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PETROLEUM IN ENGLAND.

By C. A. P. Southwell (Fellow).

Drilling operations, subsequent to the passing of the Petroleum (Production) Act of 1934, were initiated by the Anglo-Iranian Oil Company (through its subsidiary, the D'Arcy Exploration Company) at Portsdown, in Hampshire, in January 1936. Members will recall with interest that Lord Cadman, to whose enthusiasm and encouragement the search for oil in England has owed so much, was President in that year and referred to the work in his Presidential address.

The results from that date to the outbreak of war were reported in official statements, and oil discoveries by the Anglo-Iranian operations comprised a small shallow-seepage type of oil-field at Formby, in Lancashire, discovered in May 1939, and the discovery well of a new oil-field at Eakring, in Nottinghamshire. Since the outbreak of war this work has been a closed book, until the recent release by the Secretary for Petroleum, Mr. Geoffrey Lloyd, when the salient features were given to the public.

By permission of Sir William Fraser, the Chairman of the Anglo-Iranian Oil Company, I am now able to tell you something about our work during the war years.

It no doubt came as some surprise to members to hear that 380 wells of varying depths have been drilled, covering the testing of forty-five separate structural areas, and, of these, 250 are producing wells. The total effort has required 735,000 feet of drilling, and has resulted so far in the production of 2¼ million barrels of good-quality crude.

England is, therefore, a petroleum-producing country.

When war came upon us the exploration drilling programme was curtailed and the scattered drilling outfits were concentrated in the Eakring oil-field. Heavy drilling outfits, originally purchased for an exploration programme of deep-well drilling to depths of 8000 feet, were not very suitable for the rapid drilling up of the relatively shallow production at depths of between 2000 and 2500 feet proved by Eakring No. 1. Heavy derricks, 136 feet and 94 feet high, and drilling machines of various makes and capacities, powered by either steam or heavy diesels, were in use.

Field development was faced with the very necessary restrictions imposed by the need for conserving man-power for the more urgent Service needs, and with the restrictions on steel—so urgently required for munitions and shipbuilding. In addition, shipping space was not readily available for supplies of American tools, drill-pipe, and bits; moreover, the British oil-field equipment manufacturers were turning over to the manufacture of munitions.

With the development of the Duke's Wood area, which is hilly and wooded, a considerable amount of clearing and difficult road-making were necessary.

The shortage of man-power and road-making equipment caused a serious bottle-neck, because roads could not be constructed to keep pace with the drilling, but we were fortunate in obtaining the assistance, for a short time, of the Canadian Road Construction Engineers, who, with trained men and mechanical equipment, were able to construct some sections of main roads through the area.

Drilling Problems.

Progressive improvements in drilling technique were made with the object of conserving materials and achieving faster drilling speeds. Concrete foundations and substructures, necessary for exploration wells, where pressure conditions were unknown, were replaced as far as possible by recoverable timber mats. The drilling rigs were converted to electrical power, and power lines, water and mud lines were run to each forward location, the water lines being converted into the oil-production line when the well was completed. With these improvements the completion time in 1942 had been reduced to three weeks, but the moving and re-erection still required about two weeks, making a total of five weeks, against an average of nine weeks required in 1940. Drilling was also undertaken by a number of production hoists with rotary attachments.

In view of the urgent need for the maximum oil production in this country, permission was granted by the Petroleum Division in 1942 for the author to proceed to America, on behalf of the Anglo-Iranian Oil Company, to purchase new drilling outfits, in order to augment the then existing drilling force. Advice was obtained from Mr. Lloyd Noble, a drilling contractor of Ardmore, Oklahoma, and from Mr. Frank Porter of Oklahoma City. The former had had considerable experience in the Illinois Basin fields, where the drilling conditions show some comparison with those to be found in Nottinghamshire, and arrangements were made to augment the man-power by the introduction of complete drilling teams. These men, with Mr. Rosser, their Superintendent, gave us splendid service during their twelve months' stay in this country.

Unitized drilling rigs, with jack-knife portable derricks designed to give maximum mobility and to drill to 5000 feet with 4½-inch drill-pipe, were obtained and shipped to this country. Before giving details of the outfit, it may be well to mention some of the results achieved. The deepest test well so far drilled in this country has been completed with this outfit, but in this case a 136-feet derrick was incorporated instead of the 87-feet mast, and a depth of 7476 feet was reached, at which point the well was abandoned, without mechanical failure, after coring in old rocks. Taking a sequence of ten production wells drilled, averaging 2200 feet, and all completed as producers, the drilling times averaged sixty-two hours of drilling for an 8⅝-inch hole, giving an average of 31·9 feet per hour. The time required to change bits at 2000 feet and resume drilling was approximately fifty minutes, and the average time required to lay down 4½-inch drill-pipe, run and cement 8⅝-inch casing was seven and three-quarter hours. The average time required on these ten wells to drill-in and complete with liner, tubing, and rods was 28·6 hours. The total time, including a forty-eight-hour shut-down for cementing, was seven days. In assessing this achievement, mention should be made of the "restricted lighting" permitted during black-out hours. In the early stages delays were also caused owing to air-raid warnings, when drilling had to be suspended.

The operation of this drilling rig is easy, due to the friction hoisting clutch and the good brake on the drum. A spinning cat-head for spinning up the drill-pipe, although not standard equipment, was incorporated, and, with a spinning chain, resulted in great speed in making up the drilling string. The rigs are powered either by two semi-diesel 169-h.p. engines running at 1300 r.p.m., or by two 150-h.p. electric motors. A 12-inch × $6\frac{3}{4}$-inch slush-pump is set behind the motors, and is driven by Vee belts. This pump can be run as a separate unit from the draw-works by using only one motor, but it is the most common practice to use both motors compounded into the pump and draw-works. The rotary speed can be regulated by changing the speeds on the jack-shaft by using the clutch-lever next to the driller, and three speeds are available. A point of interest on maintenance of the pumps is the introduction of a small pump providing continuous oil-feed to the piston rods. The pumps are run at 50–60 r.p.m.

Instead of the conventional derrick, an 87-feet mast is used, and the combination of a mast and unitized draw-works has resulted in the moving time being reduced, in reasonable weather, to twelve hours, as against two weeks with the heavy exploration outfits. A record summer move of six and a half hours was completed at Eakring, and in one case an outfit moved from one site, and had drilled 960 feet at the next site twenty-four hours later.

The procedure of rigging-down necessary to achieve these speeds may be of some interest. The mast is unbolted from the A-frame and the cat-line taken out in front of the mast and anchored to a dead-man. The blocks are run up to the top of the derrick and secured. The mast is pulled over centre with the cat-line and then lowered by the drum-brake on to temporary trestles. The line is disconnected and spooled on the drum. The mast is then unbolted in sections and carried to the next location with a gin-pole truck. The A-frame is raised, using the cat-line, and then lowered by the brake, unbolted into two pieces, and carried off with the bottom section of the mast. The draw-works and engines complete, weighing 22 tons, are loaded on a 15-ton truck, and are not off-loaded until the foundations are ready at the next location. The steel sub-base is folded lengthwise, loaded by gin-pole on a truck and trailer, or is carried between two trucks for short moves. The foundation timbers are picked up and placed in position at the new location. These consists of ten pieces 16 inches × 16 inches × 16 feet, which are laid on the ground, this having previously been levelled by a bull-dozer and the foundation for the pumping jack installed; the timbers are then roughly levelled, and the hinged steel sub-base is laid on top of the timbers and carefully levelled. The lorry with draw-works and engines backs up to the rear of the sub-base, and a second lorry backs up to the front of the base. The lorry in front, using its winch, pulls the whole load off the truck, with the trucks holding the base in position between them; the rear lorry then drives out from under the load. The mast is laid in position, blocks are strung (manilla line is used to thread the wire line through the blocks), and the mast is bolted up and raised in position by the draw-works drum. As the mast comes to the vertical the clutch is disengaged and the mast permitted to coast over centre, to rest on the A-frame—an operation requiring some skill. The pump is positioned with truck-winches and bull-dozer, and the whole rigging-up operations eliminate as far as possible heavy and hazardous hand labour.

Fuel tanks of 1000 gallons capacity are supplied to each well drilling with diesel engines—a capacity which is sufficient to complete the operations on the production wells without further transport of fuel. These tanks are horizontal, cylindrical, and skid-mounted. They are perched on the top of the debris excavated by the bull-dozer in the preparation of the mud-pits.

Transportation is the key to rapid moving, and this can be achieved only by using specially designed transport with men trained for this particular work. The transport used to move four outfits, completing approximately one well per week each, consisted of one 15-ton winch truck, one 7–8-ton winch truck, two 5-ton winch-trucks, and one bull-dozer Caterpillar D.6. The truck bodies are very robust, with heavy wooden stringers across the chassis frames, with a 3-inch oak floor covered with steel sheets. The rear stringers are heavy section steel beams. The majority of the loads are carried on the point of balance on the rear rollers, so as to avoid the need for manual lifting or winch lifting when off-loading. This transport is the absolute minimum for moving one outfit, and the transport equipment is not spared. The four trucks in question performed over 100 moves in one year, and after eighteen months are still in service.

The formations drilled through in the producing fields are as follows:—

	Trias.
Keuper . . .	Marls and sandstones, 200–500 feet thick.
Bunter . . .	Water-bearing sandstones, *ca.* 500 feet thick.
	Permian.
Shales and marls .	200 feet thick.
Limestone . .	150 feet thick.
	Carboniferous.
Coal measures . .	Coal-bearing series, 700–800 feet thick, with coal seams a few inches to 6 feet in thickness, and thin and irregular oil sands in the basal part.
Millstone grit series .	200–750 feet thick; sandstones and grits with shale bands and fireclays, the main oil horizon being the rough rock, 50–100 feet thick, the topmost sandstone of the series.

Rock-bits are necessary throughout the drilling. In order to save the shipping of rock-bits to this country, an extended trial was given to drag-bits of various types which could be manufactured here, but these proved to be quite unsuitable. Hughes or Reed rock-bits of various types which experience has shown are the most suitable for the different formations are used. An average of about 100 feet per rock-bit was obtained when using a viscous, chemically treated mud made of dry ground, Coal Measure shale, to which was added a bentonitic material available in this country. With increased drilling speeds and more rapid completions it became possible to modify this practice without causing damage to the walls of the hole, and wells were started with clear water, to which later a little bentonitic material was added. With this circulating fluid the footage per bit improved, and as much as 800 feet of drilling has been achieved with one rock-bit, the average for production wells being six, as against thirteen bits used in the earlier wells. Conservation of rock-bits has been achieved by a Bit Service, whereby rock-bit cutters are reconditioned before the bearings are worn out. Tungsten carbide in a tubular rod is welded on to the worn tooth with an oxy-acetylene flame. The plastic deposit is then shaped with a steel rod. In some cases bits have been reconditioned twice after their first run, and it is estimated that this gives the bits an average of 70 per cent. additional life.

In the earlier wells considerable difficulty was encountered with the loss of circulation in the marls and with the building up of mud cakes on the wall of the hole when drilling through the Bunter sandstone. A very careful mud control was necessary to avoid this, and samples were sent to the mud laboratory at regular intervals, and the mud conditioned with bentonite and aquagel to specification. As an additional safeguard, a $14\frac{1}{8}$-inch hole was drilled through the Bunter, after which the hole was reduced to $10\frac{5}{8}$ inch down to the casing seat, approximately 2000 feet deep, above the first producing oil-sand; there $8\frac{5}{8}$-inch collar casing was cemented with sufficient cement to obtain cement returns at the surface to safeguard the coal seams. With the need to conserve steel and drilling bits, later wells were completed with $6\frac{5}{8}$-inch casing, which served as the oil- and water-string, drilling an $8\frac{5}{8}$-inch hole throughout, thus saving seven tons of steel per well.

Although these wells are normally one-string wells, it has been necessary in a few cases to cement a long conductor string, as excessive circulation losses have been met in the formations above the Bunter sandstone. Various methods of overcoming these mud losses have been tried, but finally a method using a 50/50 mixture of plaster of Paris and cement, with a very fast set, pumped in through tubing, proved to give a quick and successful shut-off in the zones where mud losses have been experienced; a shut-down of only two hours is required for setting. Small losses have been dealt with by a mixture of finely chopped flax straw with bentonite mud. With the low viscosity mud a high circulation speed is essential, and if this is achieved fishing troubles are reduced to a minimum.

In order to achieve the necessary drilling speed, maximum pump pressures and high circulating speed are necessary, the flush quantities giving an annulus speed of 150 feet per minute. With this, and a circulating fluid of little better than dirty water, excellent settling of the cuttings in the mud-pits has resulted, good uncontaminated samples have been obtained for the geologist, and the re-circulation of the abrasive sediment has been prevented.

With the rapid speed of drilling considerable care has been taken to keep the holes vertical. Checks for verticality are taken every 250 feet with a single shot recorder. Over-sized drill collars add the necessary weight to the bottom of the string and, with a relatively small clearance between the $5\frac{1}{2}$-inch drill collars and the $8\frac{5}{8}$ inches hole, little difficulty has been experienced in maintaining straight hole. A maximum weight equal to 1200 feet of drill-pipe has been used.

Correlation for casing seats and structure control has been obtained by a combination of samples from a screen or shale-shaker at the outlet from the conductor pipe and the use of a Penetration Recorder. Particular attention has been paid to the coal seams penetrated, from which bulk samples have been obtained and submitted to the Coal Survey Laboratory for detailed examination.

The cementing practice has been conventional. Concrete and rubber plugs are used, and ink released from an imbedded bottle stains the mud and indicates the plug position when drilled up. A Calmec quick-release cement head is used. The cementing outfit is a trailer-mounted independent unit, made on the field, and efficiently operated by locally-trained men. Forty-eight hours is allowed for the cement to set.

With a $6\frac{5}{8}$-inch water-oil string the oil-sands are drilled through with a $5\frac{3}{8}$-inch bit. The perforated liner is then run to hold back the caving fire-clays, petal baskets being incorporated in the liner at the top and bottom of each oil-sand. The well is then circulated, and rods and tubing are run in by the drilling outfit before it moves off to the next site. After moving the outfit, the pump is installed, the well being placed on production in a matter of hours.

The Oil-fields and their Production Characteristics.

The general characteristics of the three oil-fields, Eakring, Caunton, and Kelham, from which the greater part of the production is obtained are, briefly, as follows :—

Each oil-field consists of a simple, domal structure with minor faulting, containing a number of separate, sometimes lenticular, and independent oilsands; the Rough Rock, a hard sandstone, varying from 50 to 100 feet in thickness, is the main producing horizon in the larger Eakring oil-field. In this field, which is two miles long by half a mile wide, four separate oil-sands yield production in the central part of the structure, whereas in the smaller Kelham and Caunton fields only two oil-sands are present, and these are thinner, being each about 30 feet thick and separated by some 70 feet of shale. Each sand has its own particular type of crude oil and edge-water. These oil horizons lie mainly in the Millstone Grit Series of the Upper Carboniferous, but they extend upwards into the basal part of the Lower Coal Measures. The sandstones vary considerably both in porosity and permeability, the former ranging from 0 to 20% and the latter from 2 to 1000 millidarcies. The oil column is small, being of the order of 250 feet at Eakring, and only some 40 feet at Caunton.

Well spacing was originally planned at 500 feet between wells, but this was later reduced by drilling infilling wells suitably placed to give an overall well spacing of one well to $2\frac{1}{2}$ acres on the Eakring field, and one well to 3 acres on the Kelham and Caunton field—a spacing which is considered to be satisfactory for these reservoir characteristics. The initial well productions vary from seven barrels a day to as high as 375 barrels per day. When, however, the infilling drilling programme had been nearly completed, it was found that the later wells drilled yielded approximately the average production to which the majority of wells had declined at that time.

Every opportunity, so far as the speed of operations has permitted, has been taken to obtain petroleum engineering data so that the reservoir problems can be fully understood, and in this connection the fullest advantage has been taken of the experience gained in the Persian oil-fields. Before production started the pressures for any particular datum level were practically the same for the different sands in each oil-field, but, as was to be expected, after production started the pressure decline was varied in the different sands dependent on the production obtained and on the characteristics of the sand. The gas–oil ratios are small, varying between 10 and 20 volumes of gas to 1 volume of oil; the crudes are, therefore, considerably under-saturated with gas. It has been found that the production decline has been rapid until the pressure reached the saturation pressure of the crude, after which the production decline is relatively small. Wells tend to group into two types : small, low-permeability wells having a small decline throughout their life, and those with a larger initial production following the more usual decline curve of sand-field production.

The original reservoir pressure in the Eakring field was approximately 990 # at a datum level of 1700 feet below mean sea level, the highest recorded closed-in pressure being 300 #. All wells would yield a small flow, the highest flowing production recorded in an initial production test being 100 barrels per day. The original saturation pressure of the gas in the crude oil was 390 #.

The reservoir pressure in the Rough Rock has fallen since production started below this to 350 #, whereas the reservoir pressure in the Chatsworth Grit has only fallen to 700 #. Prior to production, the reservoir pressure at Kelham was 1220 # at a datum level of 2000 feet below sea level. The original saturation pressure of the gas in this field is, however, extremely low, being only 90 #. Reservoir pressures in the Middle Grit have declined as a result of production to 700 #, and in the Upper Grit to 250 # at a datum level of 2000 feet.

Information obtained since production started shows that the mechanics of these reservoirs are governed by a water drive in each sand, the flood walls of which give an irregular contour due to the variable permeability of the oil sand.

The following table gives the water encroachment at Duke's Wood resulting from a production of one million barrels :—

Eakring Field—Duke's Wood Dome.

Horizon.	Original O./W.	Oil column, ft.	Present highest water elevation.	Maximum rise in O./W., ft.
B. Sandstones	8260	238	8275	Up to 15
Rough Rock	8240	208	8310	Up to 70
Longshaw Grit	8200	110	8260	Up to 60
Chatsworth Grit	8180	62	8218	Up to 38

Note.—Elevations given in feet above a datum of 10,000 feet B.S.L. Water encroachment has been more rapid when related to the production drawn in the Longshaw and lower part of the Chatsworth Grit than it has been in the Rough Rock, owing to the greater permeability of the former.

The specific gravities of the crude oil in the Eakring and Duke's Wood domes vary in the different sands and also between the two domes.

Sand.	Eakring.	Duke's Wood Dome.
B. Sandstone	0·853	0·863
D. Sandstone	0·828	—
Rough Rock	0·848	0·861
Longshaw Grit	—	0·857
Chatsworth Grit	0·837	0·862

The specific gravities of the crude from the Kelham and Caunton fields are as follows :—

Sand.	Kelham Hills.	Sand.	Caunton.
Upper Grit . . .	0·892	Upper Grit Group . .	0·880
Middle Grit . . .	0·880	Middle Grit Group . .	0·870

It will be seen that these yield a consistently heavier oil than at Eakring.

It is of interest to note that there is a considerable difference in the rock temperatures of these fields, the temperature at Eakring being much higher than at Kelham Hills. The temperature differences are as follows :—

Depth below mean sea level, ft.	Eakring.	Duke's Wood.	Kelham Hills.
500	61° F.	60° F.	57° F.
1000	75° F.	70° F.	63° F.
1500	97° F.	85° F.	72° F.
2000	118° F.	103° F.	83° F.

The crude is greenish-brown in colour, and is of a mixed type. The motor and aviation gasoline distillates are mixed types, with naphthenic characteristics predominating, and are interesting from the standpoint of the high-octane-number values and non-knocking properties. There is a large amount of paraffin wax present in the crude—more than double the amount present in an average Mid-Continent crude. The sulphur content is low, and is distributed in a normal manner. The gasoline distillate has a low sulphur content of 0·01. There is practically no elementary sulphur in solution in this crude. Lubricating oils of high grade can be prepared which compare favourably with those from Mid-Continent crudes.

Minor differences occur between the oils in the various sands and fields, but a typical analysis of the crude from Eakring No. 1 well is given below :—

	Rough Rock, Crude.	Lower Producing Sands, Crude.
Specific gravity at 60° F.	0·848	0·828
Distillation :		
I.B.P., °C.	51	37
% Vol. to 100° C.	3·5	8·0
200° C.	21·0	27·0
300° C.	35·0	46·0
Total Distillate, %	36·5	46·0
Residue, %	61·5	50·5
Loss, %	2·0	3·5
Distillate, sp. gr. at 60° F.	0·778	0·770
Residue, sp. gr. at 60° F.	0·892	0·884
Sulphur, %	0·18	0·07
Pour point, °F.	—	50
Temperature at which wax deposition commences, °F.	85	80
Viscosity at 70° F. c.s.	—	15·09
80° F. c.s.	—	8·97
85° F. c.s.	—	—
100° F. c.s.	—	5·33
120° F. c.s.	—	4·27
122° F. c.s.	—	—
150° F. c.s.	—	—

MAIN STORE AND YARI

EAKRING OILFIELI

PUMPING WELL,

EAKRING.

PUMPING WELL,

EAKRING OILFIELD.

REMOVING DEEPEST CORE

O FAR TAKEN

N ENGLAND,

473 FT.

Surface Production Arrangements.

Surface Plant.

Pumping units have been installed at every producing well on completion. Tubing sectional liner pumps are used, mainly 2 inches, though a few $2\frac{1}{2}$ inches were used on the larger wells. The standard pump at present in use is 5 feet × 2 inches × $1\frac{3}{4}$ inches, run on 2-inch plain tubing and operated by $\frac{5}{8}$-inch sucker rods. Pumping jacks are operated by individual electric motors. Various types and sizes of pumping jacks have been installed, and 120 of the pumping units were manufactured in the United Kingdom.

The advantages to be derived from using electricity for well pumping and also to operate the 150 h.p. electric slip-ring drilling motors were made possible by the overhead electric feeders already in the district, and an agreement was entered into with the Derbyshire and Nottinghamshire Power Company to take electricity at 11,000 volts, which, at various sub-stations, is stepped down to 440 volts. On completion of drilling the conductor size is reduced and the current taken to the small individual well motors, ranging from 2 h.p. to 15 h.p., for operating the beam pump. The supply to the pumping units is by overhead lines, there being a total of seventeen miles of low-tension line and the total H.P. connected being 1186.

The oil is pumped from the various wells to the gathering stations through 2-inch lines, there being a gathering station to approximately every forty wells. The gathering stations consist of two 100-ton tanks and water separators. Individual well measurement is partly by portable tankers and partly by the installation of small well-tanks, the oil being pumped away from these tanks by the incorporation of a pump operated by the walking beam.

Main buried pipe-lines from the three fields and their gathering stations to the oil railway siding built for this traffic are 3 inches in diameter and thirteen miles in length. At the railway siding, one mile from the Eakring field, a small tank farm, consisting of four 400-ton tanks, has been incorporated in the production system. Oil is measured for royalty purposes at these tanks, and each tank has a heating coil connected to steam boilers. From this siding the crude is taken by rail to the Refinery.

Gas Treatment.

As I have already mentioned, the gas–oil ratio in these fields is small. Gas is collected from the annulus between the casing and the tubing in each well, and also from the water separators in the Eakring oil-field, totalling approximately 160,000 cubic feet per day. The gas from the wells flows through 1-inch lines into the main rich gas line, and thence to a charcoal adsorption plant situated in the Eakring field, the gasoline being recovered and the stripped gas returned to the boilers at the gathering stations for fuel.

The need to conserve the valuable fractions in the casing-head gas was considered in the early life of the field, and it was decided to instal a fully automatic charcoal adsorption plant designed for the recovery of benzole from coal-gas. The gasoline recovery consists of the pentane and heavier fractions, and can be used directly in all Company vehicles without any vapour locking occurring. Just over one gallon of gasoline is recovered from every 1000 feet of gas treated.

Production Problems.

In an endeavour to save steel, and having regard to the hard rock characteristics of the oil-sands, the early wells were completed with open hole. The occurrence of fire-clays inter-bedded with the oil-sands in this multiple sand production caused a certain amount of caving, which prevented the lowering of the pump below the casing seat. To obviate this caving, the open hole below the casing shoe was filled with 1½-inch gravel, thus preventing the wall of the hole from falling in without impeding the flow of oil. This method, whilst saving steel, still prevented the pump being lowered, and later practice has been to insert a 4½-inch perforated liner, the perforations being ½-inch holes with 12-inch spacing. This permits the pumps to be set as low as required, but the fluid level is maintained so as to cover the sand and prevent the temperature being lowered to below the point at which wax settles out. Wax troubles in the sand are not anticipated, but experiments to confirm this have not yet reached a conclusive stage.

Two problems common to many oil-fields have to be met : firstly, water separation, and, secondly, those caused by the waxy nature of the crude.

In the early life of the field the oil from the crestal wells was water-free, but as drilling proceeded down-flank the few wells producing water were flowed to a wash-tank in which the oil–water mixture was heated by steam coils and separated. With the increase in water production, now amounting to about 30 per cent. of the fluid recovered at the Eakring field, more efficient water separation arrangements have been installed. The present separators in use require the oil to pass through wood-wool packing, and these separators reduce the water content of wet oil to about 1 per cent. The oil–water fluid passes through at a rate of about 5 feet per hour. A sulphonated oil is also used as an emulsion-breaker, being added to the well fluid at the rate of about 0·003 per cent. The separators are heated to a temperature of 110° F. by steam coils, dry gas from the adsorption plant being used for steam generation.

The high wax content of the oil causes many difficulties, both in surface lines and in the upper part of the wells, as wax starts to settle out at temperatures below 80° F. In the surface lines this is overcome by go-devilling all lines daily. In the well itself the main difficulty lies in the top 700–800 feet, and the need to pull wells for mechanical de-waxing purposes has been overcome by the following means : the tubing at each well is insulated from the casing by wooden insulators to about 1000 feet, and at the tubing head by supporting it on a plastic ring; contact is made at 1000 feet in the well with the casing by welding four steel strip bows to a special collar. For de-waxing, a portable direct-current generator is taken to the well and connected to the tubing. Current of a low voltage is passed through the tubing-casing circuit with a heavy amperage (600–800), resulting in the heating of the top 1000 feet of tubing to a temperature high enough to melt the wax and enable the well to pump this away, thus obviating pulling operations.

A number of experiments has been carried out to increase production from these sands : acid treatment, water rocking with chemical water-wetting agents, and the shooting of the sands.

Of these, shooting has given the most promising results, and a shooting technique has been developed using Polar blasting gelatine exploded by time-bombs. The latest practice is to use a delay-action device produced in this country, making use of the time taken to break a lead-alloy element when in tension. When broken, the electrical contact is made, and this device has provided a very satisfactory delay timing action, being reliable and completely simple to incorporate with the electrical firing.

Explosive charges up to 400 lb. are used, lowered in containers with boosting pellets distributed throughout the charge. The normal practice is to use solid tamping—crushed gypsum—the tamp being placed on top of a canvas umbrella above the explosive. This method of tamping, whilst giving a maximum explosive effect, makes the cleaning out after the charge has been fired a simple matter.

In shooting multiple sands, difficulty has been encountered with caving fire-clay, and in this case an asbestos cement liner is run which can be drilled up after shooting. Increases as high as 200 per cent. in production have been obtained.

No discussion of war-time development of petroleum in this country would be complete without reference to two further small sources of supply developed by the Anglo-Iranian Oil Company; I refer to Formby, in Lancashire, and the original Pearson well at Hardstoft.

Attention was directed in the Memoirs of the Geological Survey to surface seepages in a peat bog underlying the Trias at Formby. Shallow wells drilled with a geophysical Failing outfit to the base of the Glacial Drift—about 100 feet—defined a seepage area amounting to some 30 acres. Of the twenty-five wells drilled, twelve gave sufficient production to justify pumping, and pumps were installed. These wells have to date produced 45,000 barrels of oil, and the production after five years is remarkably steady at about 120 barrels per week. Some of the wells are bring produced under vacuum.

An examination of the crude, combined with the slow decline, indicates that these wells may be fed from a deeper source. Where this source is has provided us with a problem to which a solution has not yet been found. A deep test located within the seepage area has been drilled to 6380 feet, the greater part through sandstones, without finding any trace of a deeper oil. At 5885 feet it penetrated a hard, silicified rock, believed to be Upper Carboniferous, or younger, and this hard formation has continued down to the present depth. The hardness of the rock is such that the hardest formation rock-bit is completely worn out after drilling for only a few minutes, and the penetration may be only a matter of inches.

The Pearson well at Hardstoft, the first producing well in England, was taken over by the Anglo-Iranian Oil Company in October 1937. In the first place, it was necessary to put the well into a satisfactory mechanical condition, with the object of deepening into the limestone to find out where the oil–water level was located and to see if more production could be obtained.

When these operations were completed, a series of experiments was undertaken in an endeavour to increase the production. Delayed acid treatment and water rocking with water-wetting agents were undertaken. As a result of this, the production from this well was improved, and 8700 barrels of oil have been produced during the war period. The well is still pumping at a rate of a few barrels of oil per day with large quantities of water.

A review of these war-time operations should not omit certain aspects which do not come within the technical sphere.

During and after the passage of the Petroleum (Production) Act in 1934, great concern was expressed in Parliament and in the Press as to the ruin of rural amenities which would inevitably follow the discovery and development of oil-fields in Great Britain. Special attention has been paid to this by Mr. Lefroy of our London office, and, at a time when every endeavour has been made to increase agricultural production, the development of oil took full account of the need for food.

With the small fields in this country it has been possible to arrange the well spacing so as to do the minimum of damage to crops and cropping, and in many places the construction of roads to the well-sites, amounting to some twenty-five miles in all, has proved of some benefit to the farmer. No derricks are left, and as soon as the drilling campaign is completed an endeavour is made to return all but a small well-site for farming purposes. Much thought has been given to the problem of returning the drilling mud-pit area to a satisfactory condition for farming. The mud-pits after drilling contain a colloidal fluid which is somewhat impervious, and which prevents the normal soil drainage unless special steps are taken to deal with this. On the advice of the Rothamsted Experimental Station, powdered gypsum is spread at regular intervals on the mud-pit; this coagulates the mud and assists drainage, and has proved to be efficacious in enabling these areas to be returned to husbandry as rapidly as possible. Before leaving this subject, I should like to express our appreciation of the ready and friendly co-operation which the farmers concerned have given us.

The development of these oil-fields and the testing of nearby structures in areas far removed from centres of industrial activity have presented a considerable problem under war-time conditions. This is especially so as the number of men available in this country who had any knowledge or experience of oil-field operations was negligible.

With a nucleus of specialists from the Company's oil-fields in Persia, a labour strength of about 800 was built up from recruits from the Labour Exchange without any previous experience. Training was necessary for all, but more especially so for the drilling crews, production pump men, and well-pullers.

The men available for these occupations were mainly ex-coal miners, unfit for employment underground, who had been released from the coal industry. The majority of these made good in their respective occupations, and it will be of interest that twenty-five have gained promotion successively from general labourer on the drilling site to driller. The schedule of reserved occupations made no provision for the deferment of unskilled workers, and many of the men finally available to us for these operations were hardly fitted for heavy work owing to age or previous industrial accidents. Out of the 800 employees 30 per cent. are over sixty years of age or under eighteen.

In view of the isolated locality, a hot food service has been in operation from which food has been made available by hot food carriers to all men working outside. This service works throughout the twenty-four hours.

Despite the arduous nature of the work now being undertaken by men recruited from the Labour Exchange, many of whom had not previously worked outside, one gains the impression of a general improvement in health.

One of the problems in industry in this country, and particularly so in the development of oil-fields, is the difficulty with which any management is faced in persuading the workers to wear proper clothing. Steel-toed shoes, suitable overalls, gloves, and helmets are very desirable, and despite war-time clothing difficulties the encouragement to wear such clothing, when it has been possible to obtain it, has made some progress. Continuous education on these lines is essential in the interests of safety and health.

In conclusion, I should like to take this opportunity of expressing our appreciation of the encouragement and assistance we have received from many Government Departments—particularly the Petroleum Division and the Ministry of Labour. The work, comprising geological, geophysical, drilling, production, and petroleum engineering activities, has had team work which, to use the words of our Chairman, Sir William Fraser, " is an example of Combined Operations." I wish to thank Mr. Jameson, Production Director of the Anglo-Iranian Oil Company, for permission to publish this data, and Mr. Bremner, the Works Manager, Mr. Dowling, and Messrs. Dickie and Benard and Adcock of the Production Department, for their assistance in preparing this paper. The results achieved are due to these men, their staffs, and the men of the district employed on the work, and to the guidance of Mr. Seamark on the drilling and fields engineering, Mr. Comins, on the petroleum engineering side, and Mr. Macdougall, responsible for the electrification, all of our Head Office staff.

MEASUREMENT OF OIL DEPTHS.

By the Measurement of Oil Depths Panel of Standardization Sub-Committee No. 1—Measurement and Sampling.

Foreword.

The Measurement and Sampling Standardization Sub-Committee was set up in 1931 to deal with the standardization and unification of methods and equipment used in the measurement of bulk petroleum products. The work of the Sub-Committee is divided among seven Panels, *viz.*

Panel I : Tank Calibration.
Panel II : Measurement of Oil Depths.
Panel III : Sampling.
Panel IV : Temperature Measurement.
Panel V : Gravity Measurement.
Panel VI : Units of Measurement, Calculations, and Tables.
Panel VII : Oil Measurement Apparatus.

An early piece of work carried out by the Sub-Committee was the publication in 1932 of the Institute's booklet "Measurement of Oil in Bulk, Part I—Standard Weights and Measures". All the seven Panels are actively engaged on their assignments with the intention of producing a comprehensive series of methods covering all aspects of oil measurement.

Panel VI has almost completed a standard work on Oil Measurement Tables, which will be published by the Institute in book form very shortly.

Panel II, having surveyed the field allotted to it, has produced the accompanying document on Measurement of Oil Depths. The methods and procedures outlined are put forward in this *Journal* for comment and criticism, in order that Panel II may be guided by the experience of others in so subsequently amending the tentative method that it can then be put forward as an I.P. standard method. The views, particularly of refinery and installation personnel on the accompanying document, will accordingly be welcomed.

The membership of Panel II responsible for this document is as follows :—

E. Stokoe (*Chairman*) : "Shell" Refining and Marketing Co., Ltd.
P. Docksey : Anglo-Iranian Oil Co., Ltd.
G. W. W. Ford : Stemco, Ltd.
A. W. Higson : National Benzole Co.
M. H. Hoffert : Anglo-Iranian Oil Co., Ltd.
H. Hyams : Asiatic Petroleum Co., Ltd.
A. Osborn : Esso European Laboratories.
W. H. Thomas : Anglo-Iranian Oil Co., Ltd.
F. Tipler : Anglo-American Oil Co., Ltd.

The specifications for the apparatus included in the Appendix have been prepared by Panel VII.

H. Hyams
Chairman, Standardization Sub-Committee No. 1.

1. Introduction.

Various methods commonly employed in the petroleum industry for the measurement of oil depths in bulk containers are summarized below. In practice, choice of method will be influenced by the nature of the material, the type and equipment of the container in which it is stored, and the accuracy required.

Whilst no brief set of standard methods can provide for all the conditions and requirements which may arise in practice, the following directions are intended to guide persons engaged in the measurement of oils in bulk.

2. Classes of Material.

The methods described cover the following petroleum products :—

Crude oil, liquefied hydrocarbon gases, natural gasoline, gasoline and related motor fuel, light petroleum solvent, white spirit, kerosine, gas oil, diesel fuel, lubricating oil, electrical insulating oil, fuel oil, molten and liquid asphaltic bitumen and bituminous emulsion.

3. Types of Tank or Container.

The apparatus and procedure described later apply to material in containers of the following types :—

(*a*) Shore tanks of various types.
(*b*) Ship and barge tanks.
(*c*) Rail and road tank cars.
(*d*) Pipelines.

Notes are also given regarding the use of oil meters for measuring oil quantities whilst in movement.

4. Definitions.

(a) Types of Container.

(i) *Conventional Container.*

A bulk container of a shape commonly employed in the petroleum industry, and in which the pressure in the vapour space above the liquid when measuring oil depths may be allowed to equal that of the surrounding atmosphere, to permit gauging via an open gauge hatch.

(ii) *Floating Roof Type Container.*

An open-top vertical cylindrical tank equipped with a floating roof of the " Pontoon ", " Pan ", or similar type.

(iii) *Vapour Tight Container.*

A bulk container intended primarily for the storage of volatile liquids, and which, although of conventional shape, is equipped with devices which necessitate the measurement of oil depths when the pressure in the vapour space above the liquid differs from that of the surrounding atmosphere.

(iv) *Pressure-Type Container.*

A bulk container specially constructed for the storage of volatile liquids under comparatively high pressures and of unconventional shape, including, for example, spheroidal, spherical, and hemispherically ended cylindrical tanks.

(b) Dip.

(i) *Dipping Reference Point.*

A point clearly marked on the dip-hatch to indicate the position of the tape when dipping.

(ii) *Dip.*

The total depth of liquid in a container measured directly by means of a dip tape and weight, or graduated rod, reaching to the bottom of the container.

(iii) *Average Dip.*

Where more than one dip is taken in a container the average dip is the average of the measurements so obtained, calculated in accordance with Section 8.

(c) Ullage.

(i) *Ullage Reference Point.*

A point clearly marked on the ullage hatch, or on an attachment located above or below the ullage hatch, and situated at a distance above the tank bottom greater than the maximum liquid depth in the container.

(ii) *Ullage.*

The distance, measured in suitable units, between the ullage reference point and the upper surface of the liquid in the container.

(iii) *Average Ullage.*

Where more than one ullage is taken in a container, the average ullage is the average of the measurements so obtained, calculated in accordance with Section 8.

(d) Water Measurement.

(i) *Water Dip.*

The depth of water in a container measured by any of the methods described in Section 6 (d) (i).

(ii) *Average Water Dip.*

Where more than one water dip is taken in a container the average water dip shall be the average of the measurements so obtained, calculated in accordance with Section 8.

(iii) *Water Bottom.*

A layer of water at the bottom of a container, and of such depth as completely to cover the bottom.

(iv) *Sludge or B.S. & W.*

When the nature of the material being measured is such that there is no clear separation between the oil and any water at the bottom of the container, the term sludge is used in the succeeding paragraphs to imply a layer of sediment, emulsion, and/or water present at the bottom of a container.

(e) Calibration or Tank Table.

(i) A table constructed so as to show the capacities of, or volumes in, a container corresponding to various liquid levels.

5. General Directions and Precautions.

Choice of Method.

(a) Measurements in Shore Tanks.

The three methods most generally employed for the measurement of oil depths in shore-tanks are: dipping, ullaging, and the use of direct reading gauge glasses.

When measuring large shore tanks, both ullage and gauge glass readings may be affected by certain slight errors for which it is difficult to apply accurate corrections. Choice of method will be influenced by personal preference, local custom, the nature of the oil being measured, and by other considerations, but in general it is recommended that for accurate work dips should be taken except when circumstances make it desirable to use some other method.

For measuring volatile liquids stored in closed containers under pressure, gauge glasses are convenient, and may be preferred to the indirect or troublesome methods necessary for dipping closed containers. Similarly, the possibility of serious errors when endeavouring to dip shore tanks containing obstructions or sediment may be avoided by taking ullages; the method will also be found convenient when measuring very viscous oils or materials such as liquid bitumen at high temperatures.

Hydrostatic gauges of various types are sometimes employed to measure containers inaccessible by normal methods of measurement, but reference should be made to sub-section 6 (h). Although float gauges may be found useful for many operational requirements, they are not recommended for taking official measurements for quantitative purposes.

(b) Measurement in Ship and Barge Tanks.

Barge tanks may be ullaged or dipped according to circumstances, but it is recommended that tanks with sloping bottoms, or containing obstructions which might lead to error, should preferably be ullaged.

Owing to various obstructions which normally impede dipping, ships' tanks should be ullaged whenever practicable, even when dips are also taken for special purposes.

(c) Measurement in Rail and Road Tank Cars.

Road tank vehicles are usually provided with dip or ullage sticks calibrated in units of volume, and applicable only to the tanks for which they have been prepared.

Rail cars are preferably measured by weighing, but when weighbridges are not available, ullages (in units of length) are usually measured from a suitably placed reference mark. Frequently a so-called ullage plate is securely fixed at a convenient level in the tank, and the volume corresponding to the ullage plate is marked on the shell of the car. It is recommended that even when the weighing method is used, ullages should be taken after filling and before discharge, and should be recorded for checking purposes in case of discrepancy.

(d) Measurement of Oil in Pipelines.

(i) Installation and Refinery Pipelines.

When it is known that a given length of pipeline is completely full of oil, the volume of oil which it contains can readily be calculated from the length and internal diameter of the line. In practice, however, it is found that many of the discrepancies which arise when measuring oil-stocks or oil transfers result from incomplete filling or emptying of pipelines. It should be noted that the time and trouble expended in careful measurement of oil depths in a container may be largely nullified if the quantity of oil in an associated pipeline cannot be measured accurately.

The precautions to be taken will be influenced by the size and gradient of the line, the nature of the oil, and by various other circumstances, and in view of the complexity and diverse nature of the difficulties which may be encountered, only general indications can be given in the succeeding paragraphs.

Difficulties when measuring the quantity of oil in pipelines can be considerably reduced if it is possible to provide a regular and satisfactory slope when the pipelines are installed. Similarly, air vents and drain-cocks installed respectively at high and low points in the system will assist in verifying whether a pipeline is full or empty.

When measuring light oils, and under favourable circumstances, pipelines may be satisfactorily emptied by pumping water through the line. Alternatively, lines may be satisfactorily filled with oil by pumping down one pipeline and back into the tank via another pipeline, so as to displace all air and water from the line before taking a measurement of oil depth. Difficulties frequently arise when endeavouring to empty pipelines completely, and unless conditions are favourable, more accurate results will usually be obtained when pipelines are satisfactorily filled before measurement.

When measuring heavy products, water cannot normally be employed for pipeline clearance, and heated viscous materials frequently cannot be allowed to remain in a full pipeline for the period of time required for tank settling and measurement. In these circumstances it is usual to clear the pipeline as completely as possible by the use of compressed air. When pipelines are known to be full before clearance, the quantity received should be compared with the calculated capacity of the line. Difficulties are frequently met when endeavouring to clear pipelines by air blowing, but errors may sometimes be minimized by using the same air pressure and procedure before and after a movement.

(ii) Estimation of Quantities in Long-Distance Pipelines.

Air vents and drain cocks cannot normally be used throughout long pipelines over open country, and differences in level may make it difficult to fill or empty the system completely for measurement purposes. Problems may arise which have not yet been completely solved, particularly if the system contains an unknown quantity of water.

When the line contents cannot be measured before pumping, but the specific gravity or colour of the material in the line differs considerably from that of the material to be pumped, samples may be drawn at frequent intervals at the receiving point, and the line contents may be segregated for measurement by diverting the flow when line samples indicate that the line contents have been displaced into part of the receiving tankage. Alternatively, and for the same purpose, dye may be introduced into the line at the delivering point when pumping commences. When methods of this type are employed, the rate of pumping should be sufficiently high to prevent serious mixing in the line.

Where it can be assumed that the system is completely full whilst pumping is in progress, pipeline contents may be approximately estimated by taking synchronized tank measurements at the receiving and delivering points during the pumping. If the total of the quantities in the delivering and receiving tankage when pumping with the line full be subtracted from the total of the quantities in the delivering and receiving tankage before pumping commenced, the difference, neglecting any pumping loss, will give an approximate indication of quantity which was required to complete the filling of the system. Other methods may be devised according to circumstances.

General Precautions.

(i) Official measurements should be taken by, or under the immediate supervision of, a person of skill and previous experience in measuring oil depths.

(ii) Whenever practicable, measurements in a container should be taken in the same manner, at the same position or positions in the container, and by the same or similar apparatus, before and after a movement of oil in bulk.

(iii) Gauge tapes should be free from kinks, rust, etc., and in general any apparatus used for measuring oil depths should, when relevant, be clearly legible, and should be periodically verified by comparison with suitable standards.

(iv) As far as practicable, apparatus used for measuring oil depths should be made of nonspark generating material.

(v) In general, oil depth or ullage measurements should not be taken during thunderstorms or other atmospheric electrical manifestations or disturbances.

(vi) Measurements should preferably be taken in duplicate.

(vii) Measurements should be recorded immediately they have been taken, and before leaving the tank should be agreed by all the interested parties present.

(viii) Before taking oil depth or ullage measurements for official purposes, time should be allowed for the cessation of any movement of the oil surface, and for the settlement of water and sediment. When measuring viscous materials, time should also be allowed to permit any entrained air to rise to the surface.

(ix) When foam rests on the surface of the oil, the oil depth must not be measured by dipping or ullage until the foam has subsided or has been cleared from the oil surface beneath the gauge hatch.

(x) When measuring for official purposes, precautions should be taken to ensure that oil cannot flow into or out of the container whilst measurement is in progress. For example, when measuring the compartments of a ship before discharge, all tank suction and other valves which might permit gravitation from one compartment to another should remain closed until all necessary measurements have been completed.

(xi) Ullages or dips should preferably be taken through dip hatches giving direct access to the oil surface. Dip pipes should not be used for official measurements except when pipes of satisfactorily perforated design are used to improve accuracy of measurement in special circumstances.

(xii) When taking oil depths or ullage measurements for official purposes, the depth of water should also be measured at the same position or positions in the container.

(xiii) When taking oil depths or ullage measurements for official purposes, the average temperature of the oil being measured should be determined at the time of measurement.

(xiv) When taking oil depths or ullage measurements for official purposes, samples for the determination of specific gravity and for the determination of any other characteristics required for measurement purposes should preferably be taken at the time of measurement.

(xv) Before measuring for official purposes the conditions of any pipelines which may be involved in the measurement should be checked.

(xvi) Whenever practicable, the bottoms of shore tanks should preferably be completely covered with water when oil depth or ullage measurements are taken for official purposes.

Special Precautions—Vertical Shore Tanks without Water Bottoms.

When oil depths are measured in vertical shore tanks for the purpose of calculating the corresponding volume of oil, serious errors may arise if due allowance is not made for irregularities in the tank bottom and possible movement of the bottom plates.

Methods for determining bottom allowances are being dealt with by the Tank Calibration Panel of Sub-Committee No. 1, and, when necessary, due allowance should be made for bottom irregularities if water bottoms are not carried. When accurate measurements are required, it is recommended that the bottoms of tanks involved in movements of oil in bulk should be completely covered with oil, both before and after the movement takes place.

If it is necessary to discharge a tank vessel into an empty storage tank for which an accurate bottom allowance has not previously been ascertained, an estimate of the bottom allowance, if any, may be made by pumping from the vessel a quantity of oil sufficient to cover the bottom. Discharge is then interrupted and careful measurements are taken in the ship and shore tanks. Only the upper portions of the smallest practicable number of ships' tanks should be utilized for this purpose; all cargo compartments of the vessel should be measured before and after the operation, and allowance should be made for any changes in the quantity of oil in pipelines. The method is dependent on the accuracy of the ship's calibration tables, and should therefore not be employed when more accurate means are available.

The application of a fixed bottom allowance will not compensate for additional errors which may arise when the bottom plates move as a result of changes in the oil head or in the condition of the subsoil. It is recommended that tanks liable to bottom movement should not be measured by ullaging nor by the use of gauge glasses, but should be dipped whenever practicable. Errors resulting from bottom movements can frequently be reduced by increasing the number of suitably spaced gauge hatches used for taking dips. For example, in cases of difficulty, tanks have been provided with four dip hatches spaced equidistantly round the perimeter, a centre dip hatch and four additional dip hatches spaced equidistantly round a circle midway between the centre dip hatch and the vertical side of the tank, nine dips being taken and averaged in accordance with Section 8.

The special precautions to be taken are summarized below :—

(i) The allowance, if any, to be made for bottom irregularities should be measured, and should be verified at convenient intervals.

(ii) Whenever practicable, the tank bottom should be completely covered with oil before and after a transfer of oil in bulk.

(iii) Measurements should not be taken for official purposes when the bottom is partly covered with oil or water.

(iv) When official dips must be taken in tanks liable to bottom movement, measurements should be taken from all available suitably placed gauge hatches in order to reduce errors as far as practicable.

Note.—Special precautions to be observed in the measurement of individual products in different types of containers are included in the description of each method.

6. Procedure.

(*a*) Measurement in Vertical Cylindrical Tanks (Conventional Type).

(i) *By Dip.*

A gauge tape and weight in accordance with Appendices (i) and (ii) should be employed. In use, the dip tape, with dip weight attached, should be lowered carefully through the oil until the weight just touches the tank bottom. The tape must be held taut, and the dip weight must not be allowed to tilt whilst the dip is being taken. The tape is then withdrawn, and the length of tape, which has been wetted with oil, is read by inspection to the nearest graduation. With the preferred type of tape and weight the tape reading will be the gross oil depth, but with certain other tapes allowance must be made for the length of the weight. The use of tapes subject to an allowance of any kind is not recommended, and, whenever practicable, tapes should be standardized so that no allowance is necessary for the length of the weight.

When measuring light oils, as for example gasoline, the weight should be lowered carefully through the surface without causing splashes and ripples. Lowering of the weight by means of the tape should preferably be stopped a short distance from the tank bottom, so as to allow time for any slight disturbance of the liquid to subside before the weight is allowed gently to touch the bottom of the tank. Immediately the weight has touched the bottom, the tape should be withdrawn and the reading taken. A clear reading will usually be obtained if the tape is first wiped with a dry or slightly oily rag, but in cases of difficulty when measuring extremely volatile oils, ullage paste may be smeared on the tape in the vicinity of the expected reading before taking a measurement. Chalk or any other porous material should never be used to facilitate reading.

When measuring viscous oils, difficulties due to surge are less pronounced, but it is important that the weight should be allowed to rest lightly touching the tank bottom for a few seconds until the oil has risen to the correct level on the tape. If the tape is withdrawn too soon after touching the tank bottom, time may not be allowed for the normal meniscus to form around the tape, and low readings may be obtained.

The following precautions should be taken :—

(*a*) Dip hatches or other openings used for dipping should be provided with a dipping reference point situated so that the dip weight touches a flat portion of the tank bottom, well clear of seams and rivet heads, and so that the dip weight does not foul heating coils or other obstructions within the container.

(*b*) The gauge tape should be kept near to the dipping reference point each time a dip is taken.

(*c*) The approximate height of the dipping reference point above the tank bottom should preferably be clearly marked near the dip hatch.

(*d*) When a container is provided with more than one dip hatch a number, or other means of identification, should be clearly marked near each hatch.

(*e*) A flat bottomed dip weight should not be used when measuring highly viscous oils, nor when there are appreciable quantities of rust and sediment on the tank bottom. Under these circumstances the heavy type of standard dip weight (see Appendix (ii) *a*) should be employed.

(ii) *By Ullage or Outage.*

A gauge tape and ullage rule, the latter in accordance with Appendix (iii) should be employed. An ullage reference point should be clearly and permanently marked on the gauge hatch, or on an attachment rigidly located above or below the hatch or hatches to be used for ullaging. In use, the ullage rule should be attached to the end of the gauge tape, and should be lowered carefully through the ullage hatch by means of the tape, until the rule nears the oil surface. The rule is then lowered slowly, so as to avoid causing splashes or ripples, until the bottom of the rule enters the surface of the oil. After allowing time for the cessation of any slight disturbance on the surface, the rule is lowered further into the oil until a convenient reading on the tape is precisely in line with the ullage reference point. The rule is then removed, and the length of rule which has not been wetted with oil is read off. The sum of the reading on the tape opposite to the reference point, and the reading on the ullage rule, is the ullage or distance between the reference point and the oil surface.

ALTERNATIVE METHOD.

When an ullage rule is not available, ullages may be measured by using a gauge tape in conjunction with any attachment of suitable weight. The procedure is similar to that described above, but the weight is lowered through the surface of the liquid until a reading can be obtained on the gauge tape. The tape is then withdrawn, and the difference between the length of tape which has been wetted with oil and the tape graduation which was opposite to the ullage reference point is the ullage. The method is not recommended, and should not be used when an ullage rule is available. In practice it is usually found that the addition of two measurements is more convenient and less liable to error than is a subtraction made on the tank top. Accurate results may be obtained, however, by either method.

The following precautions should be taken :—

(*a*) As far as practicable, precautions should be taken to ensure that the height of the ullage reference point above the tank bottom remains constant. If the gauge hatch is liable to movement owing to flexibility of the roof plates to which it is attached, the ullage reference point should preferably be marked on a rigid attachment securely fixed to the vertical shell of the tank.

(*b*) The height of the ullage reference point above the tank bottom should be clearly marked near the ullage hatch, and should be periodically verified.

(*c*) When a container is provided with more than one ullage hatch, a number or other means of identification should be clearly marked near each hatch.

(iii) *By Gauge-Glass.*

A gauge-glass constructed and installed in accordance with Appendix (iv) may be used to measure depths of light oils, but gauge glasses are not recommended for measuring opaque, viscous, or heated materials.

In use, the gauge glass at the oil level is first drained, and is then flushed through before the oil depth is measured. The glass is flushed by opening the cocks or valves at its upper and lower ends so as to allow oil from the tank to flow freely into it. The bottom cock is then closed to the tank, and the glass is emptied by opening the appropriate connection.

The glass is to be flushed through and drained not less than three times. The number of flushings and the time the oil remains in the glass before emptying must be such that when the oil depth is read the oil in the glass is substantially the same in temperature and density as that in the tank at the level of entry into the glass. If there is any doubt on this point, flushing, draining, and measurement of the oil depth must be repeated until substantial constancy in the measured depth is obtained.

As soon as flushing is completed, the gauge glass is again filled with oil from the tank, and as soon as any surging has stopped, the oil depth is read at once, with the connections at both ends of the gauge open to the tank.

The oil depth must be the height corresponding to the bottom of the oil meniscus in the glass as read on the associated graduated scale by applying a level straight edged ruler or set square to the scale and the bottom of the meniscus in the usual way.

The following precautions should be taken :—

(*a*) Gauge glass scales should be strongly and accurately constructed, and should be securely fitted closely alongside the gauge glasses. They should preferably be provided with seals preventing unauthorized movement of the scale relative to the tank.

(*b*) Readings should not be taken when the sun is shining directly on the glass. Glasses should be shielded from sunlight, and should preferably be situated on the side of the tank least exposed to the sun.

(*c*) The gauge glasses and their accessories should be carefully maintained and kept in clean and sound condition.

6. (*b*) Measurement in Barge and Ships' Tanks (Conventional Type).

(i) *Barge-Tanks by Dip.*

The procedure for dipping barge tanks is substantially the same as that described under 6 (*a*) (i) above, but it is recommended that the following additional precautions should be taken :—

(*a*) Before commencing dipping, the correct positions from which measurements should be taken should be ascertained by reference to the barge personnel, or by consulting the barge calibration tables, if available. When large manholes are used for dipping purposes, it is recommended that they should be marked with fixed dipping points, in order that measurements shall always be taken from the same reference point. When such marks are not provided, the gauger should preferably note the positions used for dipping when recording the measurements obtained.

(*b*) Precautions should be taken to ensure that the dip-weight does not foul any obstruction which might prevent the weight reaching the tank bottom. In cases of doubt this can frequently be checked by observing the tape reading corresponding to the top of the gauge hatch, and comparing this measurement with careful measurements similarly taken in other compartments of the barge.

(*c*) At least two measurements should preferably be taken at each dip hatch, and the surface of the liquid should be carefully observed, so as to detect any noticeable swirl or movement of the liquid surface. Should the barge be rolling or pitching, then such number of dips should be taken as may be necessary to ensure that a reasonably correct average measurement is obtained. Any unusual difficulty in obtaining agreement in check dips, as for example during rough weather, should preferably be recorded at the time of taking measurements.

(*d*) If the barge to be dipped is aground, precautions should be taken to avoid errors due to any noticeable list or trim. The list and trim may be measured and due allowance made; alternatively, a dipping pipe of satisfactorily perforated design may be used to ensure that dips are taken in a direction perpendicular to the normal plane of flotation of the barge.

(*e*) Before dipping barges which are aground and noticeably listed, the oil level in the tanks should be inspected, and official dips should not be taken if the oil has risen past the calibrated height of any tank, so as to touch the roof plates.

(ii) *Barge Tanks by Ullage.*

The general procedure for ullaging barge tanks is substantially the same as that described in Section 6 (*a*) (ii), but, where relevant, the additional precautions given above in 6 (*b*) (i) and given below in 6 (*b*) (iii) should be taken.

(iii) *Ships' Tanks by Ullage.*

The general procedure for ullaging ships' tanks with gauge tape and ullage rule is substantially the same as that described in section 6 (*a*) (ii), but the following additional precautions should be taken :—

(*a*) Before commencing ullaging, the correct positions from which ullages should be taken should be ascertained by reference to the ship's personnel or to the vessel's calibration tables. In some vessels ullages are taken from sighting ports situated in the tank lids, whilst other vessels are equipped with separate ullage plug-holes, and it is important that measurements should be taken from the correct point above the liquid surface. In all cases when reporting ullages the record should indicate the positions from which the ullage has been taken, and whether the tanks are numbered from forward or from aft.

(*b*) Care should be taken to ensure that ullages are measured from the correct ullage reference point, and that, for example, ullage plug-washers or similar accessories are not included in the reading. When ullages are taken from sighting ports situated in the tank covers, it may be necessary to ensure that the packing between the tank lid and the tank coamings has not been compressed or expanded, so as substantially to alter the distance between the ullage reference point and the tank-bottom. This can frequently be checked by means of a second reference point fitted inside the hatch coamings, or alternatively, by comparing the over-all height of the tank with that shown on the calibration tables.

(*c*) When taking ullages, the surface of the liquid should be carefully observed, so that any swirl or movement of the liquid surface may be detected. If the vessel is moving as a result of rough weather, for example, or if for any other reason there should be appreciable movement of the liquid in the tanks, then several ullages should be taken, in order to ensure that a reasonably correct measurement is obtained. Any unusual difficulty in obtaining agreement in check ullages should preferably be recorded at the time of taking the measurements.

(*d*) Whenever practicable, the draft of the vessel, both forward and aft, should be noted at the time of ullaging, as also any appreciable inclination to port or starboard.

(*e*) When ullages are used for calculating official quantities, any necessary allowance for the effect of trim should be made when possible by applying trim corrections to the measurements taken.

Ullage Sticks.

When the oil level is within a few feet of the ullage reference point, ullages are frequently taken by means of "ullage sticks". These usually comprise a graduated wooden stick fitted with a cross piece, the graduations reading downwards from a zero level with the bottom edge of the cross piece. In use, the stick is passed through the ullage hatch and is allowed to hang vertically into the oil by means of the cross-piece. The stick is then removed, and the length of stick which has not been wetted with oil is read directly on the graduated scale.

Although good results may be obtained with an accurate and carefully used ullage stick, the method is not recommended, and preferably should not be used when a gauge tape and ullage rule are available. If used, the stick should be treated to prevent "creep", and the graduations should be carefully checked before use. Care should also be taken to ensure that the stick is used without causing ripples on the oil surface and hangs freely in a vertical position.

6. (*c*) Measurement in Horizontal Cylindrical Tanks (Conventional Type).

(i) *By Dip.*

Horizontal cylindrical tanks may be dipped by means of a gauge tape and weight, the procedure being substantially the same as that described in Section 6 (*a*) (i). Alternatively, a dip rod may be used for tanks of small diameters; these dip rods are usually made of non spark generating metal, and may be graduated to give direct readings in gallons, etc., or, when used in conjunction with tank capacity tables, are graduated in feet, inches, and fractions of an inch.

It is recommended that the following additional precautions should be taken when dipping horizontal cylindrical tanks :—

(*a*) The gauge hatch should be situated vertically above the longitudinal centre line of the tank.

(*b*) When tanks are divided into two or more compartments, compartment numbers or other means of identification should be clearly marked on or near the appropriate gauge hatches.

(*c*) When dip rods are used, they should be carefully lowered into the oil, so as to disturb the oil surface as little as possible. Precautions should also be taken to ensure that the rod is allowed to hang vertically when a dip is taken.

(*d*) The slope of the tank when calibrated should be recorded, and should be checked periodically by appropriate means. When tanks are divided into more than one compartment, precautions should particularly be taken to avoid errors due to change in slope resulting from uneven loading of tank foundations.

(*e*) The internal bulkhead or bulkheads of multi-compartment tanks should be sufficiently rigid to prevent deformation when adjacent compartments contain oil at different levels.

(ii) *By Ullage.*

The procedure for ullaging horizontal cylindrical tanks is substantially the same as that described under 6 (*a*) (ii), but the additional precautions given above in Section 6 (*c*) (i) should be taken.

(iii) *By Gauge Glass.*

Gauge glasses installed in accordance with Appendix (iv) may be used for measuring oil depths in horizontal cylindrical tanks, the procedure being substantially the same as that described in Section 6 (*a*) (iii), but it is recommended that additional precautions (*b*) and (*d*) of Section 6 (*c*) (i) should be taken.

Horizontal cylindrical tanks for storing volatile products should preferably be sited north to south, the gauge glasses being installed at the northern ends of the tanks.

6. (*d*) Measurement of Water (Conventional Type Container).

(i) *By Water Finding Rule or Sounding Rod, and Paste or Paper.*

The water finding rule (Appendix (iii)), which may be part of the ullage rule, is thinly coated with water finding paste on one or more vertical sides, and is lowered into the container until it lightly touches the bottom. The rule should be allowed to remain touching the bottom for the period of time necessary to obtain a clear water reading. The rule should be maintained in a vertical position, and must not be allowed to lean or sag whilst remaining at the bottom of the container. If a clear reading is not obtained during the first immersion of the rule, any paste affected by water should be removed from the rule, and a fresh coating should be applied before again lowering the rule into the container.

If the depth of water to be measured is greater than the graduated height of the water finding rule or sounding rod, paste may be thinly applied to the gauge tape. The gauge tape is then used in conjunction with a dip weight or rule of such length that there should be at least two inches of graduated tape between the water reading on the tape and the highest point of the dip weight or rule. The tape must not be allowed to sag whilst the dip weight or rule is allowed to remain touching the bottom of the container.

The procedure for using water finding paper is similar to that described above, with the exception that instead of coating the rule or tape with paste, a strip (or strips) of water finding paper is securely attached to the instrument employed. Precautions must be taken to ensure that the position of the water finding paper on the instrument does not change during the measuring operations. Paste is more convenient than paper in use, but if difficulty in obtaining a correct reading is experienced when using paste in heavy oils, particularly heated heavy oils, it is recommended that paper should be employed.

The following precautions should be taken :—

(*a*) When measuring the water depth, the gauge tape should be kept near to the dipping reference point used when taking the corresponding oil dip.

(*b*) When measuring water depths in black oils it may be necessary to wash the oil from the surface of the water finding agent (paste or paper) with a solvent before the reading can be observed. Gasoline or some other solvent which will not affect the water finding agent should be used for this purpose, and must be employed in such manner that the water reading is not altered.

(ii) *By Gauge Glass.*

A gauge glass installed in accordance with Appendix (iv) may be used for the measurement of water depths provided that :—

(i) The water level is between the upper and lower ends of the glass.

(ii) The oil level is higher than the top of the upper connection between the container and the gauge glass.

To measure the depth of water, the gauge glass is first drained, and is then flushed through before the water depth is measured. The glass is flushed by opening the cocks or valves at its upper and lower ends, so as to allow liquid (water and/or oil) from the container to fill the glass, after which the glass is emptied by opening the appropriate connection. Alternatively, water or oil may be allowed to flow steadily through the gauge glass. The number of flushings and the way in which they are performed may vary according to the construction of the gauge, but flushing should be performed so that when the water depth is read all air or vapour has been removed from the gauge glass and its accessories, and so that the oil and water in the glass are substantially the same in temperature and density as the oil and water in the tank at the level of entry into the glass. If there is any doubt on this point, flushing, draining, and measurement of the water depth must be repeated until substantial constancy in the measured depth is obtained.

As soon as flushing is completed, the gauge glass is again filled with oil and water from the tank, and as soon as any surging has stopped, the water depth is read at once, with the connections at both ends of the gauge open to the tank. When the construction of the gauge glass so permits, two readings should preferably be taken by manipulating the connections to the tank, so that the water level in the glass before placing both ends of the glass in direct communication in the tank are respectively above and below the true water level in the container.

The water depth must be the height corresponding to the surface of separation between the oil and water in the glass, as read on the associated graduated scale by applying a level straight edged ruler or set square to the scale, and to the surface of separation in the usual way.

When gauge glasses are used to measure water depths, the corresponding oil depth should preferably also be measured by gauge glass, and when practicable the same continuous graduated scale should be used for reading both oil and water depth. The precautions given in Section 6 (*a*) (iii) should also be observed.

(iii) *The Estimation of Sludge in Heavy Oils.*

The problem of measuring oil depths in tanks containing heavy oil and sludge has not yet been completely solved, and it may be impossible to obtain accurate readings when using method (i) or (ii) above. It may not only be difficult to obtain a true reading of the depth of sludge at the gauge hatch or gauge hatches, but the level of sludge or emulsion may vary in different parts of the tank, thus making it almost impossible to obtain a true average depth. Furthermore, the main body of the oil may contain water in suspension, which in turn may not be evenly dispersed throughout the oil.

The methods to be adopted in cases of difficulty will depend on the purpose for which measurements are required, and can best be judged in accordance with the experience of the gauger. The following notes will indicate some of the methods which may be employed.

An estimate of the water in suspension can usually be formed by drawing a series of samples and submitting them to laboratory examination for water content; for example, samples may be drawn at every foot of oil depth from the centre dip hole and from one of the side dip hatches. The number of samples to be drawn can best be judged according to the circumstances and the accuracy required.

An approximate measurement of the depth of sludge or emulsion may sometimes be made by applying water finding paper to all the vertical sides of several water finding instruments. Water finders are then lowered to the bottom of the tank through each gauge hatch, and are secured so that they remain vertical. The instruments are allowed to remain undisturbed at the bottom of the tank, and are then removed for examination. The period of time required to obtain a satisfactory reading may vary according to the circumstances, and is best determined by experiment. Although accurate results cannot always be obtained in this manner, it is frequently possible to estimate depths of free water and sludge by careful inspection of the papers at the end of the immersion period.

In more difficult cases, a sample " thief " of uniform cross-section and with transparent sides may be found useful. The " thief " is fitted with a bottom closure device which can be operated from the tank top. In use, the apparatus is lowered to the tank bottom, and is allowed to remain there with the upper and lower ends open to the tank contents for at least 30 minutes. The bottom is then closed by means of a cord operated from the tank top, and the apparatus is removed from the tank. With comparatively fluid oils, the water level may sometimes be read by inspection, but should this not be possible, the whole contents of the " thief " are run into a sample can, and the percentage by volume of water and sediment is determined by laboratory analysis. The corresponding depth of water and sediment in the tank is then calculated by applying the laboratory result to the effective height of the apparatus.

It should be noted that if the tank is fitted with a bottom gauge glass for water measurement, and if free water is present at the lower connection between the tank and the glass, it is sometimes possible to obtain a clear line of separation between water and oil in the gauge-glass, even though there may be a layer of emulsion inside the tank. This gauge-glass reading may closely represent the true level of separation between oil and water at the part of the tank where the gauge-glass is situated, but nevertheless, if the level of the sludge layer varies in different parts of the tank, the gauge glass reading obtained in this way may not represent the true average height of the sludge. Gauge glass readings when obtainable should therefore be checked by the use of a "thief" or some other method, from as many dip hatches in other portions of the tank as may be available. Gross dips should also be taken at these points, in order to estimate the average nett depth of oil.

When circumstances permit, errors in estimating the amount of sludge and water in suspension in a large diameter tank may be considerably reduced by deferring measurement until the upper layers of comparatively dry oil have been removed by normal deliveries, or the like, using a swing arm or high suction in order to avoid draining sludge from the tank bottom. If necessary, the amount of water in the oil so delivered may be checked by the analysis of suitable line samples drawn during delivery. When the tank contents have been reduced as far as possible, the remaining oil and sludge may then be transferred to a tank of smaller diameter, fitted with heating coils. The mixture of oil and sludge is heated if necessary to accelerate settling, and after allowing as long as possible for the water and sediment to settle to the bottom, careful sampling and measurement as described above should then give a closer estimate of the quantity of sludge to be obtained than would be possible in the larger diameter tank. Similarly, if the oil has subsequently to be blended with less viscous oils in the course of normal operations, greater accuracy may be obtained by deferring the measurement of sludge and water until the specific gravity and viscosity of the oil have been reduced by such blending.

6. (*e*) Measurement in Containers with Floating Roofs.

In tanks of this type the roof rests on the surface of the oil, with a seal between the roof and the shell of the tank. The floating roofs used at present are usually of the Pontoon, Pan, or similar type, so named because of their construction. When the roof descends to a certain distance above the bottom of the tank it comes to rest on supports.

(i) *By Dip.*

Measurements should be taken through the gauge-hatch or gauge hatches located on the roof top substantially in the manner described in 6 (*a*) (i). It is recommended that the following additional precautions should be taken :—

(*a*) Presence of water, snow, or other foreign material on a roof which is floating will change its displacement, and should preferably be removed prior to gauging. If it is impossible to remove foreign materials from the roof, then their total weight should be estimated as closely as possible. For roofs not provided with automatic water-drains the depth of water resulting from rainfall may be estimated by the use of a suitably installed rain gauge.

(*b*) When measuring official dips before and after an oil movement, the number of persons present on the roof, when floating, should preferably be the same.

(*c*) The oil depth when the roof is resting on its supports just clear of the oil surface, and the depth (according to the oil density) at which the roof is just fully floating should be determined for all grades of oil.

(*d*) When accurate measurements of volume are required, dips should not be taken when the floating roof is partly floating and partly resting on its supports. If this condition cannot be avoided, it is recommended that before official measurements of oil depths are taken, water should be pumped into the tank, or any existing water bottom should be reduced, until the roof is either fully floating or is resting on its supports completely clear of the oil.

(*e*) Petroleum vapours may accumulate above floating roofs, particularly when the oil level in the tank is low, and adequate safety precautions should therefore be taken when gauging. It is recommended that at least one other person should be stationed at the top of the tank shell whilst gauging is in progress on the roof.

(ii) *By Ullage.*

When it would normally be dangerous to descend on to the roof, as for example in hot climates, or when the gases evolved by the product contain hydrogen sulphide, tanks may be provided with one or more rigid arms bearing reference points to permit measurement by ullage from the top of the tank. The procedure is substantially the same as that described in Section 6 (*a*) (ii), the gauge-hatch covers being operated by cords or similar means.

6. (*f*) Measurements in Vapour Tight Shore Tanks.

(i) *By Vapour Tight Dip Hatch Assembly.*

The gauge tape and weight are enclosed in a vapour tight " look box," which is fastened on to the top of the tank. A gate valve is installed between the " look box " and the tank, so that when the valve is shut the apparatus may be opened without loss of vapour from the tank, the precise design of the " look box " varying according to the manufacturer. The apparatus used should be carefully inspected and maintained, and should possess an adequate margin of strength having regard to the maximum pressure which may be encountered in service.

To measure the oil depth the vapour tight " look box " is attached to the tank top, and after ensuring that the apparatus is securely closed, the separating valve is cautiously opened. The dip weight, ullage rule, or water finder is then lowered into the tank by operating the gauge tape by means of an external handle or wheel.

The procedure for measuring the dip, ullage, or depth of water is substantially the same as that described in Sections 6 (*a*) (i), 6 (*a*) (ii), and 6 (*d*) (i), the readings on the tape, ullage rule, or water finder being observed through the vapour tight window in the "look box". Ullage paste should always be used to facilitate reading the oil level.

(ii) *By Dip Pipe and Tank Pressure Manometer.*

Volatile petroleum products are sometimes stored in closed vapour tight tanks of the type in which a gauging pipe is attached to the roof and is free to move up and down in accordance with roof flexure. Since the oil in the gauging pipe is open to the atmosphere, but the vapour space inside the tank is closed, the oil depth in the gauging pipe will be higher or lower than that in the tank when the pressure in the vapour space is higher or lower than that of the atmosphere. A manometer, usually filled with kerosine, is therefore mounted on the roof and connected with the vapour space.

To measure the oil depth, the tank is dipped through the gauging pipe, using a gauge tape and dip weight as described in Section 6 (*a*) (i), and the pressure or degree of vacuum indicated by the manometer at the time of dipping is recorded with the observed oil depth. The manometer reading in inches of liquid is corrected for the difference in density between the liquid in the manometer and the oil in the dip pipe, and the corrected manometer reading is then subtracted from the observed dip if the tank is under pressure, and added to the observed dip if the tank is under vacuum.

In practice, difficulty may be experienced due to oil surging in the dip pipe, and errors may arise if the density of the oil in the dip pipe differs from that of the oil in the tank. The method is therefore not recommended for taking official measurements.

The following precautions should be taken :—

(*a*) The internal diameter of the dip pipe should be as large, and the cross sectional area and volume of the dip weight should be as small as practicable.

(*b*) The level of any water at the bottom of the tank must be below the bottom end of the dip pipe.

(*c*) The dip pipe cover should be provided with a small vent, and this should be kept clear in order to avoid surging in the pipe when the cover is removed.

(*d*) It is recommended that before dipping, a careful ullage should be measured from the top of the dip pipe, and that when dipping, the distance between this ullage reference point and the bottom of the tank should also be noted. (This distance may vary according to the pressure on the roof.)

The oil depth obtained by dipping should be in close agreement with the difference between the ullage and the distance to the tank bottom, both measured from the top of the dip pipe. Failing such close agreement, time should be allowed for any surging to cease, and measurement should be recommenced, or, alternatively, another dipping method should be employed.

(*e*) It is recommended that the gauger should record in his note-book both the gross dip and the observed manometer reading, in order that any error in applying the corrections may be verified later, if necessary.

(*f*) When accurate measurements are required for official purposes, the tank should be opened to the atmosphere by suitable safe means, and the oil depth should be measured in the normal manner through one or more dip hatches open to the atmosphere, and not fitted with dip pipes. When circumstances permit, loss of vapour when opening the tank for measurement purposes may be reduced by deferring measurement until the manometer reading is small. This can frequently be achieved by arranging to measure in the evening or early morning.

(iii) *By Gauge Glass.*

The procedure described in Sub-section 6 (*a*) (iii) should be employed.

6. (*g*) Measurement in Pressure Type Shore Tanks (Spheroids, Spheres, Hemispherically Ended Cylindrical Tanks, etc.).

(i) *Spheroidal Pressure Type Tanks.*

Both noded and plain type spheroidal tanks deform slightly in shape during loading and unloading, as a result of changes in pressure and weight of the liquid. Although this slight deformation does not affect materially the actual volume of the contents of the tank (due to the rigid bracing of the walls of the tank), gauge glass scales, when used, should be constructed to allow for adjustment when needed or when calibrating the tank.

Spheroidal tanks may be measured by means of suitably installed gauge glasses, the method of use being substantially the same as that described in Section 6 (*a*) (iii).

Alternatively, a vapour tight gauge hatch assembly may be employed. The assembly should be installed directly above a datum plate, and preferably near the centre of the tank. The datum plate should be a horizontal metal plate rigidly supported from the bottom of the tank at zero capacity level, or at some known distance below zero capacity level. In use, measurements are taken substantially as described in Section 6 (*f*) (i), dips being measured from the datum plate.

If the gauging device does not contain a compensating reference point, the height of the reference point above the datum plate must be determined each time the ullage method is used. When ullages are taken for official purposes, it is recommended that the gauging height should be checked whenever practicable.

(ii) *Spherical Pressure Type Tanks.*

Spherical tanks are usually so rigidly constructed that no sagging or distortion of the shell occurs. When such tanks are in use, changes in pressures due to changes in hydrostatic head are usually relatively small compared with the vapour pressure of the liquid stored in them, and therefore the chief problems in their gauging result more from the nature of the contents than from any deformation of the tank.

Due to the high working pressures in spherical tanks and the highly volatile nature of the products stored in them, measurement by vapour tight gauge hatches is not recommended. Suitably installed gauge glasses should be used for official measurements, the procedure being substantially the same as that described in Section 6 (*a*) (iii).

6. (*h*) Measurement by Means of Hydrostatic Gauge.

Hydrostatic gauges are usually of the manometer or dial reading types. In principle, the gauges are installed so as to indicate the hydrostatic pressure resulting from the head of oil in the tank to which they are connected. Sometimes the hydrostatic gauge is installed at a distance from the tank being measured, and the tank pressure is conducted to the instrument by means of compressed air; the fundamental principle, however, remains the same.

Application.

(i) *Measurement in Ship's Oil Fuel Bunker Tanks.*

Hydrostatic gauges are frequently used to measure the weight of oil contained in ships' double-bottomed bunker tanks and other compartments not readily accessible for measurement by dipping or ullaging. Such gauges are frequently calibrated in tons of oil.

It should be noted that just as measurements by dipping can only give the height of the oil column in the tank in feet or similar units, hydrostatic gauges can only indicate the pressure of the oil column in the tank above the datum level of the instrument in pounds per square inch or similar units. Gauge scales in tons are calibrated from the dimensions or calibration tables of the tank, and are dependent on the accuracy of these tables. Unless the datum point of the gauge is centrally placed in the tank, substantial errors may arise when the ship is trimmed or listed. Furthermore, unless the tanks are uniform in horizontal cross section, errors may arise when the density of the oil differs from that for which the scale has been calculated.

Apart from the fundamental errors indicated above, hydrostatic gauge readings may be subject to various small errors for which it is not usual to apply corrections when measuring ships' oil fuel bunker tanks. Hydrostatic gauges of the type usually used for this purpose are convenient in use, but it is recommended that their readings, whether in tons or other units, should not be accepted as official measurements for quantitative purposes.

(ii) *Measurement in Shore Tanks.*

Hydrostatic gauges are sometimes used to measure weights of oil in shore tanks. Such gauges may be equipped with various devices to increase the accuracy of measurement and reading, and when carefully constructed, well calibrated, and maintained in good condition, satisfactory results may be obtained when measuring vertical tanks of substantially uniform cross sectional area.

Choice of method as between the direct measurement of oil depths and the use of a hydrostatic gauge must obviously be decided according to circumstances, but if hydrostatic gauges are used the following precautions should be observed :—

(*a*) The gauge and its connections should be carefully installed in accordance with the maker's instructions, and should be sheltered from the effects of weather, frost, etc.

(*b*) The connections between the tank and the gauge should be as short as possible.

(*c*) All practicable corrections should be applied to ensure that the gauge reading represents as accurately as possible the pressure of the liquid column being measured.

(*d*) When gauges are calibrated to indicate oil depths, or the total volume or weight of tank contents, the density on which the scale has been based should be marked on the instrument.

(*e*) If the pressure in the vapour space above the oil differs from that of the atmosphere, suitable compensating pipes should be fitted, or corrections should be made by other means.

(*f*) The level of water, if any, in the tank should be measured independently, and due allowance should be made.

(*g*) When measurements are made before and after a movement of oil, due allowance should be made for any movement of tank bottom plates and for any change in the weight of oil below the datum line of the instrument resulting from change in density or other causes.

(*h*) When the area of the horizontal cross section of the tank is not uniform throughout the depth of oil measured, hydrostatic gauges should preferably not be used for official measurements, except when normal dipping or ullaging methods cannot be employed. If used, due allowance should be made for the density of the oil being measured.

6. (i) Measurement in Rail and Road Tanks.

General.

As far as possible, measurements should be made in suitable weather conditions, and in the case of insulating oil, in particular, care should be taken to prevent ingress of moisture.

Before taking a measurement, precautions should be taken to ensure that the tank is standing on a level section of road or line, and that the liquid in the tank is quiescent and the surface free from foam.

(i) *By Dip.*

Measurement by the dip or innage method is generally made by means of a dip rod, and is usually employed only for road tanks.

In making a measurement, the dip rod, which may previously have been calibrated for the tank being dipped, is lowered slowly into the tank through the dip pipe or manhole. The rod is next withdrawn, and the depth or volume indicated at the highest point on the rod reached by the liquid is read as accurately as is practicable.

When making measurements by means of a gauge tape, the tape is therefore the chief problems in their gauging result more from the nature of the contents than from any deformation of the tank.

Due to the high working pressures in spherical tanks and the highly volatile nature of the products stored in them, measurement by vapour tight gauge hatches is not recommended. Suitably installed gauge glasses should be used for official measurements, the procedure being substantially the same as that described in Section 6 (*a*) (iii).

6. (*h*) Measurement by Means of Hydrostatic Gauge.

Hydrostatic gauges are usually of the manometer or dial reading types. In principle, the gauges are installed so as to indicate the hydrostatic pressure resulting from the head of oil in the tank to which they are connected. Sometimes the hydrostatic gauge is installed at a distance from the tank being measured, and the tank pressure is conducted to the instrument by means of compressed air; the fundamental principle, however, remains the same.

Application.

(i) *Measurement in Ship's Oil Fuel Bunker Tanks.*

Hydrostatic gauges are frequently used to measure the weight of oil contained in ships' double-bottomed bunker tanks and other compartments not readily accessible for measurement by dipping or ullaging. Such gauges are frequently calibrated in tons of oil.

It should be noted that just as measurements by dipping can only give the height of the oil column in the tank in feet or similar units, hydrostatic gauges can only indicate the pressure of the oil column in the tank above the datum level of the instrument in pounds per square inch or similar units. Gauge scales in tons are calibrated from the dimensions or calibration tables of the tank, and are dependent on the accuracy of these tables. Unless the datum point of the gauge is centrally placed in the tank, substantial errors may arise when the ship is trimmed or listed. Furthermore, unless the tanks are uniform in horizontal cross section, errors may arise when the density of the oil differs from that for which the scale has been calculated.

Apart from the fundamental errors indicated above, hydrostatic gauge readings may be subject to various small errors for which it is not usual to apply corrections when measuring ships' oil fuel bunker tanks. Hydrostatic gauges of the type usually used for this purpose are convenient in use, but it is recommended that their readings, whether in tons or other units, should not be accepted as official measurements for quantitative purposes.

(ii) *Measurement in Shore Tanks.*

Hydrostatic gauges are sometimes used to measure weights of oil in shore tanks. Such gauges may be equipped with various devices to increase the accuracy of measurement and reading, and when carefully constructed, well calibrated, and maintained in good condition, satisfactory results may be obtained when measuring vertical tanks of substantially uniform cross sectional area.

Choice of method as between the direct measurement of oil depths and the use of a hydrostatic gauge must obviously be decided according to circumstances, but if hydrostatic gauges are used the following precautions should be observed :—

(a) The gauge and its connections should be carefully installed in accordance with the maker's instructions, and should be sheltered from the effects of weather, frost, etc.

(b) The connections between the tank and the gauge should be as short as possible.

(c) All practicable corrections should be applied to ensure that the gauge reading represents as accurately as possible the pressure of the liquid column being measured.

(d) When gauges are calibrated to indicate oil depths, or the total volume or weight of tank contents, the density on which the scale has been based should be marked on the instrument.

(e) If the pressure in the vapour space above the oil differs from that of the atmosphere, suitable compensating pipes should be fitted, or corrections should be made by other means.

(f) The level of water, if any, in the tank should be measured independently, and due allowance should be made.

(g) When measurements are made before and after a movement of oil, due allowance should be made for any movement of tank bottom plates and for any change in the weight of oil below the datum line of the instrument resulting from change in density or other causes.

(h) When the area of the horizontal cross section of the tank is not uniform throughout the depth of oil measured, hydrostatic gauges should preferably not be used for official measurements, except when normal dipping or ullaging methods cannot be employed. If used, due allowance should be made for the density of the oil being measured.

6. (i) Measurement in Rail and Road Tanks.

General.

As far as possible, measurements should be made in suitable weather conditions, and in the case of insulating oil, in particular, care should be taken to prevent ingress of moisture.

Before taking a measurement, precautions should be taken to ensure that the tank is standing on a level section of road or line, and that the liquid in the tank is quiescent and the surface free from foam.

(i) *By Dip.*

Measurement by the dip or innage method is generally made by means of a dip rod, and is usually employed only for road tanks.

In making a measurement, the dip rod, which may previously have been calibrated for the tank being dipped, is lowered slowly into the tank through the dip pipe or manhole. The rod is next withdrawn, and the depth or volume indicated at the highest point on the rod reached by the liquid is read as accurately as is practicable.

When making measurements by means of a gauge tape, the tape is lowered slowly into the tank through the manhole until the dip weight just touches the bottom of the tank, the tape is withdrawn, and the depth indicated at the highest point on the tape reached by the liquid is read as accurately as is practicable.

With both dip rod and gauge tape, at least two determinations must be made, and providing these are in satisfactory agreement, the mean value is recorded.

When measuring a tank containing gasoline, a little ullage paste spread on the dip rod or tape at an appropriate level assists in detecting the level reached by the gasoline.

The precautions given in Sections 6 (*a*) (i) and 6 (*c*) (i) should be observed where relevant, and it is further recommended that the following precautions should be taken :—

(*a*) Any free water should be removed from the road or rail car before measurements are taken.

(*b*) The temperature of the oil should be determined and recorded when the measurement is taken.

(*c*) When the capacities or volumes of delivery or other pipes have been included in the tank table or dip rod calibration scale, care should be taken to ensure that such pipes are full of oil when a measurement is taken.

(*d*) When dip rods are calibrated in units of volume, or for any other reason should only be used to measure a certain tank or tanks, precautions should be taken to ensure that the correct dip rod is employed. Both the rod and the tank or tanks should be clearly marked with some permanent means of identification, and particular care should be taken when removable tanks are moved from one vehicle to another.

(*e*) When removable tanks are moved from one vehicle to another, care must be taken to ensure that they are re-installed with the same slope, if any, as when calibrated.

(ii) *By Ullage.*

Road tanks are sometimes measured by means of ullage sticks. The sticks are provided with an ullage reference mark or with a cross piece near the upper end. In use, the stick is carefully lowered into the tank until the reference mark or the lower edge of the cross-piece is level with an ullage reference point on the tank gauge hatch, the stick is then removed, and the reading noted. Road vehicle ullage sticks are usually calibrated upwards from the bottom in units of length or in units of volume or capacity, the sticks extending almost to the bottom of the tank.

Rail car tanks are frequently fitted with a so-called " ullage plate " fixed at a suitable level inside the tank ; the volume corresponding to the level of the ullage plate is then usually stamped on the outside of the car. The true ullage may be measured by means of a gauge tape and ullage rule (Section 6 (*a*) (ii)) but a suitably shaped ullage stick (Section 6 (*b*) (iii)) is frequently employed. At least two determinations should be made, and provided these are in satisfactory agreement the mean value is recorded.

The precautions given above in Section 6 (*i*) (i) should be taken.

(iii) *By Weighbridge.*

When a weighbridge is available, the weight of material in a road or rail-tank car may be determined by weighing the vehicle before and after filling or emptying. The corresponding volume at standard temperature or at the temperature of measurement, according to requirements, is then calculated from the nett weight and the specific gravity at the required temperature.

The method is usually used for measuring asphaltic bitumen, electrical insulating and lubricating oils, or for other materials which cannot conveniently be dipped or ullaged. Weighbridges are frequently used for other materials, however, and it is recommended that, when practicable, dips or ullages should also be measured and recorded, in order to provide two different sets of measurement in case of dispute, and to control possibilities of loss through leakage, etc.

The following precautions should be taken :—

(*a*) Any free water should be removed from the road or rail car before measuring the tare or gross weight.

(*b*) The weighbridge should be checked at frequent intervals, and should be kept free from accumulations of water, dust, and other material which might affect its accuracy.

(*c*) When weighing road vehicles, no person should be in or on the vehicle, and the engine should not be running whilst weighing is in progress.

(*d*) When a high degree of accuracy is required, only a weighbridge, calibrated, if possible recently, by the local Weights and Measures Authority should be used, and precautions should be taken to eliminate errors due to rain, wind or other weather conditions.

7. Measurement of Volume by Means of Bulk Meters.

Introduction.

Meters of the positive-displacement type may be used for the measurement by volume of various petroleum products which are normally handled as liquids. Where refined or finished products are concerned, the use of these meters is mainly for measurement into drums, cans, or similar packages, or for measuring deliveries into or out of rail or road tank cars. Displacement meters also find uses in fields, refineries, and oil installations—for example, in the measurement of crude oil flowing through "gathering" lines, oil passing through long-distance pipelines, volumes delivered in blending operations, and deliveries to and from storage tanks.

The following notes are not intended to apply to flow meters of the orifice, Pitot tube, or similar types, and it is recommended that information regarding the characteristics of the various types of flow meters should be obtained when required by reference to manufacturers and to the various standard works dealing with these instruments.

Applicability.

Displacement meters may normally be obtained for measuring petroleum products ranging from gasoline to fuel and lubricating oils of low viscosity.

If it is desired to measure extremely volatile liquids, highly viscous oils, corrosive liquids, or materials at high temperatures, the meter manufacturer should be fully advised of the proposed working conditions, in order that a suitable type of apparatus may be installed.

Description of Meters.

Meters differ widely in construction and capacity, and they may be obtained in sizes suitable for use on pipes ranging from ½ inch to 6 inches in diameter.

Meters may be provided with horizontal counters or vertical dials calibrated to record the volume in suitable units—*e.g.*, Imperial gallons, etc., of material passed through the meter.

Meters may be obtained for measuring liquids under gravity flow or being pumped at various maximum working ranges up to 1000 lb. per square inch.

A strainer should be fitted on the inlet side of the meter as close as possible to the meter; the mesh size of the gauze in the strainer should be such as not unduly to restrict the flow of the material.

Unless conditions are such that no air can be entrained with the product being measured, an air eliminating device should be installed on the inlet side of the meter. When materials are pumped, it is further recommended that a suitable check valve be fitted on the discharge side of the eliminator, when the resulting slight additional back pressure assists in the removal of air.

Checking of Meters.

All meters should be periodically tested for accuracy, and any adjustment made to conform to any official regulations that may be in force.

Rate of flow on any meter will depend not only on the amount of head or pump pressure, but also on the viscosity of the liquid, length of pipe-line, installation, condition, etc. Similarly, the rated accuracy may not be obtained if the rate of flow through the meter is above or below the maximum limits specified by the makers. Before connecting a meter to the pipe-line, the manufacturers' instructions label or installation booklet should therefore be read for information regarding the installing of meters.

Measurement of Volume when Filling Barrels, Cans, etc.

The meter is usually capable of automatically measuring, recording, and discharging a pre-determined quantity into barrels, cans, etc. The number of barrels, etc., filled should be recorded on the counter assembly.

When it is desired that the volume delivered by the meter should be constant when corrected to a standard temperature, a "temperature compensator" should be fitted. This may be a device which is manually adjusted according to the readings of a thermometer inserted in the pipe-line close to the meter, and according to the nature of the material being measured. Temperature compensators are included in the design of certain types of meter, and are supplied as an essential part of the equipment.

Measurement of Volume when Filling Road and Rail Wagons.

Meters for this service usually have up to 3-inch inlet and outlet; to save weight, a combined air eliminator and strainer is used. A pre-setting counter and valve is fitted to enable a pre-determined quantity of liquid to be measured.

Measurement of Volume for Bulk Installations.

Large meters are used for this service, and a battery of meters connected in parallel is sometimes installed in order to permit the measurement of higher rates of liquid flow.

The maximum permissible rate of flow varies according to the size and type of meter and the service for which it is being used. As an example, it may be stated that the maximum permissible rate of flow for meters obtainable at the present time, and suitable for 6-inch diameter pipe-lines will normally be between 500 and 900 Imperial gallons per minute, according to the make of meter, whether the service is continuous or intermittent, and the nature of the material being measured.

8. Methods of Reporting and Averaging Measurements of Oil Depths.

(a) Shore Tanks.

When the oil depth in a container is measured from more than one gauge hatch, the gauger normally records in his notebook the measurements which he obtains, and any subsequent averaging for the purpose of computing volume is performed separately.

It is recommended that the measurements recorded by the gauger should be, as far as possible, the readings observed on the various instruments employed, and that, for example, when it is necessary to make allowance for the length of the dip weight, the tape readings should be recorded in the notebook, together with a separate note indicating the length to be added.

Although fractions or decimals of a division may be estimated for special purposes, measurements are usually recorded to the nearest graduation of the gauge tape or other instrument employed, apparatus being usually marked in $\frac{1}{8}$-inch, $\frac{1}{10}$-inch, $\frac{1}{16}$-inch, or millimetre graduations, according to requirements and local custom. In general, it is recommended that apparatus should be graduated in the smallest units in which measurements are normally to be recorded, to avoid the necessity for estimating parts of a graduation.

Averaging.

When dips are taken through more than one gauge hatch of a vertical tank, it is usual to calculate the quantity of oil in the tank by averaging the measurements so obtained, and applying the average to the tank calibration table. Various methods of averaging are commonly employed, including the following :—

(i) If the tank has two or more gauge hatches spaced equidistantly round a circle near the tank perimeter, the dips are added together and divided by the number of dips taken.

(ii) If the tank is provided with a centre gauge hatch in addition to two or more gauge hatches spaced equidistantly near the tank perimeter, the side dips are frequently averaged in accordance with (i) above; this average is then added to the centre dip, and the total is divided by two.

(iii) Certain tanks are provided with a centre dip hatch, four dip hatches spaced equidistantly near to the tank perimeter, and four intermediate dip hatches spaced equidistantly round a circle midway between the centre dip hatch and the perimeter. The average dip is calculated by averaging the four outside dips, and adding this average to the four intermediate dips and the centre dip, the total being divided by six.

Other methods may be devised according to circumstances and local custom.

When shore tanks are ullaged, similar methods may be used, but any directions which may be given on the appropriate tank calibration table should be carefully followed.

When tanks contain a water bottom, the water dip corresponding to each oil dip taken should be measured and the water dips should then be averaged by the same method employed for averaging the total heights. Tanks not provided with an accurate tank bottom calibration table should not be measured for official purposes when the bottom is only partly covered with water, but when this condition cannot be avoided, the average oil dip is frequently estimated by subtracting each water dip from the oil dip at which it occurs, and then averaging the nett oil dips so obtained in the normal way.

(b) Ships' Tanks.

Ships' cargo tanks are usually ullaged, and owing to the large number of compartments which may require measurement, the gauger is frequently accompanied by a second person, who records the measurements, the gauger verifying that each reading has been written down correctly before proceeding to the next compartment. Alternatively, the gauger may chalk each ullage near the ullage hatch from which it was taken, and may record the readings in his notebook when all measurements have been taken.

It is recommended that, when practicable, the two systems should be combined, in order that any discrepancies, or confusion between the ullages of port and starboard tanks, may be detected when the measurements first recorded are compared with the chalked readings on completing ullaging.

When check ullages are to be taken during the consecutive discharge of multi-grade cargoes, measurements chalked on the tank tops before commencing discharge will be found convenient, the arrival ullage being readily observed near each gauge-hatch as the check ullages are taken.

Certain ships are provided with tank tables showing the volume corresponding to each ¼ inch of ullage, and if ullages are recorded to the nearest ¼ inch, there is a considerable saving in time, and the risk of clerical error is greatly reduced when making the subsequent calculations. Although ullages may be recorded with greater precision, readings in ¼ inches are adequate for most practical purposes. Quantities based on ships' measurements are frequently required at loading ports for comparison with the official shore quantities immediately loading is completed, and it is therefore recommended that, when practicable, ships' officers should be provided with tank tables showing volumes or capacities corresponding to each ½ inch or ¼ inch of ullage.

Owing to the very limited accuracy of most ships' calibration tables, and to various other factors which may affect the measurements taken, the same degree of accuracy in measuring cargo quantities cannot be achieved as is possible in the case of shore tanks. Official documents of quantity should, therefore, be based on shore measurements whenever practicable.

Averaging.

When a ship's cargo tanks are provided with two ullage hatches, both measurements should be recorded, and care should be taken that average measurements, when required, are calculated in accordance with any directions which may be given in the appropriate tank calibration tables.

(c) Pipelines.

It is recommended that the length and diameter of all pipelines which may be involved in bulk oil measurements should be carefully measured when the lines are installed, and should be recorded on a suitable plan. Pipeline plans for oil-measurement purposes may be constructed so as to show the length and size of lines, or, alternatively, so as to show their volumes or capacities in suitable units. The position of stop valves should be clearly marked, and the plan should be amended as and when additions or modifications are made.

The condition of all relevant pipelines, whether full or empty, should be recorded in the gauger's notebook when tank measurements are taken, and should preferably be shown on official documents of quantity. When using such measurements for calculating purposes, due allowance should be made, when necessary, for changes in the temperature or specific gravity of the oil in each length of pipeline.

APPENDIX.

Oil Measurement Apparatus—Specifications.

"Measurement of Oil Depths" mentions the apparatus which should be used in the determination of liquid levels in oil containers. It was felt desirable to specify some of the more important and more frequently used pieces of equipment, but it should be emphasized that the specifications covered by this Appendix are intended as guides to the types which experience has proved to be satisfactory rather than as fixed standards. Comments and criticisms on these specifications will be welcomed. There can be no objection to the continued use of apparatus of different design where such equipment is known to be equally satisfactory in operation and will give results to the same degree of accuracy.

The Gauging Group of Sub-Committee XV of A.S.T.M. Committee D-2 is also giving its attention to the preparation of specifications for oil measuring apparatus.

(i) Dip Tapes.

1. *Material.* Carbon steel of approved quality.

2. *Construction.* Fitted with a swivel at the end of the tape which allows the dip weight or combined ullage rule and water finder to be attached.

(a) *For Use with Dip Weights of Standardized 6-inch Length.*

This tape is graduated so that it is complementary to the dip weight, zero being calculated from the bottom of the dip weight. A spring swivel (dog chain type) fitted to the tape so that the first foot mark on the tape will be 6 inches from the *inside* of the bottom end of the swivel.

(b) *For Use with the Combined Ullage Rule and Water Finder.*

This tape is also fitted with a spring swivel (dog chain type), but with zero at the *inside* of the end of the swivel.

***Note.* (i)—It is of importance, owing to the similarity of the two methods of construction described above, that the two types of dip tape should not be confused one with the other. The type (a) when measured to the inside end of the swivel is 6 inches shorter than type (b). Type (b) is normally reserved for use only with the ullage rule and water finder. Should the full-length tape type (b) be used for dipping with a 6-inch weight, then the length of the weight *must* be added to the readings taken.**

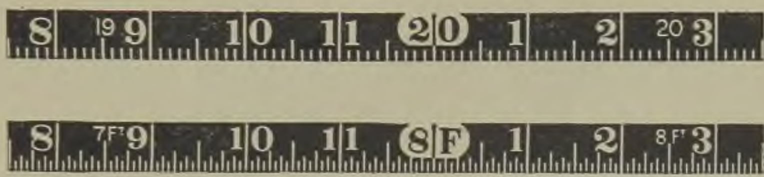
3. *Dimensions.*

Width. $\frac{1}{2}$ inch or $\frac{5}{8}$ inch, as required.
Thickness. Approx. 0·01 inch.

4. *Calibration.* At 20° C. This to be marked on the tape.

5. *Error.* At 20° C. and against a tension equivalent to 10 lb. in horizontal position when supported throughout the whole length, error not to exceed one-half the smallest scale division.

6. *Graduation* (*on one side*). Feet, inches, and tenths (alternatively sixteenths) throughout entire length. Figuring for each foot to be shown in small figures at 3-inch intervals, every whole foot marked with a figure on a bright tablet, background dead black. Figures to be deeply etched and well raised. *See* Figs. 1 and 1(*a*).



FIGS. 1 AND 1(*a*)
DIP TAPES.

7. *Overall Length.* As required.

8. *Emblem or Name.* As required.

Note. (ii)—If winding frame, case, or dip-weight is additionally required, this should be clearly stated.

(ii) DIP WEIGHTS.

For Light Oils:

1. *Material.* Brass or other non spark generating material, sufficiently hard to resist damage by coming into contact with steel.

2. *Shape.* *See* Fig. 2.

3. *Dimensions.*

Length. 6 inches to the *top* of hole where swivel connection with the dip tape is made.

Diameter. Centre section $1\frac{1}{8}$ inches, tapering to a diameter of $\frac{1}{2}$ inch, at the base.

Thickness of metal connection at top of weight to be not less than 0·20 inch or more than 0·25 inch.

4. *Weight.* About $1\frac{1}{2}$ lb.

5. *Graduations.* Nil.

For Heavy Oils.

1. *Material.* Brass or other nonspark generating material, sufficiently hard to resist damage by coming into contact with steel.

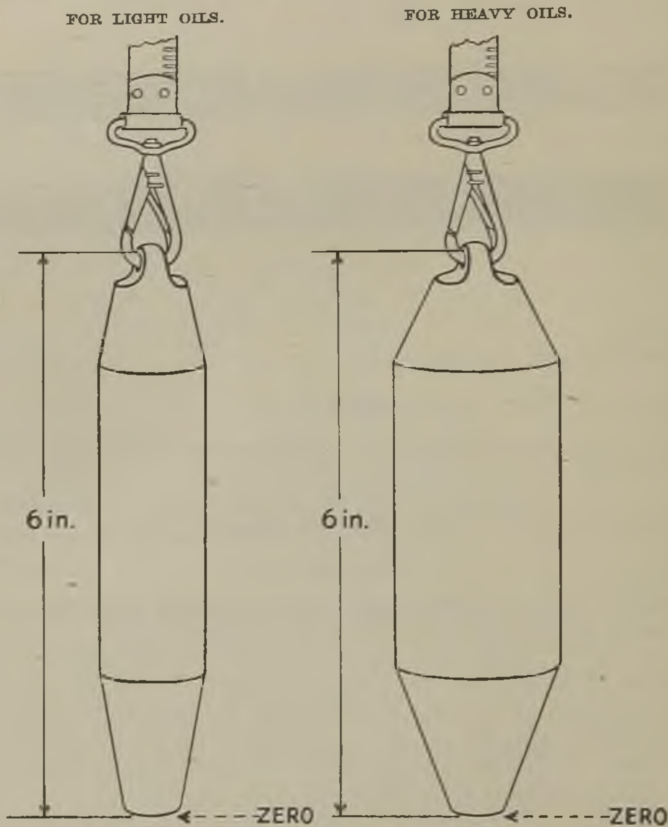
2. *Shape.* *See* Fig. 2(*a*).

3. *Dimensions.*

Length. 6 inches to the *top* of hole where swivel connection with the dip tape is made.

Diameter. Centre section $1\frac{3}{4}$ inches, tapering to a diameter of $\frac{1}{2}$ inch at the base.

Thickness of metal connection at top of weight to be not less than 0·20 inch or more than 0·25 inch.



FIGS. 2 and 2(*a*).

DIP WEIGHTS.

4. *Weight.* About $3\frac{1}{2}$ lb.

5. *Graduations.* Nil.

(iii) Combined Ullage Rule and Water Finder.

1. *Material.* Brass or other non spark generating material, sufficiently strong to resist damage by coming into contact with steel. The front face to be fitted with an ebony strip about one-third of the width. *See* Fig. 3.

2. *Shape.* *See* Fig. 3.

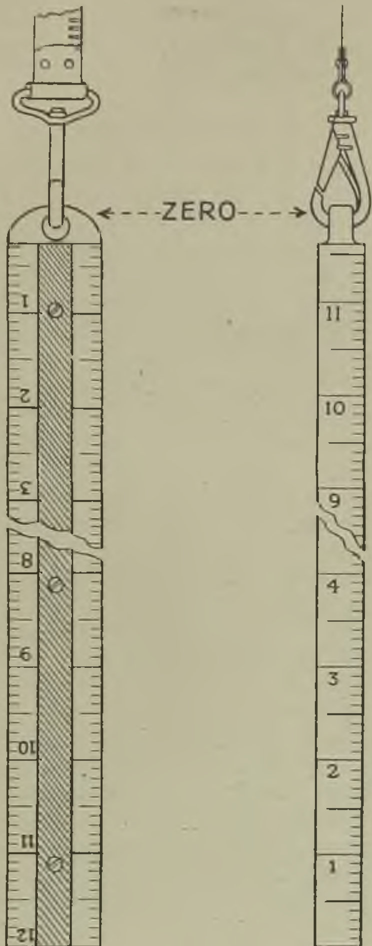


Fig. 3.

COMBINED ULLAGE RULE AND WATER FINDER.

3. *Dimensions.*

Length. 12 inches to the *top* of the hole where the swivel connection with the dip tape is made.

Width. About 1 inch.

Thickness. About ½ inch.

Thickness of metal connection at top of weight to be not less than 0·20 inch or more than 0·25 inch.

4. *Weight.* About 1¾ lb.

5. *Graduations.* Graduated on the front face in inches, in tenths of an inch (or sixteenths), reading downwards from a zero point at the top of the hole which is at the junction between the swivel at the end of the dip tape and the ullage rule. Graduated on both the side faces in inches, in tenths of an inch (or sixteenths), reading upwards from the bottom.

(iv) Gauge Glasses.

The tank shall be equipped with liquid level sight gauge glasses which may be of the conventional glass tube (boiler) type, or the more robust safety type, which consists of thick glass plates suitably clamped in a metal housing. The former is suitable for all ordinary pressure storage conditions, but in the case of light liquid hydrocarbons stored in high pressure spheres the latter may be preferred.

The gauge glasses shall not exceed 3 feet in length, and shall be installed alongside a stairway on the side of the tank least affected by weather. The reading range of each adjacent pair of glasses shall overlap approximately 2½ inches, so that a range of from 1 foot below the lowest point of the tank to the full capacity of the tank shall be covered. Gauge scales shall be installed closely alongside each individual glass, and securely adjusted so as to give an accurate and continuous reading from the zero point (which should be marked during calibration of the tank on some rigid structural member) to the full capacity level.

The connections for each gauge glass shall be a pipe of non corrodible metal not less than ½ inch in diameter. The lower connection shall extend into the tank for a distance of from 3 to 6 feet, and shall be provided with a means for draining, and the upper connection for a distance of 1 inch (to prevent clogging by scale or rust). Both connections should be fitted, at the junction with a gauge glass, with a fitting of standard type incorporating a ball check and a quick acting valve. In the case of the boiler type gauge glasses the fitting will also comprise a properly constructed packing gland to hold the end of the glass tube securely. Use of gauge columns is not recommended.

In hot climates, where liquid light hydrocarbons are being stored, it is advisable to furnish insulating boxes around gauge glasses, otherwise boiling of the liquid in the glass is apt to render difficult the correct reading of the liquid level. These insulated boxes should be so arranged as to keep the sun's rays from the glasses and lower the rate of heat absorption sufficiently so that, after flushing the glass, there is time for the meniscus to settle down and the reading to be taken before boiling starts again.