two Type 15 A/S frigates. These ships were chosen simply because they were the only ones at that time in which space could be made available to install the necessary equipment. Eventually, due to uncontrollable factors, only one ship, H.M.S. *Ulster*, could be utilized.

At this stage the only available information consisted of disconcerting stories about someone (the name could never be remembered) who had had ghastly experiences with tanks full of unpumpable emulsions.

To add to our difficulties, the Oil in Navigable Waters Act was beginning to loom large on the horizon. Under the terms of this Act it would be prohibited for a ship to discharge overboard a mixture of oil and water which contained more than 100 parts per million of oil, i.e., less than a double tot of oil per ton of water. On the other hand, deballasting had to be of such a rate that modern fuelling requirements could be met.

The first concrete conclusion emerging from these conditions was that ballasting to meet all requirements could only be by replacement (i.e., tanks must be emptied of oil and then filled with water, and vice versa) and that displacement systems could be disregarded.

By this time a Working Party comprising members from E.-in-C., D.N.C. and the Yarrow-Admiralty Research Department (Y-A.R.D.) had been set up, and a contract had been placed with Y-A.R.D. to investigate the problems associated with ballasting. The need to obtain early information was pressing since the designs for the G.P. frigate and the G.M. destroyer both provided for ballasting.

TRIALS

All available sources of information were tapped, and many trials carried out with widely varying degrees of success.

H.M.S. 'Redpole'

Arrangements already existed in *Redpole* to ballast and de-ballast certain F.F.O. tanks through the F.F.O. suction main and, after a few modifications to the system, a series of trials was proposed. It soon became obvious that this simple arrangement had numerous drawbacks. Far too much oil was left in the tank when the pump lost suction, and this spread itself throughout the ballast water giving a contamination during subsequent de-ballasting of over 400 parts per million. The amount of water remaining in the tank after de-ballasting also caused some embarrassment and on one occasion led to a black-out.

Wooden filling was fitted in the base of one tank to reduce the amount of oil left when suction was lost, the suction being taken from a sump formed in the filling. Since maximum clearance of oil before admitting ballast was considered so important, Y-A.R.D., in conjunction with Messrs. Andre Rubber Co. Ltd., were developing a flexible rubber suction entry. This consisted of a rubber bell-mouth attached to the suction pipe, which could sit on the tank bottom and thus ensure a very low suction. Two of these were available by this time and they were fitted to the suctions in the ballast tanks.

The results were quite astonishing. The depth of oil left in the tank when suction was lost was approximately half an inch and on subsequent discharge of ballast from the tanks the contamination was never above eight parts per million until the interface was approached. 80 per cent of the ballast water was discharged before the contamination limit of 100 parts per million was reached. The wood filling fitted in one tank appeared to produce no advantage over the other tank not so fitted.

The flexible suction entries were left in the tanks to determine the long term effect of oil on the perbunan rubber. One was later removed for use in *Cumberland*, and after some two years service it has shown no signs of deterioration.

H.M.S. ' Ulster '

By the time *Redpole's* trials came to an end *Ulster* was just completing conversion and had fitted a trials system, the main feature of which was independent oil and water systems to minimize contact between the two liquids. This is shown in FIG. 1 where the separate ballast/de-ballast line, F.F.O. suction line and the stripping system can be seen.

It was expected to be able to discharge overboard at least 85 per cent of the ballast water and arrangements were made to deal with the oily water that remained. These consisted of a fuel renovating tank fitted with heating coils and a spray rail for the introduction of additives, and a 2 ton/hr centrifugal separator with two discharge test tanks for clean water and reclaimed oil.

Much design and test work had by now been carried out on the flexible suction entries and 2½ in. bore entries were available for *Ulster's* stripping system. One of these is shown in FIG. 2.

At this stage a flexible entry had not been developed to suit the 5 in. de-ballast suction, and a metal bellmouth was formed at the end of the pipe. Compared with the 5 in. flexible suction entry later developed this bellmouth was of smaller diameter and, due to its rigidity, had to terminate higher in the tank.

The point at which de-ballasting must cease is dependent on three factors: the amount of oil on the surface of the water, the height of the suction in the tank, and the velocity at the suction entry. The latter two aspects are affected by the form of the suction entry employed. The flexibility of the above mentioned suction entry permits it to sit on the tank bottom, thus giving the lowest possible suction, and the large diameter of the entry reduces the velocity of flow at any point and, consequently, delays the formation of vortices which tend to draw surface oil down into the suction. This point was carried a stage further in *Cumberland*, and will be discussed later.

Having dealt with the problem of vortex formation, the question of weiring was then considered. This had to be kept to an absolute minimum as it tended to carry surface oil down into the body of the ballast water and produced early contamination in the suction entry. In *Ulster* limber and drainage arrangements, low down in the tanks, were enlarged where possible so that differences in liquid level on either side of internal obstructions during de-ballasting were reduced.

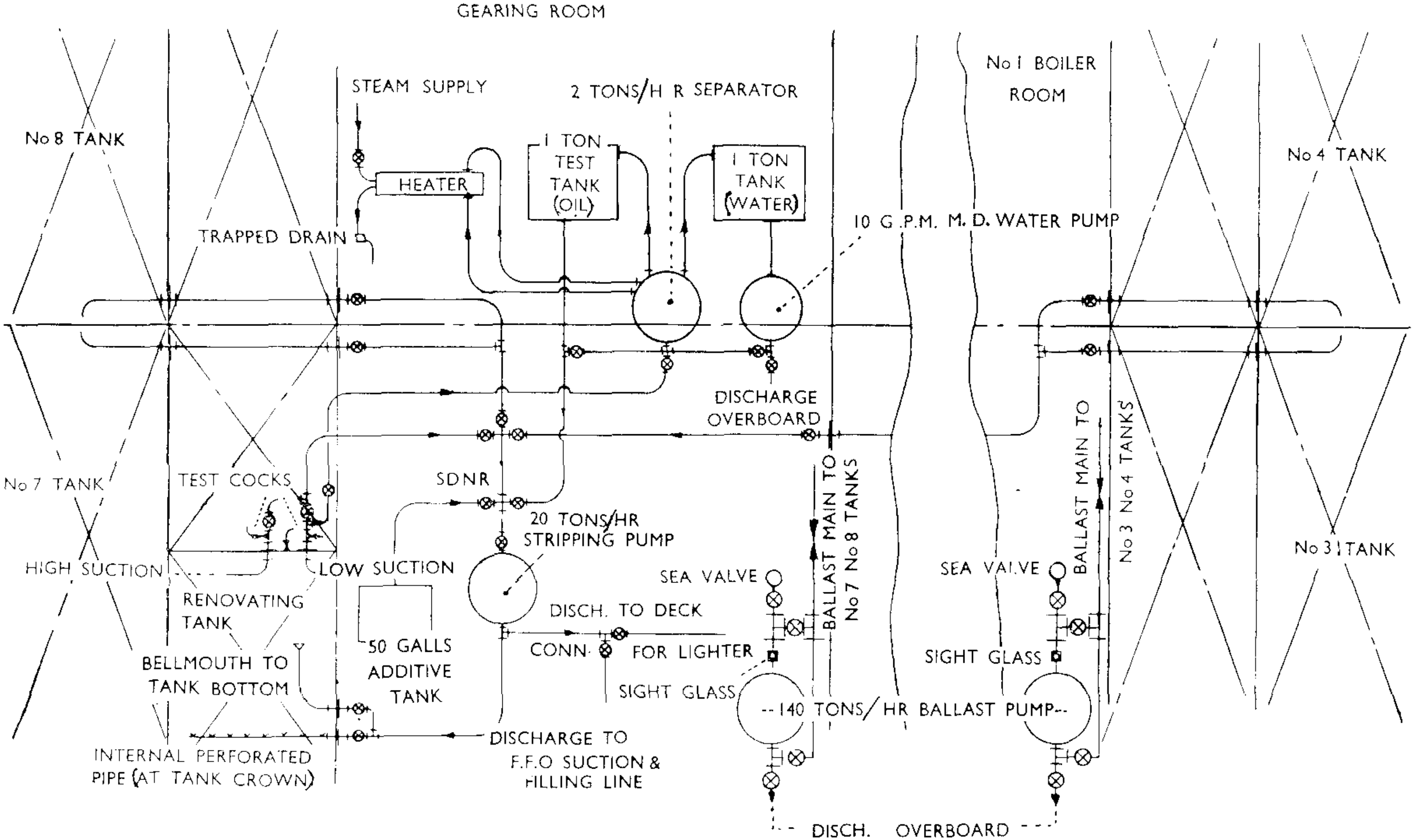

FIG. 1—H.M.S. 'ULSTER'—BALLASTING ARRANGEMENTS

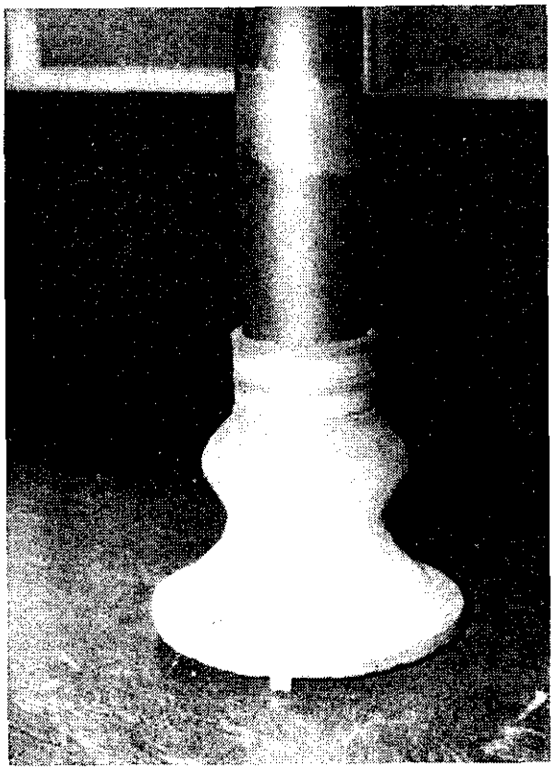

Fig. 2—Flexible Suction

Pockets formed by hull and longitudinals where oil could lodge were filled with cement, and wooden filling was fitted in one of each pair of ballast tanks to try to reduce the amount of oil/water left after stripping.

There being no satisfactory mechanical or electrical way of detecting small amounts of oil in the ballast discharge, visual indication was relied on, and a small full bore sight glass was fitted in the ballast pump suction.

The procedure was that oil would be used first from the ballast tanks, the oil remaining after losing suction to be stripped from the tank via the stripping main, and transferred to other storage tanks. The tanks were then to be ballasted. During de-ballasting a careful watch was to be maintained on the sight glass, and at the first trace of oil de-ballasting would cease. The oily water left in the tank would then be transferred, via the stripping pump to the renovating tank for further separation.

Certain aspects of the system, principally pump and valve design, and de-ballast suctions, were rather unsuitable but *Ulster* has now used the system since mid-1957 with very satisfactory results. De-ballasting has been possible down to about 12 inches (1·5 tons) without producing overboard contamination, and the sight glass proved very effective for detecting the first flecks of oil.

Tests on the centrifugal separator showed that it would fulfil its rated output, but it was necessary to strip and clean the bowl assembly every watch.

The measure of success achieved with *Ulster's* arrangement can be judged by the fact that after a full ballasting cycle on all four tanks the strippings were found to have almost completely separated after 24 hours in the renovating tank without the use of heat or additives. Using the high and low suctions, the majority of the oil and water could be removed ; the oil being fit to burn (less than 2 per cent water), and the water clean enough for overboard discharge. After five complete ballasting cycles *Ulster* had collected only eight tons of residue that required chemical separation.

These results indicated that the centrifugal separator was redundant, especially in view of the man-hours required to keep it running satisfactorily.

H.M.S. 'Cumberland'

Using the *Ulster* system as a basis, and incorporating later developments by Y-A.R.D., a comprehensive ballasting trials system was fitted in *Cumberland* to gain experience with both double-bottom and deep tanks.

Two different types of stripping pump, two static oily water separators and filters were fitted with an arrangement to enable several combinations of components to be tested.

An eductor was fitted in place of a ballast pump in view of its smaller weight and bulk, and the known availability of a large supply of firemain water in

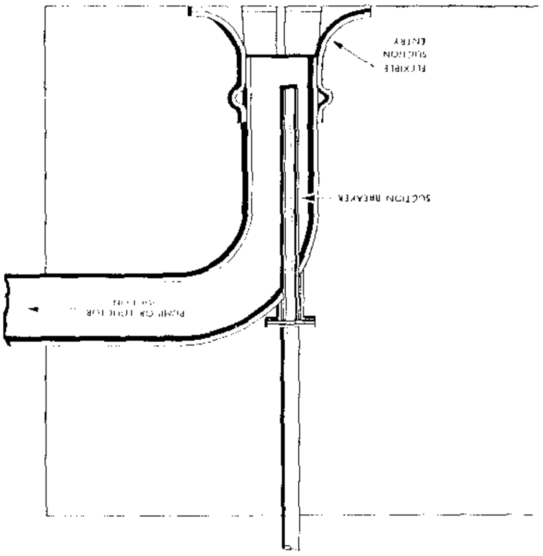

FIG. 3 Y-A.R.D. SUCTION BREAKER

New Construction ships to fulfil pre-wetting requirements. A length of plastic pipe was fitted in the eductor suction for observing contamination during de-ballasting.

Trials on a suction breaker (see (FIG. 3) were to be included, and both surface and residue 'stripping' techniques were to be evaluated, together with the comparative efficiency of the flexible bellmouth type of suction entry and a duct with a flexible rubber curtain which had been developed especially for use in D.B. tanks (see FIGS. 4 and 5).)

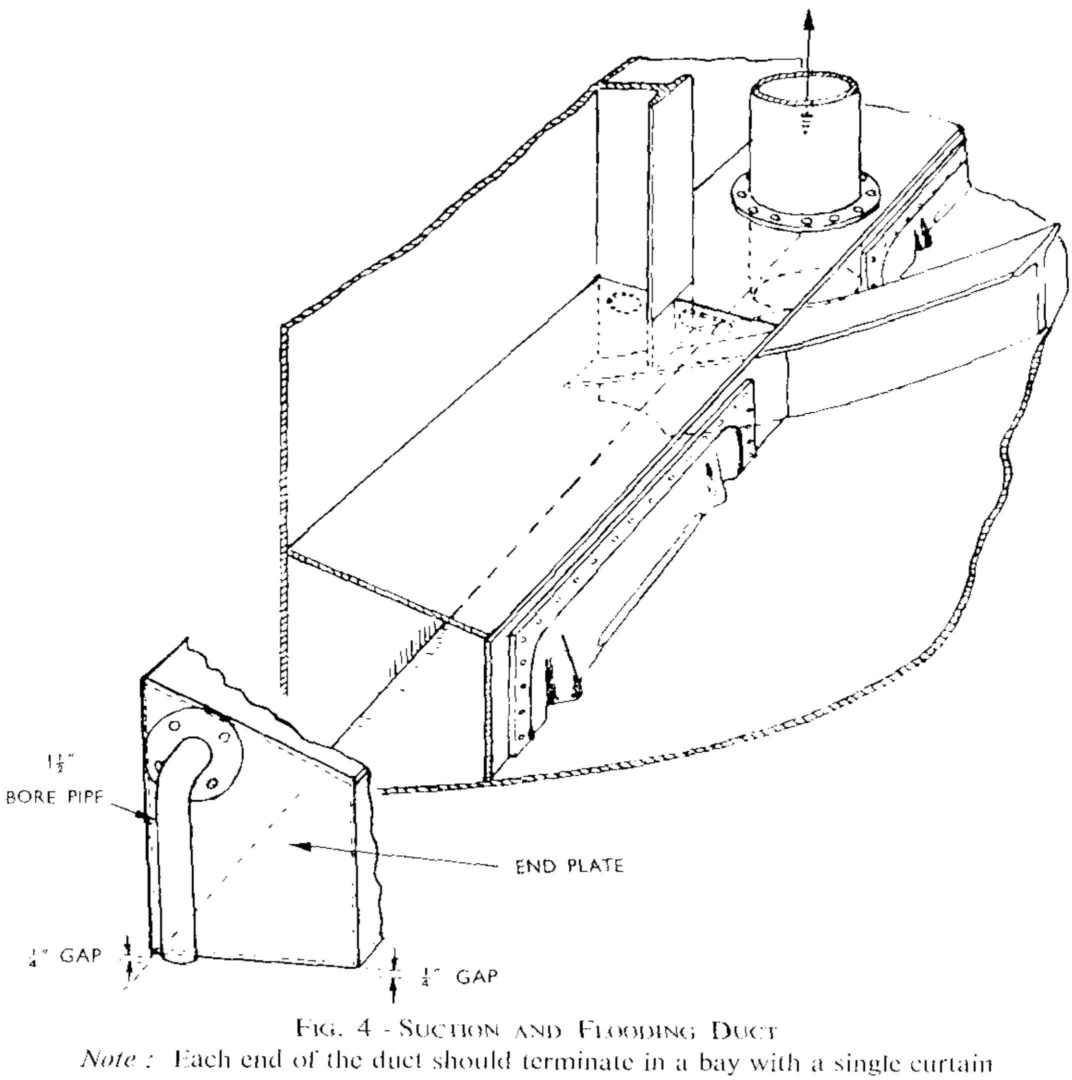

FIG. 4 - SUCTION AND FLOODING DUCT

Note : Each end of the duct should terminate in a bay with a single curtain

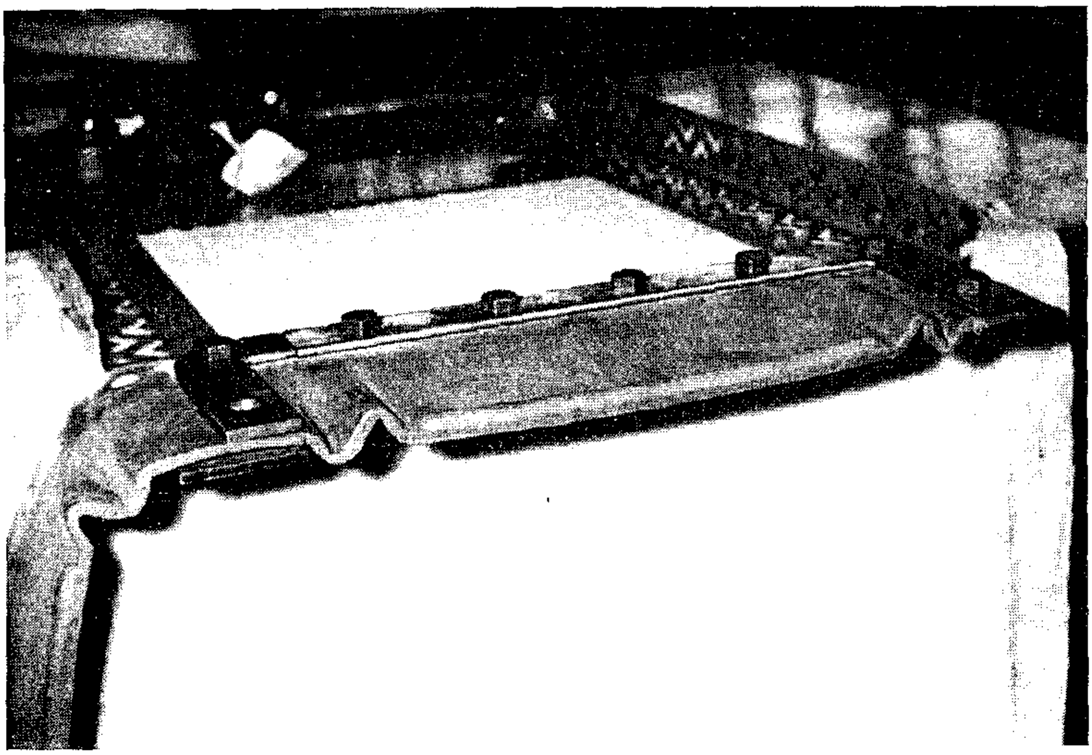

FIG. 5—FLEXIBLE RUBBER CURTAIN ON TEST RIG

First Trials Season

(*a*) No. 27 D.B. Tank

Since the velocity of flow at the suction determines largely when vortices will form, and as rapid de-ballasting is essential, the idea of a suction along the whole tank length, giving uniform flow in all bays and a relatively low velocity, was conceived. In No. 27 tank there are three longitudinal bays formed by the box vertical keel and, to induce uniform flow throughout, suction and flooding ducts were, therefore, fitted on either side of the vertical keel, their suctions combining outside the tank. Ballast water is introduced through the duct thus clearing it of residual oil, a 1½ in. bore vent pipe being fitted at the crown of each end of the duct to prevent a pocket of oil being left in the top of the duct when the tank is ballasted.

Earlier trials in *Birmingham* using the ship's existing ballasting arrangements had shown that contamination was heavy when attempting to de-ballast a double-bottom F.F.O. tank, due to the tank shape and its internal structure. Particular interest was, therefore, centred on the D.B. tank trials in *Cumberland*. Emergency design fuel (650 sec Redwood No. 1) was used for these trials and it was proved that with adequate limbering, flexible suction entries on the stripping system, and the use of a plastic filler to minimize pockets, efficient stripping was possible. This, together with the low velocity achieved at the suction entry during de-ballasting gave contamination-free discharge of ballast water down to about 1,000 gallons (approximately 6·5 per cent of the tank contents), while permitting a discharge rate of up to 100 tons per hour. The remaining oily water was transferred to the renovating tank and, in all trials, complete natural separation resulted within 24 hours. The arrangements for D.B. tanks were, therefore, considered satisfactory.

(*b*) No. 36 Tank

In this deep tank, trials involving residue stripping and flexible suction entries for de-ballasting were carried out. The residue stripping was again very effi-

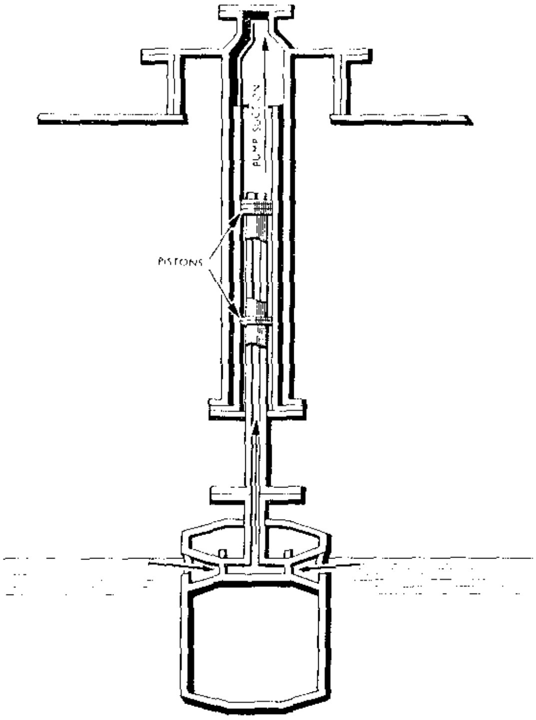

Fig. 6—Meehan's Floating Strum

cient and subsequent de-ballasting down to approximately 2.5 per cent of tank contents proved possible using the 6 in. flexible suction entry.

(*c*) No. 30 Tank

This was selected for the renovating tank, since it most nearly approached the optimum shape, i.e., narrow and tall, promoting natural separation of oil and water and making separated oil easier to remove. It was equipped with heating coils giving 3 sq ft/ton heating surface, a suction at the base of the tank for clearing reclaimed water, and the other at two-thirds of the height of the tank for removing clean oil. A spray rail, fitted in the crown of the tank, was connected to the discharge side of the stripping pump so that additive could be distributed over the surface of the mixture in a uniform fine spray.

A new additive, now known as Fomescol, was to be tested ; preliminary trials in *Birmingham* having indicated that its performance in this application was superior to that of Teepol. As previously stated, in all the ballasting trials in *Ulster* and *Cumberland* the strippings had separated out without using heat or additives. This was most encouraging, but since both ships were working in warm climates it could not be considered conclusive. *Cumberland*, therefore, set about making her own emulsions so that separating techniques could be evaluated.

An emulsion was made by circulating oil and water from the renovating tank through the stripping pump and back to the tank via the spray rail. Having produced the emulsion it was heated for 24 hours but very little water separated out. A solution of Fomescol was prepared and 0·05 per cent of the tank content by volume was added via the spray rail. Within another 24 hours most of the emulsion was broken and after a further 48 hours the oil and water layers were sufficiently pure to be passed to a storage tank and overboard respectively. There was a thin layer of emulsified oil left between the clean oil and the water but there was insufficient time for further investigation. A sample of the original emulsion was retained and after three days approximately 3 per cent of the water had separated out, but no change was detected during a further two months standing, which gives an indication of the stability of the emulsion obtained.

Second Trials Season

During *Cumberland's* second season a suction and flooding duct was fitted in the deep tank to compare its performance with two flexible bellmouth type suction entries. The prototype of the stripping pump ordered for the G.P. frigate was installed for testing, and a series of renovating trials was carried out.

RED HERRINGS

Naturally, during the course of this investigation several ideas were tested and rejected, and brief reference is made to them below.

The Suction Breaker

This was a device designed to provide a positive cut off in de-ballasting when the known contamination level was reached in the tank. Later trials included a modified type designed to slow down the de-ballasting rate as the level approached the danger zone and eventually to cut off the suction completely before the ingress of oil in the suction occurred. The suction breaker (FIG. 3) consisted of an open ended pipe let into the de-ballast suction, the trials suction breakers in *Cumberland* being adjustable. As the level in the tank approached the level of the lower end of the pipe during de-ballasting, air would be drawn into the ballast suction pipe through the suction breaker, thus destroying the eductor vacuum. In the D.B. tank, trials of both types of suction breaker were unsatisfactory. The plain type was partially successful in the deep tank, but in a seaway there was a tendency to 'gulp' after initial breaking of suction vacuum.

Admiralty and ship's officers (*Cumberland* and *Ulster*) preferred to rely on visual indication of the point at which de-ballasting should cease, since the level at which oil commences to be drawn in varies with conditions while in ballast, and the grade of F.F.O. carried. This method, which ensures that the minimum of strippings is left on all occasions, has now been adopted. An additional warning in the shape of a float operated light has been proposed to give notice that the level is being approached at which oil can be expected to appear.

The suction breaker may well have a useful application in large commercial ships, where ship movement is less lively.

Oily Water Separators

Centrifugal separators were tried out in H.M.S. *Ulster* and, as previously mentioned, were rejected due firstly to the good results obtained without them, and secondly to the heavy maintenance load involved in keeping them running.

Static oily water separators were fitted in *Cumberland* for trials but the good results obtained using the renovating tank proved them to be an unnecessary complication. In addition the Department of Scientific and Industrial Research carried out trials on a wide range of static separators and, with one exception, they all produced an unacceptably contaminated discharge when presented with an appreciable concentration of oil. The one exception was not given a realistic trial as it was presented with large globules of oil which are much easier to separate than the particles found in practice.

These two considerations together with the additional weight and space involved in fitting either type led to the rejection of separators.

Surface Stripping

Considerable work was carried out on investigating the feasibility of stripping the oil layer from the surface of the liquid in a ballasted tank.

After trials of a modified scum pan in a T.C.V. had shown a certain amount of promise, a surface stripping device designed to work with an oily water separator was developed by Mechans and fitted in T.C.V. *Caldy*. This is shown in FIG. 6.

Difficulty was experienced in operating the floating strum since it tended to hunt synchronously with its associated reciprocating pump. Chatham Dockyard modified the design to prevent this, but it was then found that the strum gradually settled lower in the tank until suction was being taken from below the scum. It was apparent that further design effort was required on this device, and that the piston arrangement made it susceptible to sticking if the ship was rolling. Since the development of another device which had no moving parts and was comparatively simple was well advanced, it was decided not to continue work on the Mechan's strum.

FIG. 7—STRIPPING FUNNEL

The other device referred to was an elastomeric stripping funnel and supporting spider developed by Y-A.R.D. and Messrs. Andre Rubber Co. for trials in *Cumberland*. This is shown in FIG. 7, and FIG. 8 shows the funnel undergoing a test. A spray rail was fitted around the tank to assist the flow of surface scum to the funnel, and to maintain the liquid level at the necessary height. The arrangement is shown in FIG. 9.

The trials indicated that this method of stripping was not wholly suitable for H.M. ships. The volume of strippings from one incomplete trial (complete clearance of surface oil being impossible) was excessive, and showed that, because of their bulk, strippings would have to be dealt with directly by an oily water separator.

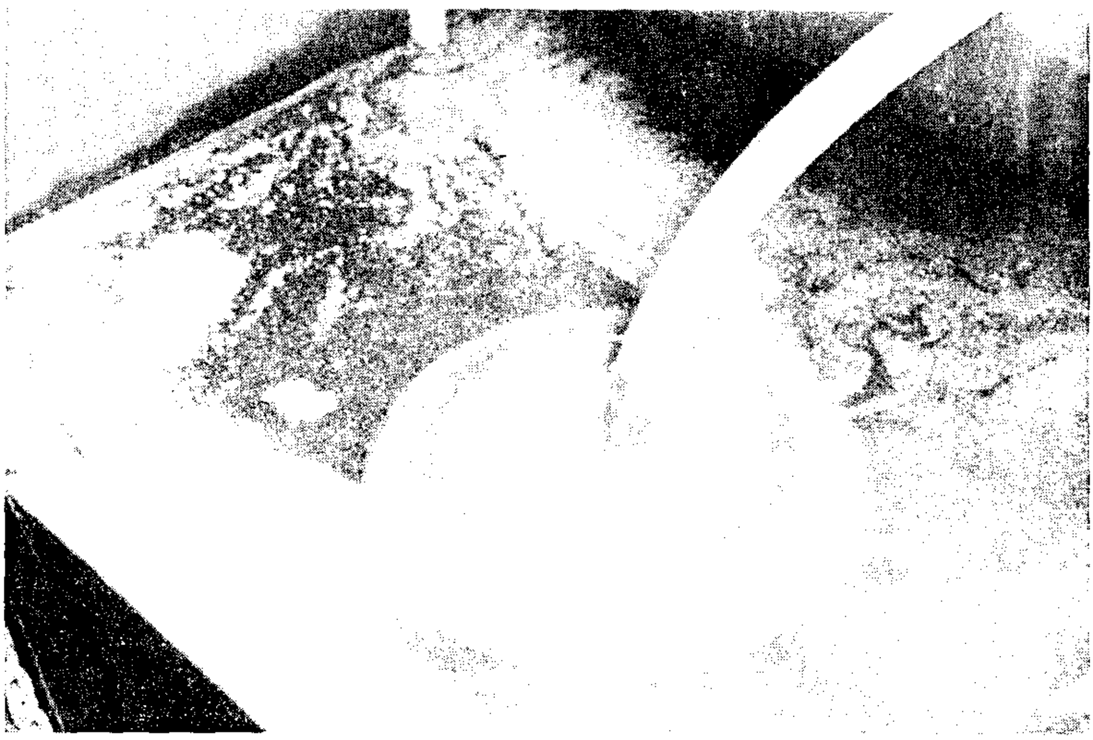

FIG. 8—STRIPPING FUNNEL UNDERGOING TEST

The D.S.I.R. trials on separators, and our own in *Cumberland*, showed the unsuitability of oily water separators for this type of mixture. These facts, together with the extremely good results obtained by residue stripping led to the abandonment of surface stripping trials.

RESULTS AND CONCLUSIONS

Certain faults were found with the renovating system in *Cumberland*, but we are confident that subsequent modifications will eliminate them. Additive introduction has been reviewed and a new system drawn up. Uniform renovating tank heating proved difficult, but recent proposals using a combination of

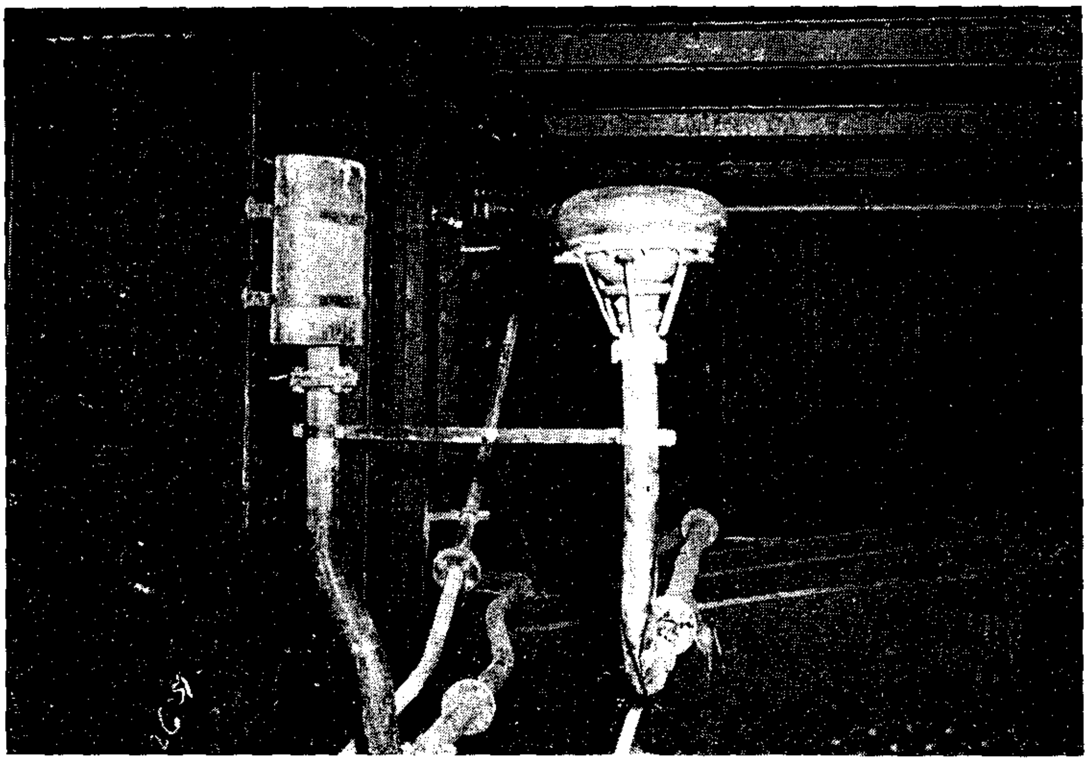

FIG. 9—STRIPPING FUNNEL ARRANGEMENT

conical and helical coils will, it is hoped, finally provide the answer.

Two renovating tanks are recommended, so that one can be used for separating while the other is receiving strippings. These tanks can be used for fuel storage in wartime, when all 'strippings' may be discharged overboard.

Cumberland's 1958 trials showed the de-ballast duct to be slightly superior to the twin bellmouth suction entries and D.N.C. has accepted the use of the duct in certain deep tanks, although it does somewhat restrict tank inspection.

'Mashing' by pumps and 'valvery' is an important feature, even with chemical separation, since it affects the time a mixture takes to separate in a renovating tank. The Department of Scientific and Industrial Research has produced an evaluation of the 'mashing' properties of a wide range of pumps, and their conclusions should prove valuable when selecting pumps for installation. Valves will generally be of the lubricated plug type, to reduce turbulence and resistance.

All the trials have now been analysed, and a Manual of Fuel Tank Ballasting will shortly be published. This contains complete instructions on the installation of ballasting systems, together with the theory behind the various component parts. Many factors not mentioned in this article are included, such as shape and disposition of baffles for flexible suction entries, designed to defer vortex formation.

A full range of flexible suction entries has been developed by Andre Rubber Co. to meet all requirements, and details of these are also given in the manual.

In general it can be stated that all known problems on ballasting of fuel tanks have been tackled and, subject to the systems being correctly operated, no major difficulties should be encountered.

The undertaking has involved numerous departments and ships, and has caused a certain amount of inconvenience to a lot of people during the past two years. It is hoped that this article, explaining briefly what has been achieved, will provide some measure of compensation to all those whose co-operation made possible the successful completion of the investigation.