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CODE OF ELECTRICAL PRACTICE FOR THE PETROLEUM INDUSTRY.

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Preface.

I have been requested to present this paper in my capacity of Chairman and spokesman of the Sub-Committee of the Institute of Petroleum appointed to draft the Code of Practice forming its subject.

I would like, at the outset, to pay a sincere tribute to my fellow-members on the committee and others associated with the work for the enthusiastic attention they have devoted to the production of the Code. It has not been easy for any of them to spare the time and trouble they have so willingly given to see it through.

We are all alive to the imperfections of the result, but feel that a fair start has been made to fill an important need, and that if the Code is kept under regular revision as experience is gained in its application and to keep it abreast of electro-technical development, it will be of considerable and lasting service to the petroleum industry.

It is not easy to make a paper of this kind interesting, or indeed very informative, to any who have not read the draft Code itself. All I can do in a short space is to give some account of the work of the drafting committee and indicate the form and scope of the Code and some of its more important basic aspects.

The Code was compiled with the idea of its being issued by the Institute of Petroleum as a guide to appropriate electrical practice applied solely to the petroleum industry. Some parts of it are still under consideration by various committees of the Institute, and it has recently been suggested by the B.S.I. that when it has reached final form it might instead be issued by them as a B.S. Code of Practice.

Neither this paper nor the Code itself purports to embody or disclose any original work, but merely to survey and correlate the work and views of other workers in this field and to extract and set out reasonable and practical rules for the guidance of those concerned with electrical matters in the industry.

Certain controversial matters that have emerged during drafting will be mentioned in the hope that these may draw suggestions for improvement.

Origins of the Code.

As might be expected by those of us who knew of his pioneering work in the application of electrical power to all purposes in the petroleum industry, and the continuing interest that he took during his lifetime in all matters electrical, the idea of compiling a British Code of Electrical Practice related specifically to the problems and conditions encountered in that industry, originated in the mind of the late President of the Institute, Mr. Christopher Dalley.

He, like others of us concerned in this work, had become increasingly conscious of the growing need for the development of standard lines of electrical equipment especially suited to these conditions. Also, as refinery processes and products became more diverse, the variety of kinds and sources of risk increased, so that one had at times to look to the practice followed in other industries to find guidance for certain applications in our industry, and he felt that a compilation giving fairly general guidance on the selection of suitable electrical equipment and methods of installation would be helpful.

In addition, it was felt that such a Code would assist British manufacturers in meeting the needs of the industry overseas as well as at home.

During 1941 some attention had been directed to the matter by the Petroleum Division of the Ministry of Fuel and Power in connection with proposals formulated by them for the protection of oil storages under war-time conditions. These proposals included certain recommendations relating to the use or incidence of electricity, including lightning and static.

In 1942 a Government Petroleum Installations Committee was set up by the Ministry of Fuel and Power, and formulated, as part of a special report, rules for the use of electricity in buried installations for spirit storage. These rules were subsequently adopted by the Petroleum Board and the Government Departments concerned, and are at present in operation.

Requests were at this time received by the Institute from Great Britain and overseas for guidance in regard to these matters, and this intensified Mr. Dalley's feeling that, although not easy to achieve in war-time, a code of practice generally representative of the views of the industry itself should if possible be produced.

Discussions in the Institute and the industry generally made it apparent that, particularly in regard to oilfields, where conditions vary enormously, and to a lesser extent in refineries and installations overseas, a considerable diversity of opinion and practice prevailed.

In the absence of authoritative guidance, and indeed in some cases of suitable plant and equipment available from Britain, some British concerns had necessarily adopted American plant and practice or developed their own.

Moreover, apart from the obvious desire of all concerned to follow safe, sound and reasonably uniform practice, there appeared to be some danger that unless the industry itself produced some guidance, unnecessarily onerous or unsuitable and hampering regulations might be imposed upon it from without through imperfect knowledge of the nature and extent of the risks involved on the part of those framing the regulations.

Committee of Electrical and Allied Matters.

The first step taken by the Institute was the formation in January, 1943, of a committee known as the Committee of Electrical and Allied Matters, under the Chairmanship of Mr. Dalley, to explore the matter.

This Committee was generally representative of the major British oil companies operating in Britain and overseas. Its terms of reference were to collate and review existing authoritative rules for particular conditions and to obtain particulars of the rules and practice followed by the major companies, which together would form a basis for regulations to be issued by the Institute of Petroleum. In addition to dealing with electric power and lighting, guidance was to be given in regard to protection against lightning and static electricity.

DRAFTING SUB-COMMITTEE.

After arranging to obtain for consideration particulars of the electrical practice followed by the major companies, a sub-committee composed of electrical engineers connected with these companies was formed, with myself as Chairman.

Our terms of reference were very wide, comprising consideration of the above-mentioned applications of electricity and incidence of electrical phenomena throughout the industry—as Mr. Dalley put it, " from the oil well to the kerbside pump."

It soon became apparent that certain premises for which special provision is already made in Government or Local Government regulations, such as tankers and public garages, should for the time being be excluded from the purview of the Code.

It was also recognized that special consideration may later require to be given to the requirements of such processes as can repairing with electrically heated soldering irons.

It may be mentioned that since the Drafting Committee began its work the whole question of the use of electricity in so-called dangerous industries has received, and is still receiving, widespread attention. A notable paper has been read before the I.E.E. upon " Industrial Fire Risks " by W. Fordham Cooper and F. H. Mann, which touches upon the risks encountered in the petroleum industry, among others. Several articles dealing with the design and installation of flameproof and intrinsically safe apparatus have appeared in the technical press.

An extremely valuable and comprehensive Review of Electrical Research and Testing with regard to F.L.P. enclosure and Intrinsic Safety of Electrical Apparatus and Circuits has been issued by the Ministry of Fuel and Power which goes a long way in clarifying ideas about the problems involved in these matters and the technical factors entering into their solution. The review makes it clear that a good deal of further research is needed, especially in regard to intrinsically safe apparatus and circuits, before complete solution of the many problems is achieved, but at least the nature of these can now be seen with considerable clarity, and the limitations of solutions offered so far can be largely defined with safety.

A committee of the I.E.E. is at present engaged upon drawing up a section of rules for the installation and maintenance of flameproof apparatus. Committees of the B.S.I. are engaged in revising the B.S. Specifications for F.L.P. and for intrinsically safe apparatus and circuits. The revised Specification No. 229 for F.L.P. apparatus in particular is of especial importance to the petroleum industry, as it will classify types and requirements of such apparatus over a wider range and in much greater detail than hitherto.

The Institute of Petroleum is represented on these committees, and to some extent the needs of the industry will be met by this co-operation, but the full ground is not covered by this outside work, and it is still felt that a comprehensive Code specifically and solely concerned with our aspects of the problem, and representative of the views of British oil interests, is desirable.

In this connection it may be mentioned that the Drafting Sub-Committee is composed of electrical engineers, all of whom have had a number of years experience in the oil industry which, taken together, covers oilfield, refinery, and distribution practice. It is a committee of users, not manufacturers or civil servants. They are not so much concerned with design as with the requirements of design. They are, however, *not* chemists, drillers, producers, or refiners, so that in assessing risks they have necessarily had recourse to advice based upon the experience of their chemical and other specialist colleagues.

The attitude of the electrical committee has been, in effect, to say to their colleagues, " You tell us the nature and properties of a given atmosphere and we shall tell you whether or not it is safe to use electrical apparatus in it at all and if so what type of available apparatus to employ and how to instal and use it."

Another point to bear in mind is that the Code is concerned primarily with avoidance of ignition of inflammable atmospheres by electric arcs or sparks, and *not* of danger to life from shock or toxicity. This last point is of importance, as in the majority of cases in the oil industry avoidance of toxic concentrations will automatically exclude risk of explosion. Customary precautions taken in this connection, therefore, render the industry safer from electricity risks than might appear at first sight.

Form of Code.

The Code is divided into four main Sections, namely :—

Section I.—**Introduction** describing the scope and purpose of the Code.

Section II.—**Definitions** of the terms requiring to have a specific meaning attached to them to make the intent and application of the Rules clear and unambiguous.

Section III.—Explanatory **Schedules** to describe the purpose and basis of the Rules.

Section IV.—The **Rules** themselves.

Section V.—**Recommendations** covering certain suggested precautions not given mandatory status.

With the exception of the Introduction and the Recommendations, each of the above sections is sub-divided under various headings to facilitate reference to particular applications.

The method followed in compiling the Code has been to refer any particular subject requiring special study for its clarification to one member of the Committee, who has produced for general discussion a draft Schedule, a section of Definitions and a set of Rules dealing with it.

A general review was first made of American codes of rules and explosion-proof apparatus, British coal-mining practice, and F.L.P. apparatus, also of British rules, such as those contained in the Petroleum (Consolidation) Act, those issued by the Railway Clearing House, the Home Office, the Ministry of Labour and National Service, and the Indian and Canadian Governments, as well as the statements of practice followed by the major oil companies and the rules recently formulated by Government committees.

This review indicated that to extract the essential information from these and put this into a form capable of general application and acceptance would require something more than the production of a bald set of rules without explanation.

In view particularly of differences in terminology rather than intent, it was found desirable to attempt to define clearly not merely the electrical terms employed, but other terms used in the industry and the conditions of risk likely to be encountered.

It may be suggested that to define or assess the nature of what may be described as the petroleum or chemical factor of the risk is not within the province of the electrical engineer, but before he can recommend suitable electrical plant and precautions he must know something of the physical and chemical nature of the atmosphere in which it is to operate. This has been recognized by the other Committees referred to previously who are dealing with certain aspects of the problem. F.L.P. plant, for instance, is classified by the permissible gap between flange faces, which depends on the nature of the atmosphere which is likely to surround it, so that a classification of such atmospheres is necessarily included in its specification.

It is not customary, in codes of practice, to include much in the way of explanatory matter, but in the present case it was considered desirable to describe rather more fully than usual the nature of the problems dealt with and the principles underlying the comparatively brief rules and recommendations finally arrived at. One reason for this was that it would help officials and engineers in the field, especially overseas, who could not readily obtain advice or explanation, to interpret the intent of the Code and apply it to unusual cases.

The following brief comments on each section of the Code will bring out the main points in each which may give rise to useful discussion :—

Section I.—Introduction.

This explains that the Code does not purport to indicate what constitutes safe and reliable electrical practice in general, but is intended rather to supplement existing regulations in this respect with guidance in regard to the application of *special* electrical practice and apparatus to the particular conditions encountered in the petroleum industry with a view to the avoidance of fire or explosion.

Reference is made to the similarity that exists to some extent between the petroleum and coal-mining industries, but it is pointed out that on the whole conditions in the oil industry are considered to be less hazardous than in coal mining.

Section II.—Definitions.

The objects aimed at in framing definitions of terms used in the Code were :—

(*a*) To secure some measure of brevity in the rules themselves without introducing ambiguity.

(*b*) To identify, by means of consistent terms, conceptions that are given different and often ambiguous or unacceptable names in several different codes.

(*c*) To define certain conditions, classes of risk, etc., which seemed to call for exact definition, and for which no very clear definitions appeared to exist in other publications.

As originally drafted the definitions were fairly numerous, and some of them were rather clumsy, but, with the assistance of a special Panel of the Nomenclature Committee, they have been greatly reduced in number and improved in clarity of expression. Terms which may be taken as commonly understood have been excluded, and only those about which ambiguity might lead to a misinterpretation of the intent and application of the Code have been retained.

Particular interest naturally attaches to the definitions of dangerous atmosphere, dangerous location, and dangerous area.

It was at first hoped that all conditions encountered might be classed as either safe or dangerous, the latter class being embraced within the above definitions, but it was later decided that in regard to oilfields it seemed essential to introduce an intermediate class described as remotely dangerous.

It may be mentioned that the necessity for something of this kind has been recognized by other authorities.

The arguments on this question will be indicated in the remarks made about the corresponding explanatory schedules.

For the present it is sufficient to state that the somewhat arbitrary distance of 50 feet from a dangerous location or a possible point of emission of a dangerous atmosphere, which is taken as defining a dangerous area or space, accords with the definition laid down in the rules of the Petroleum Installations Committee of the Ministry of Fuel and Power referred to previously.

In regard to electrical definitions, those given in the Glossary of Terms numbered B.S.S. 205 have been adopted so far as they apply. Definitions are given of additional electrical terms used in the Code, *e.g.*, " non-sparking " apparatus suitable for use, with adequate precautions, in remotely dangerous areas in oilfields.

The definition of flameproof demands some notice. It is that given in the current issue of B.S.S. 229–1940, but this Specification is at present under revision. When revised it will be found to be greatly expanded and clarified. So far as can be seen at present, the new B.S.S. 229 will not conflict in any way with our Code, but, on the contrary, will confirm its principles and assist in its application.

A point of difference between practice as preferred and prevalent among British concerns and that laid down in the American codes concerns the use of armoured cables. These are not accepted in dangerous areas in America, but preferred in Great Britain. The point was referred by the Committee to American authorities, but the reasons given in reply were not, in our opinion, entirely satisfactory, or sufficient to change our view.

It emerged, however, that the term "armoured cable" has a different significance in America from that in Great Britain, so it was considered desirable to include a definition of our classes of such cable, since we would permit these, but *not* permit those of the American description.

In view of the special problems surrounding the use of flexible cables, a sub-section defining the terms used in this connection is included.

A section is given dealing with lightning protection terms in which both American and British practice has been drawn upon, and an indication of the source of each definition is given.

The definitions in the section devoted to oilfield terms are necessarily open to argument, but it is believed that their intent is clear, which is the main consideration.

Section III.—Schedules.

It is not possible in the compass of a brief account to deal with the explanatory Schedules in detail. Each would warrant a paper to itself for its adequate treatment.

All that will now be attempted is to mention the main purpose and points of each :—

Schedule A.—This gives a broad classification of dangerous atmospheres as used in the Code and a correlation of these classes with Buxton Groups (as at present classified) for British flameproof apparatus and with the American National Board of Fire Underwriters' classification of corresponding explosion-proof apparatus.

This is to facilitate the purchase of appropriate apparatus from manufacturers in either country.

It is pointed out that for the majority of dangerous conditions encountered in the petroleum industry, Buxton Group II or N.B.F.U. Class I Group D equipment is suitable.

The selection of suitable equipment for special conditions falling outside of the above Groups will be simplified when the revised B.S.S. 229 is issued.

It should be noted that the Code Class B—correlated with Buxton Group II and N.B.F.U. Class I Group D—includes vapour from petroleum having a flashpoint of 130° F. or less.

The figure to be taken for the limiting flashpoint, and indeed the desirability of giving one at all, was the subject of a good deal of discussion, but it was finally included as representing safe practice and affording a ready guide to the man on the spot in assessing where the dangerous area conditions might apply.

Schedule B.—This is complementary to Schedule A, and indicates the main factors affecting the degree of danger introduced into an atmosphere by the presence of an inflammable gas or vapour.

It points out that the more readily-inflammable gases may not in practice necessarily create the most dangerous conditions. Hydrogen, for instance, although highly inflammable, will, because of its extreme lightness, rise rapidly with little diffusion in still air, so that if electrical apparatus be installed at ground level and reasonably distant from any potential source of leakage of gas, and means are provided for the ready escape of gas at high level, it is unlikely that a dangerous atmosphere will accumulate near the electrical apparatus.

The importance of layout in regard to ventilation to ensure that dangerous gases are drawn away from, and not towards electrical apparatus is stressed.

Dangerous conditions are shown to be most likely to arise with a gas or vapour having high inflammability, wide range of inflammable concentration in air, density equal to or greater than that of air, low humidity, and improperly directed ventilation.

A list of typical gases and vapours encountered in the petroleum industry classified to correspond with Schedule A is given.

Schedule G.—This gives notes upon incidence of risk of fire arising from electrical causes. It points out that for a fire or explosion to occur involving an electrical cause two factors must co-exist:

(*a*) There must be a dangerous atmosphere; and
(*b*) There must be an electric spark, arc or hot spot.

It then suggests three ways of avoiding a dangerous combination of these two factors. These are:—

(1) To suppress or eliminate entirely the dangerous atmosphere, in which case an electric spark can occur without danger.

(2) Conversely, to eliminate or suppress entirely any chance of an electric spark (or a flame resulting from it) reaching a surrounding dangerous atmosphere, in which case special attention to the suppression or elimination of such an atmosphere is unnecessary.

(3) To pay attention to both factors—*i.e.*, the suppression of the atmosphere and the elimination of the spark or flame—to an extent in each case and in such a manner that the combined probability of their occurring simultaneously is so remote as to be negligible.

One or other of the first two methods is customary and appropriate in the majority of cases in refineries and installations.

The third method is one that has been permitted in certain circumstances by the Code in oilfield practice only. Here it can usually be arranged by the adoption of customary suppressive measures at a well that a dangerous atmosphere is normally *unlikely* to arise at any time, although it may do so occasionally.

In the same way, with *non-sparking* motors and apparatus a spark is similarly unlikely to arise at any time, since all normally sparking parts are flame-proof enclosed, although it may do so in the abnormal event of a fault developing.

With such conditions the combined probability of the two factors of danger arising simultaneously is very remote, and this combination of precautions is considered to be adequate.

The rules introduce safeguards, including the use of gas-testing apparatus, to provide for conditions arising from failure of suppressive or safety measures of either kind.

Discussions have revealed some confusion of thought and a tendency to loose expression on this subject, and in view of its primary importance, it seems desirable to dwell a little further on it at this stage.

The definition of dangerous atmosphere is clear and simple. It is: "An atmosphere containing any inflammable gases or vapour in a concentration capable of ignition by an electric spark or arc." An atmosphere at any place must, under this definition, obviously be either safe or dangerous at any given moment of time.

As a step towards defining a dangerous area we have introduced and defined the term "dangerous location" to fix a point from which the extent of a dangerous area shall be measured.

At this stage a qualification is introduced. A dangerous location is defined as one where a leakage or emission of a product which can produce a dangerous atmosphere is *normally likely to arise*. It should be noted that this does *not* mean that a dangerous atmosphere is normally *present or persisting*. There is a persisting *risk* of its *arising* but *not* a persisting *atmosphere*. The decision as to where such conditions exist is of course a matter for the judgment of the occupier.

In the view of the Committee, confirmed by the major oil companies consulted, where there is a known persisting—*i.e.*, ever-present dangerous *atmosphere*—electrical apparatus of any kind should be kept out of it.

Where, however, there is merely a normal or persisting *risk* or likelihood of such an atmosphere arising at any time—though it is not usually present—then that point is a dangerous location surrounded by a dangerous area, and the appropriate electrical practice is flameproof or the equivalent.

Where there is a remote—*i.e.*, infrequent or non-persisting—risk of a dangerous atmosphere arising, that constitutes a remotely dangerous location surrounded by a remotely dangerous area, and the stringency of the electrical precautions may be correspondingly relaxed.

A brief summary may help to clarify these notions and fix them in mind. Given in decreasing order of danger we have :—

(1) *Continuously dangerous surrounding conditions : i.e.*, Dangerous atmosphere always present.

Practice : No electricity to be used.

(2) *Dangerous surrounding conditions : i.e.*, Dangerous atmosphere, although usually absent, normally likely to arise at any time. This is the usual case in refineries and installations.

Practice : F.L.P. or the equivalent.

(3) *Remotely dangerous surrounding conditions : i.e.*, Usually safe, but a dangerous atmosphere remotely likely to arise in abnormal circumstances through failure of precautionary measures for its avoidance. This is the case in parts of many oilfields.

Practice : Non-sparking electrical apparatus with certain safeguards to provide against failure of preventive measures.

(4) *Safe surrounding conditions : i.e.*, Dangerous atmosphere never present or likely to arise.

Practice : Industrial equipment.

It may be mentioned that since condition (1) above does not, in the view of the Committee, permit the use of electricity it is not specifically mentioned in the Code Rules but is referred to in the Recommendations.

The remainder of Schedule G deals specifically with conditions on oilfields. An attempt is made to classify oilfield areas into safe, remotely dangerous, and dangerous, so as to enable appropriate electrical practice to be applied at any place.

In framing the classification the contribution of danger by each of the following factors to any particular case is considered :—

(1) *Nature of crude.*—It is assumed that all crudes are capable of giving rise to a dangerous atmosphere if not confined at the surface.

(2) *Type of operation—i.e.,* drilling or producing. Drilling operations may be dangerous or remotely dangerous, depending on method and other factors, but never safe. Producing operations with an open system are dangerous, but with a closed system only remotely dangerous.

(3) *Pressure in and depth below surface of oil reservoir.*—Pressure conditions are described as subnormal, normal, or abnormal, depending on whether the pressure at the oil horizon is less than, equal to or greater than the equivalent hydrostatic head.

For purposes of assessing risk at the surface, the first two classes—*i.e.*, subnormal and normal—are grouped together and a margin of permissible excess pressure at the surface is provided by taking salt water for calculating hydrostatic head and then adding 150 lbs./sq. in. before classing conditions as abnormal.

This reduces the classes to two—viz., Normal and Abnormal.

(4) *Type of drilling operation.*—Distinctions are drawn between wildcatting or exploring, outstepping, and exploitation or infiller, all of which are defined.

Combining the above factors and considerations gives the following classification of areas around oil wells :—

Dangerous areas—within 50 feet of :—

(*a*) A producing well with open system of production (or any point where the crude comes out into the open).

(*b*) A wild-cat well throughout drilling operations.

(*c*) An infiller well being drilled in a known " abnormal " area.

Remotely dangerous areas—within 25 feet of :—

(*a*) A producing well with closed system of production.

(*b*) An infiller well being drilled in a known normal area with an adequate closed system of drilling.

Other areas on oilfields are classed as safe or dangerous in accordance with the general definitions of these terms.

In view of the difficulty of laying down drilling and producing methods considered adequate to ensure that the potentially dangerous area around a well may be classed as remotely dangerous, the Code requires routine gas tests to be carried out near the well in an area classed as remotely dangerous, so that should a dangerous atmosphere arise, through the failure or temporary derangement of suppressive measures, this will not persist unobserved. On such an atmosphere being observed the Code requires electricity to be cut off from all but F.L.P. or equivalent equipment until conditions have again been brought under control.

It may be mentioned that routine gas-testing accords with the practice of one major oil company which has extensively applied electric drilling and oilfield electrification generally. Their experience indicates that, owing to the open nature of the rigs employed, and using adequate suppressive measures in a normal area, a dangerous atmosphere, if it arises, rarely travels more than a few feet from the point of its emission before safe dispersion occurs. This experience supports the adoption of 25 feet as the radius of extent for a remotely dangerous area.

The electrical precautions described in Schedule G call for little comment; they merely indicate the relaxation of completely F.L.P. or equivalent type construction that is admissible in a remotely dangerous area, and that this permits of a wider application with safety and economy of modern methods of electric drilling than would otherwise be possible.

Schedule C.—This deals with the question of static electricity other than lightning. Much of the information given in it has been drawn from Circular No. C 438, dated 1942, issued by the U.S. Department of Commerce, National Bureau of Standards, and from a paper read by J. M. Pearson of the Sun Oil Co., Philadelphia, to the American Petroleum Institution in Chicago in 1940.

The early part of the schedule describes in a non-technical manner the commonly accepted basis of the phenomena associated with the generation, accumulation, and discharge of static electricity. The unexpected dangers that may arise from induced and bound charges are described.

We need not here concern ourselves with the technical aspects of static, but may refer briefly to some of the practical points arising from them.

As a particular source of danger, among others, it is shown that when a composite stream of light petroleum liquid and an immiscible contaminant such as water flows through a pipe, especially at high velocity, the particles are alternately pressed together and torn apart, also similarly pressed against and torn away from the pipe wall. The result is that a charge of one sign is accumulated on one liquid and a charge of opposite sign on the other. If the pipe is long enough, an equilibrium condition is reached at which leakage and recombination of charges equals the rate of their production.

Experiments carried out at Delft, Holland, and elsewhere have determined the order of value of charges and potentials obtainable in this way. The maximum observed current flow carried by the stream corresponds to about $1{\cdot}7 \times 10^{-9}$ amperes per gallon per minute of flow.

It is found that at velocities below about 3 ft./sec. no charge accumulates.

Such charges are not in general important in the pipeline, although this should be earthed for the safe discharge of bound charges on the pipeline when this is drained, or the contents changed, but they become important when discharged into tanks.

Here the liquids separate. The heavier—usually water—takes one charge with it to the bottom, where it can be drained away by earthing. The other expands like a gas through the body of the oil. Some of it reaches the tank walls on the way up, the remainder rises to the surface. The only path for this to the metal wall, whence it can flow round to be neutralized, is across the oil surface. If the surface resistance is high, the rate of leakage across it may be less than the input of fresh charges. In such a case the potential will rise until a flash-over occurs. With lighter spirits the atmosphere in the vapour space will usually be too rich to ignite, but with oils in the kerosine range this is not usually so and a fire may result.

Safeguards for these conditions are set out in the Schedule and the Rules. They include not only intelligent earthing, but such suggestions as the introduction of incoming streams low down in tanks.

The problems presented by different types of tanks are discussed, and precautions appropriate to each described.

The later part of the schedule describes conditions arising during the filling and emptying of road and rail cars, and shows the benefit of careful attention to earthing and other precautions before any oil is permitted to flow into or out from such containers.

The process of the building up of static charges on road cars by the passage of tyres over the ground is described. This trouble, as indeed all static troubles, is little in evidence in normally humid atmospheres, but may be a serious source of danger in very dry climates of, say, 60 per cent. or less relative humidity.

An oil company has given particulars of a fire that occurred on one of their refineries in the Middle East. It was established that this arose from a discharge of static electricity accumulated through the impingement of a stream of oil on to a splash plate. They carried out a series of experiments duplicating the conditions but at various humidities. At relative humidities above 55–57 per cent. the sparking disappeared altogether, but at lower humidities the sparking was dangerous and caused ignition.

Schedule D.—Deals with protection against lightning. Owing to the great variation in conditions of all kinds affecting this problem, few rules can be laid down to be of general application.

It is pointed out that the extent to which it may be desirable or necessary to protect buildings or structures will depend on an assessment of the following factors :—

(1) The frequency and severity of thunderstorms likely to occur in the locality concerned.

(2) The degree and extent of danger to life of operating personnel or occupants of any building or structure arising from its susceptibility to being struck by lightning.

(3) The importance attached by the owners to damage or destruction by lightning of any particular building or structure.

(4) The possibility of a fire spreading to neighbouring property and the importance attached to this.

(5) Any local regulations which may require lightning protection in any particular case.

(6) The nature of the soil and the pollution of the atmosphere.

Reference is made to the following publications dealing very fully with the practice to be applied :—

(*a*) " Code for Protection against Lightning." National Bureau of Standards Handbook H. 21 issued 2nd November, 1937, by U.S. Department of Commerce.

(*b*) " Protection of Structures against Lightning." British Standard Code of Practice C.P.I. 1943.

The various principles and practice to be applied to structures where, after an assessment of the requirements of the case, it is decided that protection is desirable, are described in considerable detail. Particular attention is given to the case of oil tanks, most of which of modern design are found to be self-protecting.

Where protection is applied, stress is laid upon regular testing of the protective system. This is important, as earth resistance will usually vary greatly throughout the year in any locality not always waterlogged.

Schedule E.—This schedule is largely a precis of electrical protective systems and devices. It draws attention to the differences in the requirements of such devices when applied to system and plant protection.

It arose out of discussions on the desirability or otherwise of a growing tendency to put forward earth leakage protection as a general safety measure. The Committee were not entirely in agreement with this tendency, and a main purpose of the schedule was to indicate the various forms of such protection and their limitations, and to put them into some perspective with other forms.

It is hoped that this question will be clarified by discussions at present proceeding in committees of other Institutes. Meantime, excepting in connection with certain applications of flexible cables, the Code does not make the use of earth leakage protection obligatory.

It is felt that in its present form this schedule is not entirely appropriate to the Code, and since it gives rise to no mandatory Rules, it may eventually be omitted or considerably revised.

Some discussions on the question of earth leakage protection by those present this evening would be helpful in arriving at a decision on this question.

Schedule F.—This deals with the use of flexible cables in dangerous areas. At the outset it is stressed that, wherever practicable, an electrical installation should comprise fixed apparatus and permanent wiring of appropriate type.

It is recognized, however, that this is not always practicable, and appropriate types of cables, fittings, and methods of connection are described.

One prevalent source of danger has been flexible cables or so-called "cords" connected to the mains and used with portable handlamps. Although this question has received, and is now receiving, prominent attention it has not, in the view of the Committee, yet been satisfactorily solved, and they have therefore meantime forbidden the use of such a method of lighting in dangerous areas, although it is permitted in American practice.

The cases where earth-leakage protection and electrical interlocking are considered desirable are described and the intent of the rules in these connections is explained. To a large extent modern coal-mining practice has been followed, but it may be noted that the Code requirements in this particular case regarding provision against earth leakage are somewhat more stringent than those laid down in the Mines Regulations (Amendments).

The importance of regular inspection and adequate maintenance of all flexible cables is stressed.

Section IV.—Rules.

These are divided into four main series :—

Series 100 are of general application, and are subdivided into those that apply in any area and those that are specific to a dangerous area.

Series 200 deal with precautions for the avoidance of danger from static in relation to process plants, pipelines, tanks, ships, road or rail vehicles, and so on where a dangerous atmosphere may be present or arise.

Series 300 deals with protection against lightning in relation to oil tanks, buildings, and telephone lines where a dangerous atmosphere may arise.

Series 500 is devoted solely to oilfields, and therefore is largely concerned with relaxation in electrical safety precautions permissible in remotely dangerous areas, and in stating the safeguards under which this relaxation may be applied. This series is still under consideration by the major oil companies, and will no doubt at least require final editing.

Short of quoting the Rules in full, there is little that can be said about them, as all are important.

It may, however, be said that they do not conflict with the intent of those issued by the Petroleum Installations Committee so far as these apply.

Section V.—Recommendations.

This is a very short section. It comprises a few suggestions, which arose out of discussion, for possible rules, but which it was decided should not be given mandatory status.

Perhaps the most important is the last, which recommends that electricity shall not be used in a known persisting dangerous atmosphere.

CONCLUSION.

It will be appreciated that this paper deals with the Code in its present draft stage, and that its order and content may be amended during final editing.

THE INSTITUTE OF PETROLEUM.

A meeting of the Institute of Petroleum was held at Manson House, 26 Portland Place, London, W.1, on Wednesday, 9th May, 1945. The President, Professor F. H. Garner, was in the Chair.

A paper on "Code of Electric Practice for the Petroleum Industry" was read by Mr. Alan D. Maclean. [See pp. 379–392.]

DISCUSSION.

The President complimented Mr. Maclean on the able manner in which he had accomplished the formidable task of presenting the subject.

Referring to Schedule B of Section III, which dealt with dangerous atmospheres, the President commented on the fact that, after considerable discussion, the flashpoint chosen for vapour was 130° F. He asked Mr. Maclean to enlarge on the reasons why that particular temperature was chosen, and whether it should depend on the particular atmospheric temperature involved. Thus, for tropical climates, perhaps a different temperature might have been chosen from that applying to temperate climates.

He also asked for a brief description of the difference between the American and British cables referred to by Mr. Maclean.

Mr. Alan D. Maclean, after thanking the President on behalf of himself and the members of the Sub-Committee for his very kind introductory remarks, replied that there had been much discussion before 130° F. was fixed as the flashpoint for vapour. After the matter was discussed it was referred back to the various companies, and one opinion was that kerosine could never produce a dangerous condition in the vapour space. That, however, was not true; if there were a fire, one of the most dangerous things was an empty kerosine tank. The Sub-Committee had decided at one time that it could not put forward any figure that was uniformly acceptable. One large oil company to whom the matter was referred had stated that their practice was to adopt the figure of 130° F.; and this was adopted. It was not mandatory, but illustrated, for example, what products of higher flash, such as fuel oils, were unlikely to give rise to explosive conditions in the vapour space.

In reply to the President's question concerning cables, the type of cable the Sub-Committee had in mind was a 3-core cable, paper-insulated and lead-covered. The American armoured cable was usually a V.I.R. multi-core cable, sheathed with a flexible metallic tubing; or at any rate, it looked like that. A considerable number of tests, comprising pressure and other tests, was specified for the flexible tubing. But whereas the armouring on the British cable was a built-up armouring, the American cable was drawn into its armouring, and in the view of the Sub-Committee was not satisfactory to use for flameproof purposes. On the other hand, the arguments used against the British armoured cable were considered by the Sub-Committee to be quite invalid.

The matter was referred to the American National Board of Fire Underwriters, who had stated their adherence to the view that rigid conduit was the only satisfactory thing to use in dangerous areas. They had pointed out that the degree of safety in a hazardous location was dependent on the ability of the armoured cable to withstand mechanical injury and to prevent flame or sufficient heat being transmitted to the surrounding atmosphere to create hazard; they believed that a rigid conduit was best able to resist.

The Sub-Committee disagreed with that view, however, and after study of the American specification for armoured cable, had agreed that it was unsuitable. The comparison, therefore, was really between the British armoured cable and solid-drawn tube armouring. The type of armouring which consisted of flexible metal tubing had not the properties that we required in our armoured cables; the multi-core cable was just pulled into a flexible tube.

Mr. R. R. Tweed, recalling his earlier associations with the late Mr. Christopher Dalley, who would have been delighted by the results which had been achieved by the Institute's Sub-Committee, said that when Trinidad was about to adopt their own code of electrical practice, Mr. Dalley had urged them to await the code which was being prepared by the Institute for the whole industry, as he knew that it would be a work of some value. Events had proved that Mr. Dalley was perfectly justified, and one could only hope that the code would be completed and printed and placed in the hands of the Colonial Office as soon as possible. Mr. Tweed congratulated Mr. Maclean and his colleagues on the Sub-Committee for the great work they had done.

Mr. Maclean expressed his appreciation of Mr. Tweed's remarks, and said it was a matter for great regret that Mr. Dalley had not lived to see the work through.

Mr. H. Fossett asked if Mr. Maclean could expand his remarks on the definition of a dangerous area or locality, for definition seemed to be a tricky problem. For example, reference had been made to the specific distance of 50 ft. around a well or other plant as delineating a dangerous area in certain conditions. He wondered whether the Sub-Committee could consider the extension of the definition of a dangerous area. He had in mind, for example, the storage of liquefied gas, and envisaged a mishap in a pressure storage tank which could induce a dangerous area of very much greater extent under the influence of external factors, such as weather conditions (humidity, and so on). He could visualize dangerous conditions existing over an area extending hundreds of feet from the point at which the gas was released.

Mr. Maclean replied that the problem of relating the size of a dangerous area to the particular conditions giving rise to the danger, rather than defining a dangerous area as being the area within a circle of given diameter, was the crux of the whole problem, and had given rise to more discussion among the members of the Sub-Committee than had any other matter. They had tried to give a definition of a dangerous area which would be of universal application. Articles had been published in the technical press recently, some from America and other countries, suggesting that such factors as length, breadth, and height of buildings, as well as prevailing wind, should be considered in arriving at a decision as to the definition of a dangerous area. But the Sub-Committee considered that to ask any occupier to go into all those factors before deciding to take precautions in any area was to ask too much; it would be much too academic. The Sub-Committee had been governed to some extent by the Petroleum Installation Committee's ruling, after that committee had considered the matter carefully. Some of the oil companies had, as a rough guide, defined a dangerous area as within 100 ft. from the point of probable emission of a dangerous atmosphere; other companies had adopted other distances. The Sub-Committee had considered that 50 ft. was the minimum distance it could safely recommend; at the same time, for all the applications which the Sub-Committee could think of, it was a safe maximum. If there were wind, there would be rapid dispersion; and it was only a wind which would distort the shape of the dangerous area from the circular. Inasmuch as tests had indicated that usually an inflammable mixture dispersed within a distance of 5 ft., and practically never persisted beyond that distance, it was reasonable to say that 50 ft. was well beyond the distance within which adequate dispersion would occur. They did not take account of the nature of the source of the danger as a factor extending the area of danger. He gathered that Mr. Fossett had in mind the storage of gases under pressure, and the possible bursting of the containers.

Mr. Fossett said he was thinking of storage at pressures up to, say, 30 lbs.

Mr. Maclean suggested that in such a case the occupier would take precautions, anyhow, in designing the container to suit the pressure, and he doubted very much that it warranted qualifying the definition. There appeared to be some confusion of ideas in this matter. We were not concerned with how far the inflammable contents of such a container might travel should it burst, nor with the distance that the effects of an explosion in it, under such a mishap, might extend. We were concerned in defining how near a spark might be brought to it without igniting normal emission of inflammable gas from it—*i.e.*, how far such normal emission might travel without being safely dispersed so as to preclude its ignition by a spark. He did not think it logical to take an emergency condition of that kind and try to arrive, on that basis, at a definition which would be of universal application. It would be difficult if the whole area of operations had for such a reason to be regarded as a dangerous area; one could not then, for instance, have an ordinary office on it. He felt, therefore, that Mr. Fossett was viewing the matter from a wrong standpoint and introducing irrelevant factors as warranting a qualification of the definition. At the same time, he would be pleased to discuss the matter if Mr. Fossett wished to quote a special case, such as that of a butane tank, for instance.

MR. FOSSETT said he was not thinking of specific instances, but was concerned with the possible effect of external factors on the definition.

MR. MACLEAN replied that no provision was made in the definition for such emergency conditions; it merely stated that a dangerous area was that within 50 ft. of any dangerous location; and a dangerous location was a place where a dangerous atmosphere might normally arise, as listed in the classification. He did not think they could go further. But the members were always prepared to consider suggestions.

MR. A. L. FORD asked whether laboratory apparatus, which was an integral part of the petroleum industry, was covered by the Code of Electrical Practice. He had in mind particularly the hot plates and ovens used for the evaporation of solvents such as benzene, and drying of acetone-treated glass apparatus, for they were often not flameproof, nor were they intended to be.

MR. MACLEAN replied that it was not the intention to cover laboratory apparatus or anything of that kind, because laboratory processes were not covered by the Factory Acts or by any special regulations. The people working in laboratories were a class apart and the engineers rather liked to keep out!

MR. FORD said that he would like to see the Code applied to the laboratories, particularly bearing in mind that nowadays a large number of the people working in the laboratories had been very quickly and very "shoddily" trained; they had to work quickly, they did not know anything about electricity and they received no help from above.

MR. MACLEAN did not think there would be any objection to the application of the Code to laboratories by anyone who wished so to apply it. But there was no specific mention of laboratory apparatus in the Code.

MR. FORD recalled an occasion on which there had been a slight explosion, which was not serious, when gum-dishes had been put into an oven. There seemed to be a good chance of something happening when a solvent was being evaporated on a hot plate; he personally had not experienced that, however.

MR. F. H. MANN, who was invited to comment on the question of applying the Code to laboratory apparatus, said it would appear that the Code could be applied quite readily to industries generally where explosives and inflammable materials were handled.

Chemical laboratories were a perfect bane, because whereas they began by providing a field for experiment, they ended by becoming minor media for production, because often the laboratory was the most convenient place in which to make a few specialized products. It should be seen that the laboratories did not overstep their functions and blow up the whole works.

Throwing out a challenge with regard to earth-leakage protection, he said that Mr. Maclean had rather been against it; and one could understand that, because discrimination was always difficult when one tried to apply sensitive protection of that kind. On the other hand, if one depended on fuse protection, for example, it was necessary that a fairly heavy current should flow before the fuses would operate, and the damage from consequent arcing, if it occurred in flameproof apparatus, might vitiate its whole function. If one had protective apparatus in series on a big installation, circuits supplying important process work might be shut down as a result of a fault on some minor sub-circuit : hence there was plenty of scope for development of sensitive protective gear in the direction of increased discriminative properties, which at present were dependent mainly on the use of expensive pilot cables or less reliable time lagging.

The main fact to be borne in mind was that sensitive protection by earth leakage is desirable in a dangerous industry to avoid disruptive effects on flameproof apparatus which might lead to serious risk of fire or explosion.

Mr. Maclean said that earth-leakage protection had been used very largely in coal-mining practice. There was quite a considerable difference between the conditions obtaining underground, in a confined space with a dusty atmosphere and not very much light, with the difficulties of maintenance and inspection which existed normally in coal mines, and the more spacious, better-lighted, and easier conditions which obtained mostly, or could obtain, in the petroleum industry. The Sub-Committee had felt, therefore, that simplicity should be achieved as far as possible. He was a great believer in simplicity ; he believed that a good mechanical job was usually the best electrical job, and was best also from the maintenance and inspection points of view. Simplicity was more easy to attain in the petroleum industry than in some other industries, and that factor had influenced the Sub-Committee to some extent and had helped them to keep an open mind on the earth-leakage protection problem. Quite apart from the fact that some gadgets were expensive, the less gadgets there were and the less tricky the method of achieving an object, the better. If one could provide a simple arrangement and ensure that it was simply and adequately maintained, one was to that extent better off.

Mr. J. A. B. Horsley said he was interested to know that the Sub-Committee proposed to ban the use of portable mains-fed electric lamps, bearing in mind that they were extensively used to-day in many situations where there was a risk of fire or explosion. He asked whether the Sub-Committee had considered the use of low voltage obtained through a step-down transformer of limited output for this service, or what alternative means of providing the necessary lighting they contemplated.

Mr. Maclean replied that the Sub-Committee had excluded the use of trailing cables connected to the mains, for carrying current at mains voltage to portable lamps, because they considered it to be dangerous. The use of mains voltage portable lamps had given rise to trouble, and the Sub-Committee did not like them. But they had not excluded other portable apparatus, such as the flameproof handlamp, which was not connected to the mains at all, or various other types that had been produced. There was, for instance, a lamp operated by compressed air. However, perhaps Mr. Morris, who had been concerned mainly with that section of the Code, might care to deal with the matter.

Mr. W. S. Morris said that the industry had derived guidance from Mr. Horsley with regard to the mains-voltage portable lamps, and had abandoned them after he had pointed out the difficulty of overcoming the risks involved.

So far as the lamp itself was concerned, there was always the danger of the glass being broken due to dropping and of the exposed filament remaining at a high temperature for a sufficient time to ignite any gas in the atmosphere. In addition, there was the possibility of leakage to the frame, and the frame sparking to earth. To guard against the last-mentioned risk an all-insulated lamp fitting would be required. With regard to the flex, even though it was armoured it was not satisfactory, because in the event of breakdown the protection would not always act quickly enough to eliminate any chance of external sparking. It would be very difficult to instal a form of earth-leakage protection on a portable lamp circuit taking something like a fraction of one ampere.

As to alternative means of lighting, there were several kinds of portable handlamps covered by the Ministry of Labour and National Service certificates. Included in the apparatus so certified was a compressed air mercury vapour lamp, which, however, was not exactly portable, for it weighed something like 16 lbs.; but it was very useful to hang up inside a vessel such as a tank while the latter was being cleaned. Due to its weight, the compressed-air operated lamp was not suitable for use in columns unless it could be taken to one platform and left there.

For small work such as barrel inspection there were available various kinds of lamps operating on voltages of 12 or less and, in respect of these, Ministry of Labour and National Service certificates were issued.

Mr. E. Thornton, referring to the cutting off of current in certain circumstances when dangerous atmospheres arose, said that a good deal of information about it was contained in a paper written by the Chief of the Paris Power Company. He would like to hear more about it.

Mr. Maclean replied that that matter was dealt with at considerable length in the Code itself. The requirements with regard to cutting off the electric power applied to the oilfields section. In a remotely dangerous area it was required that the lighting circuits should be completely flameproof, and entirely separate from the power circuits. Then a suitable switch had to be provided for use in the event of a dangerous atmosphere arising. If that switch were within the dangerous area it must be fully flameproof, and if it were outside the dangerous area it could be of the industrial type. But the switch *must* be provided so that the power to any of the circuits which were not flameproof could be cut off. Thus, flameproof circuits were required to be provided only to the minimum extent, sufficient to ensure that the necessary lighting, and so on, was available; they could then remain on.

Mr. T. P. Preist, commenting on a remark that in a persistently dangerous atmosphere no electricity would be permitted, asked if that meant no electricity at all, or no electricity for power use. Being interested in remote signalling apparatus, he was concerned because, if no electricity at all were permitted, there would be no possibility of using telephones, remote controls, etc. It might be that the dangerous atmosphere was always toxic, in which case, he supposed, the problem did not arise. But he would like more information on the matter, because intrinsically safe low-voltage apparatus might be excluded unnecessarily.

In the section of the Code dealing with protection against lightning in dangerous areas there was reference to the protection of telephone lines; but no mention was made of the protection to be given to telephone lines which were adjacent to power lines which might be affected.

Mr. Maclean said there was no specific statement in the Code that the use of electricity was not permitted anywhere; prohibition was only inferred. But all the major oil companies had stated that, where dangerous atmospheres persisted, they themselves would not instal it. The Sub-Committee had merely drawn up the rules and regulations concerning the use of electricity in what they had described as dangerous areas; and dangerous areas were those in which dangerous atmospheres were normally likely to arise. They had not gone so far as to say that electricity was not to be used, but they were prepared to give an opinion if asked for it.

With regard to danger from lightning, they had stated that there should be no overhead lines at all inside a dangerous area; the terminal pole must be outside the area.

Mr. Preist said he had in mind that there might be overhead telephone lines running parallel with overhead power lines outside the danger area, and the telephone wires might be carrying a dangerous charge due to a defect on the power system at some distant point.

Mr. Maclean pointed out that an arrester was provided on the terminal pole, which latter must be outside the dangerous area; the telephone lines would carry on from there underground.

Mr. Preist suggested that that was hardly sufficient, and he thought that isolating transformers, sparkgaps, and possibly drainage coils may be necessary for full safety.

Mr. Maclean said that the Code dealt with protection against the danger arising from power lines; he would turn it up, and would communicate with Mr. Preist. He added that the discussion of points of that sort was extremely valuable.

Mr. Raynor, recalling Mr. Maclean's statement that the oil companies would themselves preclude the use of electricity where a dangerous atmosphere persisted, put forward the case in which a dangerous gas was likely to arise and it was desired to prevent a dangerous concentration of it. Thermo-couples could be used as a measuring device, he said, so that one could detect when the dangerous gas began to arise.

Mr. Maclean said the Sub-Committee had not dealt with that matter specifically, so that he could not give the Code answer.

Mr. A. W. Gillett said the problem with regard to instruments was extremely complex. The lay-out of a room with instrument panels and with small pipelines containing dangerous gases gave rise to a whole series of problems. He would like to see some sort of recommendation or some indication of what was required in respect of plant lay-out in order to meet that situation.

A matter which Mr. Maclean had not discussed was the quite common practice of driving machinery through dividing walls. He asked whether the back sides of those walls were treated as remotely dangerous areas.

Mr. Maclean said that a quite considerable section of the Code was devoted to both of the problems Mr. Gillett had raised.

Mr. Gillett, in reference to flameproof apparatus, said it was not always recognized how much work was required in order to guarantee that flameproof apparatus was maintained to 100 per cent. efficiency; if it were not so maintained, then one was living in a fool's paradise.

Commenting on the difficulty of testing a conduit system which had been installed for, say, ten years, he said that whereas a fault in a V.I.R. armoured cable could be located at the particular point where the sparking occurred, in a conduit system there might be corrosion in one part and a fault 100 yards away, and inasmuch as the gas had got into the system, the whole run was vulnerable.

For small lighting installations was there insistence on the use of lead-covered cables throughout, or were the ordinary armoured cables adequate? Further, he asked whether the Sub-Committee had considered the development of a lighting fitting for the remotely dangerous areas. Flameproof apparatus places a limitation on the light intensities practicably achievable. The position might be met by using a flameproof standby lighting system in conjunction with a normal system, which could be cut off, with the power, under emergency conditions.

Mr. Maclean replied that the points raised by Mr. Gillett had been dealt with in the Code, which would be available shortly.

A number of wiring methods were put forward in the Code, and the reasons for adopting them were given. Others were being considered also by a Committee of the Institution of Electrical Engineers; he was very hopeful that that Committee and the Sub-Committee of the Institute of Petroleum were thinking along the same lines and that they would arrive at the same answers.

Expressing agreement with Mr. Gillett's remarks concerning conduit, he added that we in Britain preferred to limit the size of conduit used; beyond that limit of size it was preferred to use armoured cable.

He believed the use of the ordinary armoured cables was allowed for lighting circuits; but he asked if Mr. Morris would confirm that.

Mr. Morris said that armoured cable with lead covering was specified; plain armour without lead covering was not allowed.

Mr. Maclean, after commenting that the use of lead-covered cable drawn into conduit was not allowed, asked Mr. Morris why the Sub-Committee had not approved plain armouring for the smaller sizes of cable.

Mr. Morris replied that in the absence of a lead sheath there was a risk of vapours penetrating the armouring and attacking the insides of the cables.

Mr. F. G. Rappoport was interested to know when the Code would be available for use, because his company was engaged on an important project in connection with which the Code would be extremely valuable.

Associating himself with Mr. Tweed's remarks concerning the late Mr. Christopher Dalley, with whom he had been very closely associated in the field, he said that Mr. Dalley had given much valuable advice on electrical matters. His advice on lightning conductors especially, and the installation of conductors in accordance with that advice, had enabled one to sleep more soundly in the knowledge that every precaution had been taken.

The President said the time when the Code would be available depended on the Engineering Committee. It was obviously desirable to issue the Code as complete as possible but it might be found preferable to issue it in its present form so that it would be available for comments from a wide circle of those interested.

Mr. E. Thornton asked whether the Sub-Committee had given consideration to what sort of electricity was safe; and he commented that highly apprehensive people would turn down all sorts of things merely because they involved the use of electricity.

Mr. Maclean said that in drawing up the Code the Sub-Committee had endeavoured to cash in on the work of others as far as possible. In other words, they had said that the apparatus in a dangerous area must be flameproof, intrinsically safe, or approved for use in a dangerous area, having regard to the various possibilities that could arise there.

However, no doubt Mr. Horsley could put one's mind at rest as to what was and what was not intrinsically safe. Presumably at very low voltages the conditions were intrinsically safe. But he asked Mr. Horsley whether a dangerous spark could arise, for instance, from a 2-volt circuit.

Mr. J. A. B. Horsley agreed with the proposal to exclude electricity, for general purposes and in the ordinary forms, absolutely from places where there was a persisting risk of explosion; but he suggested that for certain purposes and in innocuous forms the use of electricity could be allowed, by providing that the exclusion should not apply to electrical apparatus and circuits which were so constructed that any part could be exposed to the atmosphere without the risk of igniting inflammable gas. That would admit, for example, the use of thermo-couples for recording temperature from a distance, and various similar instruments. In short, intrinsically safe apparatus and circuits could be admitted.

A 2-volt battery in itself might seem to be perfectly harmless, but it was not the voltage alone which decided whether or not a spark would ignite inflammable gas. If the battery were used to operate a bell, the inductance of the circuit might be sufficient to produce an incendive spark.

He did not agree with drawing a sharp distinction between areas where there was risk of dangerous conditions arising frequently and those where it was infrequent by admitting, in the latter, the use of apparatus that was not flameproof.

Commenting on the great interest that had been taken during recent years in flameproof enclosure, he said the principle of construction was by no means new. It had been known and practised for many years in mining applications.

Commenting on the point that American practice excluded the use of what we knew as armoured cables, he said that his own prejudice—and he could not put it higher because he had no real body of experimental evidence to back it—was in favour of a wire-armoured cable. It was quite possible to burn a hole through steel conduit as the result of an arc cable fault inside.

With regard to earth-leakage protection, its use in coal mines in Britain had been generally adopted although its introduction was at first opposed for just those reasons mentioned by Mr. Maclean. They did not aim at great sensitivity but were content with operation at 10 or 15 per cent. of the rated full load current of the circuit, with a minimum of 5 amps. His primary object in advocating leakage protection had been to reduce the fire risk. He did not claim that it would prevent fatal shock, or the possibility of igniting gas; but it did reduce the risk as compared with overload protection. That was especially true in circuits requiring considerable power.

Where the mains-fed, portable handlamp was the only effective way of providing for necessary local lighting, he felt that one would get very much nearer to safety by limiting the possible current input into a fault.

In conclusion, Mr. Horsley congratulated the Institute of Petroleum on having taken in hand itself the task of preparing a Code of Electrical Practice, through a fully representative Committee of practical engineers.

On the motion of the PRESIDENT, the hearty thanks of the meeting were extended to Mr. Maclean for his paper.

MR. G. S. AMBROSE subsequently wrote :

"I gained the impression at the meeting from some of the queries which were raised that the questioners were in a somewhat ambiguous position, not having had the opportunity of reading the Code, and for the same reason some of those present may be under some misapprehension from the points raised and the replies given. Mr. Maclean has, therefore, suggested that I write you direct so that consideration may be given to the points below in any report of the meeting in the Journal of the Institute.

> "(*a*) To dispel any impression that the rules in the Code as drafted may restrict development or impose additional restrictions, it may be pointed out that the rules do not interfere in any way with the existing and established electrical practice of the major oil companies.
>
> "(*b*) That when recommending banning the use of electricity in any area where a dangerous atmosphere is always present, the Electrical Committee first of all agreed quite definitely that nowhere in the petroleum industry (where lighting or power is normally required) does such a condition in fact exist.

"In the discussion both Mr. Mann and Mr. Horsley referred to earth-leakage protection and it was not made clear that we fully appreciate the value of this type of protection but find difficulty in its practical application, due :—

> "(1) to the limitation of the equipment offered by manufacturers, the bulky nature of the devices and to the excessive cost of earth-leakage trips on flameproof apparatus,
>
> "(2) more particularly in locating such devices in the distribution system.

"For instance, if there is a built-up starter switchboard in a pumphouse controlling individual motors varying from 85 h.p. down to 7½ h.p., earth-leakage trips on each starter involve an excessive cost and still leave the incoming cable unprotected, whereas earth leakage further back cannot be said to give the required sensitivity and protection to provide both for all motors operating simultaneously, and for one small motor running by itself.

"I had intended to voice these opinions at the meeting, which, however, terminated somewhat abruptly before I had the opportunity."

MR. MACLEAN, in a written reply, agreed with the remarks communicated by Mr. Ambrose.

The length of time occupied by the paper and the discussion had deterred him from responding to the President's concluding remarks, but he would like to record his appreciation of these and to thank those who had contributed to the discussion for the many interesting and valuable points which they had raised. These would be of considerable help to the Institute in considering the final form of the Code.

THE DETERMINATION OF THE PRESSURE-VISCOSITY COEFFICIENT AND MOLECULAR WEIGHT OF LUBRICATING OILS BY MEANS OF THE TEMPERATURE-VISCOSITY EQUATIONS OF VOGEL AND EYRING.

By A. Cameron, Ph.D.

Summary.

1. The viscosity η_t of an oil at any temperature t° C. can be determined from Vogel's equation $\eta_t = k \exp. \left(\frac{b}{t + \theta_t}\right)$, where k, b, and θ_t are constants for any oil. From a study of Erk and Eck's accurate viscosity–temperature data it is shown that θ_t can be put equal to 95 for almost all oils without appreciable error.

2. The viscosity η_p at any pressure and at a given temperature t can be expressed by the exponential law.

$\eta_p = \eta_0 \exp. (\phi P)$, where η_0 is the viscosity at atmospheric pressure and temperature t, ϕ is a constant for any given oil at temperature t, and p is the pressure. It is shown that the product, A, of ϕ and $(t + \theta_p)$ is approximately constant, when $\theta_p = 52$.

3. It is found possible to obtain A in terms of the temperature characteristics of the oil. (i) If $\theta_t = 95$ and $\theta_p = 52$, then $1/A = 9{\cdot}00 - 4{\cdot}20 \times 10^{-3} b$. (ii) If N equals the ratio viscosity at 70° F./viscosity at 140° F., then $A = 0{\cdot}12 + 10^{-2} N$.

4. Over a small temperature range it is possible to put $\theta_p = \theta_t = 73$. This gives a combined expression for η_{pt} the viscosity at any pressure and temperature. As before, A can be found in terms of b.

5. For fatty oils θ_p is found to be 85. It appears that A is constant and equals $1{\cdot}4 \pm 18$ per cent. for all fatty oils other than castor oil, which equals $1{\cdot}7 \pm 10$ per cent.

6. M the molecular weight of an oil can be calculated from the constants in Vogel's equation by means of the empirical relations :—

$$M = 0{\cdot}546\,(b^{1\cdot47} \,.\, k^{0\cdot473})_{\theta=95}$$

or

$$M = 0{\cdot}588\,(b^{1\cdot517} \,.\, k^{0\cdot517})_{\theta=73}$$

of which the former is to be preferred.

Pressure, Temperature–Viscosity Equations.

A great deal of work has been published on the dependence of the viscosity of oils on the temperature. The two most generally known equations relating the two are the Walther[1] and the Vogel[2] formulæ.

The Walter formula is stated as :

$$(\nu + \alpha) = A \exp. \left(\frac{b}{T^c}\right)$$

where ν = viscosity in centistokes,
T = absolute temperature,
$A = 1$,
α, b, and c are constants for any given oil.

Vogel's formula is :—

$$\eta = k \exp. \left(\frac{b}{t + \theta}\right)$$

where η = viscosity poises,
t = degrees Centigrade,
k, b, and θ are constants for any given oil.

Erk and Eck [3] have examined the validity of these formulæ between 20° and 80° C. for a considerable range of oils.

Vogel's formula is the most satisfactory, but is complicated to use, as there are three constants to be chosen for each oil. It had already been established [4] that α, the constant in the Walther formula which varies between 0·7 and 0·95, could with a reasonable degree of accuracy be put equal to 0·8. This simplified the formula considerably, as it allowed a viscosity–temperature chart to be constructed with log T as abscissa and log log (ν + 0·8) as ordinate.

Analysing Erk and Eck's data, it was seen that θ in Vogel's formula varied round a mean of 95, with extremes of 109 and 78. If θ is put equal to 95 for all oils, it is possible to construct a viscosity–temperature chart with $\frac{1}{t + 95}$ as abscissa and log η as ordinate. The accuracy of the relation varies with the difference between the optimum value of θ and 95. To test this point some of Erk and Eck's results were plotted on a large scale, and the errors of intrapolation and extrapolation worked out according to Erk and Eck's formula,

$$\Delta\eta\% = 100 \times \frac{\eta \text{ calc.} - \eta \text{ meas.}}{\eta \text{ measured}}.$$

The results obtained are shown below.

Vogel I is the formula using the optimum value of θ, which is listed in each case.

Vogel II uses $\theta = 95$. The Walther formula is the A.S.T.M. formula with $\alpha = 0{\cdot}8$.

Erk and Eck's Data.

Erk and Eck Oil Number.	Temp., t° C.	Viscosity meas. poise.	$\Delta\eta$, %.		
			Vogel I.	Vogel II.	Walther.
			$\theta = 96{\cdot}721$.		
1935/2 Table I	20·00	0·146	—	—	—
	40·02	0·0680	—	0·0	+0·9
	59·99	0·0386	−0·5	—	—
	80·01	0·0249	—	+0·16	−4·7
			$\theta = 77{\cdot}99$.		
1930/3 Table VII	17·01	4·68	—	—	—
	38·00	0·943	−0·8	+2·3	+1·2
	51·22	0·445	−0·4	+1·1	+0·5
	58·15	0·318	—	—	—
	73·52	0·169	—	−3·9	−1·4
			$\theta = 109{\cdot}404$.		
1934/1 Table VIII	18·955	4·51	—	—	—
	40·29	1·19	—	−1·8	0·0
	59·90	0·471	+0·1	—	—
	79·91	0·223	—	+2·8	+0·7

These figures show that the Vogel II has the same order of accuracy as the simplified Walther formula, even in the case of oils 1930/3 and 1934/1, where the difference between the θ's of Vogel I and Vogel II is maximum. Erk and Eck also examined the straight exponential relation $\eta = k \text{ exp. } \left(\frac{a}{T}\right)$, and showed that it was not at all suitable for oils.

This Vogel formula is much easier to use than the Walther type, as, firstly, as will be shown below, it can be related to Eyring's theoretical work on viscosity. Secondly, in any theoretical work on the variation of viscosity it is possible to define a viscosity–temperature scale with a zero at -95° C., so that viscosity varies exponentially with T_V the " viscosity–temperature " according to the law

$$\eta = k \text{ exp. } \left(\frac{b}{T_V}\right).$$

Now Eyring and his co-workers have published several papers on the theoretical derivation of an equation relating viscosity with temperature and pressure. They have shown [5] that the viscosity of simple liquids such as pentane and ether can be calculated from the equation

$$\eta = \frac{Nh}{V} \text{ exp. } \left(\frac{\Delta F + p\Delta V}{RT}\right)$$

where η = viscosity poises,
N = Avogadro's Number,
h = Planck's Constant,
V = volume of 1 gram-mole of liquid,
ΔF = Free energy of activation for flow,
ΔV = Free volume,
R = gas constant,
T = absolute temperature,
p = pressure kg./sq. cm.

ΔF is found to be approximately one-third or one-fourth of the latent heat of evaporation of the liquid and ΔV = one-sixth or one-seventh V.

If the pressure is small—that is, atmospheric—the equation becomes

$$\eta = \frac{Nh}{V} \text{ exp. } \left(\frac{\Delta F}{RT}\right).$$

For any given liquid this becomes

$$\eta = k \text{ exp. } \left(\frac{a}{T}\right),$$

where k and a are constants.

If the temperature is kept constant the viscosity at any pressure can be expressed by the relation

$$\eta_p = \eta_0 \text{ exp. } \left(\frac{p\Delta V}{RT}\right)$$

where η_p = viscosity at pressure p and temperature T,
η_0 = viscosity at atmospheric pressure and temperature T.

or

$$\eta_p = \eta_0 \text{ exp. } (\phi p),$$

where ϕ is a constant for any given oil and temperature.

Now, Suge[6] has shown that for a considerable number of oils this exponential law holds. Eyring's theory predicts that ϕ varies inversely with the absolute temperature. This in point of fact does not occur, and Suge gives a further exponential law to account for the variation of ϕ with temperature.

Summing up, then, it appears that the variation of the viscosity of oils with temperature can be described by the empirical relation $\eta = k \text{ exp. } \left(\frac{b}{t+95}\right)$, while theory predicts the straight exponential law $\eta = k \text{ exp. } \left(\frac{a}{T}\right)$. The actual variation of viscosity with pressure appears to fit the theoretical law $\eta_p = \eta_0 \text{ exp. } (\phi p)$.

In the following sections the possibility of combining these two equations to a general form will be examined.

This general equation is :—

$$\eta_{pt} = k \text{ exp. } \left(\frac{b + Ap}{t + \theta}\right)$$

where η_{pt} = viscosity at pressure p kg./cm.^{2} and temperature t° C.,
k, b, and θ are constants as before,
$A = \phi\ (t + \theta)$.

It is first necessary to see how ϕ varies with the temperature, and if, within the probable experimental error, it can be fitted into the relation $A = \phi\ (t + \theta)$. Should θ not equal 95, the correct value must be ascertained. As in point of fact θ is not universally equal to 95, we will use the subscripts t and p in describing θ in the temperature–viscosity or pressure–viscosity equations respectively.

Before this is undertaken a review of experimental work published on the effect of pressure on viscosity is given. It will be done in some detail, because, as far as is known, no comprehensive list of references exists on this subject. An attempt will be made to classify the types of curves found into three or four classes for convenience of future discussion.

Published Work.

A study of the literature shows that a considerable amount of work has been published on the pressure–viscosity characteristics of oils, but the temperature–viscosity characteristics of the oils investigated are very rarely given. This naturally considerably decreases the amount of work that can be used. It is useless to obtain ϕ if b and k are unknown.

The majority of the data used here is obtained from two papers by Suge.[7, 8] They are written in Japanese, but after reading the paper written in English[6] it is possible to follow the Japanese papers with only the minimum of translation. The chief difficulty is the names of the oils, some of which are in Japanese. The translation of them will therefore be given.

In the 1932 paper twenty oils are examined at 18° C. The first twelve are given in English (pp. 880–881), the remainder are as follows: Oil No. 13 is Liquid Paraffin; 14, Heavy Oil No. 2; 15, Rape; 16, Castor;

17, Hemp; 18, Camellia; 19, Whale, and 20 is Horse Oil. The detailed results follow in the same order as the list on pp. 880, 881. No data are supplied for the temperature–viscosity relationship of the oils, and efforts to trace them have not been satisfactory. All the oils examined follow the exponential pressure–viscosity law.

In the next paper—1933—the viscosities were measured at different pressures and temperatures. Some oils are listed in English or German, and the rest in Japanese. In the table on p. 651 we have, reading downwards, Mobiloil B, Autoil 2, Castor Oil, Rape Oil, Whale Oil, Voltol, Flugol, Ossag V 14, Heavy Fuel Oil and Special Heavy Oil. Further results are given on pp. 659 ff.; these oils are: Heavy Oil No. 1, Heavy Oil No. 2, Special Heavy Oil, Heavy Fuel Oil, Miri and Tarakan Diesel Oil. The Special Heavy and Heavy Fuel Oils are the same as those given on p. 651. The only oils that did not follow the exponential pressure viscosity law were the two diesel oils. The graphs of these two had a slight positive curvature (this is taken here as meaning the centre of curvature is on the positive side of the curve).

The earliest accurate measurements on the pressure–viscosity effect were by Hyde.[9] The experiments were all carried out at 40° C., and a number of other physical properties—the dielectric constant, specific heat, surface tension, setting point, flash point—were also measured at 40° C. The viscosity and density were determined over a range of temperatures. Of the mineral oils, three gave the straight-line exponential law for the pressure effect, and two—Mobiloils A and BB—gave graphs with positive curvature. The results of experiments on fatty oils will be considered later.

Further very accurate work has been carried out by R. B. Dow,[10] who gives only graphical and not numerical results, but from Fig. 2 of his paper the values of the viscosities of a Pennsylvanian extracted oil at four different temperatures can be obtained. These results, if transposed to semi-logarithmic paper, all give straight lines. The atmospheric pressure viscosities can be read from the curves.

Kleinschmidt,[11] working under the auspices of the Lubrication Committee of the American Society of Mechanical Engineers, has published a number of results, but gives the viscosity–temperature characteristics of his oils only in the cases of Veedol Medium and Mobiloil A. The same applies to the work of Hersey and Shore,[12] but this latter work is valuable in that it demonstrates very well the effect of repeated cycles of pressure on an oil. This is instanced especially in the case of Veedol Medium, where the viscosities vary considerably for repeated pressure cycles. This result shows how similar is the effect of large pressures to that of low temperatures, as it is well known that once an oil has frozen under low-temperature conditions it takes a considerable time for all the wax crystals to dissolve. In the same way, once an oil has frozen under pressure, subsequent viscosities will differ appreciably from each other, even though the pressure at which the measurement is made is well below the freezing pressure of the oil. Now, in gears or other bearing surfaces where high pressures are applied to the oil, any given particle of oil is under pressure for a very short time, in the order of milli-seconds. This means that the oil will almost certainly not freeze, but exhibit some sort of "superpressure" effect (analogous to super-cooling), during the short time that the pressure is actually applied. Experimental results, obtained from oils that have started to freeze under pressure, are therefore not applicable to such systems. It may be noted that Cragoe [13] has put forward an interesting application of Clausius–Clapeyron's equation by which the pressure required to freeze an oil may be determined from the pour point.

Suge (p. 1252 ref. 6 or p. 893 ref. 7) found that partial solidification occurred in a number of oils between about 1000 and 1500 kg./sq. cm. at 18° C. He states [7] that if 10% of solid paraffin was dissolved in liquid paraffin the freezing pressure dropped from 1300 to 400 kg./sq. cm.

Kiesskalt [19] obtained, with "Veedol medium" and lard oil, similar values for the freezing pressure.

Dow [14] described experiments with three different types of crudes: from Pennsylvania, Oklahoma, and California—*i.e.* paraffinic, mixed paraffinic–naphthenic, and asphaltic crudes, respectively. The atmospheric pressure viscosities appear anomalous, as they do not give straight lines when plotted on the A.S.T.M. chart. Corrections were subsequently published by Everett,[15] and these amended values give linear plots. The Californian oil gives a slight curvature on the log viscosity–$(1/t + 95)$ graph, which is unusual. The log viscosity pressure curves are linear, except for the 130° F. Californian oil, which has a negative curvature, and also the 99° C. Pennsylvanian oil curve. Curves of this particular shape are also shown by six Pennsylvanian oils described by Dibert, Dow, and Fink.[16] There is a rapid rise in viscosity at low pressures, and then the curve flattens out to give a straight line of normal slope. It is difficult to judge if these deviations are real or due to an inaccuracy of the instrument.

Wolarowitsch,[17] working in Moscow, and therefore presumably using Russian, which may have been napthenic crudes, found negative curvatures with some oils. Bridgman [18] has also observed this type of curve with several simple organic liquids.

Typical plots of log–viscosity against pressure are drawn in Fig. 1.

The linear plot is illustrated by Suge's Autoil No. 2 at 40° C. in Fig. 1, curve 1; this type is the most common. Of the other types, an oil giving a positive curvature is the next most common though it is not very often seen. A typical example is Hyde's Mobiloil A, which is shown as curve No. 2. Negative curvature is exampled by Wolarowitsch's oil No. 4 or by the Californian oil investigated by Dow [14] at 130° F. This latter is shown in curve No. 3, and this type is not at all frequent. The anomalous type with the sudden rise of the log-viscosity pressure curve is shown by the oils described by Dibert, Dow, and Fink, or by the Pennsylvanian oil at 99° C. investigated by Dow.[14] The pressure–viscosity curve of this oil is plotted as curve 4, Fig. 1.

Summing up, then, most oils give a straight-line relation between log-viscosity and pressure. A few give curves with positive curvature, and a smaller number have a negative curvature. Two investigations have shown the anomalous type pictured in curve 4.

Of the five oils measured by Wolarowitsch, oil No. 4 had a negative curvature and oil No. 2 was measured only at 16° C., so that the viscosity–temperature curve cannot be drawn. The remaining three—Nos. 1, 3, and 5—gave a linear exponential viscosity–pressure law, and will be discussed later.

As far as is known, the only remaining published work is by Kiesskalt.[19] Here the relative increase in viscosity of twelve oils (eight mineral and four fatty) is measured at 400 atmospheres and 50° C., and at 880 atmospheres and 80° C. He gives the corresponding relative decrease of viscosity at atmospheric pressure at these two temperatures, referring to 20° C. as unity. Thus we have the pressure–viscosity coefficient for 50° C. and 80° C. taken at 400 and 880 atmospheres, respectively. It means, however, that we have no method of checking up the linearity of the pressure–log-viscosity curve, as there is only one point at each of the two

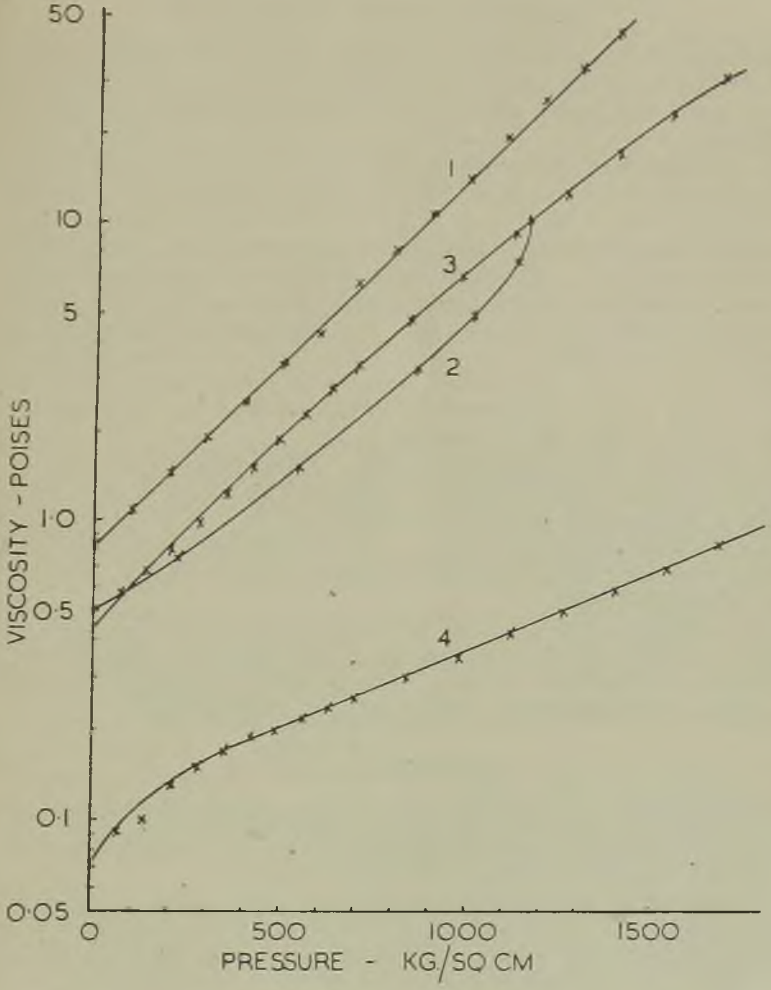

FIG. 1.

temperatures. On these grounds it was felt that the figures were not sufficiently complete to use.

It is now necessary to see if ϕ; the pressure viscosity coefficient, when multiplied by $(t + \theta)$ is constant.

VARIATION OF ϕ WITH TEMPERATURE.

ϕ decreases regularly with temperature, and it is necessary to find the law it follows. Suge proposed an exponential relation. From the foregoing work one would expect the product of ϕ and $(t + \theta_p)$ to be a constant.

A preliminary investigation showed that the product $\phi \times (t + 95)$ was not constant, as it decreased with increasing temperature. In order to find if ϕ did vary with $(t + \theta_p)$, $1/\phi$ was plotted against temperature. If a straight line resulted, the value of the intercept on the temperature axis would be equal to θ_p. The results were satisfactory, as all the oils examined gave a straight-line relation, and normal lubricating oils gave values for the intercept between 40 and 60. The fuel oils investigated by Suge, which had very small viscosities, gave very low values of θ_p, while Voltol, which is a polymerized oil, has a much higher value of θ_p, equal to 83. Neglecting these, as they are not normal straight lubricating oils, the mean value of θ_p is found to be 52.

There were some exceptions to this. Wolarowitsch's oil No. 1, for instance, gave a value of θ_p equal to 230, and his oil No. 3 gave the same value of the pressure–viscosity coefficient ϕ at 60° as it did at 22° C. The value of θ_p for oil No. 5 was 26° C. It was considered that these extreme values were more likely to be due to experimental conditions, and so these results were neglected.

It is unfortunate that θ_p does not equal 95, the value of θ_t, as it would then be possible to use one formula to take both the pressure and the temperature effects into account. The possibility of using 73, a mean of θ_p and θ_t, was investigated. This would give the equation

$$\eta_{pt} = k \exp. \left(\frac{b + AP}{t + 73}\right),$$

where η_{pt} is the viscosity at pressure p and temperature t. This leads to errors in the pressure–temperature equations, but over a limited temperature range they are not too serious, as is shown below.

The errors in the viscosity–temperature curve using θ_t equal to 73 instead of 95 can be determined from Erk and Eck's data, as was done above. Taking their oil No. 1935/2, the percentage error, $\Delta\eta$ per cent., at 40·02° C. is $-$ 5·3 per cent. and at 80·01° C. is $-$ 6·5 per cent., as compared with an error of 0·00 and + 0·16 per cent. with the Vogel II formula $(\theta_t = 95)$.

The error in the pressure–viscosity coefficient A is illustrated by figures calculated from some of Suge's results (Mobiloil B) which he obtained over an extended temperature range. We will test the values of $\phi \times (t + \theta_p)$ over the experimental range of 1 to 156° C., taking θ_p equal to 52 and 73. These figures are typical, and are given as they cover a larger temperature range than any other published experimental results.

Values of $\phi \times (t + \theta_p)$.

Temp., °C.	1.	10.	18.	30.	40.	50.	65.	105.	124.	156.	Av.
$\theta_p = 52$	0·232	0·185	0·204	0·203	0·206	0·212	0·221	0·191	0·194	0·210	0·204
	0·191	0·198	0·204	0·205	0·205	0·207	0·208	0·204	0·199	0·200	
$\theta_p = 73$	0·324	0·247	0·265	0·255	0·253	0·256	0·257	0·217	0·217	0·231	0·257
	0·266	0·265	0·265	0·257	0·252	0·250	0·245	0·231	0·223	0·220	

This shows that A, the product $\phi \times (t + \theta_p)$, is constant when $\theta_p = 52$ and falls when $\theta_p = 73$. The variation is not very serious in the second case, and it amounts to about ± 15 per cent. at either end of the scale.

In conclusion, then, we see that the use of the constant $\theta_t = 95$ for the viscosity–temperature relation gives results as accurate as the simplified Walther equation, and using $\theta_p = 52$ for the pressure–viscosity equation gives results, for straight lubricating oils, which are within the experimental variation.

The mean $\theta_{pt} = 73$ can be employed and a combined equation evolved, which is reasonably accurate over a small range. This is useful for theoretical calculations, when a single equation is needed to take account of the effects of both temperature and pressure on the conditions obtaining in an oil film.

Correlation of b and A.

Now, if the two equations for the effect of pressure and temperature on viscosity are related to Eyring's theoretical equation, b should be some function of ΔF, and A some function of ΔV. Now, ΔF is an energy of activation, and thus some function of the latent heat of evaporation. Fenske, McCluer, and Cannon [20] have shown experimentally that the latent heat of evaporation per gram of all the lubricating oils investigated by them were sensibly constant. The latent heat of evaporation per gram mole must therefore be proportional to the molecular weight of the oil. ΔV is a fraction of the molecular volume of the oil, and must therefore also be related to the molecular weight.

Thus, as b and A are both functions of the molecular weight, they should be related to each other.

Previously Kiesskalt,[19] using a rather complicated expression for the viscosity temperature curve of an oil, correlated the viscosity–pressure effect with its viscosity–temperature characteristics. Cragoe [13] also noticed there was a relation, but did not give any quantitative expression for it.

The values of b and A have been worked out for the oils which have been discussed above, and if b is plotted against A, it is seen the two quantities are definitely related, though not linearly. It was found, however, that a plot of $\frac{1}{A}$ against b gave a straight line. If $\left[\frac{1}{A}\right]_{\theta_p = 52}$ is plotted against $[b]_{\theta_t = 95}$, the equation of the resulting straight line drawn through these points is :—

$$\left[\frac{1}{A}\right]_{\theta_p = 52} = 9{\cdot}00 - 4{\cdot}20 \times 10^{-3}\,[b]_{\theta_t = 95}.$$

Values for A and b were also worked out taking $\theta = 73$ for both A and b, and this resulted in a similar straight line with the same slope, and the equation relating the two quantities is :—

$$\left[\frac{1}{A}\right]_{\theta=73} = 6{\cdot}8 - 4{\cdot}2 \times 10^{-3}\,[b]_{\theta=73}.$$

The first equation is very much more accurate than the second.

Instead of using 6 to determine A, N the ratio of the viscosity at two temperatures was used, as this is simpler than 6 to work out. The two temperatures chosen were 70° F. and 140° F. N is defined as the ratio of the viscosity at 70° F. to the viscosity at 140° F. (at atmospheric pressure); thus N equals exp. $2{\cdot}161 \times 10^{-3}[b]_{\theta=95}$. Now as there is a relation between A and b, one must exist between A and N. The plot of A against N is shown in Fig. 2. The best curve between the points is a straight line with a slope of $1{\cdot}00 \times 10^{-2}$ and on intercept on the A axis of 0·12. The relation between A and N is therefore given by the relation :—

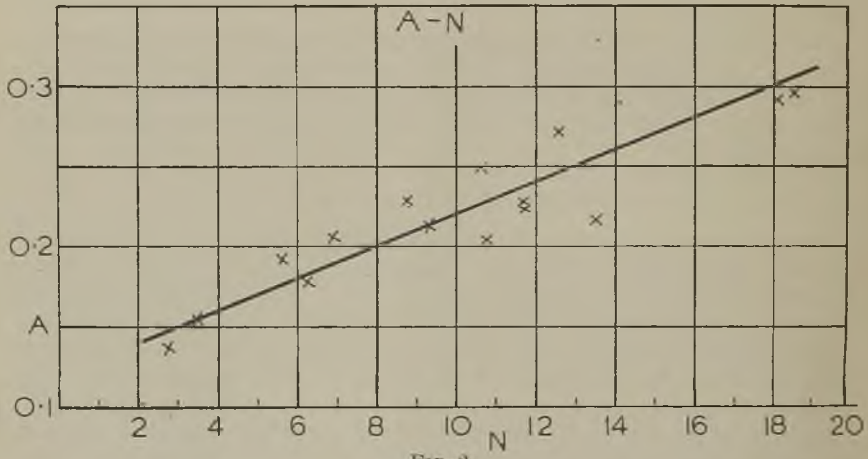

Fig. 2.

$$A = 0{\cdot}12 + 10^{-2}N.$$

Any two temperatures could of course be taken, but 70° F. and 140° F. were used, as they are commonly employed in practice.

It must be emphasized that these relations are empirical and rest on the available published material, and further work may lead to modified and more accurate forms. Their use in this present empirical form is, however, necessary until such time as the theory of viscosity is sufficiently advanced to deal with the hydrocarbons found in lubricating oils.

This equation simplifies the pressure–viscosity problem, as it is possible to obtain an approximate value of the pressure–viscosity coefficient from a knowledge of the temperature–viscosity characteristics of the oil.

It is clear, of course, that this does not take into account oils that give curved exponential pressure–viscosity plots, but as these are only slightly curved, and do not often occur, the possible error is not as serious as might be expected. Further, it is hoped to show elsewhere that the oil pressures reached in gear lubrication are of the order of 2000 kg./cm.^{2}, where the errors in viscosity resulting from considering all oils as obeying the exponential law are not too large.

The ideal oil is clearly one that has a small temperature–viscosity coefficient (high V.I.) and large pressure–viscosity coefficient. The equation shows that these are mutually exclusive in a straight oil. A high V.I. automatically brings about a low-pressure viscosity coefficient. It appears that this can, to a large extent, be overcome by using a low V.I. naphthenic oil and improving the V.I. by the use of an additive such as poly*iso*butylene. Dow [21] found that ϕ for a Pennsylvanian distillate of 100 V.I. was 1·78 at 130° F., while a Californian distillate of 16 V.I. had ϕ equal to about 2·9 (the exact value is uncertain as the log–viscosity–pressure graph is curved). If the V.I. of the Californian distillate was brought up to 100 by the use of poly*iso*butylene, ϕ dropped to 2·3, which is still appreciably higher than the Pennsylvanian oil.

The use of V.I. improvers is, however, limited by the fact that they increase the viscosity of the base oil to which they are added. Thus to obtain a finished oil of a certain specified viscosity the original base oil has to much lighter. In general, b falls as the viscosity of the oil falls, and thus may be below that of a normal straight high V.I. oil. There would in this case then be no advantage in starting with a low-viscosity naphthenic oil and adding a large amount of V.I. improver over the normal high V.I. straight oil.

Viscosity–Pressure Coefficient of Fatty Oils.

Fatty oils have been studied quite extensively, though industrially they are not so important as mineral oils. The first point that emerges from a comparative study of mineral and fatty oils is that the pressure–viscosity coefficient is much lower. Further, it is seen that θ_p is much larger in the case of fatty oils than for mineral oils. Fatty oils follow the exponential pressure viscosity law with very few exceptions.

Plotting $1/\phi$ against temperature straight lines are again observed. The fairly extended measurements of Suge give values of θ_p varying between 80 and 90, with a mean cf 85. The results of Kleinschmidt and of Hersey and Shore are not always consistent, as their values of ϕ do not change regularly with temperature. This is probably due to the oil having been frozen in previous runs, which renders the results erratic. This effect of freezing is shown very well by Hersey and Shore's results for castor oil No. 2 (reference 12). This effect may explain the considerable variation of one sample compared with another.

If the values of b are plotted against A, it is seen that apparently no detailed relation exists between them, except in so far that castor oil, which has a larger value of b than any other oil, also has a larger value of A.

It seems, however, that with the exception of castor oil, all the remaining fatty oils studied—which are Lard, Rape, Sperm, Trotter, Hemp, Camellia, and Horse—have approximately the same value of A. This works out to be 1·4 ± 18 per cent. The value of castor oil may be taken as 1·7 ± 10 per cent. Both these figures are evaluated with θ_p equal to 85.

Molecular Weight.

From a study of Eyring's equation it is seen that the molecular weight comes into the various constants that determine the viscosity. It has been shown that Vogel's equation can be considered as an empirical modification of Eyring's relation, and so it was thought that it might be possible to obtain the molecular weight from the constants of Vogel's equation.

Now, neglecting the pressure–viscosity term, Eyring's equation is

$$\eta = \frac{Nh}{V} \exp. \left(\frac{\Delta F}{RT}\right)$$

where η = viscosity in poises,
N = Avogadro's number,
h = Planck's constant,
V = Volume of 1 gram-mole of liquid,
ΔF = Free energy of activation for flow,
R = Gas constant,
T = Absolute temperature.

Eyring points out that ΔF is a constant fraction of the molecular heat of vaporization. Now, if L is the heat of vaporization per gram, and M is the molecular weight, ΔF will be a fraction of LM. It has already been noted that L is constant for all oils, so that ΔF is directly proportional to M. Consider the quantity $\frac{Nh}{V}$. Nh is constant, being the product of Avogadro's and Planck's constants; V, the molecular volume, is equal to M/ρ, where ρ is the density. We can therefore rewrite Eyring's equation :—

$$\frac{\eta}{\rho} = \frac{Nh}{M} \exp. \left(\frac{M}{aT}\right)$$

where a = a constant, and η/ρ is the kinematic viscosity in stokes.

We can see that if Vogel's equation $\eta = k \exp. b/(t + \theta)$ is related to Eyring's, k should be some function of Nh/M, and b of M/a, where k and b are obtained by plotting the viscosity in stokes, not poises, against $1/(t + \theta)$.

There have been two papers published on the relation between molecular weight and viscosity, the first by Fenske, McCluer, and Cannon [20] and the second by Keith and Roess.[22] The authors of the first paper propose the following relation for the determination of the molecular weight :—

$$M = 240 + \frac{32{,}310 \log_{10} \dfrac{\text{S.U.V. } 100^\circ \text{ F.}}{280}}{305 - \text{V.I.}}$$

where S.U.V. 100° F. = Saybolt Universal Viscosity at 100° F. and V.I. = Viscosity Index.

This equation has the formal disadvantage that all the values are in technical units.

Keith and Roess do not propose any equation for the molecular weight, but leave their results in graphical form.

The kinematic viscosities of the oils used in these investigations are given by both workers, at 100° F. and 210° F., thus b and k can be determined from the equation

$$\eta = k \text{ exp. } b/(t + \theta)$$

where $\theta = 95$ or 73.

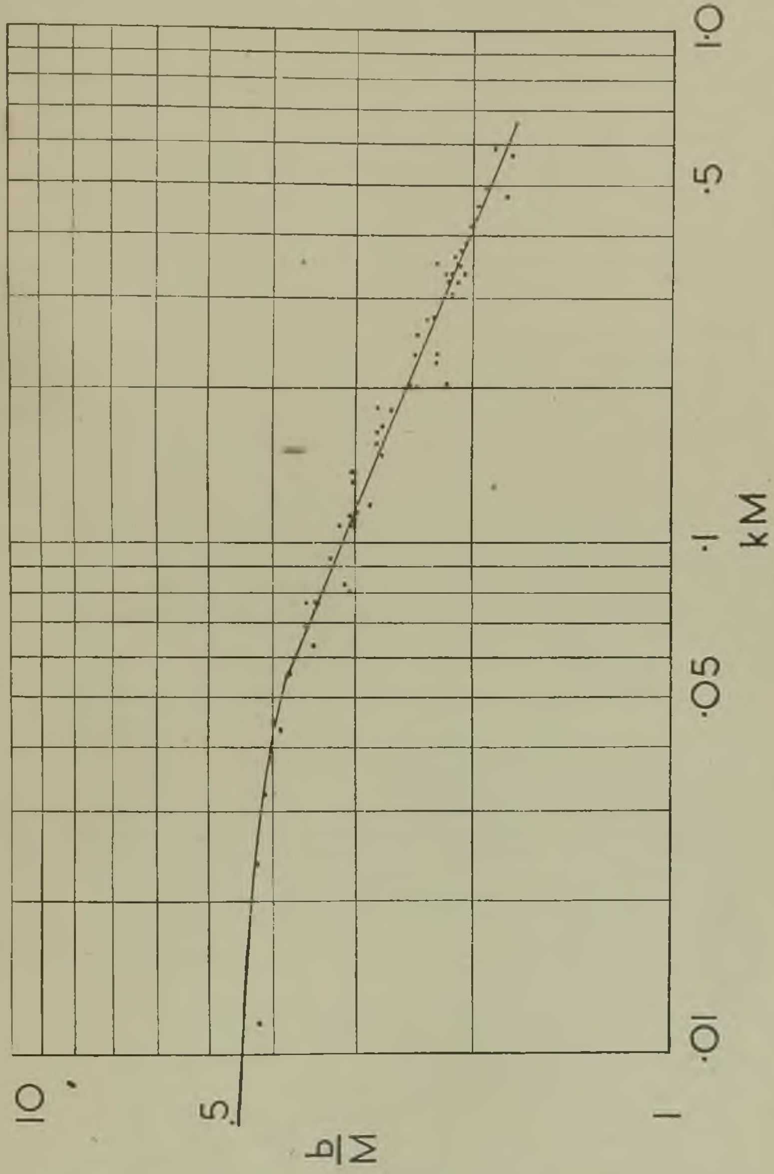

Fig. 3.

As has been shown above, the equation is much more accurate when $\theta = 95$, but it is sometimes convenient to have an approximate value of the molecular weight when the constants have been determined for $\theta = 73$.

Using both these papers, it is possible to work out kM and b/M. If

Eyring's equation was exactly applicable here kM would be constant and some fraction of Nh and b/M would equal $1/a$, which is also constant. Neither of them is constant, however, but if kM is plotted against b/M a correlation is shown to exist, as all the points fall on a single curve. It is perhaps significant that the theory gave the combination of k, b, and M that enabled all the points to fit on a single curve.

If the values of kM and b/M are plotted on log–log paper a straight line is observed for all values of kM greater than 0·06 for $\theta = 95$ and 0·10 for $\theta = 73$ (see Fig. 3). For $\theta = 95$ the equation of the straight part of the curve is $b/M = 1{\cdot}51\ (kM)^{-0{\cdot}3207}$, which can be written

$$M = 0{\cdot}546\ (b^{1{\cdot}47}\,.\,k^{0{\cdot}473})_{\theta=95}.$$

This equation is valid for kM greater than 0·06.

If θ is put equal to 73 the equation for the molecular weight is

$$M = 0{\cdot}588\ (b^{1{\cdot}517}\,.\,k^{0{\cdot}517})_{\theta=73}$$

and is valid for kM greater than 0·10.

It is interesting to note that at low values of kM, b/M tends to a constant value, as Eyring's theory requires.

It must be remembered that in these equations b and k are both determined for viscosity in stokes, and not in poises, as is normal.

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"EAGLE" SINGLE COMPARTMENT BOTTOM SAMPLER.

By R. G. Mitchell, A.R.I.C., and S. A. Hunn, A.M.I.Chem.E.*

Summary.

The advantage of being able to obtain liquid samples right from the bottom of tankage on storage installations, refineries and tankers, and the shortcomings of existing samplers for this purpose led the authors to evolve the apparatus described below, which measures 2¼ in. diameter by approximately 8½ in. high, weighs 6 lb. and is capable of obtaining 160 c.c. of liquid from the very bottom of a tank.

Description.

This sampling apparatus (see Figs. 1, 2, 3, 4, and 5), is covered by British Patent No. 566,752 and consists of a cylindrical casing with conical bottom (1) or alternatively, with a flat bottom (2), to which are fitted four legs (3). Into the upper part of the cylinder (1) is fitted a removable tapering top (4), having an air release valve (5) and a carrying handle (6), which is also provided with a loop (7) for holding the chain or cord by which the apparatus is suspended. Inside the casing (1) is inserted a sliding weight (8) of square cross section, fitted at its lower end with a valve and projecting spindle (9) which fits into the centrally positioned valve seating (10) in the bottom of the casing. A stop ring (11), prevents the weight (8) sliding out when emptying the sampler.

Operation.

The method by which the apparatus operates can be readily followed by detailing the procedure in practice.

The sampler is suspended by chain or cord through the loop in the handle and is lowered into the tank. When the valve's projecting spindle attached to the sliding weight touches the tank bottom, the outer casing falls until the legs rest on the tank bottom, thereby opening the inlet valve. The entrance to the sampler is then ⅜ in. from the tank bottom and material at and below this level is forced into the container, replacing the contained air, which is driven out through the air release valve until such time as the predetermined pressure equilibrium is established in the container and the air release valve closes.

Based on the difference in fluid head pressure at the determined level of the sample, and the air release valve, together with the weight of the metal ball in this valve, the level of the sampled liquid at the point at which the air release valve closes will be approximately at the level (12).

The sampler is then drawn up by a cord or chain, and in so doing the casing immediately rises and closes the inlet valve by the weighted spindle fitting into the valve seating, thus keeping the contents from the bottom sealed within the container.

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* In conjunction with Eagle Oil and Shipping Company's Drawing Office.

The removable tapering top is then unscrewed and the sample emptied into an appropriate container. During this operation the sliding weight is prevented from falling out of the container by means of the stop ring.

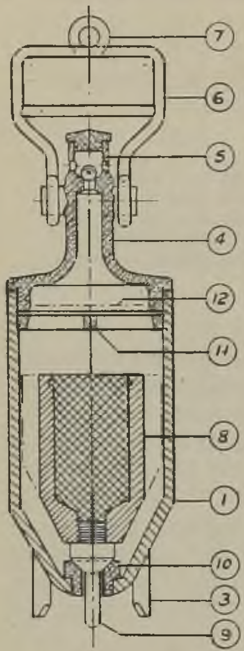

FIG. 1

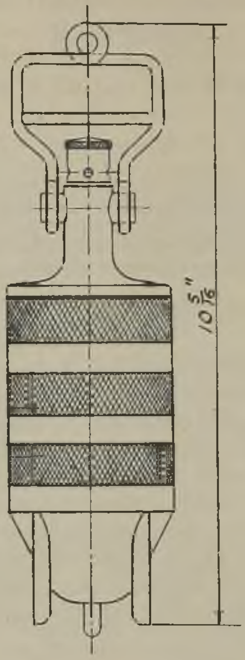

FIG. 2

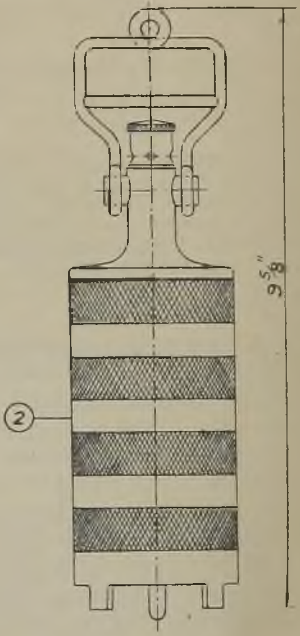

FIG. 5

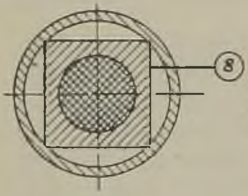

FIG. 3

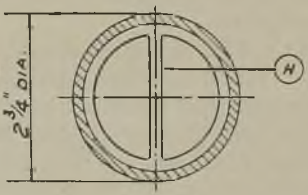

FIG. 4

ADDITIONAL CONSTRUCTIONAL DETAILS.

It was found necessary to insert a filling of lead in the sliding weight in order to obtain the required weight to ensure a positive seating of the valve, because the sampler when lowered into a tank is internally at atmospheric pressure and, where great depths of oil are concerned, the external fluid head pressure would tend to open the bottom valve before the sampler touched the tank bottom, unless the sliding weight was heavy enough to prevent this.

The bottom valve and valve seating are made to screw into their respective positions so that, should they become worn, their replacement is a simple matter.

The method of unscrewing the sampler is to hold the casing with one hand, and turn the tapering top with the other hand by means of the carrying handle. In this connection it has been found desirable to knurl the casing so as to obtain the necessary grip when the sampler is oily.

The general construction has been made as robust as possible and all parts are readily detachable to enable easy cleaning.

Time of Immersion.

The time required for the sampler to fill with oil to the predetermined level naturally depends on the viscosity of the material being sampled and varies from a few seconds with light oils to about 8 minutes with the most viscous fluids tested (95,000 sec. Redwood No. 1 at sampling temperature.)

An indication of when the sampler is full can be obtained by observing when bubbles from the air release valve have ceased to rise to the surface of the oil.

Volume of the Sample Obtained.

It has been found that the volume obtained varies slightly with the velocity with which the oil enters the sampler. This depends on the viscosity of the material being sampled and the depth but, generally speaking, the volume ranges from 165 c.c. with fluids of low viscosity to about 100 c.c. with very viscous fluids.

Efficiency.

Tests using the conical bottom sampler have indicated that with a fuel oil of 32,000 sec. Redwood I at the sampling temperature, and a water bottom as small as 0·15 in., a sample containing 84 per cent. of water can be obtained, whereas with layers of 0·3 in., or more, of water the samples contain 100 per cent. water.

Experimental.

It was noted that when the sampler was rapidly lowered to the tank bottom the water contents of the samples obtained were somewhat lower than expected, particularly when using the flat bottom type. This was found to be due to a pocket of oil becoming trapped under the sampler and sucked in when the valve opened. This trouble, however, is eliminated when the sampler is lowered slowly to the tank bottom, and it was with a view to minimising this difficulty that the conical type of bottom was developed. Generally speaking this latter type is recommended for normal use.

Conclusions.

It is considered that this Single Compartment Bottom Sampler is a great improvement over all bottom samplers known to the authors, and should prove of considerable value to the petroleum industry.

EXTENSION OF THE OCTANE SCALE ABOVE 100 O.N.

The Re-calibration of iso-*Octane + 4 ml. T.E.L./Imp. gal. in* n-*Heptane + 4 ml. T.E.L./Imp. gal.*

Introduction.

A calibration of leaded primary reference fuels was made in terms of unleaded primary reference fuels and the curve extrapolated to the limit of *iso*-octane + 4 ml. T.E.L./Imp. gal. in 1941. This work was undertaken to provide a leaded primary scale for the calibration of new batches of leaded secondary reference fuels, and was reported (*J. Inst. Petrol.*, 1941, **27** (211), 188–194).

Since that time the conditions of test have been modified, and it has therefore been necessary to determine the calibration with the new test conditions to provide a sound basis for the calibration of F6 and C13 with 4 ml. T.E.L./Imp. gal.

Method of Test.

The tentative method of test for weak mixture rating of fuels of high octane number up to *iso*-octane + 4 ml. T.E.L./Imp. gal. is now the "25° Motor Method" (I.P. 43–45 (T)). This differs from the "17° Motor Method" (I.P.T. G39 b-1940 T.) employed in the 1941 calibration, in that the throttle plate between the carburettor and induction manifold is now no longer used and the spark is fixed at 25° advanced.

Table I.

Octane Number Calibration Table for the Extension of the Octane Scale obtained by the 25° Motor Method up to 100 Octane Number, thence by Extrapolation.

iso-Octane + 4 ml. T.E.L./Imp. gal. in *n*-heptane + 4 ml. T.E.L./Imp. gal.

iso-Octane, per cent.	O.N.	*iso*-Octane, per cent.	O.N.	*iso*-Octane, per cent.	O.N.	*iso*-Octane, per cent.	O.N.
70	89·7	78	97·0	86	105·3	94	113·7
71	90·5	79	98·0	87	106·3	95	114·7
72	91·3	80	99·0	88	107·4	96	115·8
73	92·2	81	100·0	89	108·4	97	116·8
74	93·1	82	101·1	90	109·5	98	117·9
75	94·0	83	102·1	91	110·5	99	118·9
76	95·0	84	103·2	92	111·6	100	120·0
77	96·0	85	104·2	93	112·6		

PREPARATION OF PRIMARY SCALE.

Six blends of primary fuels were tested against leaded primary reference fuels in fifteen engines and the arithmetic mean for each test point determined. A curve was drawn through these points and extrapolated so that *iso*-octane + 4 ml. T.E.L./Imp. gal. was equal to 120 O.N. This extrapolation was arbitrary, but made to pass through this point in order to provide continuity with previous work.

The calibration is presented as a curve in Fig. 1 and tabulated in Table I.

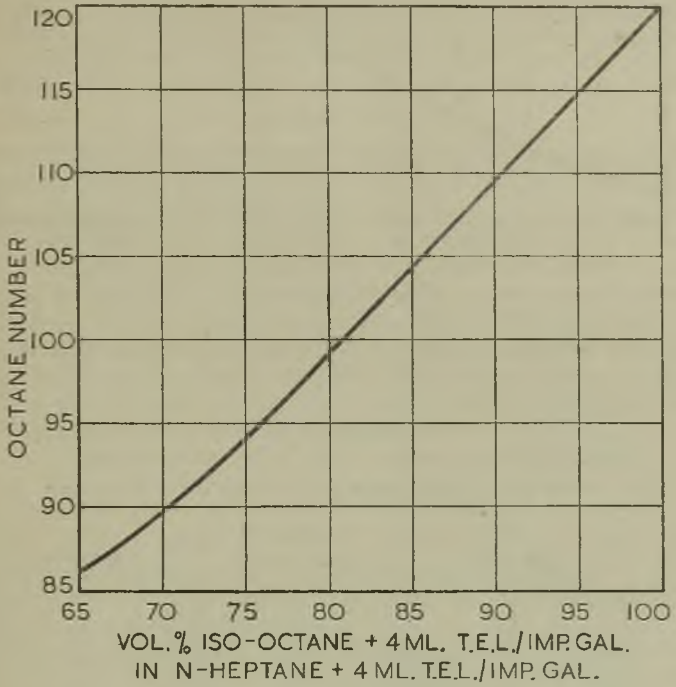

FIG. 1.

CALIBRATION (BY 25° MOTOR METHOD) OF LEADED *iso*-OCTANE AND *n*-HEPTANE AGAINST *iso*-OCTANE AND *n*-HEPTANE, EXTRAPOLATED ABOVE 100 OCTANE NUMBER.

CALIBRATION OF C.F.R. REFERENCE FUELS.

Calibration of Secondary Reference Fuels F6 + 4 ml. T.E.L./Imp. gal. and C13 + 4 ml. T.E.L./Imp. gal. by the 25° Motor Method (I.P.—43/45 (T)).

THE calibration of the above reference fuels has been determined up to and including 100 O.N. by direct tests against clear primary reference fuels and above 100 O.N. by tests against leaded primary fuels and the use of the extrapolated scale given in the preceding report.

The calibration curve is given in Fig. 2 and the data are also presented in tabular form in Table II.

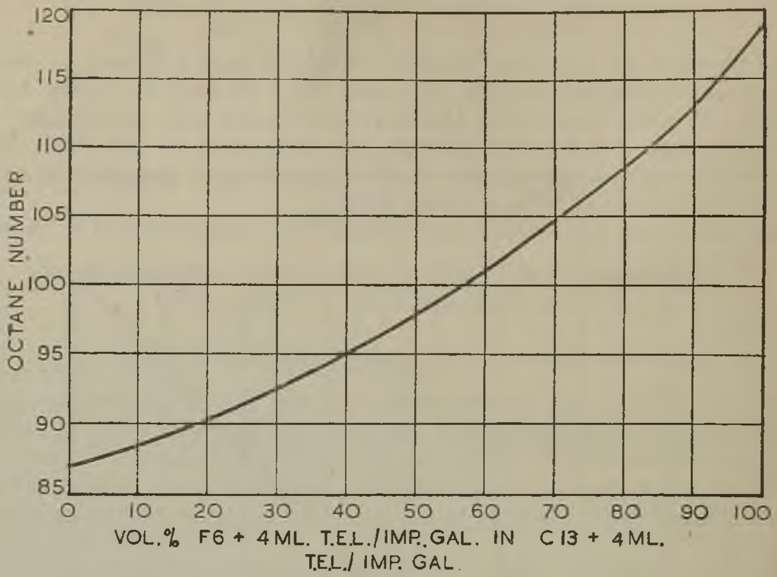

Fig. 2.

CALIBRATION (BY 25° MOTOR METHOD) OF F6 + 4 ML. T.E.L./IMP. GAL. AND C13 + 4 ML. T.E.L./IMP. GAL.

Table II.

Octane Number Calibration Table by 25° Motor Method.

F6 + 4 ml. T.E.L./Imp. gal. in C13 + 4 ml. T.E.L./Imp. gal.

F6, per cent.	O.N.	F6, per cent.	O.N.	F6, per cent.	O.N.	F6, per cent.	O.N.
0	86·8	26	91·7	52	98·5	78	107·9
2	87·1	28	92·1	54	99·2	80	108·7
4	87·4	30	92·6	56	99·8	82	109·5
6	87·7	32	93·0	58	100·5	84	110·3
8	88·1	34	93·5	60	101·2	86	111·2
10	88·4	36	94·0	62	101·8	88	112·2
12	88·8	38	94·5	64	102·5	90	113·1
14	89·2	40	95·0	66	103·2	92	114·1
16	89·6	42	95·6	68	104·0	94	115·1
18	90·0	44	96·2	70	104·7	96	116·2
20	90·4	46	96·7	72	105·5	98	117·5
22	90·8	48	97·3	74	106·3	100	119·0
24	91·2	50	97·9	76	107·1		