AN INVESTIGATION of the RISKS of EXPLOSION in the OPERATION of FLAME-PROOF MINING APPARATUS.

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by

G. HIBBERD, A.R.T.C.

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Kirkgreen
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27/12/29.

The Very Reverend Professor G. Milligan, D.D., D.C.L.,
Clerk of Senate,
The University,
Glasgow,

Dear Sir,

Adverting to your letter, in which I was instructed to amend my Thesis, "An Investigation of the Risks of Explosion in the Operation of Flame-Proof Mining Apparatus" and submit it on or before 31st Dec. 1929, I have honestly endeavoured to satisfy the requirements, and now submit my work for adjudication, amended as follows:

(1) An introduction is given explaining the reasons for undertaking the research, and showing the relationship it bears to the work of investigators who may have had a similar end in view. See Pages i-iv.

(2) The tabulated statements of results have been arranged as indicated on Page V.

(3) A reprint of a paper published in the 4th Number

of the 'Journal' of the Royal Technical College, and a mathematical investigation of "The Drop in Temperature Produced by the Passage of Hot Gases through Apertures" are given in Appendix i, pp. 84 - 88.

(4) A bibliography is given in Appendix ii, pp. 89 - 90.

Trusting that my work, thus amended, meets with approval

I am, Dear Sir,

Yours Respectfully,

AN INVESTIGATION of the RISKS of EXPLOSION in the OPERATION of FLAME-PROOF MINING APPARATUS.

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INTRODUCTION: In May, 1924, the author was awarded the Walter Duncan Research Scholarship by the Governors of the Royal Technical College, Glasgow, and with the approval of the Board of Studies of the College decided to investigate certain problems connected with the safe working of electri::cal machinery in mines.

At that time the term "flame-proof" was applied somewhat loosely to certain types of machinery intended for use underground and many machines considered flame-proof were later shown to be unsafe. This was chiefly due to the lack of suitable references for the guidance of designers and manufacturers of this type of machinery.

The problem of protecting apparatus was attacked by many eminent investigators, and in searching for a solution, the character of flame and flame movement, the various methods of initiating by electrical means an explosion of gaseous mixtures and methods of preventing excessive rise of pressure in a gaseous explosion in a partially closed vessel had to be thoroughly investigated before the real problem of adequate protection could be approached.

In this preliminary work the experimenters used spherical bronze vessels, e.g., in February 1924, in a paper read before the Institution of Mining Engineers, Professor Douglas Hay and Mr. Ira C.F. Statham gave an account of experiments, carried out in such vessels, and also mentioned that they had tested a large number of switch boxes etc., intended for use in mines. A short time later the Safety in Mines Research Board Paper No. 5 appeared under the joint authorship of I.C.F. Statham and R.V. Wheeler. This paper also gave results of investigations in which spherical bronze vessels were used, and in addition put forward certain recommendations which they considered necessary so that flame-proof conditions might obtain.

These papers were welcomed and it was recognised that a great step had been made towards the solution of the problem of safe working of electrical machinery in mines. It was felt, however, that the results obtained were only truly applicable to spherical vessels, and some difficulty arose with regard to the application of the recommendations to casings such as were already in use in mines. These casings had been evolved from long experience of the requirements having special regard to economy of space and material, and the ability to withstand the rough usage associated with mining operations. Naturally they differed greatly in material and shape from the spherical vessels used by Hay, Statham and Wheeler.

Many manufacturers had independently evolved machinery which they claimed to be flame-proof, but even after the publication of the above-mentioned papers some doubt existed among them with regard to the margin of safety of their products. This was clearly seen when Sheffield University announced that they were prepared to receive and test Flame-Proof Apparatus and issue certificates if the apparatus satisfactorily passed the tests to which they were submitted. A large number of manufacturers availed themselves of the opportunity and now possess certificates for the apparatus which passed the required tests. In the opinion of many, testing of such apparatus after application of recommendations should not be necessary. Testing might be resorted to as a precautionary measure but recommendations issued should be such that after their application the possibility of failure should not exist.

The author, therefore, decided, after careful perusal of available literature (a bibliography is given in an appendix) and after consideration of the results and recommendations given by investigators to confine himself to a research in which the vessels used would be typical examples of modern mining switch-gear casings, and to endeavour to present results in such a form that designers and others interested would have no difficulty in deciding the dimensions of flanges, gaps, etc., for casings which had to be flame-proof.

Flanged casings were obtained and experiments performed as here described. The results obtained have been presented in the form of graphs from which a suitable design for the flange of any casing and a suitable depth for the flame-proof gap can readily be found.

Abnormal conditions such as the "blowing" of a fuse under large overload conditions, the presence of coal dust in addition to gas, the effect of increased temperature of casings due to working conditions or electrical defects have all been considered. In addition the possibility of passage of flame at the bearings of protected motors has been fully dealt with.

So far as the author is aware these problems have not been discussed in any paper published in this country, and he is confident that the present work will be a useful addition to the list of publications dealing with Flame-Proof Apparatus.

SUMMARY:

1. The work was undertaken because of the necessity of presenting results in a manner that could easily be understood and applied with confidence to actual mining switch-gear casings, etc.

2. This could only be done by experimenting with casings such as were found most suitable (with regard to design and material) for use in mines.

3. The problems dealt with are entirely practical and practical solutions are offered.

4. The work bears no distinct relationship to other works which have the same object in view - viz: absolute safety in operation under all conditions likely to be encoun: :tered - but forms what should be a useful addition to the list of works on the subject of "Flame-Proof Apparatus", since it deals with problems about which very little was hitherto known.

In Appendix No. i a reprint of a paper by the author - published in the 4th Number of The Journal of The Royal Technical College - is presented together with a mathematical analysis of the drop in temperature produced by the passage of hot gases through apertures.

In Appendix No. ii a list is given of the more important works perused by the author. The writer is much indebted to their authors and freely acknowledges the assistance he received by studying their papers. In this connection it is desired to pay special tribute to the work of Professor W.M. Thornton, D.Sc., D. Eng., whose many excellent papers were a constant source of inspiration.

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AN INVESTIGATION OF THE RISKS OF EXPLOSIONS IN THE OPERATION OF FLAME-PROOF MINING APPARATUS.

Electricity by reason of its adaptability is now used extensively in coal mines, but its introduction has been accompanied by many dangers, chief among which are the possibility of ignition of coal dust and inflammable mixtures of methane and air (firedamp). A parallel potential source of ignition may be said to exist in the flame safety lamp, but the protection afforded by gauzes is such that complete confidence may be placed in modern types of lamps, and the design is such that omission of parts during assembly is inexcusable.

Unfortunately absolute reliance, in electrical appara: :tus for use underground, is not justified at present, from a safety point of view. Many protective devices have been introduced, (quite a number displaying the main features of the safety lamp) to guard against the possibility of ignition of gas and dust, but with all devices, great care in inspection maintenance and assembly of parts must be exercised if the apparatus to which they are fitted is to remain safe.

Many vague ideas exist regarding the exact nature and function of these devices, consequently, protected apparatus may become unsafe through deterioration, neglect or lack of knowledge of proper methods of maintenance of these contrivanc: :es.

Few of the original problems of protection of apparatus remain to be solved, and progress in this direction is such that the day is not far distant when it will be possible to install Apparatus, safe in every respect, and be assured that it will retain its safety features as long as the apparatus is in commission.

The present Research was conducted under the direction of the Professors of Mining and Electrical Engineering in the Royal Technical College, Glasgow, and is chiefly concerned with such methods as might be applied to underground electrical Apparatus in order to afford adequate protection from explosive mixtures of gas and air.

Demonstrations were given annually to the Senior Engineering Students of the College.

THEORY OF PROTECTION: Occurrence of Methane:-

The most common explosive gas mixture found in coal mines consists of methane and air, and is generally referred to as "firedamp." Methane is given off naturally as the coal is worked. The gas was probably entrapped during the early stages in the formation of coal, but dissociation of coal substance by great pressure and high temperatures acting over long periods of time, may partly account for its presence. If the gas were allowed to accumulate highly explosive mixtures would in all probability be formed so that to keep mixtures within safe limits dilution with air is necessary.

The "Coal Mines Act" requires that "a sufficient quantity of air shall be constantly circulated to dilute and render harmless all noxious and inflammable gases" to such an extent that the workings, shall be in a fit state for working and passing therein."

Under normal conditions every endeavour is made to maintain the required standards of ventilation, but abnormal occurrences may allow of accumulation of gas where it is least desired e.g. in the vicinity of electrical apparatus. If the system of ventilation is interrupted, say, by a fall of material in an airway, or a stoppage of the fan, gas will accumulate in dangerous proportions in "gassy" sections of the mine. The workings of the mine may also be flooded by the sudden liberation of large quantities of gas from an "outburst." In addition to the above the presence of "blowers" of gas necessitate special attention to ventilation if the formation of explosive mixtures of gas and air is to be prevented.

PRESENCE OF GAS IN APPARATUS:-

Electrical apparatus is subjected to variation of temperature during and subsequent to working periods. Expansion and contraction of the metal casings and gaseous contents will accompany each rise and fall in temperature. It follows therefore that in the process of cooling after working periods, gas will be "drawn" into the box or casing, through the joints, to maintain equilibrium of pressure with the outside. If the surrounding atmosphere contains methane, a highly inflammable mixture may thus be introduced into the casing and thereby create the required conditions for an explosion. Openings in the casing may permit of natural diffusion of gases, so that independent of temperature variations gas may accumulate in electrical apparatus. If the above conditions exist all that is necessary to initiate an internal explosion is a spark or electrical arc, and in event of flames being communicated to the outside of the apparatus, an explosion having far reaching and serious effects may be the final result. Gas tight apparatus or hermetically sealed casings would seem to be the remedy, since accumulation of gases inside casings would be prevented, but difficulty of inspection, renewal and repair, together with rough usage, and deterioration of sealing material in the humid atmospheres of mines, render the application of this measure impracticable. In the absence of sealing methods we cannot prevent the accumulation of gas in casings, so that the danger of ignition is ever present. The real danger lies in the transmission of high temperature gases and flames to the outside, and all protective methods aim at the prevention of this.

IGNITION OF FIREDAMP:-

The mixtures of $C.H._4$ (Methane) and air which on burning evolve the greatest amount of heat contain approximately 9.5 per cent of methane, and are highly explosive. In these mixtures the methane and oxygen are present in approximately the proportions necessary for complete chemical combination. If the percentage of methane be reduced below 9.5 per cent less heat will be generated by the burning mixtures since obviously the amount of heat will depend on the amount of inflammable gas present. In mixtures containing over 9.5 per cent of methane, there is insufficient oxygen present to effect complete combustion. If the percentage of methane be continuously reduced, a point is reached at which only sufficient heat is generated by the burning portion to raise an adjacent portion to the ignition temperature. With further reduction flame propagation does not take place. A similar state of affairs is reached by increasing the percentage of methane above 9.5 per cent. The points at which self propagation of flame ceases are termed the "limits of inflammability" and are 5.3 per cent and 14.8 per cent respectively. It is evident that any variation in the condition of experiment which alters the amount of heat transferred from the burning portion to an adjacent portion will alter the limits of inflammability. Factors which affect the limits are:- material and dimensions of containing vessel, initial temperature and pressure of the mixture, and state of mixture i.e. whether turbulent or quiescent.

Wheeler has shown that the most explosive mixtures are not the most readily ignitable mixtures, and also that slow burning mixtures will transmit flame through small passages when more rapidly burning mixtures would not.

Firedamp has a peculiar property by virtue of which a source of ignition must be in contact with an inflammable mixture for a definite period of time before ignition takes place, e.g. if the temperature of the source be 650°C. 10 seconds elapse between the introduction of the source and ignition of mixture; if the source is at a temperature of 1000°C ignition occurs in less than one second. The time is not occupied in bringing the mixture to the temperature of the source (this is probably effected in a small fraction of a second) but may be due to the rate at which chemical combination takes place. The rate of combination is quite measurable at 300°C and increases rapidly with temperature. This combination results in liberation of heat which raises the temper:ature of the surrounding mixture. Thus the rate of combination increases rapidly until finally the temperature is such that combination takes place throughout the mixture almost instantaneous:ly. It follows therefore that the higher the temperature of the source the shorter will be the period necessary to raise the temperature of the gas to that at which instantaneous combination is effected throughout the mixture. This is important from a mining point of view, since if flame or hot gases from an explosion in a casing, can be cooled considerably before reaching the outside, the chances of external ignition will be slight. The flames from an explosion are of short duration, and if considerably cooled, would not be in contact with the external mixture for the period of time necessary to initiate explosion at the temperature of the "cooled" gases.

POSSIBLE SOURCES OF IGNITION:-

It has been shown that any sustained flame, however small, will cause ignition of firedamp mixtures. The arc produced at a switch or controller when a circuit is opened, is of short duration but the temperature is very high and is quite capable of causing ignition of gas mixtures. Gas surrounding a fuse will be ignited if the fuse is "blown." Sparking at commutators of D.C. motors or slip rings of A. C. motors must be regarded as a potential source of ignition. Broken coils in stators and rotors of induction motors must also be regarded as dangerous, when gas is present.

TRANSMISSION OF FLAMES FROM APPARATUS TO THE OUTSIDE:-

Under the conditions described above, if the motor or

switch gear is not protected external explosion with its accompany:
:ing destructive effects will inevitably result. If the apparatus is un-adequately protected the possibility of external ignition is very great. If the casings are protected but constructed of material not sufficiently strong to withstand the force of the explosion, the conditions are equivalent to no protection. It is therefore apparent that in addition to preventing passage of flame a casing must be able to withstand the pressure developed by an explosion.

GAS EXPLOSIONS IN CLOSED VESSELS:-

When an explosive mixture of methane and air is present in a metal casing and a source of ignition is applied(say an electric spark), flame spreads rapidly from the point of ignition throughout the mixture at a rate depending on the amount of methane present. Actual measurement of the temperature of explosion have recorded 1900°C - 2100°C as the highest temperature attained. Theoretically, the temperature should be considerably higher, but the proximity of the cold walls of the containing vessel and probable dissociation of methane at high temperatures, each absorbing heat, probably together account for difference between the theoretical and recorded temperatures. Since excessive temperature development is prevented, pressure development is restrained in a like manner.

The maximum pressure recorded for methane-air explosions in completely closed vessels, is 108 lbs per sq. inch. If the joints of the vessel be separated by a small amount the pressure is reduced considerably, since part of the mixture is expelled unburnt through the space at the joints, when ignition takes place. Hot gases produced by an explosion will also escape if a gap is left at the joints of the casing.

METHODS OF PROTECTION ADOPTED:-

From the foregoing it will be evident that the provision of a large cooling surface is essential, and in methods of protection adopted, this aspect has been kept in view. In a few types of devices, cooling of flame has apparently been the principal object aimed at, and the possibility of obtaining considerable reduction of pressure while effectively cooling the flame has not received the attention it merits. Methods of protection of apparatus have so far proceeded mainly along four lines. One of the earliest methods made use of gauze and perforated plates as protective devices. These devices are founded on sound physical principles and involve the provision of large cooling surfaces consisting of wire gauze. The gauzes were separated by distance pieces, but numerous layers were necessary before the desired effect was achieved. In early applications gauzes were used for cooling purposes only; the attainment of considerable reduction of pressure seems to have been lost sight of, with the result that one of the necessary requirements of adequate protection was not obtained. In addition coal dust was free to enter the apparatus and also lodged on the gauzes and in the interstices, interrupting ventilation. The gauzes would be readily corroded, so that frequent inspection and renewal would probably be necessary. Recent research has shown that if properly applied, and entry of coal dust prevented by layers of tin or lead foil, satisfactory results may be obtained and considerable lowering of pressure be produced in event of explosion.

Labyrinth and plate protection was also tried. The device consisted of large numbers of thin metal plates so arranged and spaced that escaping gases and flames had to traverse long tortuous passages before reaching the outside atmosphere. In passing through the labyrinth, effective cooling was obtained but such was the resistance offered to the escaping gases that only slight reduction of pressure resulted. This appliance requires accurate machining and fitting, and is easily damaged. Coal dust will lodge between the plates and reduce the efficiency of the device. This device has not been extensively applied for the above reasons.

Other contrivances adopted are known as relief valves. They consist of valves, normally held closed by springs, set to open a specified distance immediately the pressure rises above a certain amount. In passing through the valves the hot gases are brought into contact with large cooling surfaces. These devices are also most effective flame coolers, but fail to cause appreciable reduction of pressure.

Special devices have special disadvantages, but dis:advantages common to all of them may be enumerated as follows.

1. The addition of devices to any apparatus means additional care in inspection and maintenance of apparatus, which of course increases cost of upkeep.
2. Machining of parts and application to casings tends to increasing price of product.
3. Special devices require expert handling, and ignorance or carelessness in handling may render the device useless and the apparatus unsafe.
4. Accumulation of dirt, grease, rust, etc., may hinder the proper functioning of the device.
5. Concentration of escaping gases at small area is not desirable.
6. Doubtful whether flame-cooling and pressure reduction can each be carried to safe limits in the same device.

FLANGE PROTECTION:-

This is perhaps the simplest and most effective method of cooling gases and lowering pressure of explosion.

It consists of providing broad flanges at all joints in casings, the flanges being so proportioned that the required degree of cooling is obtained, and by having a gap of predetermined depth between the flanges, excessive pressure development is prevented. The great advantages of flanges are simplicity, low cost and perman:tence. There is nothing that can go out of order, and maintenance and renewal costs are nil. The U. S. Bureau of Mines advocate metal to metal contact of not less than one inch at all joints. This of course means high pressure in event of an explosion, and necessitates very strong and rugged casings. No advantage is taken of the property called "lag on ignition." All that is required is cooling of flame to 700°C or thereby, and as already pointed out the lag on ignition at this temperature is such that external ignition cannot take place since the temperature is not maintained for a sufficient length of time.

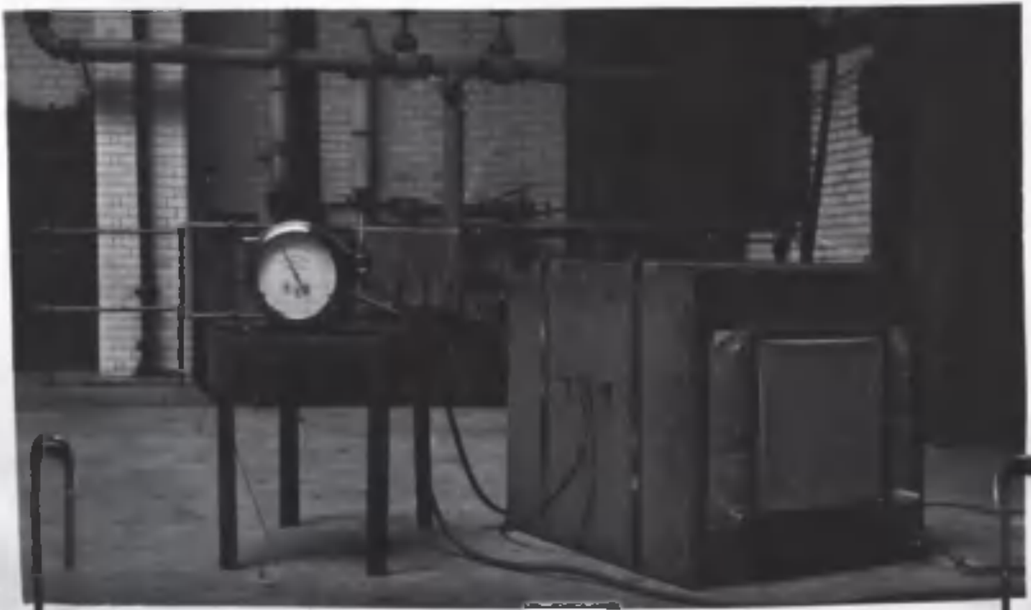
Since flange protection in our opinion offers the greatest possibilities for adequate protection of electrical apparatus for use underground, it was chosen for this particular investigation, and all casings used in the experiments were fitted with broad flanges.

FLAME PROOF ENCLOSURE:-

The "British Engineering Standards Association" give the following definition of a flame-proof enclosure:- "A flame proof enclosure is one that will withstand without injury any explosion that may occur within it under conditions of the rating of the apparatus (and recognised overloads, if any associated therewith) and will prevent the transmission of flames such as will ignite any inflammable mixture which may be present in the surrounding atmosphere."

THE FLAME-PROOF TEST:-

The following test is applied to casings to determine whether they satisfy the requirements of the above definition:- The apparatus to be tested is placed in an "Explosion Chamber" and an explosive gas mixture is introduced into it. The Explosion Chamber is now closed and filled with an explosive gas mixture, after which the mixture in the casing is ignited and the result noted. If the external mixture (i.e. the mixture in the chamber surrounding the apparatus) is ignited, flame has passed from the apparatus, and



under the conditions of the test, it is unsafe. If no external ignition occurs, the mixture is ignited by some means, to prove its explosibility. The tests are repeated until a consecutive number of similar results are obtained, and according to results the apparatus is declared safe or unsafe under the conditions of the test.

THE EXPLOSION CHAMBER:-

The "Explosion Chamber" used in the investigation consisted of a wooden box, fitted with terminals and a gas tap, and of the following dimensions:- Length 2 ft. 10 ins. Width 2 ft. 7 inches, Height 2ft. 6 ins. To prevent damage in event of an external ignition, safety valves or windows were fitted into the ends of the box. These windows were 15 ins square and during the filling stage were blocked with paper to prevent leakage. When external ignition occurred the paper windows were burst, allowing of dissipation of energy without damage to the box. If external ignition did not occur a light on the end of a stick was thrust through the paper to ignite the mixture and prove its explosibility.

METHOD OF OBTAINING EXPLOSIVE MIXTURES:-

The explosive mixtures were obtained by mixing coal-gas and air in known proportions. Objection to this might be made on the ground that coal gas is not found in mines, and that firedamp, the explosive mixture generally found in mines, should have been used instead. It may be pointed out however that the surrounding gas mixture is really only an indicator the purpose of which is to indicate when flame has passed from the internal explosion. Evident:ly then a mixture of coal-gas and air will serve the purpose admirably and such a mixture has the additional advantage that it more sensitive to ignition than methane and air (firedamp). Consid:ered in this light results obtained, using coal gas and air, will not vary greatly from those obtained using methane and air and any difference will be in favour of coal gas since a greater margin of safety will be obtained.

METHOD OF IGNITING THE EXPLOSIVE MIXTURES:-

The gas mixtures in the casing under test were ignited electrically by "blowing" a fuse, power being taken from a 250 volt. D.C. supply with a variable resistance in circuit. The fuse wire was No. 24 S.W.G. Tin and from 1½ to 2 ins.in length.

APPARATUS TESTED IN THE EXPERIMENTS:-

Each piece of apparatus tested in the experiments was fitted with fixed flanges at the joints of cover and casing. The casings were typical examples of modern mining switch-gear casings. These casings were readily adapted for experimental purposes, by tapping the sides or ends to receive a gas tap and a lead-in plug for the conductors. This adaptation did not in any way interfere with the protective features of the boxes. The use of typical switch gear casings is a step which commends itself, in that any weakness or defect in the casings could be readily detected and suggestions made for general improvement.

EXPERIMENTAL: JUNCTION BOX WITH GROOVED FLANGES:-

The first set of experiments was carried out on a junction box, detached from a gate-end circuit breaker. This box had a grooved flange 0.5 ins broad, into which fitted a cotton gasket, so that when the cover was bolted into position a very tight joint was secured. The ends of the box were blocked with pieces of wood, bored to receive terminals and a gas pipe. Leads were taken from the terminals inside the explosion chamber to those on the junction box, and short leads from the latter were bridged with a piece of fuse wire, inside the junction box. These connections having been made, the cover was bolted into position, an explosive gas mixture was introduced, and the gas pipe plugged to prevent leakage. The "windows" of the explosion chamber were now blocked with paper and the junction box surrounded with an explosive atmosphere. By closing the switch the fuse was "blown", igniting the gas in the junction box, the effect produced being noted. A large number of tests as above were made with the gasket in position and then with it removed. Typical results are shown in the following table.

TABLE 1.

Tests Made on Junction Box with Grooved Flanges 0.5 ins. Broad. Volume of Box.

0·08 Cub ft.

Cubic feet of Gas. Junction Box.	Explosion Chamber.	Current in Amps. (Igniting.)	Breadth of Flange.	Ignition. Internal.	External.	Remarks.
.020.	3.400.	26	0.5	Yes.	No.	Tape in position in Groove.
"	"	"	"	"	"	"
"	"	"	"	"	"	"
"	"	"	"	"	"	Signs of Charring.
"	"	"	"	"	Yes.	Tape removed from Groove.
"	"	"	"	"	"	"
"	"	"	"	"	"	"
"	"	"	"	"	"	"

CONCLUSIONS:-

It was found that with the gasket in position flame did not pass between the flanges, but after a few ignitions distinct signs of charring were seen, showing that if the experiments were continued the gasket might possibly be burned out, and thereby provide a passage for flame to the outside mixture. With the gasket removed external ignition took place in every experiment, indicating that a flange 0.5" broad is not in itself an adequate protective device. The tape or gasket is mechanically weak and would soon rot

in the humid atmosphere of mines, and for this reason alone could scarcely be recommended.

If for any reason the gasket had to be removed great care would have to be exercised in replacing it correctly in position in the groove, to prevent risk of providing passage for flame. Above ground with abundant light this would require ordinary care only, but underground where lighting arrangements are often far from perfect it would be a more difficult matter.

It would be better to avoid the dangers which might arise, by removing the gasket altogether and increasing the breadth of flange to one inch or more if necessary. If this measure were adopted, we would have a piece of apparatus made flame proof at the beginning and always retaining its properties, unlike a device depending for its flame proof properties on a material which readily deteriorates and hence gradually loses its properties.

EXPERIMENTAL:- PRELIMINARY:-

GATE END CIRCUIT - BREAKER WITH ROUGH MACHINED FLANGES:-

The next piece of apparatus tested was a gate-end box fitted with circuit breakers set to trip at 17.3 amperes. Part of the gear was removed to adapt the box for experimental purposes. As shown in the photograph the cover is hinged and held in position by means of eight ⅝inch. diameter bolts. The flanges were 1½inches broad and rough machined. The junction box used in the above experiments was re-attached to the gate-end box and tests similar to those already described were carried out.

After one or two tests in which external ignition did not occur, it was thought that the combined junction box and gate end box was quite safe under the conditions of the test. To confirm this, one more experiment under exactly the same conditions as the others was made. A violent external explosion resulted when the switch was closed, and on removing the junction box cover the cotton gasket was found to be completely burned through in parts, and badly charred in others. The flame proof properties of the combined apparatus were thus entirely destroyed. The junction box was removed and a piece of wood, bored to receive a gas pipe was bolted into position in its place.

A number of experiments were now carried out with the flanges of the cover and box in contact, the only gaps being those formed by the rough machining, the largest of which did not exceed .01 inches. Under these conditions it was not found possible to initiate an external explosion. By placing pieces of metal between the flanges it was possible to obtain gaps of any desired depth all round the perimeter of the cover. Experiments were thus carried out at various depths of gap until external ignition was produced by flame passing between the flanges from an internal ignition. The following table shows the average results of a large number of experiments.

TABLE 2.

Tests on Gate End Circuit Breaker. Box. Flanges $1\frac{3}{4}$ ins. Broad. Volume 1.55 Cub. ft.

Cubic feet of Gas. Gate-End Box.	Explosion Chamber.	Igniting Current in Amperes.	Breadth of Flange.	Depth of Gap.	Ignition. Internal.	External	Remarks
0.350	3.400	28	1.75ins.	0.025 ins.	Yes.	No.	Ext. Mixture Exp.
0.400	3.600	"	"	"	"	"	"
0.400	3.686	"	"	"	"	"	"
0.419	4.043	"	"	0.038ins.	"	"	"
0.420	4.039	"	"	"	"	"	"
0.451	4.023	"	"	"	"	"	"
0.490	4.400	"	"	0.055ins.	"	Yes.	Very Violent Expl. Chamber Shattered

In the last experiment of this series the Explosion Chamber was shattered. Apparently the "safety valve" paper windows did not operate rapidly enough to prevent damage to the box. A gap of 0.055 inches all round the Gate End Box would provide a large release area, and at that particular depth of gap the flanges could not have a great cooling effect on the flame from the internal explosion. When the internal ignition occurred a large mass of intensely hot flame would be projected into the external mixture from all round the box. The pressure wave preceding the flame would create considerable mechanical disturbance in the external mixture and followed immediately by a large body of flame, ignition would take place under conditions approaching detonation. Under these abnormal conditions the pressure rise would be so rapid that maximum pressure would be attained before relief was obtained by rupturing of the paper safety valves. The energy of the explosion would therefore be expended on the sides of the explosion chamber instead of being dissipated through the "safety valves." The result was of course destruction of the explosion chamber since it was not designed to withstand such pressures.

COOLING EFFECT OF FLANGES ON FLAME:-

To obtain some information on the flame that causes ignition of the external mixtures, the following experiments were performed with the gate-end box in the "open", i.e. surrounded by air. An explosive mixture was admitted to "box" in the usual manner and ignited, the distance the flame extended beyond the flanges being noted approximately. These tests were performed with the same depths of gap as were used when the box was in the explosion chamber. With the exception of the first series, i.e. with flanges in contact with each other, flame was observed in every case, often blue in colour and extending only a short distance beyond the flanges. This was chiefly noticeable with gaps up to 0.025 inches in depth. In these cases cooling had been carried out to a successful degree, and in some of the experiments in which weak mixtures were used the flame seemed to emerge at a relatively slow rate, and never exceeded one inch in length. At gaps greater than 0.025 inch the flame was brownish-red in colour and extended 3-4 inches. At gaps at which external ignition was known to occur bright red flames streaked with white, extended more than six inches beyond the flanges, when ignition took place. The flame was visible all round the casing.

IGNITION OF GAS MIXTURES AT "MAKING" and "BREAKING" CONTACT in the GATE END BOX:-

The gear removed from the box was now replaced and a number of experiments carried out to determine whether an explosion of gas could be initiated at "making" or breaking contact. A piece of strong twine was attached to the handle of the gate-end switch (which was in the OFF position), an explosive mixture was admitted to the box, then after closing the other switches, contact was made in the gate-end box by pulling the cord. The circuit-breakers were set to trip at 17.3 amperes, but as there were only 9 ohms. resistance in the circuit the short circuit current would be 27.8 amperes. It follows therefore that no sooner was contact made than it was broken by the circuit breakers operating. The flash thus produced ignited the gas mixtures in the casing. Extra resistance was introduced and the current lowered to 15 amperes. With this reduced current ignition occurred in each experiment at "break", but on one occasion ignition took place at "make". This was probably due to dirty contacts, because when they were cleaned no further ignitions occurred at "make."

CONCLUSIONS:-

The combined gate-end box and junction box may be represented as two separate chambers with a short inter-communicating passage. It has been shown that the operation of the overload releases causes ignition of a gas mixture, and in event of such an occurrence in the combined apparatus the mixture in the smaller

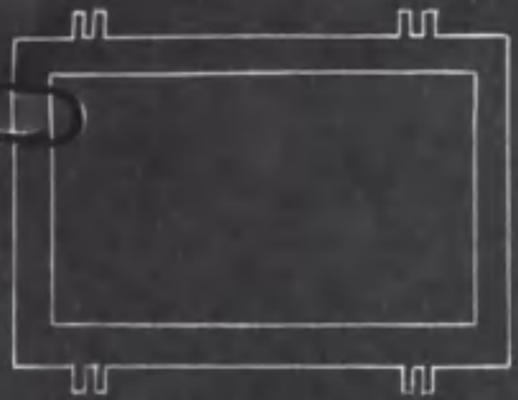


Fig 1 :- Plan Of Small Switch Box.

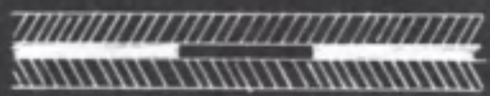


Fig 2 :- Section Showing Loose Loose Flanges In Position Forming A Gap.

Fig 3 :- Loose Flange.

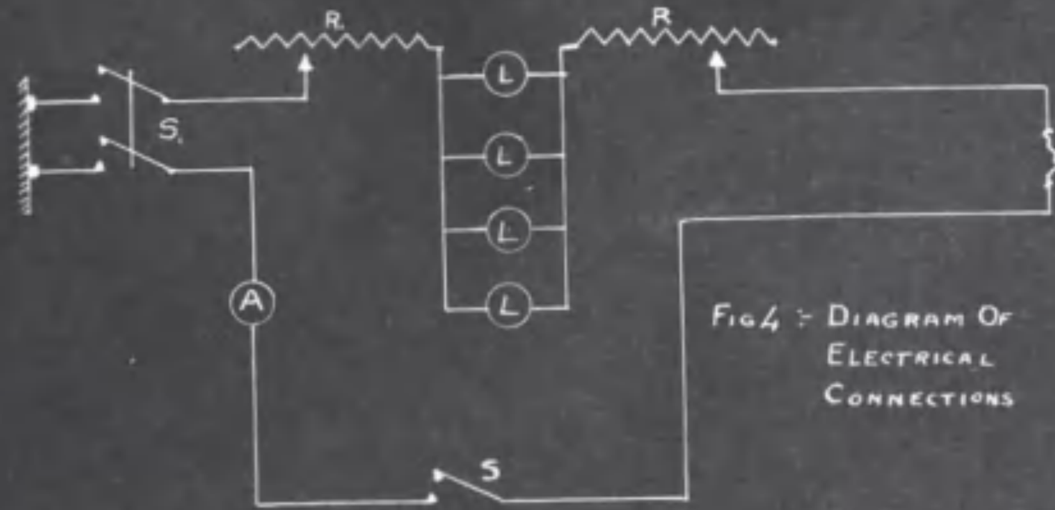


Fig 4 :- Diagram Of Electrical Connections

Fig 5 :- A; Stud Hole At Present
B; Stud Hole Bottomed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chamber would be compressed before ignition so that higher pressures would be developed. This probably accounts for the sudden rupturung and burning of the cotton gasket. With a piece of wood covering the opening over which the junction box is normally attached, the gate-end box is flame proof with gaps up to 0.038 ins. in depth between the flanges all round the perimeter. With the studs in position and the cover secured, there is little danger of an external explosion if the opening referred to above is well covered. In passing, it might be well to mention that the stud hole at the hinge communicates with the inside of the casings (the others do not). It therefore follows that if this stud is omitted the cooling properties of the flanges are of no avail because we have a direct passage from the inside of the box to the outside atmosphere. This could be prevented by bottoming the stud hole, i.e. by covering the bottom of hole with metal as shown in the fig. 5. If this alteration were made the value of the box from a flame-proof point of view would be considerably increased. The failure of the combined apparatus by the burning of the gasket is a good illustration of how adequate protection of a piece of apparatus (such as by broad flanges of gate-end box) may be rendered useless by an inadequately protected piece of apparatus (junction box with narrow flange and gasket) which is connected to it. The remedy is protection to the same degree of safety for all parts of same apparatus, always remembering that adequate protection implies sufficient strength to withstand the explosion and ability to cool the gases from the explosion.

CRITICAL LENGTH OF OPENING:-

In this series of experiments an effort was made to determine the maximum length of opening for any particular depth of gap between flanges of given breadth, which prevents passage of flame capable of igniting an explosive mixture of gases. The apparatus used consisted of two switch boxes of different volumes and fitted with flanges of different breadths. The volume of the smaller box was approximately 0.120 cub. ft. that of the larger

2.352 cub. ft., while the former was fitted with flanges 1 inch broad and the latter with flanges 1½ inch broad. The flanges were smooth machined.

The smaller box was used in the first part of the investigation. Loose sheet metal flanges (0.010 inch thick) of shape shown in fig. 3. were prepared and placed between the flanges of the cover and the box, so that when the nuts were tightened, the only passage from the inside of the box to the outside atmosphere was through a small rectangular opening. The length of the gap could be fixed and the depth altered by adding or removing loose flanges. Fig 2. shows this clearly.

The initial depth of gap was 0.1 inch, and it was found that before flame passed at a temperature sufficiently high to ignite an explosive mixture the gap had to be ⅜"inch long.

Experiments such as above were carried out with gaps of 0.08 inch, 0.06 inch, 0.042 inch etc., until 0.030 inch was reached when it was found that this depth of gap could be left all round the box and external ignition could not be produced by the flame from an internal explosion.

Tests similar to those described above were carried out on the larger box special loose flanges being prepared for the purpose.

The gate-end box already described was now adapted so that experiments similar to those above might be made on it. By so doing a better comparison was obtained and the effect of breadth of flange and volume better understood.

The results from this series of experiments are shown numbered and tabulated at the end of the thesis, while in table III selected results are given to demonstrate the manner in which the critical length varies with depth of gap and breadth of flange.

CONCLUSIONS AND DEDUCTIONS:-

This series of experiments was most interesting especially when nearing what might be termed the "critical length of opening" i.e. the length of opening which, at any given depth

Table III.

Critical Lengths Of Opening For Fixed Depths Of Gap.

No	Coal Gas in Cubic Feet		Igniting Current in Amperes	Breadth of Flange	Gap		Ignition		Remarks
	Explosion Chamber	Switch Box			Length	Depth	Internal	External	
25	3·408	·034	29	1	·375	·100	Yes	No	External Mixture Explosive
38	3·06?	·035	12	..	·875	·080	Yes	No	Do Do
[illegible]	3·028	·035	..	..	1·750	·058	Yes	No	Do Do
67	3·270	·030	..	..	6·50	·042	Yes	No	Do Do
72	3·241	·030	..	..	9·00	·038	Yes	No	Do Do
87	3·110	·030	..	..	24·000 (Perimeter)	·035	Yes	Yes	
91	3·000	·030	..	..	..	·030	Yes	No	External Mixture Explosive
101	3·010	·409	15	1·375	1·000	·100	Yes	No	Do Do
109	2·700	·300	..	..	2·875	·070	Yes	No	Do Do
127	2·850	·312	..	..	9·500	·052	Yes	No	Do Do
148	2·776	·313	..	..	70·000 (Perimeter)	·040	Yes	Yes	
154	2·700	·302	..	..	..	·036	Yes	No	External Mixture Explosive.
156	2·600	·315	..	..	..	·030	Yes	No	Do Do
204	2·000	·240	..	1·750	4·500	·096	Yes	No	Do Do
166	2·600	·350	..	..	6·250	·080	Yes	No	Do Do
181	2·400	·280	..	..	12·125	·058	Yes	No	Do Do
193	2·000	·240	..	..	15·625	·048	Yes	No	Do Do
168	2·600	·354	..	..	66·000 (Perimeter)	·038	Yes	No	Do Do

Explanation Of Terms Used

Breadth Of Flange :- The Distance The Flange Extends Outwards From The Inside Of The Box

Depth Of Gap :- The Distance Between The Flange Of Box And Flange Of Cover At The Opening Left For Escape Of Hot Gases

Length Of Gap :- The Length Of Opening [Measured Along The Flange] Left For Escape Of Hot Gases

of gap, just prevents passage of igniting flame. A small altera:
:tion of length of opening at this point decides whether external ignition will occur or not. We pass from a stage where there is quite definitely internal ignition only, to a stage where there is definite external ignition occurring apparently simultaneously with internal ignition, so short is the interval between them. Between these stages we have what might be termed a "retarded ignition" stage in which the "lag on ignition" effect is often observed. In this stage two distinct reports are heard, first the internal explosion followed by the external explosion. The area of opening has been slightly increased but cooling is still being carried to a considerable degree but not sufficient to lower the temperature of the gases below the ignition temperature of the surrounding mixture. In other words the "lag" at the degree of cooling is not of sufficient duration to prevent external ignition.

It is inconceivable that, at the short lengths of opening cooling is produced solely by contact with the flanges since only a small area is exposed to the flames and the time of contact is of short duration. The rapid expansion of the hot gases from the explosion through a small opening, will result in considerable cooling, and at these small lengths of opening must be regarded as the predominant factor in preventing ignition of the external mixture. At the critical lengths cooling is carried just sufficiently far to prevent ignition of the outside mixture, consequently any slight alteration of length will affect the degree of cooling. An increase in length increases the area through which expansion takes place. It follows therefore that expansion to atmospheric pressure will take place at a relatively less rate since the velocity of the issuing gases will be reduced as the area of opening is increased. The slower rate of expansion will maintain the temperature of the gases for a relatively longer period, so that they will issue at temperatures at which the "lag"

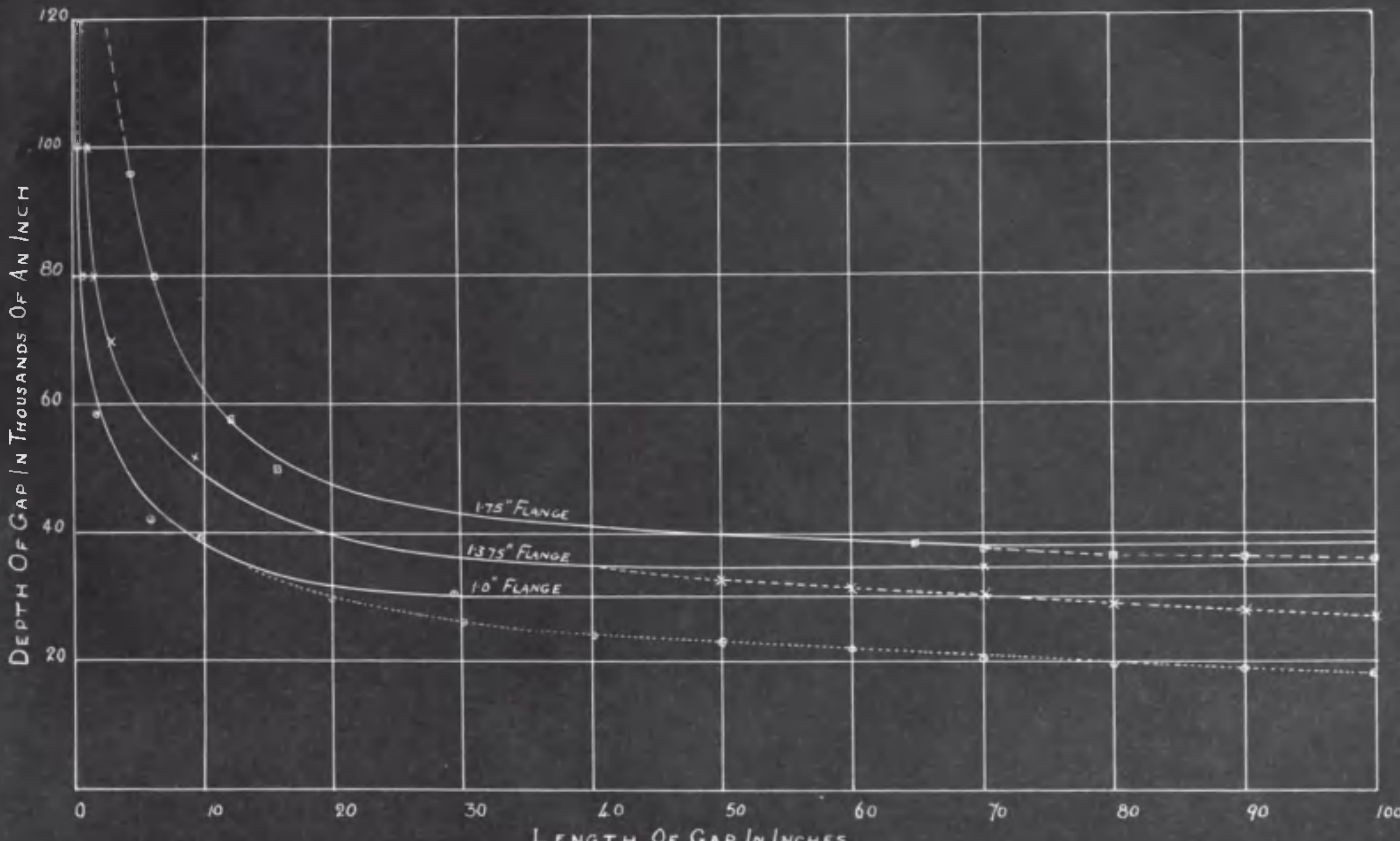


Fig. 6 :- Critical Lengths i.e. Maximum Length Of Gap Which, At Any Given Depth Of Gap, Prevents Passage Of Flame Capable Of Igniting External Explosive Mixtures

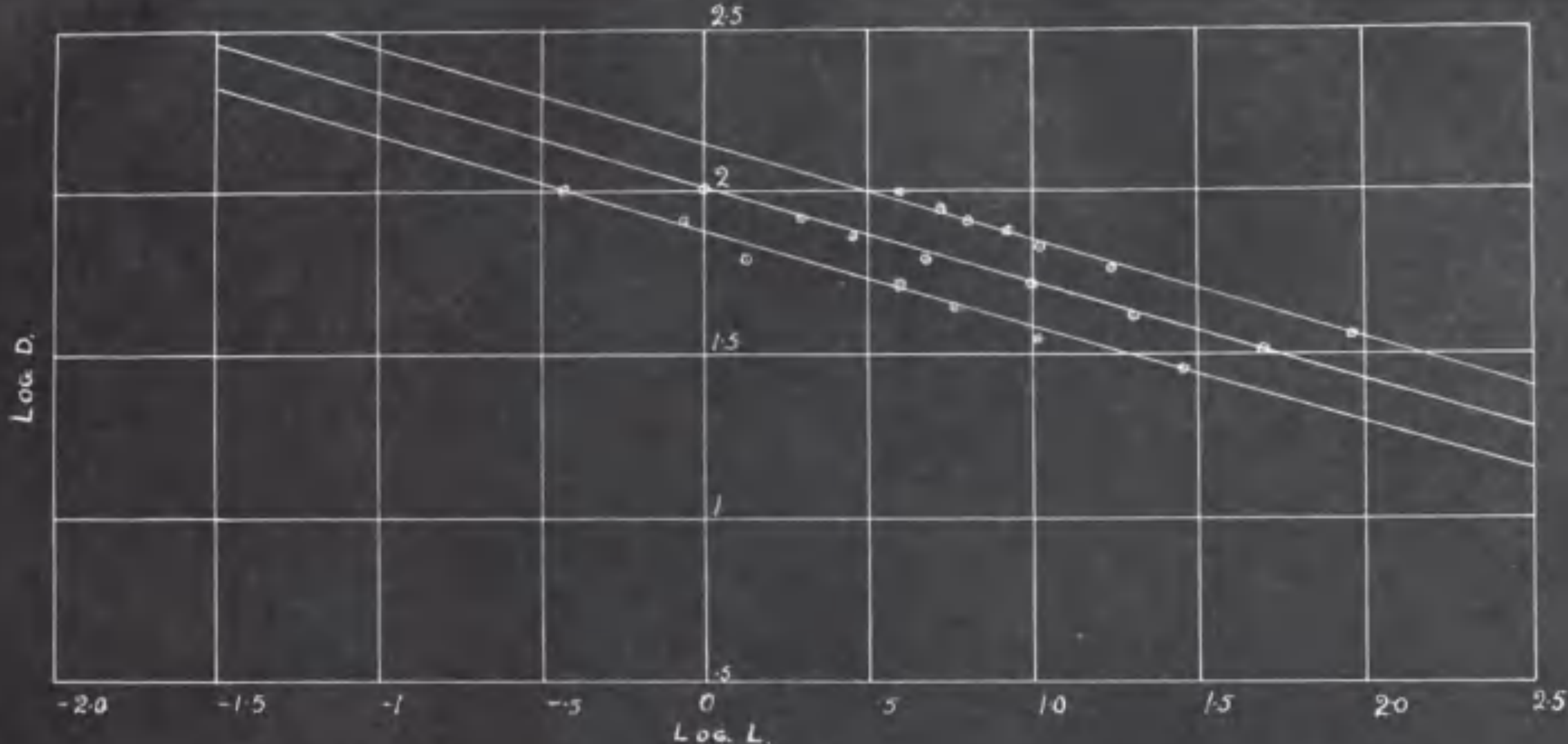
is negligible and ignition of the external mixture will result. In the "retarded ignition" stage the temperature is maintained just sufficiently long to allow of ignition of the external mixture at the particular temperature, and the distinct pause between the two explosions indicates the effect of "lag on ignition."

As the gap is reduced in depth and increased in length, a greater area of flange is exposed, so that at the smaller depths of gap cooling by contact with flanges will predominate. When we reach a depth of gap which can be safely left all round the casing, cooling of the gases from the internal explosion will be chiefly accomplished by the flanges and cooling by expansion will be negligible.

CURVES:-

From the tabulated results three curves were plotted with abscissae "Critical Length of Opening", and ordinates "Depth of Gap". (Fig. 6.) The curves are hyperbolæ with the XY ordinate as asymptotes. From log. curves equations were obtained for each curve and by extrapolation the curves were extended beyond the points obtained in the experiments.

If we regard the perimeter of each box as a critical length, and, using the equations which satisfy the curves, calculate the depths of gaps which should prevent passage of flame at the particular perimeter, we find in each case that the calculated depth is much less than that found by experiment. The reason for this difference may be explained as follows. When a gap is left all round a box we have what might be termed an unrestricted passage to the outside. Under these conditions, when ignition occurs, the rapid expansion of gas at the source of ignition will expel unburned gas near the opening. This expulsion of unburned gas will occur at all lengths of opening, and when the length of opening is the perimeter of the box the loss must be considerable, since gas will escape in all directions. The heat generated depends on the amount of combustible gas present, so it naturally follows that under the conditions described the heat given off from the



Breadth of Flange 1"

Depth of Gap D.	Length of Gap L.	Log. D.	Log. L.
100	·375	2·00	−·4260
80	·875	1·9031	−·058
63	1·375	1·7993	·1367
50	4·5	1·6990	·6532
42	5·5	1·6232	·7404
38	10·5	1·5798	1·0212
30	29	1·4771	1·4624

$\log y = a \log x + \log b$

$2·16 = -·1 a + \log b$

$1·34 = 2 a + \log b$

$·87 = -3 a$

$\therefore a = -·29$

$\therefore \log b = 1·87$

$\therefore \log y = -·29 \log x + 1·87$

$\therefore y = \dfrac{74}{x^{·29}}$

$\therefore y x^{·29} = 74$

or $DL^{·29} = 74$

Breadth of Flange 1·375

Depth of Gap D.	Length of Gap L.	Log. D.	Log. L.
100	1·00	2·00	·000
80	2·00	1·9031	·3010
70	2·875	1·8451	·4594
60	5·00	1·7782	·6990
50	10·00	1·6990	1·000
40	20·00	1·6021	1·3010
36	70·00	1·5563	1·8451

$\log y = a \log x + \log b$

$2·3 = -·1 \times a + \log b$

$1·3 = 3·3 \times a + \log b$

$1·0 = -3·4 a$

$\therefore a = -·29$

$\therefore \log b = 2·01$

$\therefore \log y = -·29 \log x + 2·01$

$\therefore y = \dfrac{102·3}{x^{·29}}$

$\therefore y x^{·29} = 102·3$

$DL^{·29} = 102·3$

Breadth of Flange 1·75

Depth of Gap D.	Length of Gap L.	Log. D.	Log. L.
100	4·00	2·000	·6021
90	5·25	1·9542	·7202
80	6·25	1·9031	·7959
70	7·50	1·8451	·8750
58	12·00	1·7634	1·0792
48	16·50	1·6812	1·2175
38	60·00	1·5798	1·7782

$\log y = a \log x + \log b$ (D = y, L = x)

$2·35 = -·7 a + \log b$

$1·40 = 2·5 \times a + \log b$

$·95 = -3·2 a$

$\therefore a = -·29$

$\therefore \log b = 2·125$

$\therefore \log y = -·29 \log x + 2·125$

$\therefore y = \dfrac{133·4}{x^{·29}}$

$\therefore y x^{·29} = 133·4$

$DL^{·29} = 133·4$

Fig 6A.

burning mixture will be very much less than the potential heat of the original mixture, and the amount of heat to be dissipated will be considerably less than when the casing is completely closed or only partly open.

The large surface provided by the flanges will readily cool the escaping gases and it will be possible to increase the depth of gap up to a point beyond the calculated depth, and still prevent passage of flame capable of causing ignition of the external mixture. Increased depth of gap will increase the area of opening and tend to increase the loss of gas at ignition, but a "depth" will be reached when only the gas in contact with the flanges will be greatly cooled, and the temperature of the gas in the centre of the passage will not be appreciably lowered. In other words the flanges will be so far separated that self propagation of flame in the gas mixture between them will be possible. It follows therefore that when this point is reached external ignition will result. The 'depth' found by experiment therefore probably represents the maximum 'depth' to prevent self-propagation of flame between the flanges, and for the reasons stated above will be greater than the calculated value, when the perimeter is regarded as the critical length.

The maximum 'perimeter gap' (i.e. maximum gap that can be safely left all round the casing) for each box is indicated by a straight line parallel to the X-axis and intersecting the curve. It does not follow that these are the safe gaps for these flanges for all volumes and perimeters; e.g. taking the smallest vessel - volume .123 cub. ft. breadth of flange 1 inch perimeter 29 inches, safe perimeter gap .030 inch. - we cannot say, that this depth of gap is safe for any casing fitted with 1 inch flanges. Casings of larger volume than .123 cub. ft. will invariably have openings with perimeters, greater than 29 inches, since they will house larger gear. Greater volume means greater potential heat for same strength of gas mixture so more heat will have to be dissipated, and if breadth of flange is to remain at 1 inch the safe perimeter gap may have to be less than .030 inch. The curves

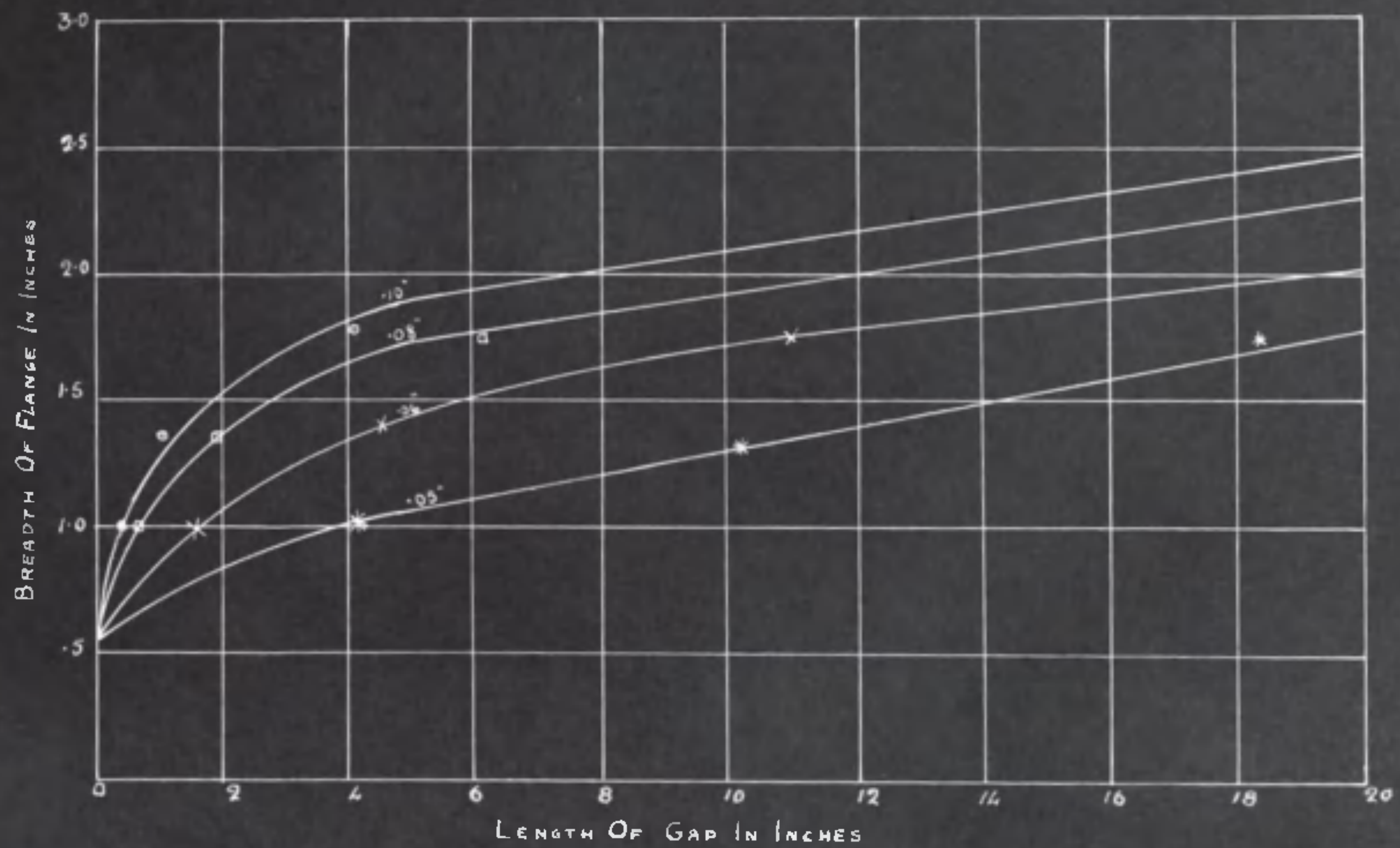


Fig. 7. Breadth Of Flange Required For Given Length And Depth Of Gap.
[Effect Of Volume Not Considered]

show that increase of perimeter (where perimeter is regarded as a critical length) necessitate a decrease in depth of gap for same breadth of flange and volume, consequently if both volume and perimeter increase while the breadth of flange remains the same, a further reduction in depth of gap will be necessary.

The alternative to reduction of depth of gap is an increase in breadth of flanges, and is indeed the more satisfactory method of retaining flame-proofness. The increase in size and weight of casings will, in general, necessitate an increase in breadth of flanges at joints for reasons other than preventing passage of flame, e.g. increase in size of holes for studs, or bolts, to retain covers in position etc. However for casings to be used in mines the flame-proof factor is the most important. It would be interesting and useful if the relationship between volume and breadth of flange could be shown by a curve or expressed by an equation.

In fig. 7 a series of curves is shown, abscissae are "Critical Lengths of Opening," and ordinates are "Breadth of Flange." Readings are taken for same depths of gap from the curves in fig. 6. The curves indicate that breadth of flange has a great effect in preventing passage of flame. For example, if we take a gap of 0.1 inch depth, we find that with flanges 1 inch broad the critical length is 0.375 inch, while with flanges 1.75 inch broad the critical length for the same depth of gap is 4.0 inches an increase of 3.625 inches in critical length for an increase in breadth of flange of 0.75 inches. In this set of curves the effect of volume of casing has not been considered.

Fig. 8 shows another series of curves in which ordinates and abscissae are "Volume of Casing" and Critical Length respective:ly. Readings for equal depths of gap are again taken from fig. 6.

Although no account is taken of breadth of flange the influence of this factor is clearly seen, since the box with the broadest flange has the greatest length of gap for a given depth of gap.

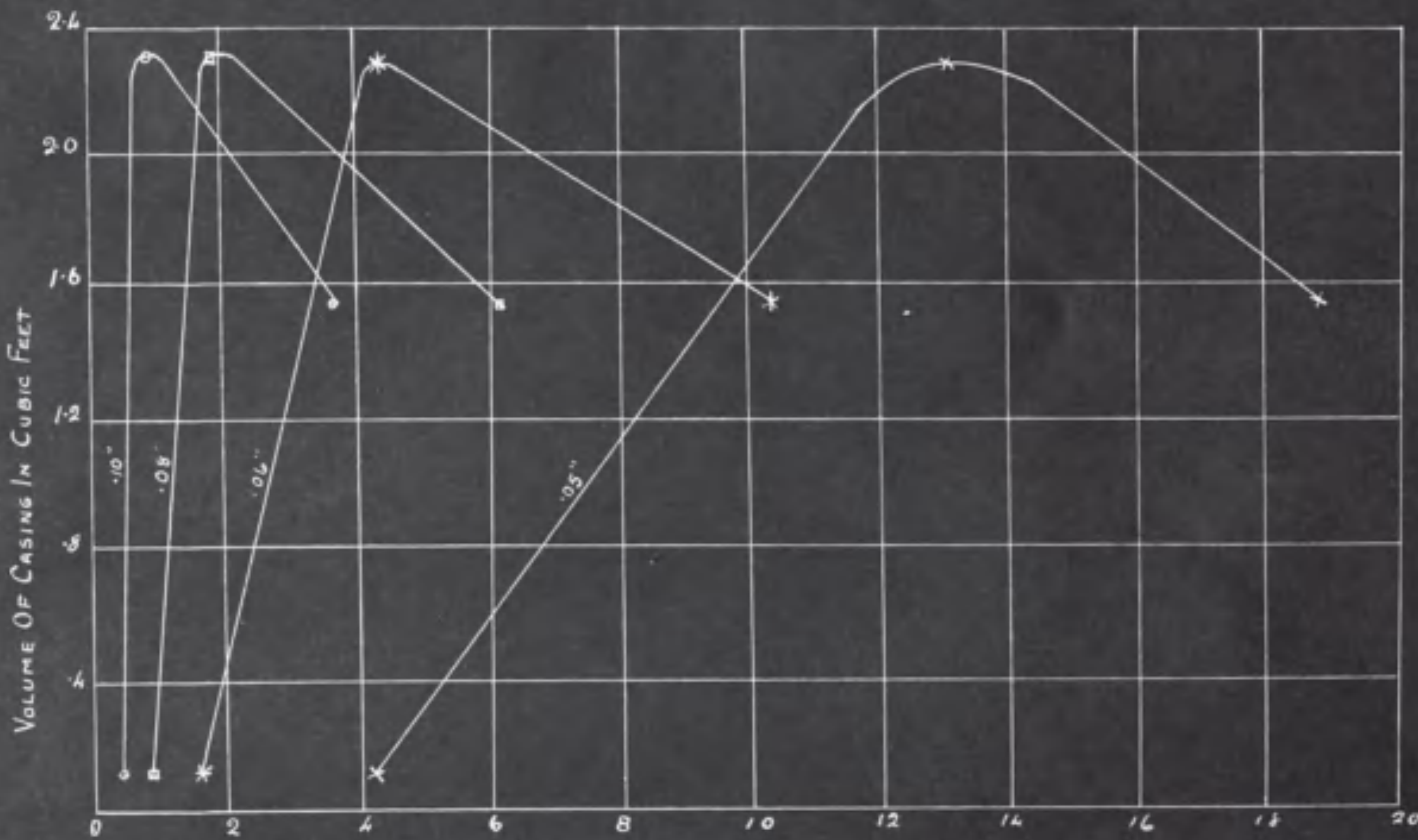


Fig 8 :- Length Of Gap For Given Volume Of Casing And Depth Of Gap
[Effect Of Breadth Of Flange Not Considered]

We cannot draw any important conclusions from these two sets of curves, since in each, no account has been taken of factors having an important influence on prevention of passage of flame.

If we consider the volume left for passage of hot gases etc., (i.e. the product of length of gap, depth of gap, and breadth of flange) we have here a figure which includes the main determining factors in preventing passage of flame. If this were plotted against "volume of casing" a satisfactory relationship would not be shown, since the curves obtained would be somewhat similar to those shown in fig. 8. This of course is due to the fact that the largest casing used in the experiments was not provided with the broadest flange consequently its "volume of passage" was not the greatest for a given length of gap.

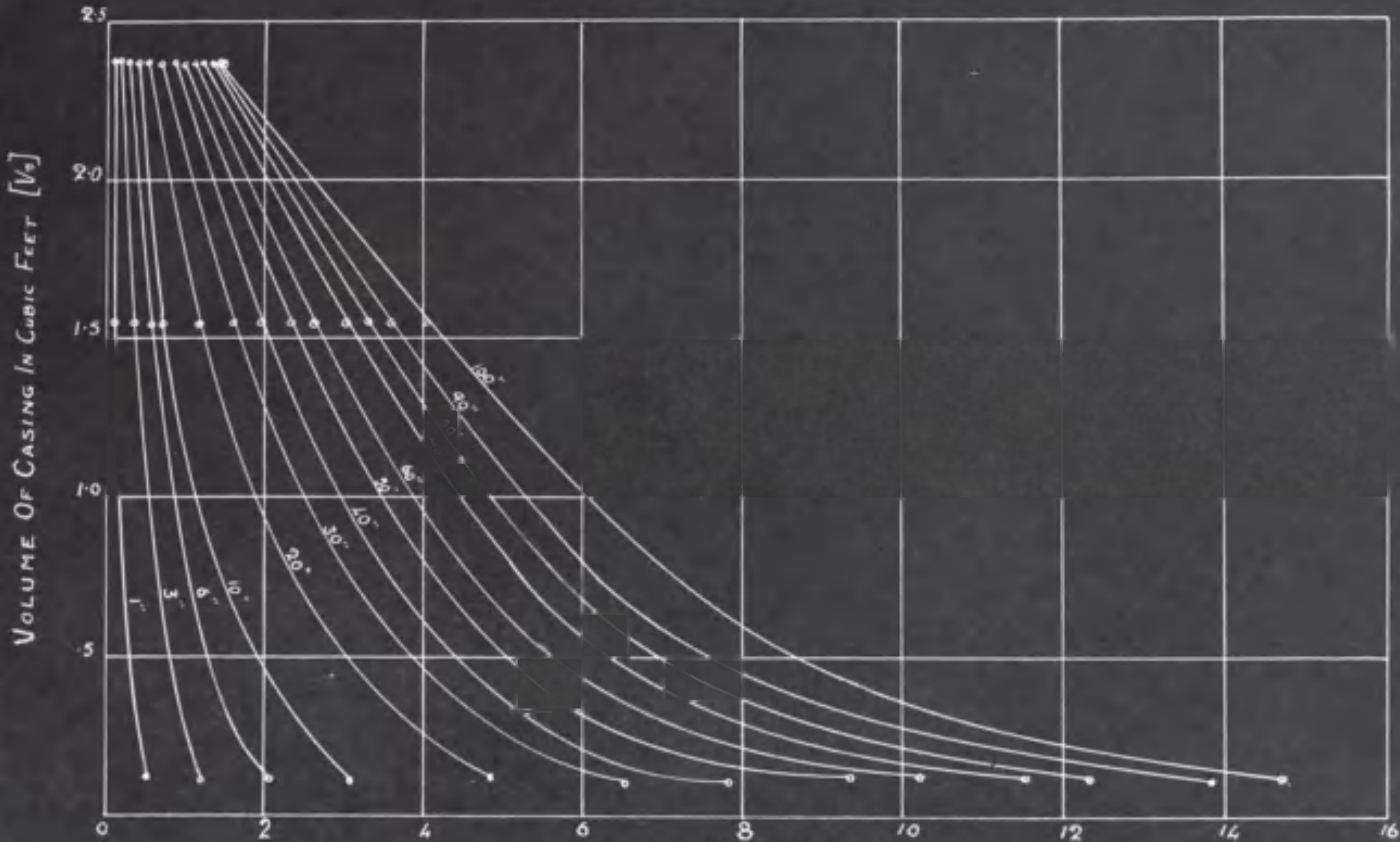
If, however we express the "volume of passage" as a ratio of "volume of casing", and plot this against volume of casing we obtain curves which will show in a satisfactory manner the relationship existing between these two factors for any given length of gap.

As the "volume of passage" is very small compared with the "volume of the casing", the figure representing the ratio will have a very small value.

We can overcome this difficulty by expressing the "volume of passage" in cubic inches and the "volume of casing" in cubic feet the result being the "volume of passage" in cubic inches, required for each cubic foot of "volume of casing," and any particular length of gap.

Calculations on this basis have been made and a table compiled (table IV), from which the curves shown in fig. 9 were plotted, showing relationship for lengths of gap between 1 inch and 100 inches.

In the calculations "lengths of gap" are regarded as "critical lengths", it follows therefore, that the "Volume of passage" given for any particular "length of gap", is that which just prevents passage of flame capable of igniting an external



$R = \frac{\text{Volume Of Passage In Cub. Ins.}}{\text{Volume Of Casing In Cub. Ft.}} = \frac{V_1}{V_2}$

Fig 9.:- Maximum Values Of 'R' For Given Volume Of Casing And Lengths Of Gap Between 1" Inch And 100 Inches

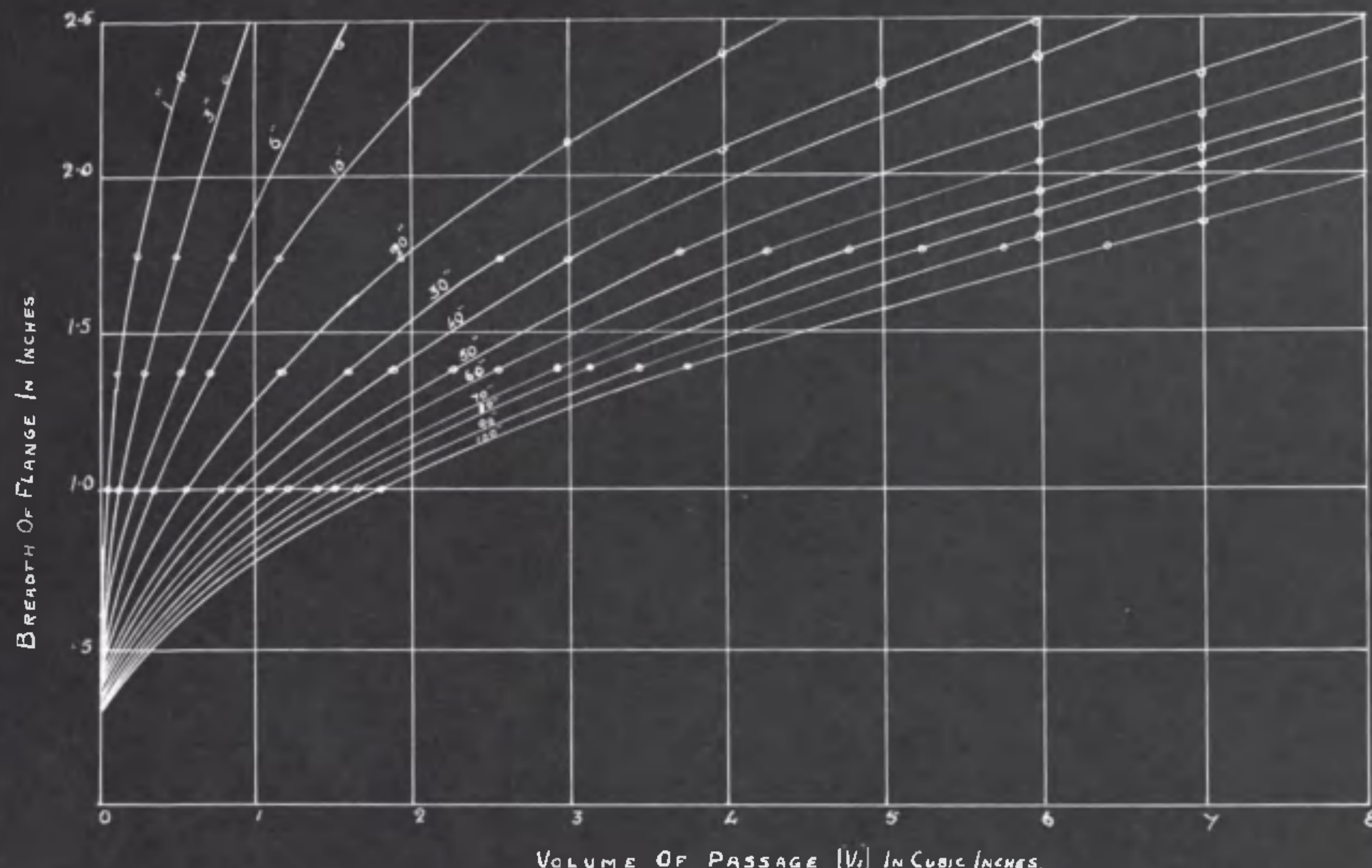


Fig. 10 :– Breadth Of Flange Required For Given Volume Of Passage At Lengths Of Gap Between 1 Inch And 100 Inches

Table IV

Calculated Values Of 'V₁' And 'R' For Values Of 'L' Between 1" And 100"

Length Of Gap (L) In Inches	Depth Of Gap (D) In Inches	Area Of Gap (A) In Sq Inches	Breadth Of Flange (F) In Inches	Volume Of Passage (V_1) (A×F) ins³	Volume Of Casing (V_2) In Cubic Feet	R = Volume Of Passage / Volume Of Casing = $\frac{V_1}{V_2}$
1	074	·074	1000	·074	·123	·577
"	103	·103	1·375	·143	2·352	·060
"	133	·135	1·750	·221	1·550	·142
3	·051	·153	1·000	·153	·123	1·243
"	·075	·225	1·375	·309	2·352	·127
"	·097	·291	1·750	·509	1·550	·328
6	·043	·258	1·000	·258	·123	2·097
"	·061	·366	1·375	·503	2·352	·209
"	·079	·474	1·750	·829	1·550	·534
10	·037	·37	1·000	·370	·123	3·008
"	·053	·53	1·375	·730	2·352	·314
"	·068	·68	1·750	1·190	1·550	·767
20	030	·60	1·000	·60	·123	4·878
"	043	·86	1·375	1·18	2·352	·501
"	056	1·12	1·750	1·96	1·550	1·264
30	027	·81	1·000	·810	·123	6·585
"	038	1·14	1·375	1·560	2·352	·662
"	050	1·50	1·750	2·600	1·550	1·677
40	024	·96	1·000	·960	·123	7·804
"	035	1·40	1·375	1·920	2·352	·802
"	045	1·80	1·750	3·100	1·550	2·000
50	023	1·15	1·000	1·150	·123	9·352
"	033	1·65	1·375	2·270	2·352	·965
"	·043	2·15	1·750	3·760	1·550	2·425
60	·021	1·26	1·000	1·260	·123	10·245
"	·031	1·86	1·375	2·550	2·352	1·084
"	·040	2·40	1·750	4·200	1·550	2·709
70	·020	1·40	1·000	1·400	·123	11·463
"	·030	2·10	1·375	2·900	2·352	1·232
"	·039	2·73	1·750	4·770	1·550	3·077
80	·019	1·52	1·000	1·520	·123	12·357
"	·028	2·24	1·375	3·080	2·352	1·309
"	·037	2·96	1·750	5·180	1·550	3·277
90	·019	1·71	1·000	1·71	·123	13·902
"	·028	2·52	1·375	3·46	2·352	1·471
"	·036	3·24	1·750	5·67	1·550	3·658
100	·018	1·80	1·000	1·800	·123	14·634
"	·027	2·70	1·375	3·700	2·352	1·575
"	·035	3·50	1·750	6·120	1·550	3·947

inflammable gaseous mixture. Consequently if we fix the perimeter of a casing of given volume (and regard the perimeter as a "critical length "), reference to the curves will give the "volume of passage" in cubic inches per cubic foot of "volume of casing," required at the length of gap, equivalent to the perimeter, if flame-proof conditions are to hold. Having obtained this figure, the total "volume of passage" for the casing under consideration is readily found.

In fig. 10 a family of curves is shown, abscissae being total "Volume of passage," and ordinates "Breadth of flange." The volume of passage is shown for lengths of opening between 1 inch and 100 inches.

It naturally follows that if we obtain the "volume of passage" required for any particular perimeter and volume from fig. 9. reference to fig. 10 will indicate the breadth of flange necessary under the circumstances, and knowing the perimeter, breadth of flange, and volume of passage, the permissible depth of "perimeter gap" (i.e. gap left between flanges all round opening) may be easily found.

Figs. 9 and 10, should prove of great use to designers of flame-proof casings, when some doubt exists regarding the proportioning of breadth of flange, and depth of gap, for any casing, the volume and perimeter of which have been fixed, by the electrical gear it is intended to house.

Three worked examples are given to illustrate the use of the curves:-

Casings of the following dimensions are required to house certain electrical gear:-

(1)	Volume 0.2	cubic feet,	opening at cover,	9 inches	by	6 inches		
(2)	" 0.6	" ,	" " "	,12 "	"	8 "		
(3)	" 1.4	" ,	" " "	,18 "	"	12 "		

Find for each the breadth of flange necessary and the maximum permissible depth of perimeter gap in order that the casing may be flame proof.

Let Volume of passage in cub.ins. = V_1
" " " casing " ft. = V_2
Let $\frac{V_1}{V_2}$ = R
Let breadth of flange in inches. = F
" perimeter of casing in inches = L
" " gap " " = D

Now $R = \frac{V_1}{V_2}$.˙. $V_1 = RV2$
And $V_1 = F x L x D$.˙. $D = \frac{V_1}{L \times F}$.
V_2 and L are given.
R and F are found from figs. 9 and 10.
V_1 and D are calculated.

(1) V_2 = 0.2 ft.^{3}, L = 2(9 + 6) = 30 ins.

From fig. 9., R, for L = 30 ins, and V_2 = 0.2 ft.^{3} is given as 5 ins^3/ft.^{3}

$$V_1 = RV_2 = 5 \text{ in.}^3/\text{ft.}^3 \times 0.2 \text{ ft.}^3 = 1.0 \text{ ins.}^3$$

From fig. 10, F, for L = 30 ins and V_1 = 1.0 in.^{3} is given as 1.1 inch.

$$D = \frac{V_1}{L \times F.} = \frac{1.0 \text{ ins.}^3}{30 \text{ in.} \times 1.1 \text{ ins.}} = .030 \text{ ins.}$$

.˙. breadth of flange required is 1.1 inch and permissible perimeter gap is 0.030 inch. (max.)

(2) V_2 = 0.6 ft.^{3}, L = 2(12 + 8) = 40 ins.

From fig. 9., R, for L = 40 in. and V_2 = 0.5 ft.^{3} is given as 4.05 in.^{3}/ft.^{3}

$$V_1 = RV_2 = 4.05 \text{ in.}^3/\text{ft.}^3 \times 0.6 \text{ ft.}^3 = 2.43 \text{ in}^3$$

From fig. 10, F, for L = 40 ins. and V_1 = 2.43 in.^{3} is given as 1.55 ins.

$$D = \frac{V_1}{LF} = \frac{2.43 \text{ in.}^3}{40 \text{ ins.} \times 1.55 \text{ ins.}} = \underline{.039 \text{ ins.}}$$

.˙. breadth of flange required is 1.55 and permissible perimeter gap is 0.039 ins. (max.)

(3) V_2 = 1.4 ft.^{3} L = 2(18+ 12) = 60 ins.

From fig. 9, R, for L = 60 ins and V_2 = 1.4 ft.^{3} is given as 3.0 in.^{3}/ft.^{3}

$$V_1 = RV_2 = 3.0 \text{ in.}^3/\text{ft.}^3 \times 1.4 \text{ ft.}^3 = 4.2 \text{ in.}^3$$

From fig. 10, F, for L = 60 ins. and V_1 = 4.2 in.^{3} is given as 1.75 ins.

$$D = \frac{V_1}{LF} = \frac{4.2 \text{ in.}^3}{60 \times 1.75} = .040 \text{ ins.}$$

.˙. breadth of flange required is 1.75 inches and permissible perimeter gap is 0.040 ins.(max.)

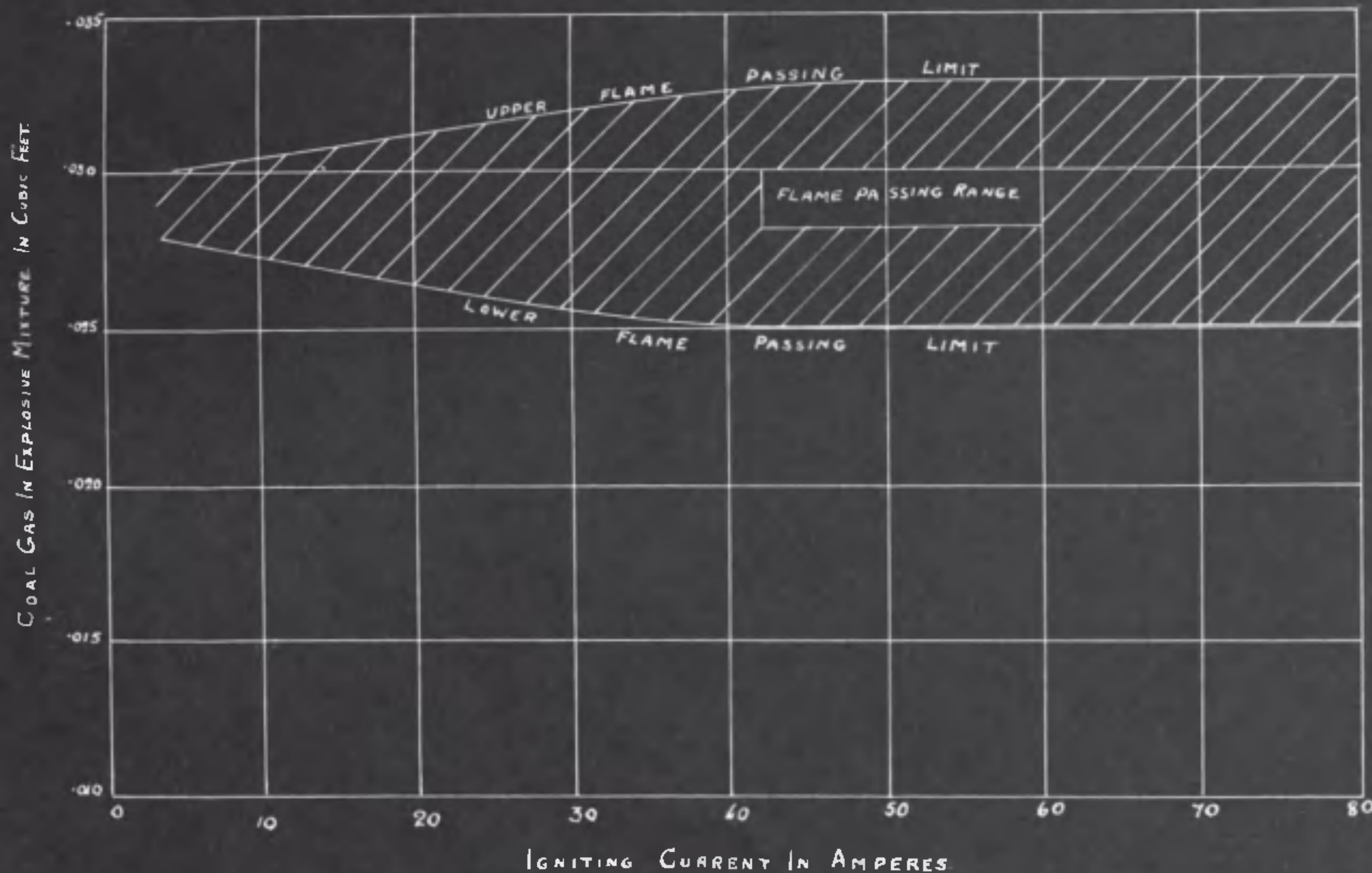


Fig 11. – Variation Of Flame Passing Range With Variation Of Igniting Current.

IGNITING CURRENT AND PASSAGE OF FLAME:-

This part of the "research" was devoted to investigating the effect of igniting currents of various strengths, on mixtures of gas near the limits of inflammability.

The small switch box (volume 0.125 cub .ft. flanges 1 inch broad) was used in the experiments. A gap 0.058 inch in depth was chosen, the critical length being 1.625 inches.

The procedure was exactly similar to that already described; an explosive mixture was introduced into the small box, the latter was now placed in the Explosion Chamber and surrounded with an explosive atmosphere, after which the switches were closed, thereby igniting the internal mixture. The results were noted.

By keeping the current constant throughout a series of experiments, in which the gas mixtures were varied from the lower to the upper explosive limits, points were obtained above and below the most explosive mixture, at which external ignition could not be produced, although the mixtureignited was within the explosive range.

On repeating the above experiments, using a higher value of igniting current other points were obtained at which flame capable of causing external ignition no longer passed.

The points so obtained might be conveniently referred to as the "flame passing limits", and the range of mixtures between the points as the "flame passing range."

The currents used in the experiments varied from 3 amperes to 78 amperes, and it was found that the "flame passing range" increased until igniting current had a value of 30 amperes. The "range" did not increase above this value of igniting current, and was found to be nearly coincident with the "explosive range".

Two sets of points, representing the "lower" and "upper" limits "of the "flame passing range", were thus obtained and are shown plotted in fig. II.

A few of the results are given in the following table.

TABLE V.

The Effect of Strength of Igniting Current on Passage of Flame from Explosions of Gas and Air Mixtures.

Gas in cubic ft. S.B.	E.C.	Ig. Cur. Amps.	Bdth. of Fl.	Gap. Depth.	Gap. Length.	Ignition. Internal.	Ignition. External	Remarks
.027	2.700	3.5	1"	.058	1.625 +	Yes.	No.	
.028	"	3.5	"	"	"	"	Yes.	
.027	"	14.5	"	"	"	"	Yes	
.025	"	14.5	"	"	"	"	No	
.024	"	33	"	"	"	"	No	Lower Limit.
.025	"	33	"	"	"	"	Yes	
.025	"	60	"	"	"	"	Yes	
.024	"	78	"	"	"	"	No	
.031	2.700	16	1"	.058	1.625 +	Yes	Yes	
.032	"	16	"	"	"	"	No	
.032	"	23	"	"	"	"	Yes	
.033	"	23	"	"	"	"	No	Upper Limit.
.0325	"	40	"	"	"	"	Yes	
.034	"	40	"	"	"	"	No	
.033	"	60	"	"	"	"	No	
.034	"	78	"	"	"	"	No	

CONCLUSIONS & DEDUCTIONS:-

The opening between the flanges was the minimum length of opening for passage of flame at the depth of gap used, consequently increase or reduction of the amount of coal gas in the mixture, by reducing the potential heat of the mixture would in itself be sufficient to prevent passage of flame.

The existance of the "flame passing range" is not surprising. As already pointed out any alteration of the conditions of experiment when working with mixtures near the explosive limits, affects these limits.

Berthelot in his experiment observed that the explosibil:
:ity of mixtures near the limits was increased, when ignition was accompanied by shock which produced mechanical disturbance of the mixture. It follows therefore that as the igniting current is increased the disturbance set up when the fuse is blown will increase. so the rate of propagation of flame will increase and time rate of development of pressure will be relatively greater. Weak mixtures will therefore burn with greater rapidity as the igniting current is increased, and conditions may be such that flame capable of causing ignition will be projected through the opening between the flanges. Points will be reached above and below the most explosive mixture where the mechanical disturb:
:ance is no longer capable of producing such marked effects, and these points will be very near, if not coincident with, the explosive limits of the mixtures used.

In the experiments the range was a maximum when the igniting current reached a value of 40 amperes, and increase of value of current beyond this did not widen the range. In Fig. 11 the results obtained are shown in the form of a graph.

Since the phenomenon is observable only at limit mixtures under abnormal igniting conditions and is apparent only when the length is increased beyond the critical length for the particular gap, it follows that if the gap is such that flame from the most explosive mixtures is effectively cooled in passing through the gap no fear need be entertained regarding the possibility of external ignition by fuses blowing under considerable overload.

A few experiments similar to those described above were carried out with gaps of 0.078 inch and 0.040 inch, and the results, in general, confirmed those already obtained.

COAL DUST:-

The effect produced by addition of coal dust to the gas mixtures.

The question of ignition of coal dust in addition to gas mixtures is one that must be considered. Where designed openings are left in casings, entry of fine coal dust will inevitably occur, if the apparatus is used in a coal mine. In all electrical apparatus, its presence is undesirable, since faulty electrical contact etc. will be produced, if the quantity of dust is excessive. The dust will also lodge in the opening and might prevent, or hinder, the effective operation of protective measures.

In order to investigate the effect of the presence of coal dust in the casing and between the flanges, in addition to explosive gas mixtures, and to determine whether the conclusions arrived at using gas mixtures alone, would have to be modified to embrace the effect of added dust, a large number of experiments were carried out.

A sample of coal was obtained and ground to pass through a 200 mesh sieve.

Proximate analysis performed in duplicate gave the following average results.

Volatile Matter.........32%	(Volatile Hydrocarbons....24.2%	(Moisture..................7.8%
Coke.......................68%	(Ash........................5.5%	(Fixed Carbon. 62.5%

QUANTITY OF DUST ADDED:-

It was decided to add dust in the proportion of one ounce per cubic foot of air space, a quantity much in excess of that necessary for propagation of flame in a dusty atmosphere. The reason was, of course, to make the test as severe as possible.

The box used in the experiments was the small box already described, having volume of 0.12 cub. ft., and flanges one inch broad. The gap chosen was 0.058 inch deep and 1.625+ inches long. This gap produces external ignition with gas mixtures.

In the initial experiments dust was placed between the flanges at the gap. It was found to have no appreciable effect, because when ignition of dust and gas took place inside, the casing, the dust between the flanges was blown out and was not ignited. The placing of dust between the flanges was therefore abandoned on this account.

The most severe conditions possible under the circumstances, were imposed on the box but only in a few cases out of a large number of experiments was it possible to obtain external ignition. In two of the cases external ignition was effected through the bursting of the box by the internal ignition, direct communication with the outside mixture being thus afforded. The bolts securing the cover of the casing were occasionally sheared also.

When the cover was removed after an experiment, dense yellowish fumes, the product of partial distillation of the coal, were found. It would seem therefore that this evolution of distilla: :tion products etc., had some effect in preventing passage of flame. If however we consider the bursting of the two boxes, and the number of bolts that were sheared, we might be inclined to suggest that dust added to the gas mixture increases the pressure attained by the explosion.

We might visualise what takes place in the box when coal dust and coal gas present in explosive proportion are ignited. Here we have two combustible substances and a certain amount of air. When the fuse "blows", ignition of the gas mixture occurs and a dust cloud is raised. Part of this dust must be consumed directly, part will be volatilised, while a certain amount will be expelled, probably unburned, from the casing. The products of this partial distillation cannot be consumed since the oxygen has been used up in the explosion of gas and burning of dust, so that the box will be filled with spent gases and volatile matter - not a very suitable medium for flame propagation. The mixture that issues from the box will therefore consist of coal dust, distillation products and gases from the explosion. Condensation and cooling of the contents of the box immediately follows, and part of the surrounding mixture will rush in through the opening. The mixture in the box may now be inflammable but the temperature

Table VI.

Pressures Developed By Explosive Gas Mixtures Under Various Conditions.

Cubic Feet of Coal Gas	Igniting Current in Amperes	Gap		Pressures Recorded [in lb/in²]			Average Pressures lbs/□"
		Length	Depth				
·015	18	·375"	·10"	5	5	5	5
·020	"	"	"	20	22	22	21·3
·025	"	"	"	39	39	38	39
·028	"	"	"	41·5	42	41	41·5
·030	"	"	"	40	44	43	42
·032	"	"	"	41	40	40	40
·035	"	"	"	32	32	33	32·3.
·040	"	"	"	23	20	22	22
·042	"	"	"	11	12	11	11·3
·015	"	·875	·080	5	5	5	5
·020	"	"	"	18	23	22	21
·025	"	"	"	34	34	33	34 –
·027	"	"	"	34	35	38	36 –
·030	"	"	"	36	37	40	38
·035	"	"	"	32	33	33	32·6
·040	"	"	"	24	18	25	22·3
·045	"	"	"	5	5	5	5
·020	"	1·625	·060	21	20	20	20
·025	"	"	"	33	32	31	32
·030	"	"	"	36	35	35	35·3
·035	"	"	"	29	32	30	30·3
·040	"	"	"	21	19	20	20
·020	"	6·0	·040	18	18	18	18
·025	"	"	"	26	30	28	28
·030	"	"	"	34	33	32	33
·035	"	"	"	24	32	27	28
·040	"	"	"	18	18	18	18
·020	"	9·0	·036	3	3	4	3·3.
·025	"	"	"	14	15	18	16
·030	"	"	"	21	21	18	20
·035	"	"	"	12	14	15	14 –
·040	"	"	"	3	3	4	3·3.
·030	"	29" [Perimeter]	·030"	6	6	5	6 –
·030	"	1·625"	·010"	39			39
·030	"	"	·030"	37			35
·030	"	"	·040"	34			34
·030	"	"	·058"	33			33
·030	"	"	·080"	29			29.

has fallen below the ignition temperature, so further ignition does not occur.

It is therefore evident that the dust cloud raised has a damping effect on the flame of the gas explosion, and the partial distillation will cause a further fall in temperature, so that gases issuing from an explosion will have a temperature considerably lower than those issuing from an explosion of a gas mixture only.

The quantity of coal dust equivalent to one ounce per cubic foot of air space, amounted to 3.5 gms. This amount of dust was practically all consumed by ten internal ignitions. Of the ten ignitions, only the last one, in general produced external ignition, being practically a gas ignition.

CONCLUSIONS:-

To sum up, we might say that the results obtained indicate that the addition of coal dust does not increase the danger of passage of flame, but rather retards it, while the pressure developed by the explosion is increased.

MEASUREMENT OF PRESSURE DEVELOPED BY EXPLOSIONS:-

An important part of this investigation lies in the measurement of pressures developed by explosions of gas and air mixtures. So far, the only point considered has been the prevention of passage of flame capable of igniting the external mixture. It is apparent however that results are incomplete without some knowledge of the pressures developed at the various 'critical lengths.'

We have already mentioned that adequate pressure release and prevention of passage of flame are the aims of all protective measures. From a "flame-proof" point of view these two factors directly oppose each other, for, while a large escape area lowers pressure it increases danger of passage of flame, and a small escape area reduces possibility of passage of flame but tends to development of high pressures. Both factors must therefore be considered when we intend to leave designed gaps between flanges, since obviously, the most suitable gap will be that

Table VII

Pressures Developed By Gas Mixtures Containing Coal Dust.

Coal Gas in Cubic Feet	Coal Dust [200 Mesh] in Grams	Igniting Current in Amperes	Gap Length	Gap Depth	Pressures Recorded in lbs/□"			Average Pressures lbs/□"
·030	Nil	21	6	·040	35	31	35	33
·030	"	26	"	"	32	33	32	32·3
·030	"	35	"	"	34	33	32	33
·030	"	42	"	"	33	32·5	32	32·5
·030	"	50	"	"	34	32	33	33
·030	"	60	"	"	33	34	32	33
·015	3·5	18	1·625	·058	9	8	8	8·3
·020	3·5	"	"	"	21	20	19	20
·025	3·5	"	"	"	29	33	[illegible]	31
·028	3·5	"	"	"	36	37	37	36·6
·029	3·5	"	"	"	37	38	39	38
·030	3·5	"	"	"	39	39	39	39
·031	[illegible]	"	"	"	38	38	38	38
·035	3·5	"	"	"	32	33	34	33
·040	3·5	"	"	"	21	21	21	21
·045	3·5	"	"	"	8	9	9	8·6
·015	Nil	"	"	"	7	7	7	7
·020	"	"	"	"	20	20	19	19·6
·025	"	"	"	"	30	32	33	31·6
·028	"	"		"	34	34	33	33·6
·029	"	"	"		34	35	35	34·6
·030	"		"	"	36	35	35	35·3
·031	"	"	"	"	36	34	35	35
·035	"	"	"	"	29	32	30	30·3
·040	"	"	"	"	21	19	20	20
·045	"	"	"	"	7	7	7	7

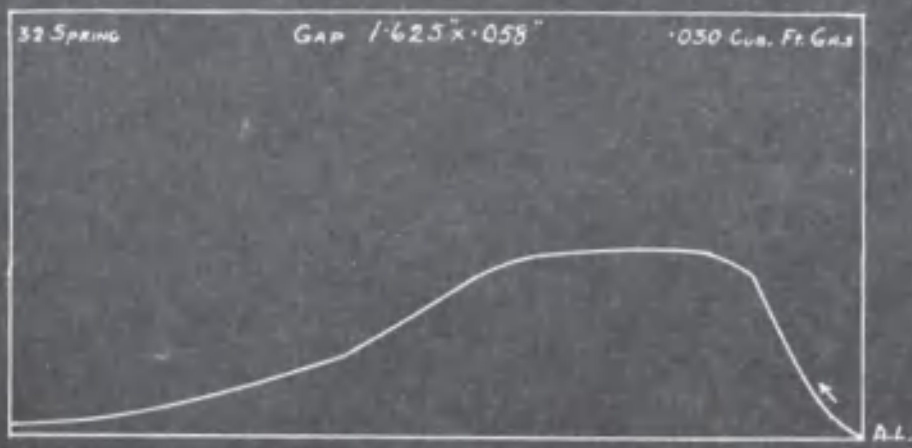


Fig 15: Reproduction Of Typical Time-Pressure Indicator Card (Read From Right To Left)

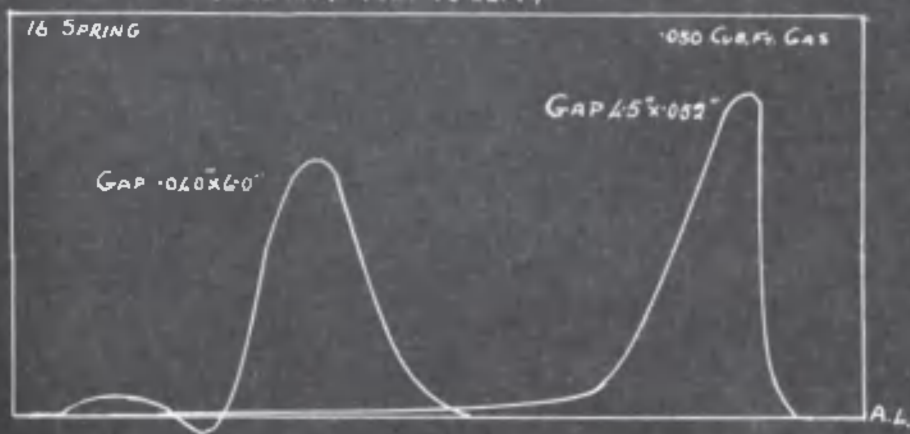


Fig 16: Reproductions Of Time-Pressure Curves [Read From Right To Left]

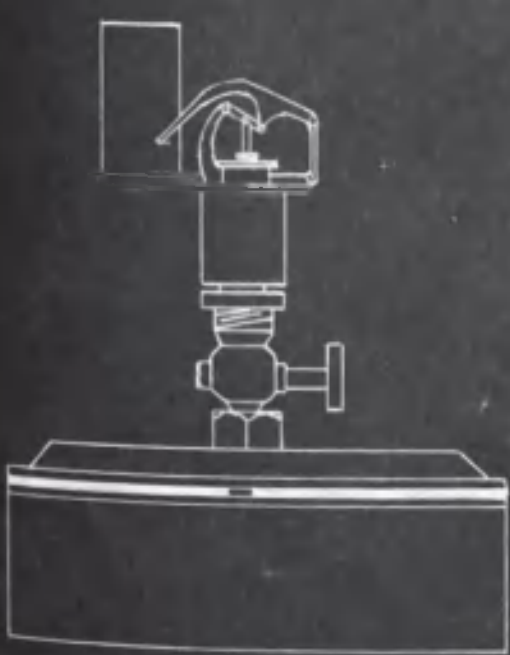


Fig 17: Switch Box With Indicator Attached

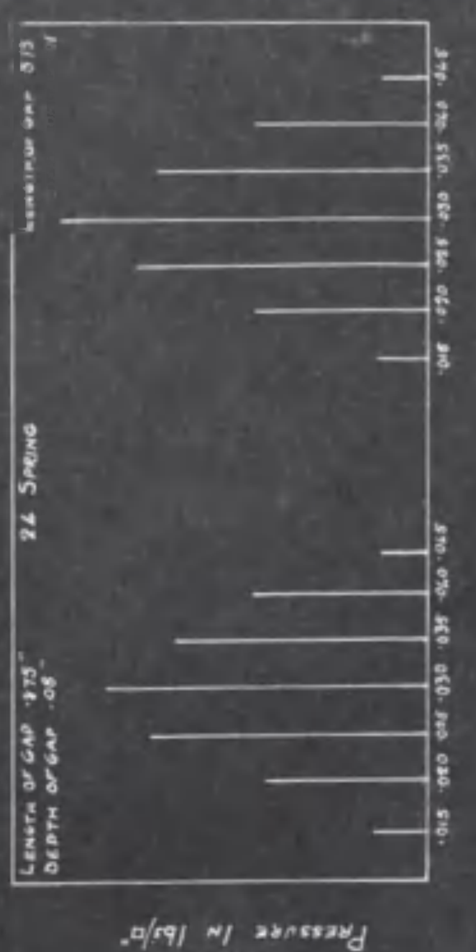


Fig 18: Reproduction Of Indicator Card Showing Method Of Recording Pressures

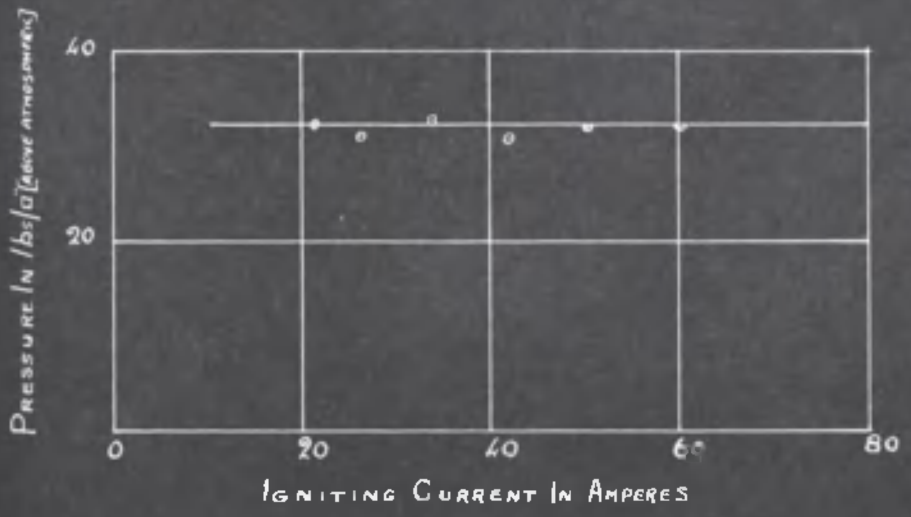


Fig. 12 :- Gas Quantity, Depth And Length Of Gap All Kept Constant

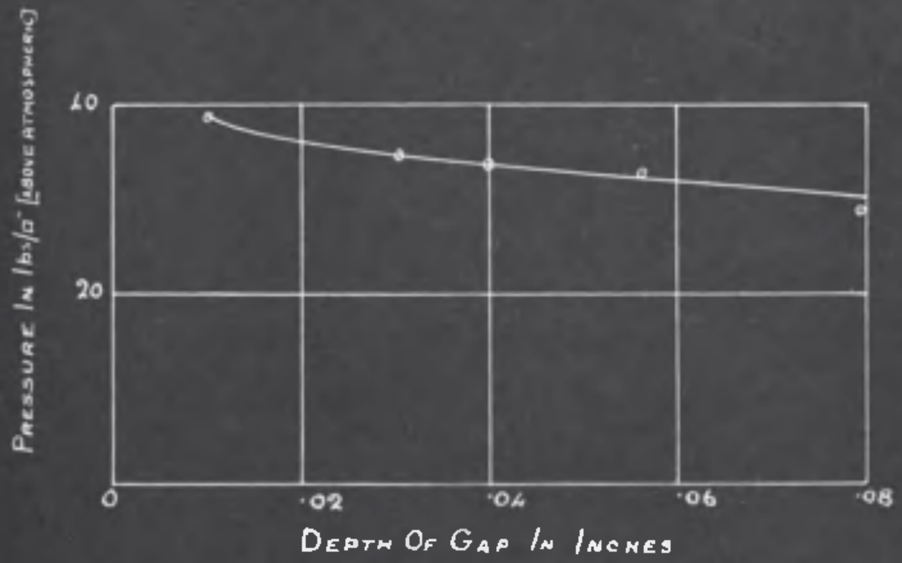


Fig 13 :- Gas Quantity, Length Of Gap, And Igniting All Kept Constant

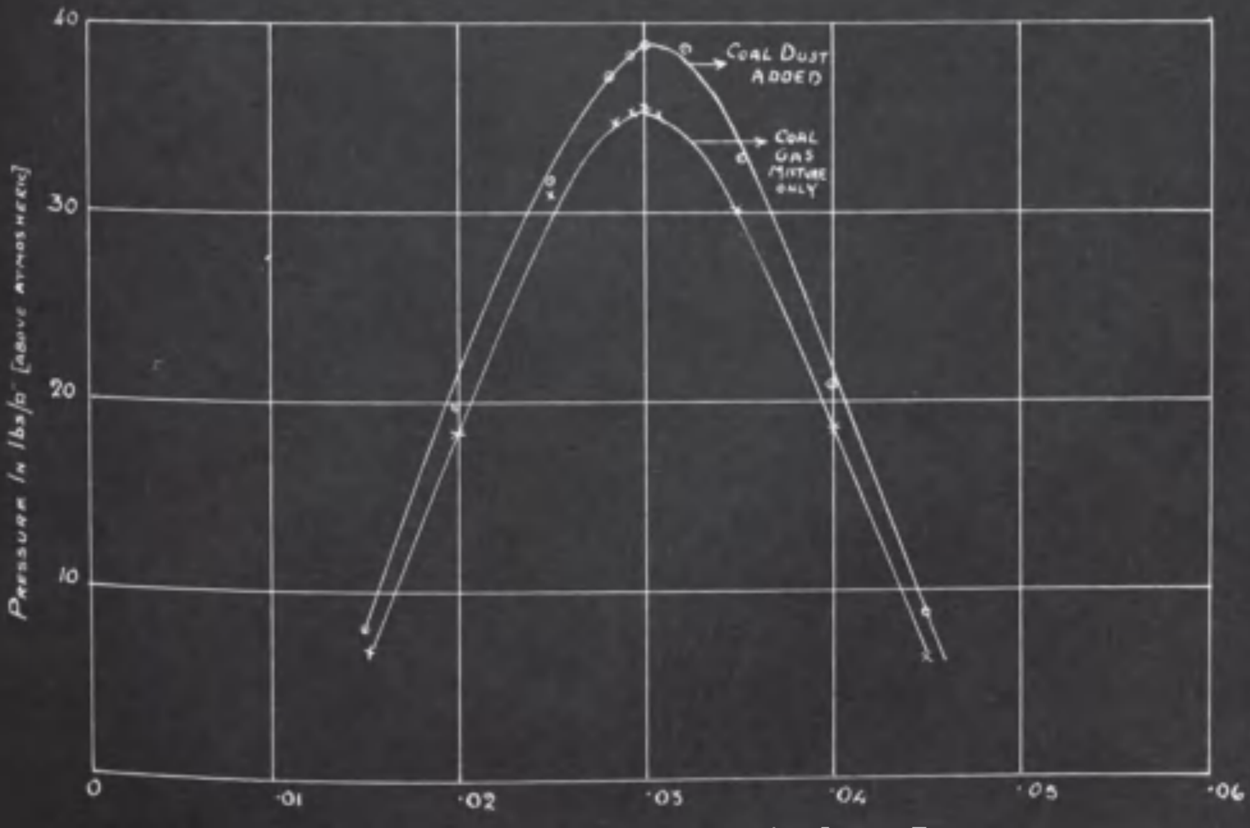


Fig 14 :- Length And Depth Of Gap And Igniting Current, All Kept Constant.

which gives the lowest possible pressure, consistent with preservation of "flame proof" properties.

Now, as the critical length increases, the "escape area" (i.e. product of "critical length and "depth of gap) increases so that we may expect lowering of the pressure developed by the explosion of the internal mixture. It has already been shown that the flange area exposed, increases, and that cooling by contact with the flanges becomes predominant, as the "critical length" increases.

Apparently then, when cooling is brought about by contact with large metallic surfaces, we may expect greatly reduced pressures, whereas when the contact area between the flanges is small, higher pressures may be expected.

It has been pointed out that when the "escape area" is small, the flange area exposed is small, and that cooling is effect:ed mainly by expansion.

Under these circumstances, we must expect relatively high pressures.

In the measurement of the pressures three factors were considered viz. gap left between the flanges, gas quantity present, and value of igniting current. Each factor can be varied at will, and in the following experiments each has been varied in turn while the other two remained constant.

Thus, three sets of results were obtained.

(a) Pressures developed with gas quantity and gap constant, and igniting current varied.

(b) Pressures developed with gap and igniting current constant, and gas quantity varied.

(c) Pressures developed with igniting current and gas quantity constant, and gap varied.

The apparatus used was similar to the small switch box already referred to, and pressures were measured by means of a steam-engine indicator (see fig. 17.) No attempt was made to obtain time-pressure records in all the experiments, but in special

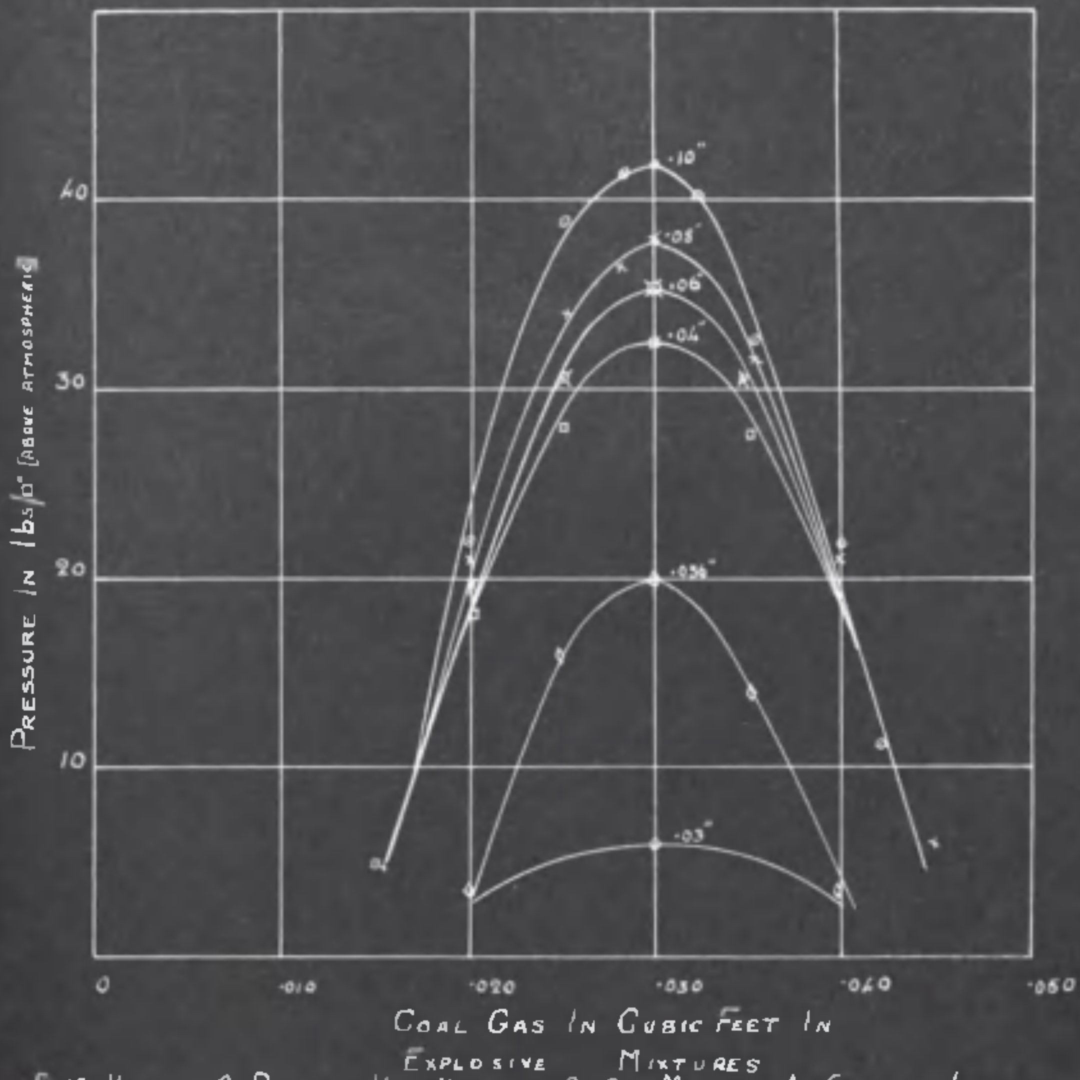


Fig 19:- Variation Of Pressure With Variation Of Gas Mixtures At Critical Lengths
Igniting Current Constant

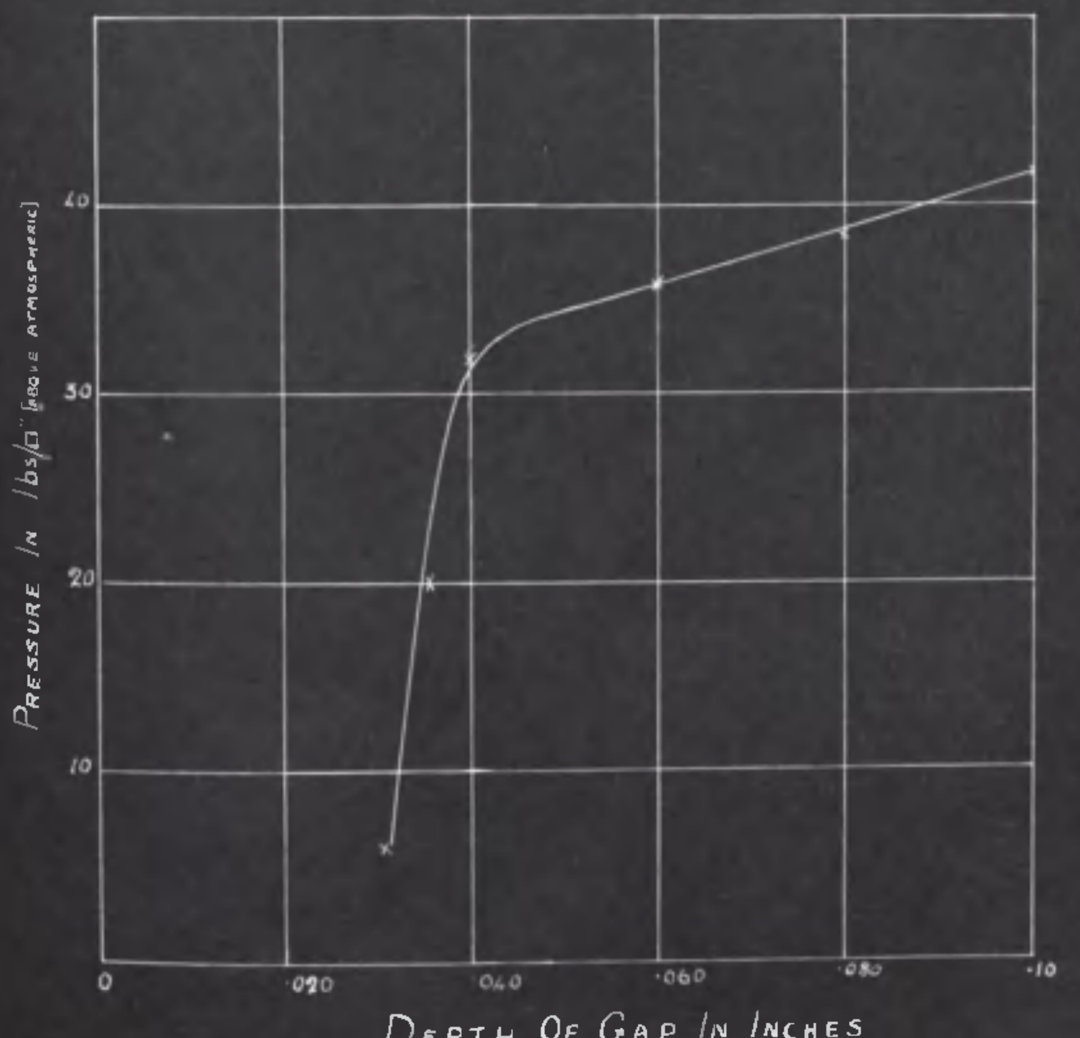


Fig 20:- Maximum Pressures Developed At Critical Lengths

experiments a few were obtained by realeasing the 'drum' of the indicator, at the moment of ignition. Typical indicator cards are reproduced in figs. 15 and 16.

The results of these experiments are best shown by means of graphs and in addition to the tabulated results curves are shown in figs, 12, 13 and 14, in which the effects of the various factors on pressure development can be readily seen.

When igniting current is the variable factor the graph of pressure is a straight line parralel to the abscissa, indicating that the value of the igniting current has not any effect on the ultimate maximum pressure of the explosion. This, of course, is what we might expect. The only effect we might look for, would be, that the pressure rise might be more rapid with a large current than with a small igniting current.

With gap and current constant and gas quantity varied the effect on pressure is naturally, very marked. We traverse the entire explosive range of gas mixtures in this series, and observe how the pressure rises rapidly from the lower limit of explosibility to the most explosive mixture, and then, as the gas quantity is increased beyond this point the pressure falls rapidly until the upper limit is reached at which pressure is very low.

By keeping the gap length, current and gas quantity constant, and varying the depth of gap from 0.10 inch to 0.01 inch, a set of pressure records were obtained from which a curve was plotted. In this graph we observe particularly the effect of decreasing the depth of gap, or in this case continually reducing the "escape area" between the flanges. As the "escape area" is reduced we gradually approach the totally enclosed state in which no provision is made for escape of gases or pressure release, and hence pressure developed is a maximum. It follows therefore that as this state is approached the pressure must increase.

PRESSURES DEVELOPED AT CRITICAL LENGTHS:-

The pressures developed by different gas mixtures at critical lengths were also measured and curves plotted from the result (see fig. 19.) The curves show that the pressure falls by small amounts until the gap is 0.04 inch. At depths of gap less than 0.04 inch the pressure fall is very rapid until we can leave a gap all round the perimeter. The pressure recorded under the latter conditions is only about 6 lbs per square inch.

We have referred to cooling by contact, and expansion, and described the conditions under which each predominates. There must, however, be a certain point at which each is equally effective, and above and below this point some characteristic must become apparent to indicate the factor which is chiefly responsible in effecting cooling of the gases from the explosion.

We have shown that pressure is a minimum when cooling by contact predominates, consequently when a point is reached at which pressures begin to fall rapidly it must be evident that the expansion effect no longer controls cooling.

The position of this point is readily detected in fig. 20 in which ordinates are "maximum pressures at critical lengths" and abscissae are depths of gap.

The point at which change occurs is 0.04 inch depth of gap. We may reasonably assume then, that cooling by contact begins to assert itself from .04 inch gap downwards and that at gaps over 0.04 inch, expansion is the chief cause of cooling, while the effect of each is apparently equal at this particular depth of gap.

PRESSURES DEVELOPED WHEN COAL DUST IS ADDED TO THE GAS MIXTURES:-

Coal dust, in the proportion used in previous experiments, was added to the box and a set of pressure records obtained. The results are shown plotted in fig. 14, and indicate that the pressure is higher than when gas mixtures alone are used. Under favourable conditions very much higher pressures than those indicated may be recorded.

GENERAL CONCLUSIONS:-

It has been shown that strength of igniting current does not affect the ultimate pressure attained by an explosion in a partially closed vessel.. We have also seen that the addition of coal dust increases the pressure developed. The most important results however are those showing the pressures developed at 'critical lengths'. These results help materially in deciding which method of protection to adopt. It is clearly evident that cooling by contact with large cooling surfaces is preferable to cooling by expansion, or any method in which resistance is offered to the escaping gases, as, for example, in passing through a special device. It is of importance to note that large cooling surfaces, from which the 'escape area' is small, do not completely satisfy the requirements, because pressure developed varies inverse:ly as the 'escape area'. In employing flanges with the proper perimeter gap between them, we provide a large cooling surface and a large 'escape area', and, consequently combine effective cooling with adequate pressure release. In this respect flange protection is superior to all protective devices, because, as we have already pointed out, it is doubtful whether the two factors can be satisfactorily combined in the same appliance.

WEBBED COVERS:-

While carrying out a series of experiments in which a stronger type of box was used it was observed that critical lengths were slightly greater than in the other casings of same dimensions. The breadth of flange was the same in each case, and the volumes were also approximately equal, so that we might have expected similar critical lengths. The material of which each casing was made was cast iron, therefore possibility of different rates of conduction of heat cannot be entertained.

In the stronger type of box there were several internal webs. This, while strengthening the box increased the internal surface area by approximately 30 sq. inches. It follows therefore that a larger cooling surfacw was presented to the hot gases of the explosion so that the temperature reached would be less than in the box in which there were no webs. The gases issuing at the opening would be at a lower temperature than under the old

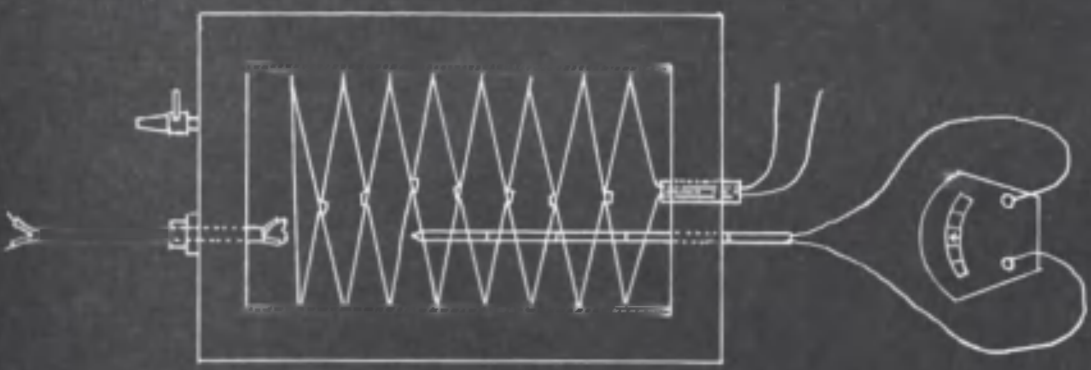


Fig 21 :- Small Switch-Box With Heating Coil And Thermo-Couple In Position As Used In Heated Casing Experiments

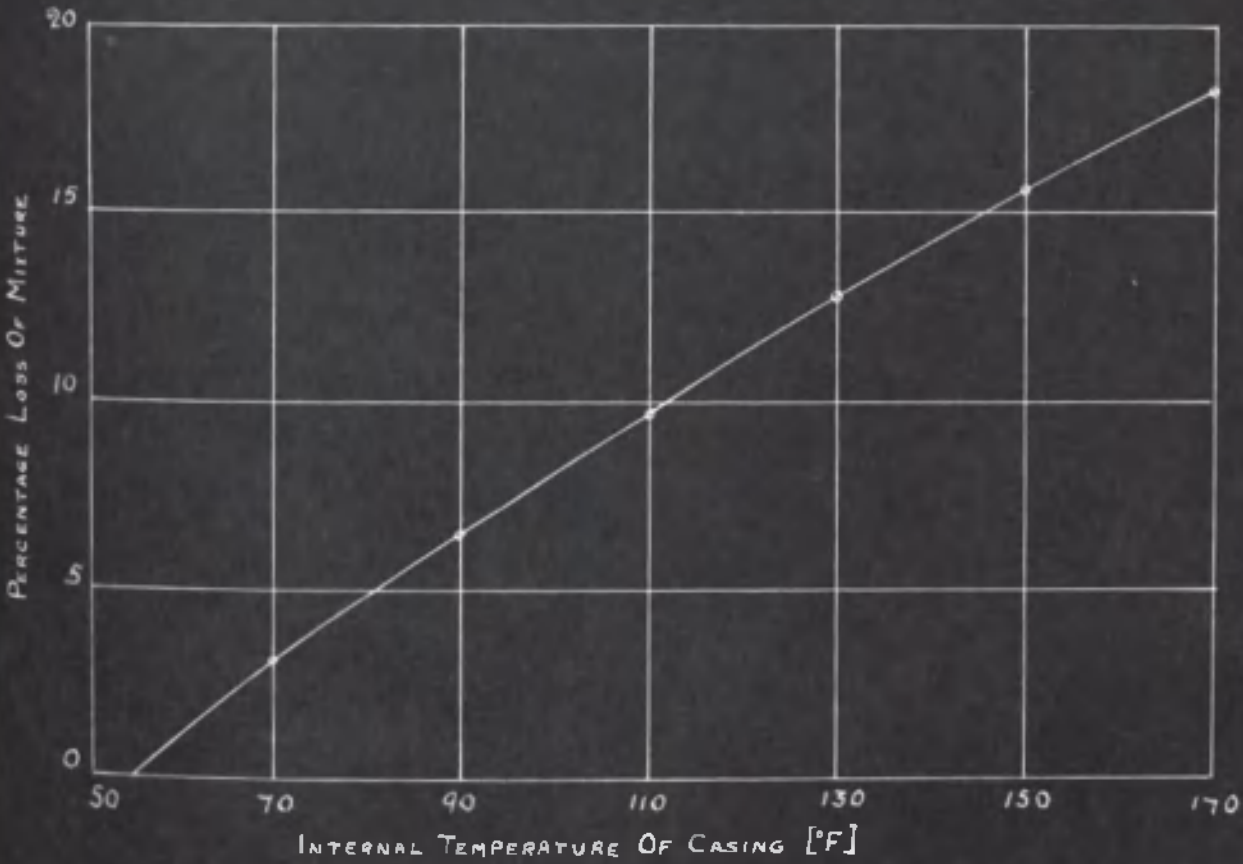


Fig 22 :- Curve Showing Reduction In "Net Weight" Of Mixture With Rise In Temperature Of Casing

Initial Temperature Of Casing 55°F

conditions, therefore an increase in the 'escape area" would be necessary before flame passed to ignite the external mixture.

The critical lengths would therefore be greater in the stronger box.

The increase in length was slight but very marked. Further investigation is necessary before definite conclusions can be arrived at, but the results are certainly indicative of what might be done in the direction of cooling gases before they pass between flanges or through protective devices.

Internal, and external webs, are already applied to casings of certain machinery used in mines, the purpose of the application being to prevent excessive rise in temperature under working conditions. The idea could be readily extended to switch-gear casings etc., to increase the cooling surface present:ed to hot gases in event of an explosion occurring, and thereby considerably assist in maintaining the flame-proof features of the apparatus.

HEATED CASINGS:-

Up to the present the experiments described have all been performed with the casings at the atmospheric temperatures prevailing at the time of experiment. Strictly speaking therefore, the results obtained, and the conclusions arrived at, apply only to ordinary atmospheric conditions.

The rise in temperature of electrical apparatus depends on the working conditions, and may be such that temperature of 100°C and over may be reached.

Electrical defects in the apparatus, will of course give rise to abnormally high temperatures at certain parts of casings, and in the following discussion are considered apart from temperature rise due to working conditions.

The problem that confronts us, is, to determine whether apparatus, flame-proof at atmospheric temperatures, still retains its properties at higher temperatures. If the properties are not

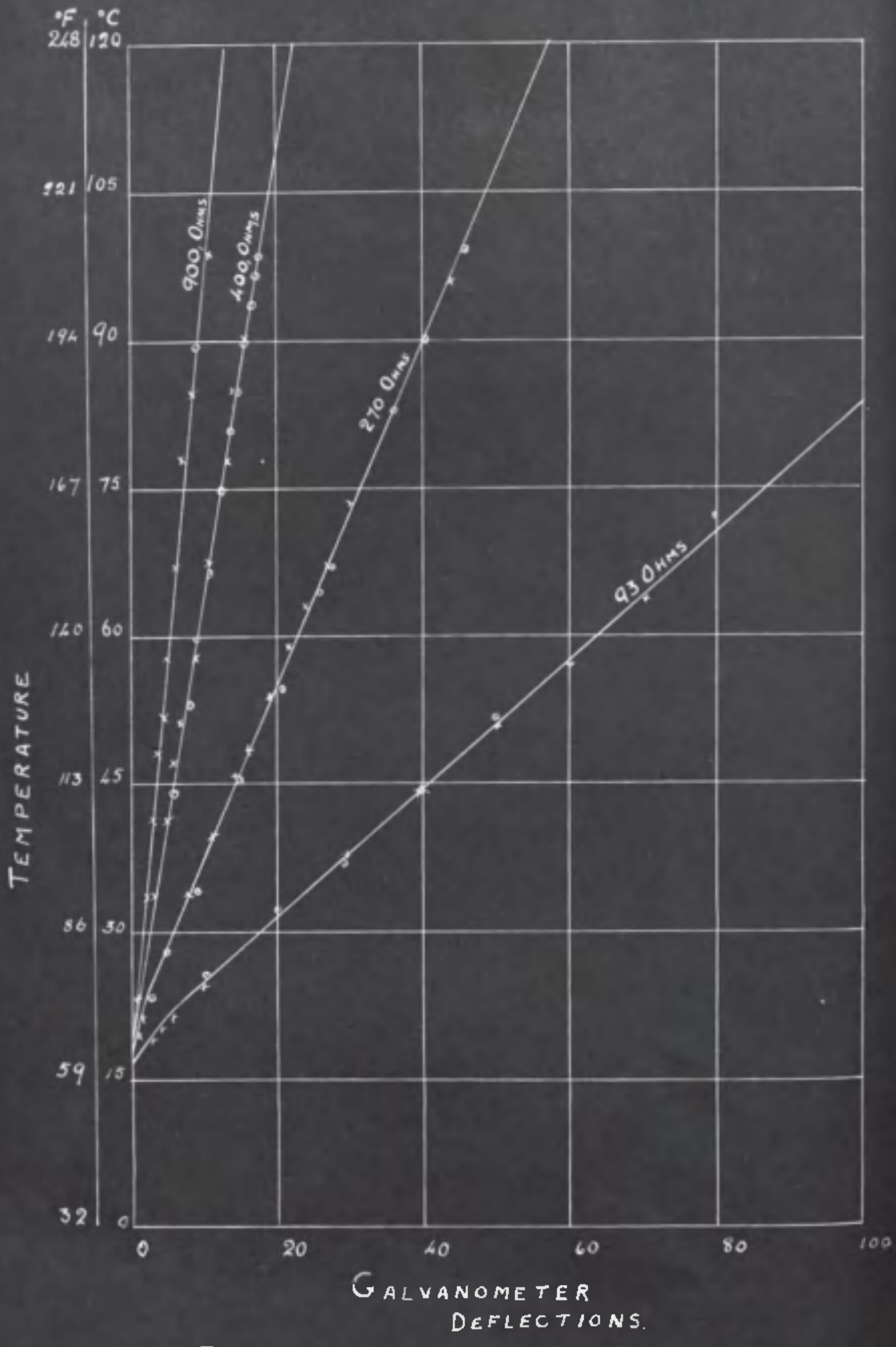


FIG.23: THERMO-COUPLE CALIBRATION CURVES

retained, we must consider what modifications are necessary to counteract the effects of the increase in temperature.

Now, ample cooling surface is essential in all protective measures, and the lower the temperature of the surface, the more efficiently will it function.

Each degree rise in temperature, will therefore reduce the efficiency of the cooling surface, and a point will ultimately be reached at which the cooling power will be negligible, so far as the cooling of hot gases is concerned.

As the temperature of the walls of the casing increase, their cooling effect on the gases, at ignition will not be so marked, and higher temperatures may be reached by the gases, if the vessel is totally closed.

The behaviour of the gaseous contents of the casing, under an increase in temperature, must also be taken into account.

Let us consider a totally closed vessel, into which a gaseous mixture at atmospheric temperature and pressure, has been introduced. According to Charles 'Law if the temperature of the casing be raised, the pressure of the gases will rise above atmospheric pressure, while the volume remains practically constant. If the contents of the vessel were explosive, higher pressures would be developed on ignition, under the latter conditions.

Now, if the vessel were only partly closed, and communication with the outside was effected, say through a small opening between flanges, totally different results would be obtained.

Free expansion is possible in this case and pressure remains constant. It follows therefore that with each degree rise in temperature a certain volume of gas , will leave the vessel. The volume of gas remaining in the vessel will be the same (approximately) at all temperatures, but the nett weight of gas will be reduced as the temperature rises. We see therefore that if the original mixture was combustible, it follows that as

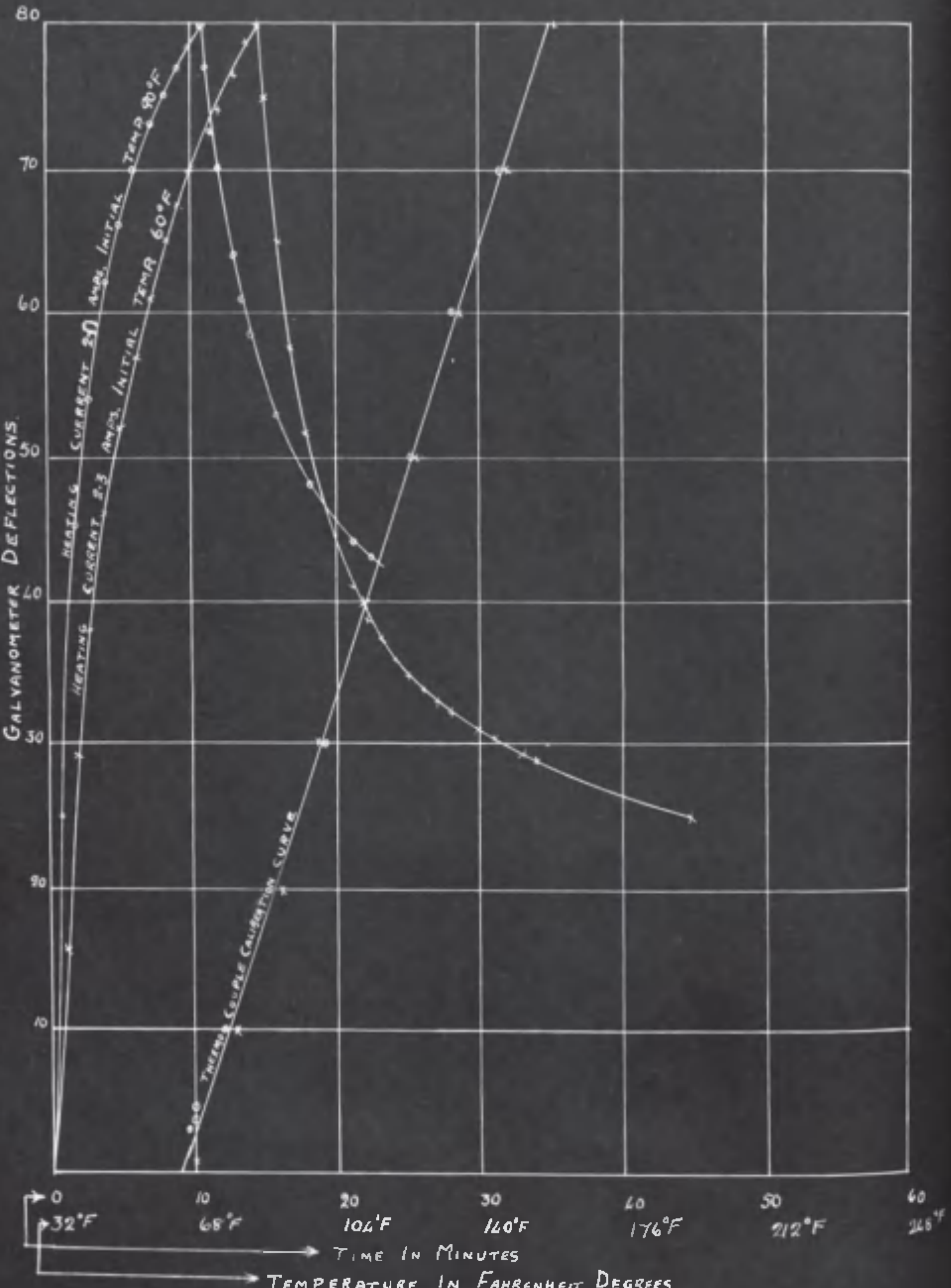


Fig. 24. — Heating And Cooling Curves. Note Effect Of Initial Temperature Of Casing On Rate Of Heating

temperature rises, the potential heat of the mixture remaining, decreases. (See fig. 22.)

It is thus evident that while the efficiency of the cooling surface is reduced with rise in temperature, in the event of an explosion occurring in the vessel, less heat has to be dissipated, so that it may still be capable of preserving the flame-proof properties so essential to safeworking.

In the case of cooling by expansion through a small opening or gap, we must consider the state of the mixture rather than the state of the vessel containing it.

We have seen that the potential heat of the mixture decreases as the temperature of the casing rises, therefore pressure developed by the explosion will be less, consequently the rate of expansion will be reduced.

The decrease in rate of expansion will of course be reflected in the range of cooling effected, and were it not for the fact that the potential heat of the mixture is less than normal, we might expect the temperatures of the expelled gases to be higher than when the initial temperature was that of the surrounding atmosphere.

In the actual experimental work the greatest difficulty was to devise a suitable method of heating the casing to the desired degree and maintaining it at that temperature.

Obviously the most suitable means was electrical, and a ni-chrome coil similar to those fitted in electrical fires was used. Temperature records were taken with a Copper-Constantan thermo-couple, calibration curves are shown in fig. 23.

The small box already referred to was adapted for the experiments, being suitably bored to receive the heating coil and the thermo-couple. The arrangement is shown in Fig. 21 and was found to be the most suitable under the circumstances.

In the initial experiments the usual explosive mixture was admitted to the box at atmospheric temperature, then heating operations were commenced, and continued until the required degree

Table VIII

Results of Calibration of Thermo-Couple and Heating and Cooling of Casing Experiments

Galvanometer Deflections	Galvanometer Resistance etc.	Temperature °C.
1.0	95 Ω	20
10	"	26
20	"	33
30	"	37
40	"	44
50	"	52
60	"	57
70	"	64
80	"	72
80	"	70
70	"	63.5
60	"	56
50	"	51
40	"	44
30	"	38
10	"	24
6	"	20
5	"	19
4	"	18.5
0	275 Ω	16.5
4	"	22.5
9.5	"	34
15	"	45.5
21	"	55
26	"	64.5
32	"	75
36.5	"	83
41	"	91
46	"	99
46	"	100
44	"	96
30	"	73.5
26.5	"	67.5
24	"	63.5
22	"	59
19	"	54.5
16	"	49
14.5	"	46
11	"	40
9	"	35
6	"	30
5.5	"	27.5
2	"	21.0
1	"	19.5
0	"	15.0
6	400 Ω	44
8	"	53.5
9	"	60
11	"	67
13	"	75
14	"	81
15	"	85
16	"	90
17	"	94
17.5	"	96.5

Galvanometer Deflections	Galvanometer Resistance	Temperature °C.
15	400 Ω	100
14	"	98
14.5	"	85
13	"	78
10.5	"	67
8.5	"	57
7	"	51.5
6	"	47.5
5	"	41
3.5	"	34
2.5	"	26
2	"	23
0	"	17
11	900 Ω	100
9+	"	89.5
9-	"	85
7.5	"	78
6	"	67
5	"	57.5
4.5	"	51
4.0	"	48
3	"	40.5
2.5	"	34
1.5	"	26
1.0	"	22
0	"	17

Time in Minutes	Galvanometer Def.	Galvanometer Res.	Heating Current in Amperes
1	15	93	2.5
2	29	"	"
3	38	"	"
4	46	"	"
5	52	"	"
6	57	"	"
7	61	"	"
8	65	"	"
9	67	"	"
10	70	"	"
11	72	"	"
12	74	"	"
13	77	"	"
14	79	"	"
14.5	80	"	Cut Off
15	75	"	Nil
16	65	"	"
17	58	"	"
18	52	"	"
19	47	"	"
20	44	"	"
21	41	"	"
22	39	"	"
23	37.5	"	"
24	36	"	"
25	35	"	"
26	34	"	"

Time in Minutes	Galvanometer Def.	Galvanometer Res.	Heating Current Amperes
27	35	95	Nil
28	33.5	"	"
29	32	"	"
30	31	"	"
31	30.5	"	"
32	30	"	"
33	29	"	"
34	29	"	"
35	29	"	"
36	28.5	"	"
37	28	"	"
38	27.5	"	"
39	27	"	"
40	26.5	"	"
41	26	"	"
42	26	"	"
43	25	"	"
44	25	"	"
45	24.5	"	"

Initial temp of casing in above experiments was 15°C

Time in Minutes	Galvanometer Def.	Galvanometer Res.	Heating Current Amperes
1	30	93	2.0
2	45	"	"
3	54	"	"
4	62	"	"
5	66	"	"
6	70	"	"
7	73	"	"
8	75	"	"
9	77	"	"
10	79	"	"
10.5	80	"	Cut Off
11	77	"	Nil
12	70	"	"
13	64	"	"
14	59	"	"
15	55	"	"
16	53	"	"
17	50	"	"
18	48	"	"
19	47	"	"
20	45.5	"	"
21	44	"	"
22	43	"	"

Initial temp of casing in above experiments was 32°C of temperature was reached. During the heating stage gas was admitted to the explosion chamber till the correct explosive mixture was obtained, the condition being adjusted so that the required temperature was reached when the correct quantity of gas had been admitted.

The internal explosions produced under the above conditions, were generally very feeble, and in a number of experiments no internal ignition was obtained.

The current passing in the coil was adjusted by means of a rheostat and in determining the value to be used for heating purposes,the coil was first brought to red heat, then the resistance was increased until visible light was no longer emitted. The coil must therefore have been at a temperature of over 300°C.

At this temperature prolonged contact with the gaseous mixture, would tend to oxidation of the combustible constituents, with production of a non-explosive or feebly explosive mass.

It is therefore evident that gas cannot be admitted to the box while current is passing through the heating coil.

The casing of course never attained the temperature of the coil, and to determine its temperature at anytime during the period of heating, and after the heating current was cut off, a number of time-temperature observations were made for different values of heating current. Time-temperature curves were plotted from the observations, and by referring to them it was a simple matter to select a rate of heating and cooling so that the required temperature of casing would be attained at a certain specified time after the heating current was cut off. See fig. 24.

During the cooling stage gas was admitted to the casing and then to the explosion chamber, the operation being completed when the casing had reached the required temperature.

By adopting this precedure the possibility of oxidation of the internal mixture was eliminated, but another undesirable feature was introduced.

As the box cooled, contraction of its gaseous contents would occur, and gas would enter from the outside to maintain equilibrium of pressure. It follows therefore that the internal mixture would gradually alter in composition as the casing cooled.

Somewhat similar results may be expected when the external mixture is admitted, before gas is passed into the small box under test.

In this case there will be a mixture containing a small quantity of coal gas, introduced by diffusion and contraction into the casing, before the real explosive mixture is admitted.

We therefore do not know the exact composition of the mixture in the casing, on account of the changes continually taking place, so that while every effort was made to have the internal and external mixtures of same composition it is doubtful if this was ever attained.

The experiments were carried out at critical lengths for gaps from .108 inch to 0.030 inch, so that any change would be readily detected, because the margin of safety is necessarily very small at critical lengths, and any slight alteration in the conditions of experiment, might produce large differences in results.

RESULTS:-

The experiment showed very clearly that the casings remained "flame-proof" until temperatures from 103°F to 110°F were reached. At temperatures above 110°F external ignition could be produced on every occasion until by continual heating the casing had reached a temperature of 155°F - 160°F, when flame capable of causing internal ignition no longer passed.

Further heating of the casing did not seem to alter the results obtained at 160°F.

CONCLUSIONS:-

It has been pointed out that the higher the initial temperature of the casing, the less will be the cooling when ignition takes place, so that the maximum temperature attained by the explosion will probably be higher than normally.

We have also observed that decrease in potential heat of mixture accompanies rise in temperature of the casing, if the latter contains an opening communicating with the outside.

Now, these two factors operate at the same time, the former increasing in power as the temperatures rises above atmospheric, while the latter becomes more apparent as temperature increases.

There is therefore every possibility that we may reach a temperature when "temperature increase of explosions" has a more powerful influence than "the reduction in potential heat effect."

When this state of affairs is reached, external ignition will occur, and will continue until the potential heat of the mixture is reduced to such an extent that the maximum temperature attained (taking into account the increase due to initial temperature) is relatively low.

Under these conditions cooling by contact or expansion, will once more assert itself and thereby prevent external ignition.

In figure 22, percentage loss of explosive mixture is plotted on a base of temperature in °F., the initial temperature being taken as 55°F, and a barometric pressure of 29.8 ins is assumed throughout.

From this graph we observe that the percentage loss of mixture is 9.75 per cent at 110°F and 16.74 per cent at 160°F and if the above hypothesis is correct these points probably represent the upper and lower limits of a flame-passing zone.

TABLE IX.

Loss of Mixture with Rise in Temperature.

Temp. in °F.	Loss in Cub.ft.	Per Centage Loss.
70	.0035	2.84
90	.0079	6.42
110	.0120	9.75
130	.0157	12.76
150	.0192	15.60
170	.0225	18.29

CALCULATION OF LOSS.

Vo. of Casing is 0.123 cub. ft.

e.g. Find volume at atmospheric temp. of 55°F that will occupy 0.123 cub.ft. at 110°F.

$$\therefore V = \frac{V_1 T}{T_1} = \frac{.123 \times 515}{570}$$

= .1110 cub. ft.

∴ 0.1111 cub. ft. at 55°F and 29.8"Bar. occupies 0.123 cub. ft. at 110°F and 29.8" Bar.

∴ volume (at atmos. pressure and temp.) that is lost = 0.123 − 0.1110 = 0.012 cub. ft.

$$\therefore \text{Per Cent. Loss} = \frac{.012}{.123} \times \frac{100}{1} = 9.75 \text{ per cent.}$$

The margin existing between ignition and non-ignition of the external mixture must be very small before the effect described above can be shown. Under the conditions of experiment stated above the effect was clearly observed.

To determine whether the effect was observable when the casing contained explosive firedamp mixtures a quantity of methane was generated from Aluminium Carbide, purified and stored in a gas tank. The necessary amount of methane was drawn from the tank as required.

The results from this series of experiments closely resembled those obtained with the coal gas explosive mixtures, as will be seem from the tabulated results at the end of the thesis.

ANALYSES OF GAS MIXTURES USED IN THE EXPERIMENTS:-

Samples drawn from the casing were analysed periodically. It is of interest to compare the results of analyses of samples, drawn when the casing was at atmospheric temperature, with those drawn after the gas had been in contact with the heated surface for a considerable time.

ANALYSES OF SAMPLES OF GAS DRAWN FROM THE CASING.

No. 1.

Barometric Pressure	30.24"
Atmospheric Temperature.	60°F.
Temperature of casing when gas was admitted.	60°F.
Temperature of casing when sample was withdrawn.	60°F.
Quantity of Coal Gas ad: mitted to casing.	.030cub.ft.
Time between admission of gas and drawing of sample.	1 minute.

(a)

Sample	45.8 ccs.	
K.O.H.	45.4 ccs.	....4ccs CO_2
Br.+K.O.H	45.3 ccs.	....1 ccs. C_mH_n.
Pyro.	38.05 ccs.	...7.25ccs. O_2
RESULT:-	0.87% CO_2	
	0.21% $C_m H_n$	
	15.80% O_2	

(b)

Sample	40.00ccs.	
KOH	39.66 ccs.	....34ccs. CO_2
Br.+ KOH	39.56 ccs.	....10ccs C_mH_n
Comb.	29.77 ccs.	..9.79ccs. Cont.
KOH	26.99 ccs.	..2.78ccs. CO_2
Pyro	26.36 ccs.	.. .63ccs. O_2 left.

O_2 in Sample = 6.32 ccs.

O_2 after comb. = .63 ccs.

∴ O_2 used in comb. = 5.69 ccs.

H_2 = Total Contraction - O_2 used in comb.

H_2 = 9,79 ccs. - 5.69 ccs.

H_2 = 4.10 ccs.

$CH_4 = \frac{2 \times \text{Cont.} - CO_2 \text{ formed}}{3} - H_2$

$CH_4 = \frac{2 \times 9.79 - 2.78}{3} - 4.1$

CH_4 = 5.6 - 4.1 = 1.5 ccs.

CO = CO_2 - CH_4

CO = 2.78 - 1.5

CO = 1.28 ccs.

RESULT.

0.85% CO_2
0.25% C_mH_n.
10.25% H_2
3.75% CH_4
3.20% CO
15.80% O_2
65.90% N_2
100.00

(c)

Sample	63.40ccs.	
KOH	62.90ccs.	.5ccs CO_2
Br.+KOH	62.70ccs.	.2ccs C_mH_n
Comb.	47.00ccs.	15.7ccs Cont.
KOH	43.00ccs.	4.0ccs CO_2
Pyro.	42.00ccs.	1.0ccs. O_2 left.

O_2 in Sample = 10.02 ccs.

O_2 after comb. = 1.00 ccs.

∴ O_2 used in comb. = 9.02 ccs.

H_2 = Total Contraction - O_2 used in Comb.

H_2 = 15.70 ccs. - 9.02 ccs.

H_2 = 6.68 ccs.

$CH_4 = \frac{2 \times \text{Cont.} - CO_2 \text{ formed}}{3} - H_2$

$CH_4 = \frac{2 \times 15.7 - 4}{3} - 6.68$

CH_4 = 9.13 - 6.68 = 2.44 ccs.

CO = CO_2 - CH_4

CO = 4 - 2.44

CO = 1.55 ccs.

RESULT.

0.79% CO_2
0.31% C_mH_n
10.53% H_2
3.86% CH_4
2.44% CO
15.80% O_2
66.27% N_2
100.00

No. 2.

Barometric Pressure	30.54"		
Atmospheric Temperature.	57°F.		
Temperature of Casing when gas was admitted.	300°F.		
Temperature of casing when sample was withdrawn.	147°F.		
Quantity of Coal Gas admitted to casing.	.0295 cub. ft.		
Time between admission of gas and drawing of sample.	12 mins.		

(a)

Sample	68.50 ccs.	
KOH	67.00 ccs	1.50 ccs. CO_2
Br.+ KOH	66.80 ccs.	0.2 ccs. C_mH_n.
Pyro.	57.00 ccs.	9.80 ccs. O_2

RESULT:-

2.2% CO_2

0.29% C_mH_n.

14.49% O_2

(b)

Sample	41.00 ccs.	
KOH	40.10 ccs.	0.90 ccs. CO_2
Br.+KOH	40.00 ccs. ...	0.10 ccs. C_nH_n.
Comb.	30.40 ccs. ...	9.60 ccs. Cont.
KOH	28.00 ccs. ...	2.40 ccs. CO_2
Pyro.	27.60 ccs. ...	0.40 ccs. O_2 left.

O_2 in Sample = 5.98 ccs.

O_2 after comb. = 0.40 ccs.

∴ O_2 used in comb. = 5.58 ccs.

H_2 = Total Contraction - O_2 used in comb.

H_2 = 9.60 ccs. - 5.58 ccs.

H_2 = 4.02 ccs.

$CH_4 = \frac{2 \times \text{Total Cont.} - CO_2 \text{ formed}}{3} - H_2$

$CH_4 = \frac{2 \times 9.6 - 2.40}{3} - 4.02$

CH_4 = 5.6 - 4.02 = 1.58 ccs.

CO = CO_2 - CH_4

CO = 2.40 - 1.58

CO = .82 ccs.

(c)

Sample	40.10 ccs.	
KOH	39.30 ccs.	...0.80 ccs. CO_2
Br.+KOH	39.20 ccs.	...0.10 ccs. CO_2
Comb.	29.80 ccs.	...9.40 ccs. Cont.
KOH	27.40 ccs.	...2.40 ccs. CO_2
Pyro.	27.10 ccs.	...0.30 ccs. O_2 left.

O_2 in sample = 5.8 ccs.

O_2 after comb. = 0.3 ccs.

∴ O_2 used in comb. = 5.5 ccs.

H_2 = Total Contraction - O_2 used in Comb.

H_2 = 9.40 ccs. - 5.5 ccs.

H_2 = 3.90 ccs.

$CH_4 = \frac{2 \times \text{Total Cont.} - CO_2 \text{ formed}}{3} - H_2$

$CH_4 = \frac{2 \times 9.40 - 2.40}{3} - 3.9$

CH_4 = 5.46 - 3.9 = 1.56 ccs.

CO = CO_2 - CH_4

CO = 2.4 - 1.56

CO = 0.84 ccs.

RESULT:-

2.15%	CO_2
0.26%	C_mH_n
9.73%	H_2
3.82%	CH_4
1.98%	CO
14.49%	O_2
67.57%	N_2
100.00	

RESULT:-

2.00%	CO_2
0.25%	C_mH_n
9.75%	H_2
3.90%	CH_4
2.10%	CO
14.49%	O_2
67.51%	N_2
100.00	

COMPARISON OF AVERAGE RESULTS OF ANALYSES OF GAS MIXTURES.

I.

Bar. 30.24. At. Temp. 60°F.

Casing at Atmospheric temp.

CO_2	0.83%	
C_mH_n	0.25%	
H_2	10.39%	18.09%
CH_4	3.80%	
CO	2.82%	
O_2	15.80%	
N_2	66.11%	81.91%

Bar. 30.54. At Temp. 57° F.

Casing at 300°F when gas ad:
:mitted.
147°F when sample with:
:drawn.

CO_2	2.11%	
C_mH_n	.26%	
H_2	9.74%	18.01%
CH_4	3.86%	
CO	2.04%	
O_2	14.49%	
N_2	67.50%	81.99%

EXPLOSIVE MIXTURES CONTAINING METHANE AND TRACES OF HYDROGEN.

I.

Barometric Pressure.	29.42"
Atmospheric Temperature.	59.0° F.
Temperature of Casing when gas was admitted.	59.0° F.
Temperature of Casing when sample was with: :drawn.	59.0° F.
Time between admission of gas and drawing of sample.	1 minute.

(a)

Sample	32.8 ccs.	
KOH	32.8 ccs.	
Br.+ KOH	32.8 ccs.	
Pyro.	26.93 ccs.	5.87ccs O_2

RESULT:-

17.92% O_2

(b)

Sample 25.20 ccs.

Comb. 20.50 ccs.

KOH 19.00 ccs. .. 6.2ccs Tot.Cont.

Pyro. 18.60 ccs. .. 0.4 ccs O_2 left.

O_2 present in sample = 4.51ccs.

O_2 after combustion. = 0.40ccs.

.'. O_2 used in com: :bustion. = 4.11 ccs.

Let T = total contraction due to combustion and absorption of CO_2 formed.

Let O = Oxygen used in combustion.

Then $H_2 = \frac{4}{3} T - 2O$

$CH_4 = O - \frac{1}{3} T$

.'. $H_2 = \frac{4}{3} \times \frac{6.2}{1} - 8.22$
$= 8.26 - 8.22$

H_2 = .04 ccs.

$CH_4 = 4.11 - \frac{6.2}{3} = 4.11 - 2.06$

CH_4 = 2.05 ccs.

RESULT:-

0.16% H_2 17.92% O_2

8.13% CH_4 73.79% N_2

(c)

Sample 21.60ccs.

Comb. 17.60ccs.

KOH 16.30ccs. ... 5.3ccs. Tot.Con.

Pyro. 16.00ccs. .. 0.3 ccs. O_2 left.

O_2 in sample = 3.82 ccs.

O_2 after com: :bustion. = .30 ccs.

O_2 used in combustion = 3.52ccs

$H_2 = \frac{4}{3} T - 2O$

$H_2 = \frac{4}{3} \times \frac{5.3}{1} - 2 \times 3.52$

$H_2 = \frac{21.2}{3} - 7.04 = 7.06 - 7.04$

H_2 = 0.04 ccs.

$CH_4 = O - \frac{1}{3} T$

$CH_4 = 3.52 - \frac{5.3}{3} = 3.52 - 1.76$

CH_4 = 1.76 ccs.

RESULT:-

0.09% H_2
8.14% CH_4
17.92% O_2
73.85% N_2

2.

Barometric Pressure 29.34"

Atmospheric Temperature 58.0°F.

Temperature of casing when gas was admitted. 300°F.

Temperature of casing when sample was withdrawn. 182°F.

Time between admission of gas and drawing of sample 9 mins.

(a)

Sample 34.2 ccs.

Pyro. 28.4 ccs. 5.8ccs. O_2

Result 17.0% O_2

(b)

Sample 25.0 ccs.

Pyro. 20.7 ccs. 4.3 ccs. O_2

Result 17.2% O_2

Average Result 17.1% O_2

(c)

Sample 29.4 ccs.

Comb. 24.2 ccs.

KOH 22.0 ccs. 7.4ccs.Tot.Cont.

Pyro. 21.9 ccs. 0.1 ccs.O_2 left.

O_2 present in Sample 5.02 ccs.

O_2 left after comb. 0.10 ccs.

O_2 used in comb. 4.92 ccs.

$H_2 = \frac{4}{3} T - 2O$

$H_2 = \frac{4}{3} \times \frac{7.4}{1} - 2 \times 4.92$

$H_2 = \frac{29.6}{3} - 9.84 = 9.86 - 9.84$

H_2 = .02 ccs.

$CH_4 = O - \frac{1}{3} T$

$CH_4 = 4.92 - \frac{7.4}{3} = 4.92 - 2.46$

CH_4 = 2.46 ccs.

Result:- 0.08% H_2

8.36% CH_4

17.10% O_2

74.46% N_2

(d)

Sample 64.4 ccs.

Comb. 52.8 ccs.

KOH 48.25 ccs. 16.15ccs. Tot. Con.

Pyro. 48.05 ccs. 0.2 ccs. O_2 left.

O_2 present in Sample 10.94ccs.

O_2 left after comb. .20ccs.

O_2 used in comb. 10.74ccs.

$H_2 = \frac{4}{3} T - 2O$

$H_2 = \frac{4 \times 16.15}{3} - 2 \times 10.74$

$= \frac{64.6}{3} - 21.48$

$H_2 = 21.53 - 21.48 = .05$ ccs.

$CH_4 = O - \frac{1}{3} T$

$CH_4 = 10.74 - \frac{16.15}{3}$

$= 10.74 - 5.38$

$CH_4 = 4.36$

Result:- 0.07% H_2

8.32% CH_4

17.10% O_2

74.51% N_2

COMPARISON OF AVERAGE RESULTS.

I. Bar 29.42. At temp. 59°F. Casing at Atmospheric Temp.	Bar. 29.34. At Temp. 58.0°F. Casing at 300°F when gas ad:mitted. Casing at 182°F when Sample drawn.
H_2 = 0.12%	H_2 = 0.08%
CH_4 = 8.14%	CH_4 = 8.34%
O_2 = 17.92%	O_2 = 17.10%
N_2 = 73.82%	N_2 = 74.48%

Where heating is primarily due to some electrical defect, very high temperatures may be reached and result in destruction of insulation etc.

If temperature of 300°C, are reached in the presence of an explosive mixture of gases, prolonged contact with the heated source will tend to oxidation of the combustible constituents with probable production of a non-explosive mass.

With higher temperatures the rate of heat production due to oxidation, may be greater than the rate of heat dissipation, and if this abnormal state of affairs be allowed to continue in: :flammation of the gas mixture will occur.

However, the smell, smoke, etc., which must be produced under such circumstances, will direct attention to the cause of the disturbance and should result in closing down of machinery etc., until the defect is remedied.

PERMISSIBLE AMOUNT OF WEAR AT BEARINGS:-

With "protected" motors we have to consider the possibil: :ity of passage of flame between the shaft and bearing, in event of excessive wear.

From consideration of results already obtained we are of the opinion that with plain bearings or ball bearings, the length of bearing necessary to support the shaft and armature or rotor, is more than actually required to prevent passage of flame.

The wear of bearing and shaft will produce a crescent shaped gap, the maximum depth of which will be the difference in diameters of the bearing and shaft.

If the length pf shaft were say, 4 inches, the gap necessary for passage of flame along the shaft, to produce external igniton would be from 3/16th." to ¼".

In actual practice such wear would never be permitted, since serious electrical distrubances or magnetic unbalance etc., would be produced, and necessitate renewal or repair of bearing.

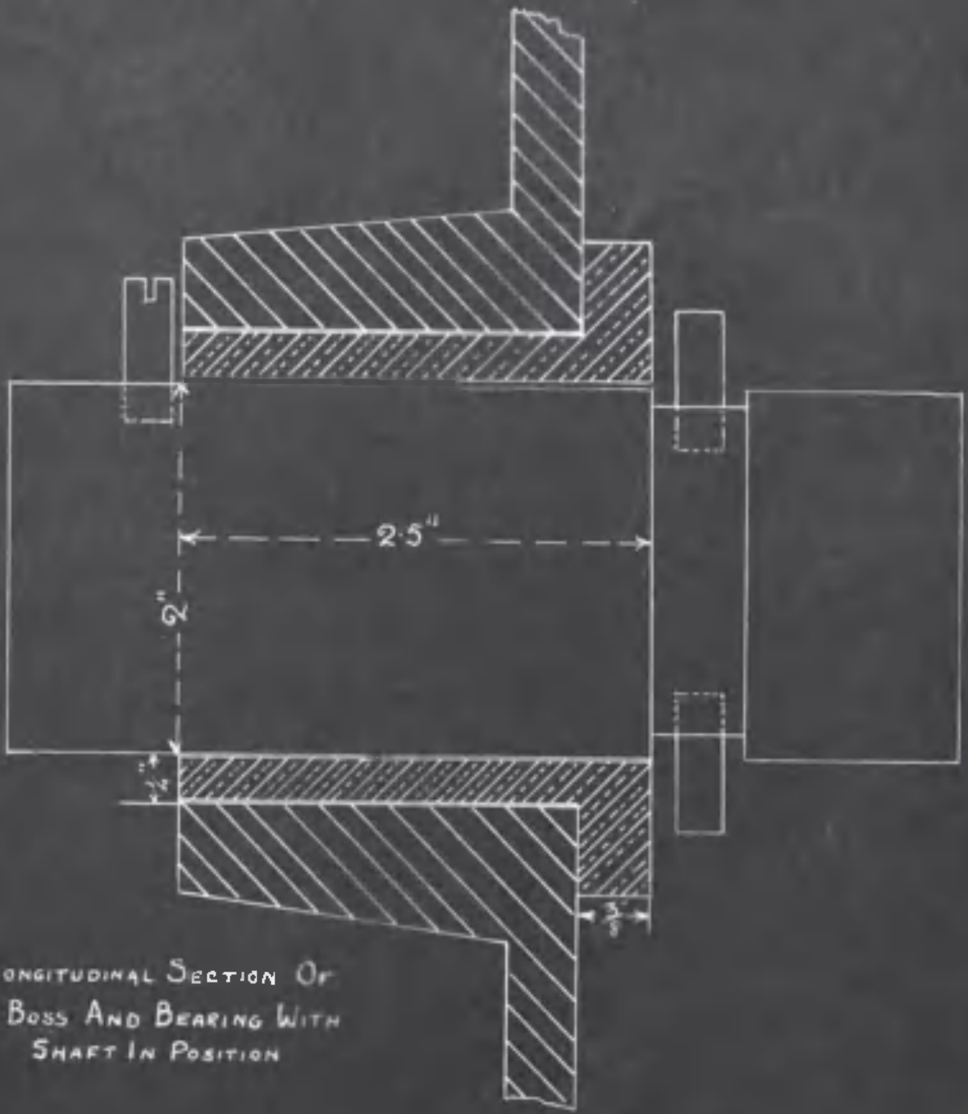


Fig. 25 :- Longitudinal Section Of Boss And Bearing With Shaft In Position

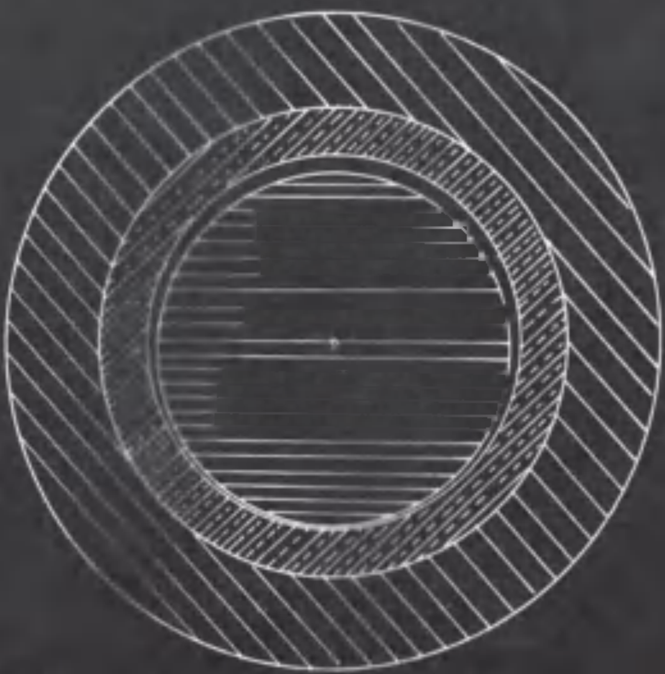


Fig. 26 :- Cross Section Of Boss, Bearing, And Shaft. Note Gap Between Shaft And Bearing, Such As Might Be Formed By Excessive Wear.

Experiments were carried out on a box of volume 2.35 cub. ft., fitted with machined flanges 1.375 inches broad. The box was made of cast iron.

A white-metal bearing was cast into an opening in the side of the casing, the dimensions of the bearing being 2 ins. internal diameter, and 2.5 ins. external diameter, and 2.5 ins. long.

The steel shaft which fitted into this bearing, was 7 ins. long and projected 2 ins. from the bearing.

A groove 0.125 ins. deep was cut in the shaft at the inside end of the bearing, and in this groove four studs were set, to prevent the shaft from being forced out during an internal explosion.

After an explosion in a partially closed vessel such as the above, condensation and cooling occur, and pressure falls below atmospheric.

It follows therefore that the shaft would be drawn into the casing after an explosion, if some means were not adopted to prevent such an occurrence.

A screw-stud was therefore set in the shaft at the outside of the bearing, and had the desired effect.

The arrangement is clearly shown in fig. 25. One end of the casing was tapped to receive a gas tap and a plug for carrying the igniting current cable, and a gap 0.01 ins. in depth was left at the flanges.

The procedure was to admit an explosive mixture of coal gas and air to the casing and ignite it by blowing a "tin" fuse.

The length of fuse used was 1.5 ins. (No. 24. S.W.G.), the igniting current being 18 amperes at 250 Volts D.C.

In the initial experiments the bearing and shaft were a "tight fit", but as the work proceeded, the shaft was gradually reduced in diameter by predetermined amounts, strict observation being kept to ascertain when flame first appeared at the bearing.

At each reduction in diameter of shaft, a number of tests were carried out in the "open", followed immediately by similar tests with the casing surrounded by an explosive atmosphere.

In none of the latter experiments was it possible to produce external ignition.

Occasionally when 'proving' the external mixture after an internal explosion, it was possible to see the flame being drawn into the casing, between the flanges and also at the bear:
:ing, the action producing a whistling sound.

In a large number of the tests the screw stud was withdrawn to see whether ignition of gas would occur when the external mixture entered the casing in the wake of the shaft, after the internal explosion.

Rapid cooling must occur since ignition of the external mixture could not be produced in this manner, but often when proving the external mixture a slight explosion could be heard within the casing, proving the existence of an explosive mixture which must have entered when the shaft was "drawn" in.

In the first series of experiments in the "open", a white emanation was discernible at the bearing during ignition.

As the shaft was reduced in diameter, this "ëmanation" gradually gave place to distinct brownish flames, with wisps of blue and a few "sparks", then as the gap became greater bright red flames and brilliant sparks were observed during ignition.

When a shaft diameter of 1.945 ins. (giving a gap of 0.055 ins.) was reached reddish-blue flames extending to the end of the shaft were apparent, and as the flames increased in luminosity the the white emanation was no longer visible.

After experimenting with the shaft dry, a film of oil was introduced. The immediate effect was considerable shorten:
:ing of the flame, and in many experiments complete quenching of flame resulted.

Considerable quantities of smoke were expelled during the explosion, and the shaft on the outside of the bearing was covered with globules of oil.

The burning of oil between the shaft and the bearing would account for the volumes of smoke at the bearing, while the globules of oil found on the shaft would be deposited there from spray of oil ejected by the gases from the explosion.

After this observation, it might be suggested that the white emanation spoken of above, was merely products of combustion expelled by the explosion. On examining the side of the "explosion chamber" a deposit of grey matter was found directly opposite the bearing indicating that the above view is probably correct.

The fifth experiment with the shaft reduced to 1.945 inches ended disastrously. The casing burst under the strain of the explosion and damaged the explosion chamber.

Part of the casing containing the shaft was carried through the end of the chamber and came to rest 10 feet from it.

On examination it was found that the casing had been sheared along the junction of the sides and bottom.

The gap at the bearing (0.055 ins) would never have been allowed to form in an actual machine, since disturbances etc., already mentioned would have necessitated renewal and repair before the wear had become so marked.

The results obtained are shown tabulated at the end of the thesis.

A smaller box made of cast steel, was now procured and adapted for experimental purposes in the manner already described. The volume of this box was approximately 0.123 cub. ft., with flanges 1 inch broad. The bearing was of brass and of the following dimensions, length 1.625 ins., internal diameter 0.625 inch, external diameter 0.875 inch.

The shaft was made of mild steel, and was 4 inches long, and had a diameter of 0.625 inch.

The shaft and bearing were intended to represent, a controller shaft and bearing.

In the first series of experiments carried out on this box the shaft and bearing were a "tight fit."

The bearing was increased in internal diameter by degrees until flame capable of causing ignition finally passed.

Sparks and flame were first observed with a gap of 0.047 in. At the bearing, the flame being blue in colour and extending and extending only a short distance.

As the gap at the bearing was increased, the flame from the explosions increased in length, and changed in colour from blue to red, while at very large gaps of the order of 0.10 inch the flame at the gap was a vivid white colour.

External ignition was ultimately produced when the difference in diameter between the shaft and bearing was 0.125 ins.

The flame produced in this case extended approximately 3 inches beyond the bearing.

Such excessive wear would never be permitted in a controller shaft and bearing, since faulty contact of studs, fingers etc., would be produced giving endless trouble, and necessitating attention before a gap of such dimensions had been formed. The results will be found tabulated at the end.

CONCLUSIONS:-

Although the first series of experiments could not be completed, sufficient data was obtained to indicate that in general the length of bearing required to support the shaft etc., in more than sufficient to prevent passage of flame between the shaft and bearing.

The danger of passage of flame need not be the deciding factor in determining the permissible amount of wear.

The factor of greatest importance is the prevention of electrical or magnetic disturbances, and if strict attention be directed to this phase of the question, no fear need be enter:
:tained regarding the possibility of ignition of gas by leakage at

the bearing.

It was found possible to complete the second series of experiments and the results are an interesting addition to those of the first series. The production of faulty contact, due to excessive wear at the bearing, has been mentioned. Arcing thereby produced would increase the possibility of ignition of explosive gas mixtures present in the controller casing. It follows that if the casing was not adequately protected external ignition might be produced, but the likelihood of passage of flame between the shaft and bearing is remote, since it is hardly conceivable that apparatus would be allowed to fall into such a state of disrepair that a difference of 0.125 inch in diameters of shaft and bearing existed.

We may conclude therefore that if beaeings are renewed when trouble in making contact is experienced, there will be no danger of passage of flame between the shaft and beaing, capable of igniting an external mixture.

GENERAL SUMMARY OF RESULTS AND CONCLUSIONS:-

1. Cotton gaskets do not constitute a permanent flame proof joint, because they deteriorate rapidly in humid atmosphere.

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2. Flanges 0.5 inch broad do not adequately protect a casing. They do not prevent passage of flame capable of causing ignition of external gas mixture, unless they are machined and in metallic contact. Even under these conditions the margin of safety is small.

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3. An adequately protected casing, maybe rendered unsafe by attaching an inadequately protected piece of apparatus to it. All apparatus should be protected to the same degree.

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4. Where flanges are internal (i.e. extend inwards from the side of the casing), all stud holes should be bottomed, since omission of a stud would provide direct communication with the outside atmosphere.

---

5. Ignition may be produced by the operation of overload releases.

---

6. Cooling of gases from an internal explosion may be effected by either of two methods, or a combination of these two methods. The two Methods are (a) Cooling by contact with a large metallic surface. (b) Cooling by expansion through a small orifice. Cooling by expansion predominates where the release area is small, consequently pressures developed by the explosion of gas mixtures are relatively high.

Cooling by contact occurs when a large release area is provided. In this case high pressure develop:ment is prevented.

Where a gap is left all round the perimeter of an opening which is protected by broad flanges, large cooling surface and large release area are combined. This state of affairs satisfies the definition of the "flame-proof casing definition of the B.E.S.A., since cooling of flame is adequate and pressures developed are low.

Devices which provide a large cooling surface and a small release area do not completely satisfy the requirements.

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7. There is a distinct "flame-passing range" in gas mixtures, and for a given depth and length of gap between flanges of given breadth, the higher the value of the igniting current (till 40 amps. is reached) the

more nearly does the limits of this range approach the limits of inflammability of the mixture.

The phenomenon is observable when the "margin of safety" is small.

---

8. Coal dust present in switch gear casings will probably interfere with the electrical continuity, and in event of an explosion of gas occurring in the casing, will tend to produce slightly higher pressures, but the flame-produced is not so intense as from an explosion of gas alone.

If the correct proportions of coal dust and gas are present very high pressures will be developed.

---

9. Increase of value of igniting current has no effect on ultimate pressure developed, but probably affects the rate of pressure development.

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10. Pressure developed is dependent upon the release area provided. Where a large release area is provided a large mass of gas is expelled unburned when ignition occurs. This tends to reduce temperature and pressure attained, since these depend on amount of gas consumed.

---

11. WEBBED COVERS:- The provision of internal webs in casings is worth considering. These in addition to strengthening the casing increase the cooling surface presented to the flame when ignition occurs. This tends to lower the temperatures attained.

---

12. HEATED CASINGS:- If casings are adequately protected (i.e. have a good margin of safety) no doubt need be entertained regarding the ability of protective measures to function properly at temperatures considerably in excess of that of the surrounding atmosphere.

Increase in temperature of the casing, whilst reducing the efficiency of the cooling surface also causes reduction of nett weight of gas contained in the casing.

This effect more than compensates for loss in efficiency of protective measures.

13. PERMISSIBLE WEAR OF BEARINGS:- With plain bearings the length required to support the load is more than necessary to prevent passage of flame along the shaft through a gap formed by reasonable wear between shaft and bearing.

Before conditions are such that flame capable of causing external ignition can pass, the electrical and magnetic disturbances will be of such a magnitude that the apparatus will have to be closed down for renewal of bearings, etc.

With controller shaft bearings the length should be from 2-3 times the diameter of the shaft, and renewals should be made when the amount of wear is such that trouble is experienced in making contact.

In each case, if the remainder of the apparatus is adequately protected there will be no danger of external ignition.

RECOMMENDATIONS:-

Broad flanges with a gap between them should be provided at all joints.

In deciding the depth of gap to be left between flanges the volume of the casing, the perimeter of the opening and the breadth of flange should all be considered..

Figs. 9 and 10 have been drawn from results obtained by experiment, and by referring to the curves the maximum depth of gap and necessary breadth of flange will be found for volumes and perimeter within the limits plotted.

The gap may be provided in a variety of ways, e.g. by means of spring washers, or studs projecting from the surface of the casing flange, but an allowance should be made for ~~working~~ washing at the ends of covers and casings, otherwise the gaps at the ends may be considerably in excess of the safe perimeter gap.

Cast steel casings are preferable to cast-iron casings, unless strengthening webs are provided in the latter.

In the experiments described in the foregoing pages, and in the interpretation of results etc., the practical aspect of the question has been considered of primary importance.

The conclusions arrived at and the recommendations and suggestions advanced are therefore made on this basis.

At all times every effort was made to reproduce a practical atmosphere, and have conditions resembling as closely as possible, those met with daily in mines.

The author desires to place on record his indebtedness to Professor Burns and Professor Parker-Smith of the Royal Technical College, Glasgow, under whose direction he worked. The kindly guidance and advice of these two gentlemen were much appreciated.

No	Gas Meter Reading	Gas in Cubic Ft. E.C.	Gas in Cubic Ft. S.B.	Igniting Current in Amperes	Breadth of Flange	Gap Length in Inches	Gap Depth in Inches	Ignition Internal	Ignition External	Remarks
1	[illegible]-99·988 99·919	·316	·043	29	1"	·5	·023	Yes	Yes	Violent Explosion Hinge Bolt Sheared Causing Cover To Lift And Allow Flame To Pass
2	[illegible] 100·165	·356	·029	〃	〃	〃	〃	Yes	No	External Mixture Explosive
3	100·[illegible] 100·642	·298	·039	〃	〃	〃	〃	Yes	No	Do Do
4	100·[illegible] 100·977	·413	·052	〃	〃	〃	〃	Yes	No	Do Do
5	100·957 101·637	·676	·046	〃	〃	〃	〃	Yes	No	Do Do
6	1·486 1·919	·433	·054	〃	〃	〃	〃	Yes	No	Do Do
7	1·965 2·601	·636	·046	〃	〃	〃	〃	Yes	No	Do Do
8	2·665 3·[illegible]	[illegible]	·044	〃	〃	·375	·060	Yes	No	Do Do
9	[illegible] 4·862	·310	·035	〃	〃	〃	〃	Yes	No	Do Do
10	4·880 5·205	·325	·038	〃	〃	〃	〃	Yes	No	Do Do
11	5·282 5·776	·676	·047	〃			〃	No	No	Fuse Connection Broken
12	5·765 6·055	·290	·034	〃		·5	·051	Yes	Yes	Thread Of Wing Nut Stripped Causing Cover To Lift
13	6·088 6·293	·205	·033	〃		〃	〃	Yes	No	External Mixture Explosive
14	6·334 6·644	·310	·041	〃		〃	〃	Yes	No	Do Do
15	6·683 7·025	·342	·039	〃		〃	〃	Yes	No	Do Do
16	7·122-7·156 7·478	·322	·034	〃		〃	〃	Yes	No	Do Do
17	7·134-7·846 8·146	·300	·037	〃		·375	·072	Yes	No	Do Do
18	8·597-8·641 8·948	·347	·049	〃		〃	〃	Yes	No	Do Do
19	9·036 9·372	·336	·066	〃		·50	·100	Yes	No	Do Do
20	10·309-10·348 10·654	·306	·043	〃		〃	〃	Yes	No	Do Do
21	10·701 13·647	2·946	·043	〃		〃		Yes	Yes	Wood Explosion Chamber Used Volume 16·6 Cubic Feet
22	13·726 16·571	2·845	·064	〃		〃	〃	Yes	Yes	Do Do
23	16·638 19·669	3·031	·067	〃		〃	·046	Yes	Yes	Two Distinct Explosions
24	25·625-25·660 28·767	2·907	·035	〃		·625	·056	Yes	No	External Mixture Explosive
25	28·766-29·080 32·408	3·408	·034	〃		·375	·100	Yes	No	Do Do
26	32·[illegible]-32·[illegible] 35·864	3·324	·039	〃		·75	·073	Yes	No	Do Do
27	35·898 39·206	3·312	·030	〃		〃	〃	Yes	No	Do Do
28	39·261 42·5[illegible]	3·312	·035	〃		1·0	·060	Yes	Yes	
29	42·611-42·632 45·368	2·617	·031	〃		〃	〃	Yes	Yes	
30	45·391 48·765	3·374	·033	〃		·375	·100	Yes	No	External Mixture Explosive
31	52·962-56·012 59·270	3·258	·030	25		1·0	·080	Yes	Yes	Two Distinct Explosions
32	59·301 62·622	3·321	·031	〃		〃	〃	Yes	Yes	External Mixture Explosive
33	65·246-65·920 69·103	3·172	·060	20	〃	〃	·060	Yes	No	Do Do
34	69·137 72·3[illegible]	3·189	·030	〃	〃	〃	〃	Yes	No	Do Do
35	72·3[illegible]0 75·617	3·297	·038	〃	〃	〃	〃	Yes	No	Do Do
36	82·158-82·186 85·338	3·252	·036	12	〃	·375	·080	Yes	No	Do Do
37	85·360-85·375 88·4[illegible]	3·051	·033	〃	〃	·625	〃	Yes	No	Do Do
38	88·445-88·520 91·586	3·066	·035	〃	〃	·875		Yes	No	Do Do
39	91·6[illegible]-91·636 94·8[illegible]	3·2[illegible]3	·033	〃	〃	〃		Yes	No	Do Do
40	94·885 98·136	3·251	·037	〃	〃	1·0	〃	No	No	Fuse Connection Broken
41	98·170 101·355	3·185	·034	〃			〃	Yes	Yes	
42	1·388 4·663	3·355	·035	〃	〃	1·75	·058	Yes	Yes	
43	4·679 7·707	3·028	·036	〃	〃	〃	〃	Yes	No	External Mixture Explosive
44	7·746 11·067	3·321	·039	〃	〃	〃	〃	Yes	Yes	Two Distinct Explosions
45	11·102 14·368	3·266	·035	〃	〃	〃	〃	Yes	Yes	Do Do
46	14·436 17·635	3·196	·060		〃	〃	〃	Yes	No	External Mixture Explosive

No.	Gas Meter Reading	Gas in Cubic Feet EC	Gas in Cubic Feet SB	Current in Amperes	Breadth of Flange	Gap Length in Inches	Gap	Ignition Internal	Ignition External	Remarks
47	17.632-17.669 [illegible]	3.342	.037	12	1"	1.75	.036	Yes	No	Internal Mixture Too Rich External " Explosive
48	[illegible] 21.339	3.387	.031	"	"	"	"	Yes	Yes	
49	24.390-24.4[illegible] -27.75[illegible]	3.385	.031	"	"	"	"	Yes	Yes	
50	27.633 27.656-30.677	3.306	.032	"	"	1.5	"	Yes	Yes	
51	30.707 33.92[illegible]	[illegible]	.030	"	"	1½	"	Yes	No	External Mixture Explosive
52	[illegible] 33.992-37.351	3.359	.031	"	"	1.375	"	Yes	Yes	Two Distinct Explosions
53	37.363 [illegible]-40.640	3.298	.030	"	"	"	"	Yes	No	External Mixture Explosive
54	[illegible] 40.657-43.969	3.257	.033	"	"	"	"	Yes	Yes	Two Distinct Explosions
55	[illegible] [illegible]	3.335	.030	"	"	"	"	Yes	Yes	
56	[illegible] [illegible]	3.256	.029	"	"	1.25	"	Yes	No	External Mixture Explosive
57	[illegible] [illegible]-57.690	3.212	.026	"	"	"	"	Yes	No	Do Do Do
58	57.610 57.640-60.873	3.026	.030	"	"	1.75	.040	Yes	No	Do Do Do
59	[illegible] [illegible]	3.250	.046	"	"	2.25	.040	Yes	No	Do Do Do
60	63.630-63.860 63.864-67.066	3.196	.030	"	"	"	"	Yes	No	Do Do Do
61	[illegible]-67.100 70.363	3.263	.030	"	"	2.75	"	Yes	No	Do Do Do
62	70.393 73.759	[illegible]	.030	"	"	3.5	"	Yes	No	Do Do Do
63	73.760-73.790 [illegible]	[illegible]	.030	"	"	4.0	"	Yes	No	Do Do Do
64	[illegible] [illegible]	[illegible]	.027	"	"	4.6	.038	Yes	No	Do Do Do
65	81.061 84.3[illegible]	[illegible]	.028	"	"	4.75	"	Yes	No	Do Do Do
66	84.330 87.600	3.270	.030	"	"	6.5	.040	Yes	No	Do Do Do
67	[illegible] [illegible]	3.270	.030	"	"	6.5	.042	Yes	No	Do Do Do
68	[illegible] [illegible]	[illegible]	.031	"	"	6.5	"	Yes	No	Do Do Do
69	[illegible] 97.680	3.270	.030	"	"	16.0	.038	Yes	Yes	Violent Explosion
70	97.830 [illegible]	[illegible]	.032	"	"	10.75	"	Yes	Yes	
71	[illegible] 104.300	3.270	.030	"	"	5.75	"	Yes	Yes	
72	[illegible] 7.371	3.241	.030	"	"	9.0	"	Yes	No	Feeble Internal Explosion External Mixture Explosive
73	7.371-7.605 10.901	3.296	.032	"	"	9.0	"	Yes	Yes	Violent Explosion
74	[illegible] 16.100	[illegible]	.031	"	"	5.0	"	Yes	Yes	Two Distinct Explosions
75	[illegible] [illegible]	[illegible]	.030	"	"	7.0	.045	Yes	Yes	
76	[illegible] [illegible]	[illegible]	.030	"	"	6.75	"	Yes	Yes	
77	[illegible] 29.100	3.165		"	"	6.0	"	Yes	Yes	
78	[illegible] [illegible]	[illegible]	.030	"	"	5.75		Yes	Yes	
79	[illegible] [illegible]	[illegible]	.033	"	"	5.25	"	Yes	Yes	
80	[illegible] [illegible]	[illegible]	.031	"	"	4.125	"	Yes	Yes	Two Distinct Explosions
81	[illegible] [illegible]	[illegible]	.031	"	"	4.00	"	Yes	No	External Mixture Explosive
82	[illegible] [illegible]	3.270	.030	"	"	4.125	"	Yes	Yes	Paper Window Blown Out, Then [illegible] External Mixture Fired
83	[illegible] [illegible]	[illegible]	.032		"	2.9	.021	Yes	No	External Mixture Explosive
84	[illegible] [illegible]	[illegible]	.031	"	"	"	"	Yes	No	Do Do
85	[illegible] [illegible]	[illegible]	.032	"	"	"	"	Yes	No	Do Do
86	[illegible] [illegible]	[illegible]	.032		"	"	"	Yes	No	Do
87	[illegible] [illegible]	[illegible]	.030		"		.035	Yes	Yes	
88	[illegible] [illegible]	[illegible]	.030	"	"	"	.030	Yes	No	External Mixture Explosive
89	[illegible] [illegible]	[illegible]	.030	"	"	"	.030	Yes	No	Do Do
90	[illegible] [illegible]	[illegible]	[illegible]	"	"	"	.030	Yes	No	Do Do
91	[illegible] [illegible]	[illegible]	.030	"	"	"	.030	Yes	No	Do Do
92	[illegible] [illegible]	[illegible]	.030	"	"	"	.030	Yes	No	Do Do

No	Gas Meter Reading	Gas in Cubic Ft EC	Gas in Cubic Ft SB	Current in Amperes	Breadth of Flange	Gap Length in Inches	Gap Depth in Inches	Ignition Internal	Ignition External	Remarks
93	25-111-26.497 29.600	2.905	·316	[illegible]	·75	·5	·100	Yes	No	External Mixture Explosive
94	27.712 30.602	2.900	·312	"	"	·625	·100	Yes	No	Do Do
95	30.956 33.856	2.900	·312	"	"	$\frac{11}{16}$	·100	Yes	No	Do Do
96	34.156 37.056	2.900	·312	"	"	·625	·100	Yes	No	Do Do
97	37.368 40.268	2.900	·312	"	"	·875	"	Yes	No	Do Do
98	40.264 43.164	2.900	·316	"	"	"	"	Yes	No	Do Do
99	43.475 46.375	2.900	·316	"		1.125	"	Yes	Yes	
100	46.696 49.596	2.900	·330	"	"	"	"	Yes	Yes	
101	49.600-50.000 53.610	3.310	[illegible]	"	"	1·0	"	Yes	No	External Mixture Explosive
102	53.332 56.224	2.900	[illegible]	"	"	"	"	Yes	No	Do. Do.
103	56.560 59.460	2.900	·312	"	"	2·25	·070	Yes	No	Do Do
104	59.670-50.[illegible] 62.683	2.900	·312	"	"	2.375	"	Yes	No	Do Do
105	62.696 65.596	2.900	·312	"	"	"	"	Yes	No	Do Do
106	65.906 68.806	2.900	·312	"	"	2·75	"	Yes	No	Do Do
107	[illegible] 86.005	2.700	·300	"	"	2·25	"	Yes	No	Do Do
108	86.305 89.005	2.700	·300	"	"	2.625		Yes	No	Do Do
109	89.305 92.005	2.700	·300	"	"	2.875	"	Yes	No	Do Do
110	92.305 95.005	2.700	·300	"	"	3·00	"	Yes	Yes	
111	95.[illegible]-95.312 98.012	2.700	·300	"	"	3·00	"	Yes	Yes	
112	98.312 101.012	2.700	·300	"	"	6·00	·032	Yes	No	External Mixture Explosive
113	1.312 4.012	2.700	·300	"	"	7·0"	·032	Yes	No	Do Do
114	4.312 7.012	2.700	·300	"	"	7·5	"	Yes	No	Do Do
115	7.324 10.124	2.800	·312	"	"	8·0	"	Yes	Yes	
116	10.332 13.332	2.800	·405	"	"	7·75		Yes	No	External Mixture Explosive
117	13.644 16.444	2.800	·312	"	"	7.875	"	Yes	No	Do Do
118	16.588-16.[illegible] 19.[illegible]	2.800	·312	"	"	7.875		Yes	No	Do Do
119	19.924 22.800	2.876	·312	"	"	8·00	"	Yes	No	Do Do
120	22.[illegible]-23.117 25.[illegible]-26.000	2.833	·312	"	"	8·25	"	Yes	No	Do Do
121	26.312 30.162	2.850	·312	"	"	"	"	Yes	Yes	Two Distinct Explosions.
122	29.[illegible]-30.475 32.325	2.850	·312	"	"	"	"	Yes	No	
123	32.637 35.550	2.913	·312	"	"	8·50	"	Yes		
124	35.842 38.752	2.850	·312	"	"	8·75	"	Yes	No	Do Do
125	39.045 41.900	2.850	·312	"	"	9·00	"	Yes	No	Do Do
126	41.903-42.225 45.072	2.850	·312	"	"	9·25	"	Yes	No	Do Do
127	44.[illegible]-47.256 50.149	2.850	·312	"	"	9·50	"	Yes	No	Do Do
128	50.043-50.405 53.255	2.850	·312	"	"	"	"	Yes	No	Do Do
129	53.564 56.414	2.850	·312	"	"	"	"	Yes	No	Do Do
130	56.727 59.547	2.850	·324	"	"	10.625	"	Yes	Yes	Gas Pipe Plug Blown Out
131	59.[illegible]-59.[illegible] 62.772	2.850	·312	"	"	"	"	Yes	No	External Mixture Explosive
132	62.[illegible]-62.[illegible] 65.957	2.850	·312	"	"	12·5	"	Yes	No	Do Do
133	65.[illegible]-66.[illegible] 69.122	2.850	·312	"	"	"	"	Yes	No	Do Do
134	69.446 72.296	2.850	·312	"	"	14·5	"	Yes	No	Do Do
135	72.[illegible]-72.[illegible] 75.[illegible]	2.700	·312	"	"	All Round	"	Yes	Yes	Wooden Plug Burned Out
136	75.600 78.300	2.700	·312	"	"	"	"	Yes	Yes	Two Distinct Explosions
137	78.[illegible]-78.627 81.327	2.700	·312	"	"	"	·038	Yes	No	External Mixture Explosive
138	81.[illegible]-81.[illegible] 84.340	2.700	·312	"	"	18·5	·052	Yes	Yes	Two Distinct Explosions.

No	Gasmeter Reading	Gas in Cubic feet E.C	Gas in Cubic feet S.B	Current in Amperes	Breadth of Flange	Gap Length in Inches	Gap Depth in Inches	Ignition Internal	Ignition External	Remarks.
139	84·312-84·662 87·362	2·700	·320	13	1·375	18·5	·052	Yes	Yes	
140	87·366-87·676 90·376	2·700	·312	"	"	16	"	Yes	No	External Mixture Explosive
141	90·689 93·389	2·700	·313	"	"	"	"	Yes	Yes	Gas Pipe Plug Blown Out
142	93·702 96·402	2·700	·313	"	"	"	"	Yes	Yes	Two Distinct Explosions
143	96·716 99·416	2·700	·315	"	"	15	"	Yes	No	External Mixture Explosive
144	99·726 102·426	2·700	·312	"	"	"	"	Yes	No	Do Do Do
145	2·736 5·436	2·700	·312	"	"	16	"	Yes	No	Do Do
146	5·750 8·450	2·700	·312	"	"	16·75	"	Yes	Yes	
147	8·762 11·462	2·700	·310	"	"	27	·04	Yes	No	External Mixture Explosive
148	11·775 14·551	2·776	·312	"	"	All Round	"	Yes	Yes	
149	14·584 17·284	2·700	·333	"	"	24	·037	Yes	No	External Mixture Explosive.
150	17·596 20·296	2·700	·312	"		27	"	Yes	No	Do Do
151	20·584-20·614 23·314	2·700	·316	"	"	30	"	Yes	No	Do Do
152	23·924-24·236 26·936	2·700	·312	"	"	40	"	Yes	No	Do Do
153	27·261 29·961	2·700	·312	"	"	All Round	·036	Yes	No	Do Do
154	30·270 32·970	2·700	·307	"	"	"	"	Yes	No	Do Do
155	33·262 35·962	2·700	·312	"	"	"	"	Yes	No	Do Do
156	34263-39·60 42·20	2·400	·315	"	1·75	1·0	·08	Yes	No	Do Do
157	[illegible]-42·572 45·172	2·600	·350	"	"	2·0	"	Yes	Yes	Short Distance Pieces Blown Out From Between Flanges.
158	45·522 48·122	2·600	·350	"	"	2·75	"	Yes	No	External Mixture Explosive
159	48·472 51·141	2·669	·350	"	"	3·5	"	Yes	No	Do Do
160	51·491-51·461 54·091	2·600	·350		"	3·5	"	Yes	No	Do Do
161	54·441 57·041	2·600	·350		"	4·25	"	Yes	No	Do Do
162	57·341 59·941	2·600	·350		"	6·25	"	Yes	No	Do Do
163	60·341 62·941	2·600	·350		"	7·25	"	Yes	No	Do Do
164	63·941 65·541	2·600	·350		"	7·25	"	Yes	Yes	
165	65·900-66·260 68·860	2·600	·350		"	6·50	"	Yes	Yes	
166	69·210 71·810	2·600	·350		"	6·25	"	Yes	No	External Mixture Explosive
167	72·060 74·760	2·600	·350	"	"	All Round	·060	No	No	Fuse Connection Found Broken
168	74·772-75·131 77·731	2·600	·354	"	"	"	·038	Yes	No	External Mixture Explosive
169	78·081 80·681	2·600	·350	"	"	"	·046	Yes	Yes	
170	81·031 83·631	2·600	·350	"	"	"	·040	Yes	Yes	Two Distinct Explosions.
171	83·921 86·521	2·600	·350	"	"	"	·039	Yes	No	External Mixture Explosive
172	86·931 89·531	2·600	·350	"	"	11	·055	Yes	No	Do Do
173	89·901-90·231 92·831	2·600	·350	"	"	12	"	Yes	Yes	
174	93·201 95·888	2·687	·350	"	"	11·5	"	Yes	No	External Mixture Explosive
175	96·176 98·776	2·600	·350	"	"	12·0	"	Yes	No	Do Do
176	98·763-99·113 101·713	2·600	·350	"	"	"	"	Yes	No	Do Do
177	2·160 4·760	2·600	·347	"	"	14·25	"	Yes	No	Do Do
178	4·944-4·964 7·564	2·600	·260	"	"	"	"	Yes	Yes	Two Distinct Explosions
179	7·588-[illegible] [illegible]	2·600	·280	"	"	"	"	Yes	Yes	Do Do
180	[illegible] [illegible]	2·600	·269	"		12·625	"	Yes	Yes	
181	13·394 15·994	2·600	·280	"	"	15·125	"	Yes	No	External Mixture Explosive
182	16·036 18·636	2·600	·242	"	"	"	"	Yes	No	Do Do
183	18·716 21·316	2·600	·250	"		12·625	"	Yes	Yes	
184	21·603 [illegible]	2·600	·257	"		15·125	"	Yes	Yes	

No	Gas Meter Reading	Gas in Cubic feet E.C.	Gas in Cubic feet S.B.	Current in Amperes	Breadth of Flange	Gap Length in Inches	Gap Depth in Inches	Ignition Internal	Ignition External	Remarks
185	[illegible] 26.467	2.000	.240	15	1.75"	15.125	.046	No	No	Fuse Not Properly Connected
186	26.477-26.717 28.717	2.000	.240	"	"	"	.050	Yes	No	External Mixture Explosive
187	28.957 30.957	2.000	.240	"	"	14.125	.048	Yes	Yes	Two Distinct Explosions
188	31.197 33.197	2.000	.240	"	"	"	"	Yes	Yes	Do Do
189	33.437 35.437	2.000	.240	"	"	16.125	"	Yes	No	Do Do
190	35.4[illegible]-35.684 37.684	2.000	.240	"	"	"	"	Yes	No	Do Do
191	37.924 39.924	2.000	.240	"	"	"	"	Yes	Yes	Two Distinct Explosions
192	40.164 42.164	2.000	.240	"	"	"	"	Yes	Yes	Do Do
193	42.404 44.404	2.000	.240	"	"	15.625	"	Yes	No	External Mixture Explosive
194	[illegible]-44.644 44.698-46.698	2.000	.240	"	"	"	"	Yes	Yes	Two Distinct Explosions
195	[illegible]-46.940 48.940	2.000	.240	"	"	[illegible]		Yes	No	External Mixture Explosive
196	49.180 51.180	2.000	.240	"	"			Yes	No	Do Do
197	51.420 [illegible]	2.000	.240	"	"	"		Yes	Yes	?
198	55.338 57.338	2.000	.240	"	"	"		Yes	Yes	?
199	57.578 59.675	2.097	.240	"		13.75		Yes	Yes	Flame Leaking Past Plug
200	[illegible]-59.178 61.178	2.000	.243	"	"	1.125	.096	Yes	No	External Mixture Explosive
201	[illegible] 64.409	2.000	.240	"	"	1.50		Yes	No	Do Do
202	64.379 66.379	2.000	.240	"	"	3.0			No	Do Do
203	66.401-[illegible] [illegible]	2.000	.240	"	"	3.75			No	Do Do
204	68.881 70.881	2.000	.240	"	"	4.50			No	Do Do
205	71.121 73.121	2.000	.240	"	"	5.00			No	Do Do
206	73.126-73.376 75.376	2.000	.246	"	"	5.50			No	Do Do
207	75.615 78.015	2.400	.240	"	"	5.50			No	Do Do
208	78.365 80.765	2.400	.350	"	"	"			Yes	
209	81.115 83.115	2.000	.350	"	"	"		Yes	Yes	
210	[illegible] 56.682	2.700	.030	3.0	1	1.25	.051	Yes	Yes	Two Distinct Reports
211	56.112 58.812	2.700	.030	5.9	"	"		Yes	No	External Mixture Explosive
212	[illegible]-88.843 91.543	2.700	.030	3.0	"	"		Yes	No	Do Do
213	91.573 94.273	2.700	.030	5.0	"	"		Yes	No	Do Do
214	94.303 97.003	2.700	.030	7.0	"	"		Yes	No	Do Do
215	97.033 99.738	2.700	.030	12.0	"	"		Yes	No	Do Do
216	99.768 102.468	2.700	.015	3.0	"	"		Y	"	Do Do
217	[illegible] 5.108	2.700	.030	3.0	"	"	"	Yes	No	Do Do
218	[illegible] 7.936	2.700	.030	4.0	"	"		Yes	No	Do Do
219	7.966 10.666	2.700	.030	14.0	"	"		Yes	No	Do Do
220	10.696 13.396	2.700	.030	3.5	"	"		Yes	No	Do Do
221	[illegible] 16.231	2.700	.030	3.5	"	"		Yes	No	Do Do
222	16.261 18.961	2.700	.030	14.0	"	"		Yes	No	Do Do
223	18.991 21.691	2.700	.030	14.0	"	"		Yes	No	Do Do
224	[illegible] 24.427	2.700		14.5	"	1 5/16		Yes	Yes	
225	[illegible] 27.157	2.700	.030	14.5	"	"		Yes	No	External Mixture Explosive
226	27.188 29.888	2.700		14.5	"	"		Yes	Yes	Two Distinct Explosions
227	29.931 32.631	2.700	.043	14.5	"	"		Yes	No	External Mixture Explosive
228	32.661 35.361	2.700	.030	14.5	"	"		Yes	Yes	
229	35.391 38.102	2.711	.030	14.5	"	"		Yes	Yes	

No	Gas Meter Reading	Gas Cubic feet E.C	S.B	[illegible]	[illegible]	Gap Length in inches	Gap Depth in inches	Ignition Internal	Ignition External	Remarks
230	[illegible]-37.756 / 40.636	5.700	.032	3.5	1	15/16	.056	No	No	Short Circuit in E.C.
231	40.566 / 43.266	2.700	.030	3.5	"	"	"	Yes	No	External Mixture Explosive
232	43.596 / 46.296	2.700	.030	3.5	"	"	"	Yes	Yes	
233	[illegible]-46.333 / 49.073	2.700	.030	3.5	"	"	"	Yes	No	External Mixture Explosive
234	[illegible] / [illegible]	2.700	.030	3.5	"	"	"	Yes	No	Do Do
235	[illegible] / [illegible]	2.700	.030	3.5	"	"	"	Yes	Yes	
236	[illegible] / 57.716	2.700	.030	14.5	"	"	"	Yes	No	External Mixture Explosive
237	57.256 / 60.006	2.700	.030	14.5	"	"	"	Yes	No	Do Do
238	60.036 / [illegible]	2.700	.030	14.5	"	1.375	"	Yes	No	Do Do
239	[illegible] / 65.466	2.700	.030	14.5	"	"	"	Yes	No	Do Do
240	[illegible] / [illegible]	2.700	.037	14.5	"	"	"	Yes	No	Do Do
241	[illegible] / [illegible]	2.700	.030	14.5	"	"	"	Yes	No	Do Do
242	[illegible] / [illegible]	2.700	.026	14.5	"	"	"	Yes	No	Do Do
243	[illegible] / 76.394	2.700	.030	14.5	"	"	"	Yes	No	Do Do
244	[illegible] / [illegible]	2.727	.030	14.5	"	1.50	"	Yes	No	Do Do
245	[illegible] / [illegible]	2.700	.030	14.5	"	"	"	Yes	No	Do Do
246	[illegible] / [illegible]	2.700	.030	14.5	"	1.625	"	Yes	No	Do Do
247	[illegible] / [illegible]	[illegible]	.030	14.5	"	"	"	Yes	No	Do Do
248	[illegible] / [illegible]	2.700	.030	3.2	"	"	"	Yes	No	Do Do
249	[illegible] / [illegible]	2.700	.030	3.2	"	"	"	Yes	Yes	
250	[illegible] / [illegible]	2.700	.030	4.0	"	"	"	Yes	No	External Mixture Explosive
251	[illegible] / [illegible]	2.700	.032	14.5		"	"	Yes	No	Do Do Do
252	[illegible] / 101.164	2.700	.035	14.5	"	"	"	Yes	No	Do Do Do
253	1.164 / [illegible]	2.700	.030	14.5		"	"	Yes	No	Do Do Do
254	3.864 / [illegible]	2.700	.032	14.5	"	"	"	Yes	No	Do Do Do
255	[illegible] / [illegible]	2.700	.038	14.5	"	"	"	Yes	Yes	
256	[illegible] / [illegible]	2.700	.030	14.5	"	"	"	Yes	No	External Mixture Explosive
257	[illegible] / 14.718	2.700	.032	3.0	"	"	"	Yes	No	Do Do
258	[illegible] / [illegible]	2.700	.030	3.5	"	"	"	Yes	No	Do Do
259	[illegible] / [illegible]	2.700	.025	3.5	"	"	"	Yes	No	Do Do
260	[illegible] / [illegible]	2.700	.030	3.5	"	"		Yes	Yes	
261	[illegible] / [illegible]	2.700	.035	3.5	"	"		Yes	No	External Mixture Explosive
262	[illegible] / [illegible]	2.700	.033	3.5	"		"	Yes	Yes	
263	[illegible] / [illegible]	2.700	.033	5.0	"	"	"	Yes	Yes	
264	[illegible] / [illegible]	2.700	.037	3.5			"	Yes	No	External Mixture Explosive
265	[illegible] / [illegible]	2.700	.035	3.5	"	"	"	Yes	Yes	
266	[illegible] / [illegible]	2.700	.037	15.5	"	"	"	Yes	Yes	
267	[illegible] / [illegible]	2.700	.037	30	"	"	.048	Yes	No	External Mixture Explosive
268	[illegible] / [illegible]	2.700	[illegible]	30	"	"	"	Yes	No	Do
269	[illegible] / [illegible]	2.700	.030	30	"	"	"	Yes	Yes	Do
270	45.000-45.035 / 47.735	2.700	.035	33	"	"	"	Yes	No	Do
271	47.764 / 50.469	2.700	[illegible]	33	"	"	"	Yes	No	Do
272	50.502 / 53.202	2.700	.033	33	"	"	"	Yes	No	Do
273	53.234 / 55.934	2.700	.032	33	"	"	"	Yes	No	Do
274	55.965 / 55.665	2.700	.031	33	"	"	"	Yes	No	Do
275	58.666-58.697 / 61.397	2.700	.031	33	"	"	"	Yes	No	Do

No	Gas Meter Reading	Gas in cubic feet EC	Gas in cubic feet SB	Breadth of Flange	Current in Amperes	Gap Length in Inches	Gap Depth in Inches	Ignition Internal	Ignition External	Remarks
276	61.347-61.627 64.129	[illegible]	·030	1"	33	1625	·058	Yes	Yes	
277	66.154 66.534	2.700	·026		33		″	Yes	Yes	
278	66.579 69.574	2.700	·025	″			″	Yes	Yes	
279	69.594 72.294	2.700	·015	″	33		″	Yes	No	External Mixture Explosive
280	72.296-72.316 75.120	2.804	·020	″	33		″	Yes	No	Do Do
281	75.142 77.842	2.700	·022	″	33		″	Yes	No	Do Do
282	77.865 80.565	2.700	·023		33		″	Yes	No	Do Do
283	80.589 83.289	2.700	·024	″	33		″	Yes	No	Do Do
284	83.414 86.114	2.700	·025	″	33		″	Yes	Yes	
285	86.136-86.162 88.862	2.700	·024	″	33		″	Yes	Yes	
286	[illegible] 91.586	2.700	·026	″	33		″	Yes	No	External Mixture Explosive
287	[illegible]-91.610 94.310	2.700	·032	″	33		″	Yes	No	Do Do
288	94.312-94.336 97.036	2.700	·024	″	49		″	Yes	No	Do Do
289	97.481-97.512 101.212	2.700	·024	″	49		″	Yes	No	Do Do Do
290	1.236 3.936	2.700	·024	″	49		″	Yes	No	Do Do Do
291	3.960 6.660	2.700	·024	″	49		″	Yes	No	Do Do Do
292	6.685 9.385	2.700	·025	″	49		″	Yes	Yes	
293	9.367-9.423 12.123	2.700	·036	″	49		″	Yes	No	External Mixture Explosive
294	[illegible]58 [illegible]558	2.700	·035	″	49		″	Yes	No	Do
295	[illegible] [illegible]	2.700	·034	″	49		″	Yes	No	Do Do Do
296	[illegible] 20.775	2.700	·034	″	49		″	Yes	No	Do Do Do
297	20.771 [illegible]	[illegible]	·033	″	49		″	Yes	No	Do Do Do
298	23.555 26.255	[illegible]	·034		49		″	Yes	No	Do Do
299	26.236 28.936	2.700	·033	″	40		″	Yes	Yes	
300	28.971 31.671	2.700	·033	″	40		″	Yes	No	External Mixture Explosive.
301	31.705 34.405	2.700	·034	″	40		″	Yes	No	Do Do Do
302	34.436 37.136	2.700	·035	″	40		″	Yes	No	Do Do Do
303	37.203-37.236 39.936	2.700	·033	″	40		″	Yes	No	Do Do Do
304	40.262-40.242 42.942	2.700	·033	″	40		″	Yes	Yes	1
305	[illegible]-43.123 45.823	2.700	·031	″	40		″	Yes	No	External Mixture Explosive
306	[illegible] [illegible]	2.700	·0352	″	40		″	Yes	No	Do Do
307	[illegible]6245 [illegible]3245	2.700	·0325	″	40		″	Yes	Yes	
308	[illegible] 56.035	2.700	·0325	″	26		″	Yes	No	External Mixture Explosive
309	[illegible]-56.092 56.792	2.700	·034	″	50		″	Yes	No	Do Do
310	56.875 59.575	2.700	·033	″	50		″	Yes	Yes	1
311	59.558 [illegible]258	2.700	·033	″	50		″	Yes	No	External Mixture Explosive
312	62.291 64.991	2.700	·033	″	50		″	Yes	No	Do Do
313	[illegible]-65.033 67.733	2.700	·033	″	50		″	Yes	No	Do Do
314	67.765 [illegible]	2.700	·032	″	23		″	Yes	Yes	
315	[illegible] 73.198	2.700	·033		23		″	Yes	No	External Mixture Exploive.
316	73.230 75.930	2.700	·032	″	23		″	Yes	No	Do Do
317	[illegible] 75.662	2.700	·032	″	23		″	Yes	No	Do Do
318	75.664-75.696 [illegible]	[illegible]	·032	″	23		″	Yes	No	Do Do
319	[illegible]	[illegible]	·031	″	23		″	Yes	No	Do Do
320	[illegible] 86.[illegible]	2.700	·031	″	16		″	Yes	No	Do Do
321	[illegible] 89.406	[illegible]	·031	″	16		″	Yes	Yes	

No	Gas Meter Reading	Gas in Cubic Feet E.C.	Gas in Cubic Feet S.B.	Current in Amperes	Breadth of Flange	Gap Length in Inches	Gap Depth in Inches	Ignition External	Ignition Internal	Remarks
322	89.608-89.638 92.338	2.700	.032	16	1"	1.625	.058			External Mixture Explosive
323	92.364 95.064	2.700	.031	16	"	"	"	Yes	Yes	
324	95.070-95.102 97.803	2.700	.032	16	"	"	"	Yes	No	External Mixture Explosive
325	97.846-[illegible] 100.548	2.700	.032	60	"	"	"	Yes	No	Do Do
326	1.582 4.282	2.700	.034	60	"	"	"	Yes	No	Do Do
327	4.316-4.808 7.808	2.700	.032	60	"	"	"	Yes	No	Do Do
328	7.831 9.731	2.700	.033	60	"	"	"	Yes	No	Do Do
329	9.764 [illegible]	2.700	[illegible]	60	"	"		Yes	No	Do Do
330	[illegible] 15.217	2.700	.033	60	"	"	"	Yes	No	Do Do
331	15.941 17.961	2.700	.024	60	"	"	"	Yes	No	Do Do
332	17.965 20.665	2.700	.024	60	"		"	Yes	No	Do Do
333	20.672 23.390	2.700	.025	60			"	Yes	No	Do Do
334	23.430-23.455 26.155	2.700	.025	60		"	"	Yes	Yes	
335	[illegible]	2.700	.024	78	"		"	Yes	No	External Mixture Explosive
336	[illegible]	2.700	.026	78	"	"	"	Yes	No	Do Do
337	[illegible] 34.487	2.700	.026		"			Yes	No	Do Do
338	34.360 37.060	2.700	.035	78	"	"	"	Yes	No	Do Do
339	37.094 39.794	2.700	.034	78	"	"	"	Yes	No	Do Do
340	39.828 42.528	2.700	.034	78	"	"	"	Yes	No	Do Do

No	Gas Meter Reading	Gas in Cubic Feet E.C.	Gas in Cubic Feet S.B.	Coal Dust in Grams	Current in Amperes	Gap Length in Inches	Gap Depth in Inches	Ignition External	Ignition Internal	Remarks
341	[illegible] 45.560	2.700	.025	3.5 Added	20	1.625	.061	Yes	No	External Mixture Explosive Dust Placed Between Flanges
342	[illegible] 48.395	2.700	.030	—	"	"	.059	Yes	No	Do Do Do Do
343	48.316 51.065	2.700	.030	"	"	"		Yes	No	Do Do Do Do
344	57.250 [illegible]	Nil	[illegible]	3.5 Added	15	"	.057	Yes	Nil	Dust Between Flanges Blown Out. Explosion Fairly Violent. Dense Yellow Smoke Seen When Box Was Opened.
345	57.304	Nil	.027						Nil	Do Do
346	57.332	Nil	.028	"		"		Yes	Nil	Do Do Fair Amount Of Flame Passed
347	[illegible]	Nil	.032		"	"		Yes	Nil	Do Do Do Do Violent Explosion
348	[illegible]	Nil	.029					Yes	Nil	Do Do Do Dust Apparently Taking Part In Explosion
349	57.418	Nil	.026	"	—	—	"	Yes	Nil	
350	57.444	Nil	.025	—	"			Yes	Nil	Less Violent Explosion
351	57.467	Nil	.023	—	"	"	—	Yes	Nil	Do Do
352	57.484	Nil	.023	—	"		—	Yes	Nil	Do Do Smaller Quantity of Dust
353	57.502	Nil	.015	?	"	"	"	Yes	Nil	Only A Small Quantity Of Dust Remaining
354	57.519	Nil	.017	?	—	"	"	Yes	Nil	Dust All Consumed
355	57.523-57.541 60.241	2.700	.018	3.5 Added	"	"	"	Yes	No	External Mixture Explosive Feeble Internal Explosion
356	60.263 62.963	2.700	.021	"	"	"	"	Yes	No	Do Do Do
357	[illegible] [illegible]	2.700	.022	—	"	"	—	Yes	No	External Mixture Explosive Oily Film On Flanges Condensed [illegible]
358	[illegible] [illegible]	2.700	.022	"	"	"	"	Yes	Yes	Two Distinct Explosions
359	[illegible] [illegible]	2.700	.022	"	"	"	"	Yes	No	External Mixture Explosive
360	[illegible] [illegible]	2.700	.023	"	"	"	—	Yes	No	Do Do Do
361	73.886 76.586	2.700	.029	"		"	.048	Yes	Yes	Cover Of Box Broken By Force Of Explosion
362	[illegible] 80.440	2.700	.023	3.5 Added	"	"	.056	Yes	No	External Mixture Explosive
363	80.447-80.473 83.173	2.700	.023	"	"	"	"	Yes	No	Do Do
364	83.193 [illegible]	2.700	.022	"	—	"	"	Yes	No	Do Do

No	Gas Meter Reading	Gas in Cubic feet EC	Gas in Cubic feet SB	Coal Dust in Grams	Current in Amperes	Gap Length in Inches	Gap Depth in Inches	Ignition Internal	Ignition External	Remarks
365	85.843–85.947 / 88.617	2.700	.026	3.5	15	1.625	.055	Yes	No	External Mixture Explosive
366	88.621–88.647 / 91.347	2.700	.026	"	"	"	"	Yes	No	Do
367	91.343–91.368 / 94.068	2.700	.025	"		"	"	Yes	No	Do
368	94.100–94.126 / 96.826	2.700	.026	"	"	"	"	Yes	No	Do Do
369	96.827–96.851 / 99.551	2.700	.024	3.5 added	"	"	"	Yes	No	Do Do Do
370	99.552–99.577 / 102.277	2.700	.025	"	"	"	"	Yes	No	Do Do
371	102.304 / 105.004	2.700	.027	"	"	"	"	Yes	No	Do Do
372	[illegible] / 14.[illegible]	2.700	.026	"	"	"	"	Yes	No	Do Do Do
373	19.864 / 22.564	2.700	.026	"	"	"	"	Yes	No	Do Do Do
374	22.570 / 25.270	2.700	.026	"	"	"	"	Yes	No	Do Do Do
375	25.247 / [illegible]	2.700	.027	"	"	"	"	Yes	No	Do Do Do
376	28.134 / 30.934	2.7[illegible]	.027	3.5 added	"	"	"	Yes	No	Do Do Do
377	30.967 / 33.667	2.700	.026	"	"	"	"	Yes	No	Do Do Do
378	33.660–33.692 / 36.692	2.700	.029	"	"	"	"	Yes	Yes	Cover Of Box Broken By Force Of Explosion
379	36.774 / 39.478	[illegible]	.030	3.5 added	18	"	"	Yes	No	External Mixture Explosive
380	39.457 / 42.157	2.700	.024	"	"	"	"	Yes	No	Do
381	42.186 / 44.886	2.700	.029	"	"	"	"	Yes	No	Do Do
382	45.117–45.140 / 47.860	[illegible]	.028	"	"	"	"	Yes	No	Do Do
383	47.846–47.871 / 50.576	2.705	.029	"	"	"	"	Yes	No	Do Do Do Only Small Quantity Of Dust Left.
384	50.606 / [illegible]	2.800	[illegible]	None	"	"	"	Yes	Yes	
385	[illegible]	2.700	.030	"	"	"	"	Yes	Yes	
386	[illegible]	2.700	.028	"	"	"	"	Yes	Yes	
387	58.917 / 61.617	[illegible]	.028	"	"	"	"	Yes	Yes	
388	61.682–61.710 / 64.410	2.700	.028	3.5 added	"	"	"	Yes	No	External Mixture Explosive
389	64.440–64.460 / 67.160	[illegible]	.026	"	"	"	"	Yes	No	Do Do
390	[illegible]–67.170 / 69.870	2.700	.029	"	"	"	"	Yes	No	Do
391	69.900 / 72.700	2.800	.030	"	"	"	"	Yes	No	Do Do
392	72.730 / 75.430	2.700	.030	"	20	"	"	Yes	No	Do
393	75.463 / 78.163	2.700	.033	"	"	"	"	Yes	No	Do Do
394	78.196 / 80.896	2.700	.031	"	"	"	"	Yes	No	Do Do Do
395	80.900–80.921 / 83.638	2.700	.031	"	"	"	"	Yes	No	Do Do
396	83.660 / 86.360	2.700	.029	"	"	"	"	Yes	Yes	
397	86.361–86.399 / 89.099	2.700	.035	3.5 added	"	"	"	Yes	No	External Mixture Explosive
398	89.110–[illegible] / 91.840	2.700	.030	"	"	"	"	Yes	No	Do Do Do
399	91.8[illegible] / 94.5[illegible]	2.700	.031	"	"	"	"	Yes	No	Do Do Do
400	94.550–94.610	Nil	.030	"	"	"	"	Yes	Nil	Red Sparks And Flames At Gap
401	94.641	Nil	.031	"	"	"	"	Yes	Nil	Do Do
402	94.672	Nil	.031	"	"	"	"	Yes	Nil	Do Do
403	100.010–100.032	Nil	.032	3.5 added	"	"	"	Yes	Nil	Less Flame.
404	100.062	Nil	.030	"	"	"	"	[illegible]	Nil	Do Do
405	100.092	Nil	.030	"	"	"	"	Yes	Nil	Do Do
406	100.122	Nil	.030	3.5 added	25			Yes	Nil	Fairly Violent. Short White Flame At Opening.
407	100.130–100.175	Nil	.045	"	"	"		Yes	Nil	Violent Explosion
408	100.223	Nil	.048					Yes	Nil	Less Violent Explosion
409	100.263	Nil	.060						Nil	Two Reports Heard.
410	100.388	Nil	.045	"	"			Yes	Nil	Do Do

No	Gas Meter Reading	Gas in cubic feet EC	Gas in cubic feet SB	Coal Dust in Grams	Current in Amperes	Gap Length in inches	Gap Depth in inches	Ignition Internal	Ignition External	Remarks
411	[illegible]	Nil	·042	3·5	25	1·095	·05	Yes	Nil	Red Flames At Gap.
412	100·630	Nil	·060	"	"	"	"	Yes	Nil	Very Weak Explosion.
413	[illegible]	Nil	·0[illegible]	"		"	"	Yes	Nil	
414	100·8[illegible]	Nil	·0[illegible]	"	"	"	"	Yes	Nil	Violent Explosion
415	[illegible]	Nil	·027	"	"	"	"	Yes	Nil	
416	100·9[illegible]-100·9[illegible]	Nil	·032	"	"	"	"	Yes	Nil	
417	100·953-100·9[illegible]	Nil	·030	3·5 added	"	"	"	Yes	Nil	Violent Explosion Fair Amount Of Flame At Gap
418	1·017	Nil	·037	"	"	"	"	Yes	Nil	Do Do
419	1·061	Nil	·044	"	"	"	"	Yes	Nil	Less Violent Explosion Flame Seems Shorter
420	1·101	Nil	·040	"	"	"	"	Yes	Nil	Do Do
421	1·126	Nil	·028	"	"	"	"	Yes	Nil	Fairly Violent Fair Amount of Flame
422	1·156	Nil	·027	"	"	"	"	Yes	Nil	Do Do
423	1·222-1·225	Nil	·025	"	"	"	"	Yes	Nil	Do Do
424	1·250	Nil	·025	"	"	"	"	Yes	Nil	Do Do
425	1·275	Nil	·023	3·5 added	"	"	"	Yes	Nil	Do Do
426	1·300 4·000	2·700	·025	"	"	"	"	Yes	No	External Mixture Explosive
427	4·000-4·050 6·750	2·700	·030	"	"	"	"	Yes	Yes	
428	6·780 9·480	2·700	·030	"	"	"		Yes	No	External Mixture Explosive
429	9·500-9·530 12·230	2·700	·030	3·5 added	"	"	"	Yes	No	Do Do Do
430	12·260-12·270 14·970	2·700	·030	"	"	"	"	Yes	Yes	Lead [illegible] fused, igniting ext mixture fuse in [illegible] intact but smoke found when box opened. Back [illegible]
431	15·000-15·010 17·710	2·700	·030	"	"	"	"	Yes	No	External Mixture Explosive
432	17·720-17·754 20·454	2·700	·030	"	17	"	"	Yes	No	Do Do Do
433	20·460-20·483 23·183	2·700	·030	"	20	"	"	Yes	No	Do Do Do
434	23·213 26·003	2·790	·030	"	30	"	"	Yes	No	Do Do Do
435	26·033 28·733	2·700	·030	"	40	"	"	Yes	No	Do Do Do
436	28·763 31·463	2·700	·030	"	60	"		Yes	No	Do Do Do
437	31·485-31·510 34·210	2·700	·035	"	60	"	"	Yes	Yes	Dust All Consumed
438	[illegible]-34·155 36·855	2·700	·045	3·5 added	"		"	Yes	No	Feeble Internal Explosion External Mixture Explosive
439	36·860-36·905 39·605	2·700	·043	"	"	"	"	Yes	No	Do Do Do
440	39·607-39·643 42·343	2·700	·036	"	"	"	"	Yes	No	Violent Internal Explosion External Mixture Explosive
441	42·344-42·346 45·046	2·700	·040	"	"	"	"	Yes	No	Less Violent Internal Explosion External Mixture Explosive
442	45·090-45·132 47·832	2·700	·033	"	"	"	"	Yes	No	Violent Internal Explosion External Mixture Explosive
443	47·850 50·550	2·700	·024	"	"	"	"	Yes	No	Do Do Do
444	50·576 53·276	2·700	·026	"	"	"	"	Yes	Yes	Traces of Dust on [illegible]
445	[illegible] [illegible]	2·700	·030	None	60	·875	·050	Yes	No	Rubber Cover Used External Mixture Explosive
446	[illegible]-66·055 68·755	2·700	·025	"		"	"	Yes	Yes	
447	68·763 71·463	2·700	·030	"	"	"	"	Yes	Yes	
448	71·498 74·198	2·700	·035	"	"	"	"	Yes	No	External Mixture Explosive
449	74·212 77·012	2·700	·036	"	"	"	"	Yes	No	Do Do Do
450	77·035 79·735	2·700	·033	"	"	"	"	Yes	No	Do Do Do
451	79·765 82·465	2·700	·033	"	"	"	"	Yes	No	Do Do Do
452	82·494 85·194	2·700	·026	"	"	"	"	Yes	No	Do Do Do
453	85·221-85·231 87·931	2·700	·024	"	"	"	"	Yes	No	Do Do Do
454	87·9[illegible]-87·960 90·660	2·700	·026	"		"	"	Yes	No	Do Do Do
455	90·687 93·387	2·700	·024	"	"	"	"	Yes	No	Do Do Do.

No	Gas Meter Reading	Gas in Cubic Feet E.C.	S.B.	Current in Amperes	Breadth of Flange	Gap Length in Inches	Gap Depth in Inches	Ignition Int.	Ignition Ext.	Remarks
456	95301-95413 96.113	2.700	.028	60	1"	.875	.080	Yes	No	Webbed cover used External mixture explosive
457	96.165 98.865	2.700	.030	"	"	"	"	Yes	No	Do Do Do
458	98.872 101.572	2.700	.027	"	"	"	"	Yes	No	Do Do Do
459	[illegible] 4.385	2.700	.028	"	"	"	"	Yes	No	Do Do Do
460	4.335 7.035	2.700	.030	"	"	"	"	Yes	No	Do Do Do
461	7.060-7.092 9.762	2.700	.032	"	"	1.125	.078	Yes	No	Do Do Do
462	9.822 12.522	2.700	.030	"	"	1.25	"	Yes	Yes	
463	12.546 14.246	2.700	.026	"	"	"		Yes	Yes	
464	15.250-15.275 17.975	2.700	.025	"	"	"		Yes	Yes	
465	17.980-18.010 20.710	2.700	.026	14	"	"		Yes	No	External mixture explosive.
466	20.720-20.767 23.467	2.700	.027	"	"	"		Yes	No	Do Do Do
467	23.300-[illegible] 26.227	2.700	.027	"	"	"		Yes	Yes	Two distinct explosions
468	26.230-[illegible] 28.956	2.700	.026	"	"	"	"	Yes	Yes	
469	28.982 31.682	2.700	.026	"	"	"	"	Yes	Yes	
470	31.716 34.406	2.700	.026	"	"	"	"	Yes	No	External mixture explosive
471	34.460-34.486 37.186	2.700	.026	"	"	"	"	Yes	No	Do Do Do
472	37.206 39.916	2.700	.026	60	"	"	"	Yes	No	Do Do Do
473	39.910-39.943 42.643	2.700	.026	"	"	"	"	Yes	No	Do Do Do
474	42.644-42.669 45.369	2.700	.025	14	"		"	Yes	No	Do Do Do
475	45.400-45.435 48.135	2.700	.025	"	"		"	Yes	No	Do Do Do
476	48.160 50.860	2.700	.025	"	"		"	Yes	No	Do Do Do
477	[illegible] 53.565	2.700	[illegible]	60	"		"	Yes	Yes	
478	53.621 56.321	2.700	.026	"	"	"	"	Yes	Yes	
479	56.317-56.361 59.061	2.700	.029	"				Yes	Yes	
480	59.070-59.112 61.812	2.700	.062	"	"	"		Yes	Yes	Leads in E.C. fused causing internal explosion. Internal fuse found intact
481	61.856 64.546	2.690	.062	"	"	"	"	Yes	Yes	Two distinct explosions.
482	64.566 67.266	2.700	.044	"	"	"	"	Yes	Yes	Do Do Do
483	67.376-67.420 70.120	2.700	.044	14	"	"	"	Yes	No	External mixture explosive.
484	70.164 72.864	2.700	.044	"	"	"	"	Yes	Yes	Two distinct explosions.
485	[illegible]-73.067 75.767	2.700	.050	60	"	"	"	Yes	No	Feeble internal explosion External mixture explosive
486	75.833 78.533	2.700	.046	"	"	"	"	Yes	No	Do Do Do
487	78.572 81.272	2.700	.045	"	"	"	"	Yes	Yes	Two distinct explosions
488	81.374 84.074	2.700	.046	"	"	"	"	Yes	No	Feeble internal explosion External mixture explosive
489	84.069 86.769	2.700	[illegible]	14	"	"	"	Yes	No	Do Do Do
490	[illegible]-86.870 89.570	2.700	.040	"	"	.40	.040	Yes	No	Do Do Do
491	89.550 92.250	2.700	.030	60	"	"	"	Yes	No	Do Do Do
492	92.251-92.261 94.961	2.700	.030	"	"	1.125	"	Yes	No	Do Do Do
493	94.982-95.012 97.712	2.700	.030	"	"	1.25	"	Yes	No	Do Do Do
494	97.720-97.750 100.450	2.700	.030	"	"	"	"	Yes	No	Do Do Do
495	100.460-100.482 3.182	2.700	.030	"	"	"	"	Yes	No	Do Do Do
496	3.300-3.330 6.030	2.700	.030	"	"	.55	"	Yes	Yes	
497	[illegible] 8.674	2.700	.024	"	"	"	"	Yes	No	External mixture explosive
498	8.619 11.319	2.700	.025	"	"	"	"	Yes	No	Do Do Do
499	11.419 14.119	2.700	.026	"	"	"	"	Yes	No	Do Do Do
500	14.160-[illegible] 16.886	2.700		"	"	"	"	Yes	No	Do Do Do
501	16.913 19.613	2.700	.027	"	"	"	"	Yes	No	Do Do Do

No.	Gas Meter Reading	Gas in Cubic feet EC	Gas in Cubic feet SB	Current in Amperes	Breadth of Flange	Gap Length in inches	Gap Depth in inches	Ignition Int.	Ignition Ext.	Remarks
501a	19·603 - 19·621 22·321	2·700	·025	60	1"	5·5	·040	Yes	No	External Mixture Explosive
502	22·371 25·071	2·700	·030	"	"	"	"	Yes	No	Do Do Do
503	25·101 27·902	2·801	·030	"	"	5·75"	·040	Yes	No	Do Do Do
504	27·932 30·632	2·700	·030	"	"	"	"	Yes	No	Do Do Do
505	30·640 - 30·670 33·370	2·700	·030	"	"	"	"	Yes	Yes	Do Do Do
506	33·416 36·116	2·700	·046	"	"	"	"	Yes	Yes	
507	36·141 38·841	2·700	·025	"	"	"	"	Yes	No	External Mixture Explosive
508	38·867 41·567	2·700	·026	"	"	6·0	·040	Yes	No	Do Do Do
509	41·580 - 41·607 44·307	2·700	·027	"	"	"	"	Yes	No	Do Do Do
510	44·337 47·137	2·700	·030	"	"	"	"	Yes	No	Do Do Do
511	47·167 49·867	2·700	·030	"	"	"	"	Yes	No	Do Do Do
512	49·898 52·598	2·700	·031	"	"	"	"	Yes	No	Do Do Do
513	52·628 55·328	2·700	·030	"	"	"	"	Yes	No	Do Do Do
514	55·358 58·055	2·700	·030	"	"	10·25	·04	Yes	Yes	
515	58·139 - 58·166 60·866	2·700	·027	"	"	"	"	Yes	Yes	
516	60·990 - 61·015 63·715	2·700	·025	"	"	"	"	Yes	No	External Mixture Explosive
517	63·718 - 63·743 66·443	2·700	·025	"	"	"	"	Yes	No	Do Do Do
518	66·443 - 66·470 69·170	2·700	·027	"	"	"	"	Yes	No	Do Do Do
519	69·197 71·897	2·700	·027	"	"	"	"	Yes	No	Do Do Do
520	71·924 74·624	2·700	·027	"	"	"	"	Yes	No	Do Do Do
521	74·631 - 74·656 77·356	2·700	·025	"	"	"	"	Yes	Yes	
522	77·376 - 77·409 80·109	2·700	·033	"	"	"	"	Yes	No	External Mixture Explosive
523	80·120 - 80·152 82·852	2·700	·032	"	"	"	"	Yes	Yes	
524	82·885 85·567	2·700	·033	"	"	"	"	Yes	Yes	
525	85·621 88·321	2·700	·034	"	"	"	"	Yes	Yes	
526	88·361 91·061	2·700	·040	"	"	"	"	Yes	Yes	Two Distinct Explosions
527	91·106 93·806	2·700	·045	"	"	"	"	Yes	Yes	Do Do
528	93·853 96·553	2·700	·047	"	"	"	"	Yes	Yes	Do Do
529	96·603 99·303	2·700	·050	"	"	"	"	Yes	No	External Mixture Explosive
530	99·371 102·071	2·700	·068	"	"	"	"	Yes	No	Do Do Do
531	2·098 4·798	2·700	·047	"	"	"	"	Yes	Yes	Two Distinct Explosions
532	4·765 6·968	2·700	·044	"	"	"	"	Yes	No	[illegible]
533	6·945 9·645	2·700	·047	"	"	"	"	Yes	No	Do Do Do
534	9·702 - 9·751 12·451	2·700	·049	"	"	"	"	Yes	Yes	Two Distinct Explosions
535	12·497 15·197	2·700	·046	"	"	"	"	Yes	No	External Mixture Explosive
536	15·243 17·943	2·700	·046	"	"	"	"	Yes	Yes	Two Distinct Explosions
537	17·984 - 17·998 20·698	2·700	·044	"	"	"	"	Yes	No	External Mixture Explosive
538	20·739 23·439	2·700	·047	"	"	"	"	Yes	Yes	Two Distinct Explosions.
539	41·606 - 41·636 43·636	2·000	·030	15	1"	1[illegible]	·062	Yes	No	External Mixture Explosive
540	43·662 45·662	2·000	·030	"	"	"	"	Yes	No	Do Do Do
541	45·932 - 45·962 48·362	2·400	·030	"	"	1·3[illegible]	·05[illegible]	Yes	No	Do Do Do
542	48·392 51·092	2·700	·030	"	"	"	"	Yes	No	Do Do Do
543	51·300 - 51·330 53·830	2·500	·030	"	"	1·0		Yes	No	Do Do Do
544	53·834 - 53·864 56·564	2·700	·030	"	"	"	"		No	Do Do Do
545	56·566 - 56·596 58·996	2·400	·030			1·0	"	Yes	No	Do Do Do

No.	Gas Meter Reading	Gas in Cubic feet E.C.	Gas in Cubic feet S.B.	Current in Amperes	Breadth of Flange	Gap Length in Inches	Gap Depth in Inches	Ignition Int.	Ignition Ext.	Remarks
546	59.000-59.031 / 61.731	2.700	.031	18	1"	1.875	.032	Yes	No	External Mixture Explosive
547	61.762 / 64.162	2.400	.031	"	"	1.95	"	Yes	No	Do Do Do Flame Extending 1" Beyond Flange At Gap
548	64.192 / 66.892	2.700	.030	"	"	"	"	Yes	"	Do Do Do
549	67.000-67.030 / 69.730	2.700	.030	"	"	2.00	"	Yes	No	Do Do Do
550	69.760 / 72.460	2.700	.030	"	"	"	"	Yes	No	Do Do Do
551	72.490 / 75.190	2.700	.030	"	"	2.05	"	Yes	No	Do Do Do
552	75.220 / 77.920	2.700	.030	"	"	"	"	Yes	No	Do Do Do
553	77.950 / 80.650	2.700	.030	"	"	2.10	"	Yes	No	Do Do Do
554	80.680 / 83.380	2.700	.030	"	"	"	"	Yes	No	Do Do Do
555	83.400-83.430 / 86.130	2.700	.030	"	"	2.25	"	Yes	No	Do Do Do
556	86.160 / 88.860	2.700	.030	"	"	"	"	Yes	No	Do Do Do
557	88.890 / 91.590	2.700	.030	"	"	"	"	Yes	No	Do Do Do
558	[illegible] / 94.530	2.700	.030	"	"	"	"	Yes	No	Do Do Do Old Box With Wearied Cover
559	94.530-94.560 / 97.260	2.700	.030	"	"	"	"	Yes	No	Do Do Do Do
560	97.300-97.330 / 100.030	2.700	.030	"	"	2.30	"	Yes	No	Do Do Do Do
561	100.060 / 102.760	2.700	.030	"	"	"	"	Yes	No	Do Do Do Do
562	5.770-5.800 / 8.500	2.700	.030	"	"	2.575	"	Yes	No	External Mixture Explosive. Old Box and Old Cover (Cleaned)
563	8.530 / 11.230	2.700	.030	"	"	"	"	Yes	No	Do Do Do Do
564	11.260 / 13.960	2.700	.030	"	"	2.50	"	Yes	No	Do Do Do Do
565	13.990 / 16.690	2.700	.030	"	"	2.54	"	Yes	No	Do Do Do Do
566	16.720-16.750 / 19.450	2.700	.030	"	"	"	"	Yes	No	Do Do Do Do
567	19.480 / 22.180	2.700	.030	"	"	2.63	"	Yes	No	Do Do Do Do
568	22.210 / 24.910	2.700	.030	"	"	"	"	Yes	No	Do Do Do Do
569	24.940 / 27.640	2.700	.030	"	"	2.75	"	Yes	No	Do Do Do Do
570	27.670 / 30.370	2.700	.030	"	"	2.875	"	Yes	No	Do Do. Do Do
571	30.400 / 33.200	2.800	.030	"	"	3.00	"	Yes	No	Do Do Do Do
572	33.230 / 35.930	2.700	.030	"	"	3.125	"	Yes	No	Do Do Do Do
573	35.960 / 38.660	2.700	.030	"	"	3.25	"	Yes	No	Do Do Do Do
574	38.690 / 41.390	2.700	.030	"	"	3.375	"	Yes	No	Do Do Do Do
575	41.420 / 44.120	2.700	.030	"	"	3.5	"	Yes	Yes	Bolt Sheared
576	44.150 / 46.850	2.700	.030	"	"	"	"	Yes	No	External Mixture Explosive (Old Box And Old Cover)
577	46.880 / 49.380	2.500	.030	"	"	"	"	Yes	No	Do Do Do Do
578	49.410 / 52.110	2.700	.030	"	"	3.625	"	Yes	No	Do Do Do Do
579	52.140 / 54.840	2.700	.030	"	"	3.750	"	Yes	No	Do Do Do Do
580	54.870 / 57.570	2.700	.030	"	"	3.875	"	Yes	No	Do Do Do Do
581	57.600 / 60.300	2.700	.030	"	"	4.0	"	Yes	No	Do Do Do Do
582	60.370-60.400 / 63.100	2.700	.030	"	"	"	"	Yes	No	External Mixture Explosive [New Box Complete (C.S.)]
583	63.130 / 65.830	2.700	.030	"	"	"	"	Yes	No	Do Do Do Do
584	65.860 / 68.560	2.700	.030	"	"	4.25	"	Yes	Yes	(New Box)
585	[illegible]-68.320 / 71.020	2.700	.030	"	"	"	"	Yes	No	External Mixture Explosive (Old Box and Old Cover)
586	71.050 / 73.750	2.700	.030	"	"	"	"	Yes	No	Do Do Do Do
587	73.780 / 76.480	2.700	.030	"	"	"	"	Yes	No	Do Do Do Do
588	76.510 / 79.210	2.700	.030	"	"	"	"	Yes	Yes	[New Box Complete (C.S.)] Bolt Found With Stripped Thread
589	79.220-79.250 / 81.950	2.700	.030	"	"	"	"	Yes	No	External Mixture Explosive [New Box With Old Cover]
590	81.980 / 84.680	2.700	.030	"	"	"	"	Yes	No	Do Do Do Do.
591	84.710 / 87.410	2.700	.030	"	"	"	"	Yes	Yes	Old Box With New Cover.

No	Gas Meter Reading	Gas in Cubic Feet E.C.	Gas in Cubic Feet S.B	Current in Amperes	Breadth of Flange	Gap Length in Inches	Gap Depth in Inches	Ignition Internal	Ignition External	Remarks
592	87·610-87·640 90·140	2·700	·030	18	1	4·25	·052	Yes	No	External Mixture Explosive [Old Box with Ribbed Cover]
593	90·150-90·182 92·882	2·700	·030	″	″	″	″	Yes	No	Do Do Do
594	92·910 95·610	2·700	·030	″	″	″	″	Yes	No	Do Do Do
595	95·640 98·340	2·700	·030	″	″	″	″	Yes	No	External [illegible] Explosive [New Box Complete]
596	[illegible]-98·530 101·230	2·700	[illegible]	″	″	4·375	″	Yes	No	Do Do Do
597	1·260 3·960	2·700	·030	″	″	4·500	″	Yes	Yes	Two Distinct Explosions
598	3·[illegible] 6·690	2·700	·030	″	″	″	″	Yes	Yes	
599	6·800-6·850 9·550	2·700	·030	″	″	″	·050	Yes	No	External Mixture Explosive [Old Box with old Cover]
600	9·580 12·280	2·700	·030	″	″	″	″	Yes	No	Do Do
601	12·310 15·010	2·700	·030	″	″	″	″	Yes	No	Do Do
602	15·040 17·740	2·700	·030	″	″	″	″	Yes	No	Do Do
603	[illegible] [illegible]	2·700	·030	″	″	″	·052	Yes	Yes	
604	[illegible]-21·000 23·700	2·700	·030	″	″	Perimeter of Box	·030	Yes	Yes	Cast Steel Box with Studs Set in Flanges to Give Gap
605	23·730 26·430	2·700	·030	″	″	″	″	Yes	Yes	Cover as above warped at ends and sides ·01 and ·003 Respectively
606	26·[illegible]-26·710 29·410	2·700	·030	″	″	″	″	Yes	No	External Mixture Explosive. Studs Filed down to Reduce Gap
607	29·440 32·140	2·700	·030	″	″	″	″	Yes	No	Do Do
608	32·170 34·870	2·700	·030	″	″	″	″	Yes	No	Do Do

E.C. Means Explosion Chamber.

S.B Means Switch Box.

No	Gas Meter Reading	Gas cubic feet E.C.	Gas cubic feet S.B.	Current in Amperes: [illegible]	Current in Amperes: Heating	Atmospheric: Bar.	Atmospheric: Temp.	Number of Flames	Gap: Length	Gap: Depth	Galvanometer Reading: Admission of Gas	Galvanometer Reading: Ignition of Gas	Gal. Kel.	Ad. °F	[illegible]	Internal	External	Remarks
604	56.627-56.650 / 57.380	2.700	.030	1.5	1.75	29.9	62.5	1	6	.036	60	58	95	155	[illegible]	Yes	No	External mixture explosive. Casing being heated during filling of E.C. [illegible] in contact with [illegible]
610	57.606 / 60.106	2.700	.024	"	"	"	"	"	"	"	80	77	"	158	154.6	Yes	No	Do Do Do Do
611	62.130-62.160 / [illegible]	2.700	.030	"	2.1	30	63.5	"	"	"	67	67	"	162	162	Yes	No	Do Do Do Do
612	62.880-62.910 / 65.610	2.700	.030	"	2.3	"	"			"	72	70	"	148	145	Yes	No	Do Do Do Do
613	65.660 / 68.360	2.700	.030	"	2.2	"	"			"	80	75	"	158	152	Yes	No	Do Do Do Do
614	53.900-53.930 / 56.630	2.700	.030	"	1.8	29.7	63		4.5	.052	30	63	"	98	137	Yes	Yes	Heating during filling of E.C. Feeble internal explosion.
615	56.650-56.679 / 59.379	2.700	.029	"	2.1	"	"			"	32	53	"	100	125	Yes	Yes	Do Do Do Do
616	59.417 / 62.117	2.700	.034	"	"	"	"			"	60	70	"	110	145	Yes	Yes	Do Do Do Do
617	62.230-62.260 / 64.960	2.700	.030	"	"	"	"			"	80	80	"	157	157	Yes	Yes	Do Do Do Do
618	64.990 / 67.690	2.700	.030	"	"	"	"			.050	45	75	"	116	151	Yes	Yes	Heating during filling of E.C.
619	67.720 / 70.420	2.700	.030	"	"	"	"			"	65	77	"	134	153	Yes	Yes	Do Do
620	70.400-70.425 / 73.125	2.700	.025	"	"	29.6	60			"	35	77	"	100	150	Yes	No	External mixture explosive, heating during filling of E.C.
621	73.551 / 76.251	2.700	.030	"	"	"	"			"	43	75	"	110	151	Yes	No	Do Do Do Do
622	76.400-76.427 / 79.127	2.700	.027	"	"	"	"				30	80		95	154	Yes	No	Do Do Do Do
623	79.420-79.452 / 82.[illegible]	2.452	.032	"	"	"	"			"	65		"	139	151	Yes	Yes	Heating during filling of E.C.
624	84.740-84.770 / 87.470	2.700	.029	"	1.8	"	"				35	35	"	101	101	Yes	Yes	Do Do
625	87.477-87.510 / 90.210	2.700	.033	"	"	"	"				30	45	"	95	[illegible]		No	External mixture explosive. Heating during filling.
626	90.262 / 92.962	2.700	.032	"	"	"	"				30	50		95	110	Yes	Yes	Heating during filling
627	92.970-93.000 / 95.700	2.700	.030	"	"	"	"				60	60	"	150	150	Yes	Yes	Do Do Do
628	96.016-96.046 / 98.746	2.700	.030	"	"	29.7	56		1.375		75	75	"	144	144	Yes	No	External mixture explosive. Heating during filling
629	98.776 / 101.476	2.700	.030	"	"	"	"			"	50	78	"	114	147	Yes	No	Do Do Do
630	2.490-2.520 / 5.220	2.700	.030	"	Nil	"	"		"	.051	0	0	"	56	56	Yes	No	Do Do Do
631	5.250 / 7.950	2.700	.030	"	"	"	"	"	"	"	0	0	"	56	56	Yes	No	Do Do Do
632	7.980 / 10.680	2.700	.030	"	2	29.[illegible]	56			"	65	72		135	144	Yes	No	External mixture explosive. Heating during filling
633	10.700-10.740 / 13.440	2.700	.040	"	2.5					"	15	15	900	961	302	Yes	No	Do Do Do

No	Gas Meter Reading	Gas in cu. feet EC	Gas in cu. feet SB	Current in Amperes [illegible]	Current in Amperes [illegible]	Atmospheric Bar.	Atmospheric Temp. F	Number of Knobs	Gap Length in.	Gap Diam. in.	Galvanometer [illegible]	Galvanometer [illegible]	Gal. [illegible]	Internal [illegible] of Casing	[illegible]	[illegible]	[illegible]	[illegible]	REMARKS.
634	13.560-13.569 / 16.269	2.700	·029	18	3·5	29.51	54	1	1.375	·050	15	18	900	261	302	Yes	No		External Mixture Explosive Casing Heating During Filling of E.C.
635	16.271-16.302 / 19.002	2.700	·029	"	"	"	"	"	"	"	10	18	"	192	302	Yes	No		Do Do Do Do
636	19.000-19.000 / 21.590	2.551	·029					"			10	?	"	192	?	Yes	Yes		Premature Ignition. Part of Coil Found at Bright Red Heat.
637	21.590-21.600 / 24.300	2.700	·030		1·75	30	55	"	"	"	10	15	"	195	303	Yes	No		External Mixture Explosive Casing Heating During Filling of E.C.
638	24.460-24.619 / 29.619	5.000	·029	"	5·0	"	"	"	"		7	10		272	"	Yes	No		External Mixture Explosive Casing Cooling During Filling of E.C.
639	29.519 / 32.219	2.700	·030	"	"	"	"	"			7	7	"	"	"	Yes	No		Do Do Do Do
640	32.270-32.300 / 35.000	2.700	·030	"	"	"			"		10	9	"	220	179	Yes	No		
641	35.500-35.250 / 37.950	2.700	·030		Nil	"	"	"	4·5	·048	—	—	—	55	55	Yes	No		External Mixture Explosive New Cover with Strengthening Webs
642	37.960 / 40.660	2.700	·030			"			"	·056	—	—	—	55	55	Yes	No		Do Do Do Do
643	40.690 / 43.390	2.700	·030	"	"		"	"		·055	—	—	—	55	55	Yes	No		External Mixture Explosive Old Cover (No Webs)
644	43.420-43.449 / 46.149	2.700	·029	"	"	"	"	"	"	"	"	"	—	55	55	Yes	No		Do Do Do
645	46.178 / 48.878	2.700	·030		"		"			·054	—	—	—	55	55	Yes	No		Do Do Do
646	48.908 / 51.908	2.700	·030			"	—	—	—	"	—	—	—	55	55	Yes	No		Do Do Do
647	55.200-55.500 / 55.190	2.700	·030					+	4·75	"	—	—	—	55	55	Yes	Yes		Old Cover
648	51.160 / 51.060	2.900	·030		—	29.1	—		—	·044	—	—	—	55	55	Yes	No		External Mixture Explosive Old Cover
649	51.092 / 60.042	2.900	·030	"	1·75		—	"	—	—	7	7	900	151	151	Yes	No		Do Do Do
650	61.021 / 63.421	2.400	·029		"	"		—	—	·030	9	9	"	179	179	Yes	Yes		
651	64.210-64.239 / 67.139	2.900	·029		2	30.0	53	"	"	·047	14	10	"	266	191	Yes	No		External Mixture Explosive Casing Cooling During Filling of E.C.
652	67.166-67.192 / 70.044	2.900	·030		Nil	—	—	"		·050	-	-	-	53	55	Yes	No		External Mixture Explosive New Box with Strengthening Webs
653	70.174 / 73.024	2.900	·030	"	"	—	"	"	"	·052	-	-	-	55	55	Yes	No		Do Do Do Do
654	73.054 / 75.454	2.400	·030	"	"	"	"		"	·060	-	-	-	53	55	Yes	Yes		Two Distinct Explosions
655	83.900-83.530 / 86.430	2.900	·030		20	30.0	57		—	·050	12	10	900	222	195	Yes	Yes		Old Box Complete Cooling During Filling
656	86.459 / 89.359	2.900	·029		—	"	"	"	"	·050	10	8	"	195	110	Yes	Yes		Do Do Do Do
657	89.600-89.664 / 92.364	2.900	·029		"	"	—	"		"	15	14	938 / 93	264	250	Yes	No		External Mixture Explosive Casing Heated at Intervals
658	92.370-92.400 / 95.300	2.900	·030		—	—	"			"	10	14		145 [illegible]	141 [illegible]	Yes	Yes		Casing Cooling During Filling of E.C.

No	Gas Meter Reading	Gas in cu. ft. EC	Gas in cu. ft. SB	Current in Amperes: Igniting	Current in Amperes: Heating	Atmosphere: Bar. (in.)	Atmosphere: Temp. °F	Length of Flame	Gap: Length in inches	Gap: Depth in inches	Concentration: Percentage of Gas	Concentration: [illegible] of Gas	Gal. NES	Interval Time of Cooling: Ao °F	Interval Time of Cooling: Io °F	Ignition: Internal	Ignition: External	Remarks
659	95·500–95·530 [illegible]·430	2·900	·030	16	Nil	30	57	1"	·475	·050	—	—	—	57	57	Yes	No	External Mixture Explosive
660	98·460 101·360	2·900	·030	–	2	–	–	–	–	–	10	7	600	139	114	Yes	Yes	Leakage past Thermo-Couple Tube
661	101·390 104·290	2·900	·030	–	2	29·7	55	–	–	–	10	7	900	195	157	Yes	No	External Mixture Explosive
662	4·600–4·629 7·329	2·900	·029	–	2·5	29·6	56	–	–	–	17	10	–	249	194	No	No	Fuse was blown but no internal explosion occurred. External Mixture Explosive
663	7·355 10·255	2·900	·024	–	2·1		–	–	–	–	8	6	–	165	136	Yes	No	External Mixture Explosive.
664	10·255 13·155	2·900	·029	–	–		–	–	–	–	11	9	–	207	178	Yes	Yes	
665	13·500–13·530 16·430	2·900	·030	–	Nil	–	–	–	–	–	—	—	—	56	56	Yes	No	External Mixture Explosive
666	16·460 19·360	2·900	·030	–	2	–	57	–	–	–	5	3	900	126	95	Yes	No	Do Do Do
667	19·390 22·290	2·900	·030	–	–	–	–	–	–	–	7	5	–	155	126	Yes	No	Do Do Do
668	22·32[illegible] 25·230	2·900	·030	–	–	–	–	–	–	–	9	7	–	161	133	Yes	No	Do Do Do
669	[illegible] 28·155	2·900	·030	–	2·5	30·1	–	–	–	–	8	7	–	167	153	Yes	No	Do Do Do
670	28·164–28·193 31·093	2·900	·029	–	–	–	–	–	–	–	9	6·5	–	161	147	Yes	Yes	Two Distinct Explosions
671	31·122 34·022	2·900	·029	–	–	–	–	–	–	–	5	6·5	–	126	119	Yes	Yes	
672	34·031–34·060 36·960	2·900	·029	–	–	–	–	–	–	–	4	4	–	112	112	Yes	Yes	
673	37·661–37·690 40·590	2·900	·030		Nil	30·30	58	–	–	–	—	–	–	58	58	Yes	No	External Mixture Explosive
674	40·620 43·520	2·900	·030	–	2·0	–	–	–	–	–	3·5	2·5	900	[illegible]	92·5	Yes	No	Do Do Do
675	43·550 46·450	2·900	·030	–	–	–	–	–	–	–	6	4	–	[illegible]	113	Yes	Yes	
676	46·310 49·180	2·900	·030	–	Nil	–	60	–	–	–	—	–	–	60	60	Yes	No	External Mixture Explosive
677	49·210 52·110	2·900	·030	–	–	–	–	–	–	·052	—	–	–	60	60	Yes	Yes	
678	52·139 55·039	2·900	·029	–	2	–	–	–	–	·050	6·5	4	900	50	115	Yes	Yes	
679	55·069 57·969	2·900	·030	–	–	–	–	–	–	·048	6·5	5	–	150	129	Yes	Yes	
680	58·200–58·230 61·130	2·900		–	–	–	–	–	–	·046	7·5	5·5	–	163	136	Yes	No	External Mixture Explosive.
681	61·160 64·060	2·900	·030	–	–	–	–	–	–		10	7	–	198	157	Yes	Yes	
682	64·089 66·989	2·900	·029	–	–	–	–	–	–		8	5·5	–	170	136	Yes	No	External Mixture Explosive.
683	67·000–67·029 69·929	2·900	·029	–	–	–	–	–	–		7·5	6·0	–	163	163	Yes	No	Do Do Do

No	Gas Meter Reading	Gas Cubic EC	Gas in Mixture SB	Current in Amperes: Igniting	Current in Amperes: Heating	Atmospheric: Bar ins	Atmospheric: Temp °F	Belling Flanges	Gap: Length in inches	Gap: Depth in inches	Galvanometer Reading: Beginning of Gas	Galvanometer Reading: Ignition of Gas	Gal. Res	Temp of Casing: Ad. °F	Temp of Casing: IG °F	Ignition: Internal	Ignition: External	Remarks
684	69.932-70.001 / 72.601	2.900	.024	18	9.0	30.59	60	1	.075	.044	10	7	900	194	157	Yes	No	External Mixture Explosive.
685	73.200-73.290 / 76.130	2.900	.030	"	2.5	30.58	60		"	"	12	7.5	"	204	165	Yes	No	Do Do Do Feeble Internal Explosion
686	76.350-76.350 / 79.220	2.900	.029	"	2.0	"		"			8	6.5		170	130	Yes	No	External Mixture Explosive
687	79.289 / 82.155	2.900	.029		2.5	30.2	55	"		"	11	7.5	"	205	157	Yes	No	Do Do Do
688	85.217 / 88.117	2.900	.029	"	"			"			14	10	"	246	191	Yes	No	Do Do Do
689	88.146 / 91.046	2.900	.029	"	"							8		191	163	Yes	No	Do Do Do
690	89.180-89.291 / 92.431	2.900	.031	"	2.4	29.52	54					8		244	165	Yes	No	Do Do Do Feeble Internal Explosion
691	94.960 / 97.860	2.900	.028	"		"			"	"	11	7.5		246	154	Yes	Yes	
692	97.250 / 97.390	2.900	.038	"	Nil	29.4	52	"	.375	.046	—	—	—	52	52	Yes	Yes	Gas admitted to explosion chamber before mixture admitted to ignition box
693	100.298 / 100.376	2.900	.030	"	"	"				.060	—	—	—	52	52	Yes	No	Do Do Do External Mixture Explosive
694	100.350 / 103.250	2.900	.030	"	2.5	"		"	"	"	10	7	900	196	150	Yes	No	External Mixture Explosive
695	6.150 / 6.180	2.900	.030				"	"	"	"	8	7	"	163	150	Yes	No	Do Do Do Gas admitted to explosion chamber first
696	9.080 / 9.110	2.900	.030						"	"	5	5	"	121	121	Yes	No	Do Do Do Do
697	12.010 / 12.060	2.900	.030						"	.062	4	4	"	109	109	Yes	No	Do Do Do Do
698	14.940 / 16.920	2.900	.030		2.50				"	"	6	6	"	135	135	[illegible]	No	Do Do Do Do
699	17.870 / 17.900	2.900	.030			29.44	54		"		6	6	"	137	137	Yes	No	Do Do Do Do
700	18.100-21.006 / 21.036	2.900	.030						"		5	5	"	123	123	Yes	No	Do Do Do Do
701	23.936 / 23.966	2.900	.030							.066	8	8	"	165	165	Yes	No	Do Do Do Do
702	23.970-26.870 / 26.900	2.900	.030						"	.065	6.5	6.5	"	144	144	Yes	No	Do Do Do Do
703	26.930 / 29.830	2.900	.030		Nil				"	.066	5	5	"	123	123	Yes	Yes	
704	32.830 / 37.860	5.000	.030		2.5	29.4	54.5		"	.062	4.5	4.5	"	116	116	Yes	No	Gas admitted to explosion chamber first External Mixture Explosive.
705	35.560 / 35.590	2.900	.030		"	29.57	56			.064	6	6	"	139	139	Yes	No	Do Do Do Do
706	38.290 / 38.320	2.900	.030		"	"			"	.065	7	7	"	152	152	Yes	No	Do Do Do Do
707	41.220 / 41.249	2.900	.029		"	"			"	"	8	8	"	167	167	Yes	No	Do Do Do Do
708	44.149 / 44.178	2.900	.029		Nil	"			"	.074	5	5	"	125	125	Yes	Yes	

No	Gas Meter Reading	Gas in Cubic feet EC	SB	Current in Amperes Igniting	Heating	Atmosphere Bar Ins.	Temp °F	Breadth of Flange	G A Length in inches	Depth in inches	Galvanometer Reading [illegible] of gas	[illegible] Ignition of gas	[illegible]	A.D. °F	I.G. °F	Ignition [illegible]	External	Remarks
709	65·130 - 65·020 65·050	2·900	·029	18	2·8	29·15	56	1	1·375	·065	6·5	9·5	900	187	187	Yes	No	External Mixture Explosive.
710	51·100 - 56·000 56·029	2·900	·029		2·5	"	"	"	"	·066	6	6	"	139	139	Yes	Yes	
711	46·050 - 50·050 50·085	2·900	·029	"	"	"	"	"	"	"	9	9	"	140	140	Yes	No	External Mixture Explosive.
712	50·100 - 56·529 56·735	2·700	·029	"	Nil	"	"	"	"	"	5	5	"	125	125	Yes	Yes	
713	56·788 59·488	2·700	·028		"	"	"	"	"	"	1·5	1·5	"	87	87	Yes	Yes	
714	63·200 - 65·900 66·930	2·700	·030		"	29·58	57	"	"		—	—		[illegible]	?	Yes	Yes	
715	67·630 67·660	2·700	·030	"	"	"	"	"	"	·064	—	—		57	57	Yes	No	External Mixture Explosive
716	70·360 70·390	2·700	·030	"	"	"	"	"	"	"	—	—	—	57	57	Yes	No	Do Do Do
717	9·760 12·660	2·900		"	2·70	30·09	56·5	"	"	·065	[illegible]	[illegible]	900	194	[illegible]	Yes	No	Do Do Do
718	" 15·560	2·900				"	"	"	"		[illegible]	[illegible]	"	191	[illegible]	Yes	No	Do Do Do
719	" 18·460	2·900				"	"	"	"		[illegible]	5	"	125	125	Yes	No	Do Do Do
720	" 21·160	2·700		"	2·7	30·36	57·5	"	"	"	11	8	"	209	167	[illegible]	[illegible]	Do Do Do
721	" 23·860	2·700		"	"	"	"	"	"	"	9	8	"	182	167	Yes	No	Do Do Do
722	23·900 - 26·600	2·700		"	Nil	30·12	61	"	"	·068	—	—	—	61	61	Yes	No	Do Do Do
723	" 29·300	2·700			"	"	"	"	"	"	—	—		61	61	Yes	Yes	
724	" 32·000	2·700			2·7	"	"	"	"	·067	13	10	900	240	190	Yes	No	External Mixture Explosive
725	" 34·700	2·700		"	Nil	"	"	"	"	·065	8	7	"	171	157	Yes	No	Do Do Do
726	" 37·400	2·700		"	"	"	"	"	"	"	5	5	"	130	130	Yes	No	Do Do Do
727	" 40·100	2·700		"	"	"	"	"	"	"	6	3·5	"	116	[illegible]	Yes	No	Do Do Do
728	" 42·500	2·700		"	"	29·34	58	"	"	"	[illegible]	7	"	182	[illegible]	Yes	No	Do Do Do
729	45·500 45·530	2·700	·030		"	29·62	56		5·125	·065	—		—	56	56	Yes	Yes	
730	45·230 45·260	2·700	·030	"	"	"	"	"	"	·063		—		56	56	Yes	No	External Mixture Explosive
731	50·960 50·990	2·700	·030	"	"	"	"	"	"	·044	—	—	—	56	56	Yes	Yes	
732	53·690 53·720	2·700	·030	"	"	"	"	"	"	"	—			56	57	Yes	Yes	
733	56·400 56·450	2·700	·030	"	"	"	"	"	"	[illegible]	—				56	Yes		External Mixture Explosive

No	Gas Meter Reading	Gas in cubic ft EC	Gas in cubic ft SB	Current in amperes Igniting	Current in amperes Heating	Atmosphere Bar ins	Atmosphere Temp °F	Length of Flame	Gap Length	Gap Depth	Quantity of Gas	Quantity of Air	Gal Res	Internal Temp Ab °F	Internal Temp Ig °F	Ignition Internal	Ignition External	Remarks
734	56530-59220 / 59.300	2.700	.030	18	Nil	29.5	56	1	5/25	.043	–	–	–	56	56	Yes	No	External Mixture Explosive
735	62.000 / 62.030	2.700	.030	–	–	–	–	–	–	.044	–	–	–	56	56	Yes		
736	64.730 / 64.760	2.700	.030	–	–	–	–	–	–	–	–	–	–	56	56	Yes	Yes	
737	67.460 / 67.490	2.700	.030	–	3.0	29.4	56	–	–	–	4	4	900	111	111	Yes	Yes	
738	67.350 / 70.120	2.700	.030	–	–			–	–	–	10	7	–	194	152	Yes	No	External Mixture Explosive
739	70.320 / 72.950	2.700	.030				–	–	–	–	5	4	–	126	113	Yes	Yes	
740	72.980 / 75.610	2.700	.030			–	–	–	–	–	8	6	–	167	140	Yes	Yes	
741	75.710 / 78.410	2.700					–	–	–	–	4.5	3.5		119	105	Yes	Yes	
742	78.440 / 81.140	2.700	.030			–					3	3	–	98	98	Yes	No	External Mixture Explosive
743	53.860 / 53.870	2.700	.030	–	2.7	–	–			.042	8	6	–	167	140	Yes	No	Do Do Do
744	53.900 / 86.600	2.700	.030	–	Nil	–	–			.042	5	4.5	–	136	119	Yes	No	Do Do Do
745	86.630 / 89.330	2.700	.030	–	–	–				.043	4	4	–	112	112	Yes	Yes	
746	89.360 / 92.060	2.700	.030	–			–			.044	1.5	1.5	–	78	78	Yes	Yes	
747	94.760 / 94.790	2.700	.030	–	2.7	29.30	57			.043	7	6	–	154	140	Yes	Yes	
748	94.850 / 97.550	2.700	.030	–	Nil	–	–	–	–	–	4.5	4	–	119	112	Yes	No	External Mixture Explosive.
749	100.280 / 100.250	2.700	.030	–	2.7		–	–	–	.042	7	6	–	152	140	Yes	No	Do Do Do
750	100.280 / 102.980	2.700	.030	–	Nil		–	–	–	.043	5	4.5	–		119	Yes	No	Do Do Do
751	5.610 / 5.710	2.700	.030	–	2.7		–	–	–	.042	6	5	–		126	Yes	No	Do Do Do
752	5.740 / 8.440	2.700	.030		–			–	–	.043	7	6	–		140	Yes	Yes	
753	8.670 / 11.370	2.700	.030	–	Nil		–	–	–	.042	5	4.5	–		119	Yes	Yes	
754	11.200 / 13.910	2.700	.030		–		–	–	–	–		3	–		98	Yes	No	External Mixture Explosive
755	13.930 / 16.630	2.700	.030	–	–		–	–	–	–	3	3	–		98	Yes	No	Do Do Do
756	10.360-10.390 / 99.040	2.700	.030	–	–		54	–	10.5	.037	–	–	–		54	Yes	Yes	
757	54.790 / 54.850	2.700	.030	–	–		–	–	–	.040	–	–	–		54	Yes	Yes	
758	57.520 / 57.550	2.700	.030	–	–		–	–	–	.035			–		54	Yes	No	External Mixture Explosive

No	Gas Meter Reading	Gas EC	Gas SB	Current in Amperes Igniting	Current in Amperes Heating	Atmosphere Bar (in)	Atmosphere Temp °F	Gap of Flange	GA Length in	GA Depth	Galvanometer Reading Approach of Gas	Galvanometer Reading Withdrawal of Gas	Gal Res	Internal Temp of Casing AD °F	Internal Temp of Casing IG °F	Ignition Internal	Ignition External	Remarks
759	[illegible]-31·280 30·280	2·700	·034	18	Nil	29·25	54	1	10·5	·035	—	—	—	54	54	Yes	No	External Mixture Explosive
760	32·980 33·010	2·700	·030	"	2·7	"	"	"	"	"	7	6	900	[illegible]	137	Yes	No	Do Do Do
761	33·040 35·740	2·700	·030	"	Nil	"	"			"	4	4	"	109	109	Yes	Yes	
762	35·440 38·470	2·700	·030	"	2·5	29·52	57				7	6	"	151	137	Yes	No	External Mixture Explosive
763	41·170 41·900	2·700	·030	—	Nil	—	—				5·5	5	—	130	123	Yes	No	Do Do Do
764	41·238 43·932	2·700	·035	"	"	"	"				4	4	"	107	107	Yes	No	Do Do Do
765	[illegible]-46·770 46·800	2·700	·030	"	"		"				4	5·5	"	107	100	Yes	Yes	
766	49·300 49·530	2·700	·030	—	3	29·52	54				?		"	?	?	No	No	[illegible] Explosive [illegible] for two minutes. Coil at dull red heat. No internal ig.
767	52·230 52·260	2·700	·030	—	Nil	"					—		—	54	54	Yes	Yes	
768	54·960 54·990	2·700	·030	"	—	—	"	—	"	·055	—		—	52	54	Yes	Yes	
769	57·6[illegible] 57·7[illegible]	2·700	·030	"	"	"				·070	—		—	54	54	Yes	Yes	
770	57·750-60·630 60·660	2·700	·030	"	—	"				·071	—	—	"	54	54	Yes	Yes	
771	63·180 63·210	2·700	·030	—	—	"		"		·075	—	—	—	54	54	Yes	Yes	Leakage at joints of loose flanges
772	66·310-69·010 69·040	2·700	·030	—	"	30·09	55·5	—	·25	·108	—	—	—	55·5	55·5	Yes	No	External Mixture Explosive New loose flanges
773	71·740 71·770	2·700	·030	—		"	"	—	·25	·108	—	—	—	55·5	55·5	Yes	No	External mixture explosive. Interval of 2·3 min elapsed [illegible] applied during [illegible] the ignition of the ext. mix.
774	71·800 74·500	2·700	·030	—		"	"	—		·125	—	—	—	55·5	55·5	Yes	Yes	
775	77·200 77·230	2·700	·030	"	2·7	"	"	"	"	·106	8	7	900	166	152	—	—	Fuse wire slipped or melted by heat of coil. Igniting circuit not complete.
776	79·930 79·960	2·700	·030	—	"	—	"	"	"		9	7	"	180	152	Yes	Yes	External mixture ignited first (intermittently). There followed immediately an internal explosion which forced a puff out of the [illegible]
777	79·990 82·690	2·700	·030	"	Nil	"	"		"		6·5	6	"	145	138	Yes	No	External Mixture Explosive
778	82·720 85·420	2·700	·030				"	"	"	"	5	4·5	"	124	117	Yes	No	Do Do Do
779	85·450 88·150	2·700	·030	"	"	"	"	"			4	4	"	110	110	Yes	Yes	
780	90·850 90·880	2·700	·030	—	2·7	30·3	57	"			6·5	6	"	147	140	Yes	No	External Mixture Explosive
781	90·910 93·610	2·700	·030		Nil	"		"		"	5·5	5	"	135	126	Yes	Yes	
782	93·640 96·340	2·700	·030	—	"			"				3	"	109	98	Yes	Yes	
783	96·370 99·070	2·700	·030		"	"	"	"		"	2	2	"	84	84	Yes	No	External Mixture Explosive

No	Meter Reading	Gas in Cubic feet EC	Gas in Cubic feet SB	Amperes Igniting	Amperes Heating	Atm Bar Ins.	Temp °F	[illegible]	Gap Length in inches	Depth in inches	Time Heating Admission	Time Heating Ignition of Gas	Total Res	Internal Temp of Casing AD °F	Internal Temp of Casing IG °F	Ignition Internal	Ignition External	Remarks
784	99.070 – 101.770 101.800	2.700	.030	18	Nil	30.35	57		.375	.087		—		57	57	Yes	No	External Mixture Explosive
785	1.830 4.530	2.700	.030	″	2.5	″	″	″	″	″	4	4	900	113	113	Yes	No	Do Do Do
786	7.230 7.260	2.700	.030	″	″	29.24	58	″	″	″	6	5.5	″	141	134	Yes	No	Do Do Do
787	9.960 9.990	2.700	.030	″	Nil	″	″	″	″	″	4.5	4.5	″	120	120	Yes	No	Do Do Do
788	12.690 12.720	2.700	.030	″	″	″	″	″	″	″	4	5.5	″	113	106	Yes	No	Do Do Do
789	15.420 15.450	2.700	.030	″	″	″	″	″	″	″	3	3	″	99	99	Yes	No	Do Do Do
790	18.150 18.180	2.700	.030	″	2.7	″	56	″	7/16	″	4	4	″	111	111	Yes	Yes	
791	20.880 20.910	2.700	.030	″	Nil	″	″	″	″	″	3	3	″	97	97	Yes	Yes	
792	23.610 23.640	2.700	.030	″	″	″	″	″	″	″	—	—	—	56	56	Yes	Yes	
793	26.340 26.370	2.700	.030	″	″	29.1	59	″	″	″	—		—	59	59	Yes	No	External Mixture Explosive
794	29.070 29.100	2.700	.030	″	″	″	″	″	″	″	—		—	59	59	Yes	No	Do Do Do
795	31.800 31.830	2.700	.030	″	2.8	″	57.5	″	″	″	6	5	[illegible]	[illegible]	[illegible]	Yes	No	Do Do Do
796	34.530 34.560	2.700	.030	″	Nil	″	″	″	″	″	3	2	″	99	[illegible]	85	[illegible]	Do Do Do
797	37.260 37.290	2.700	.030	″	2.7	″	″	″	″	″	7	6	″	152	140	Yes	No	Do Do Do
798	39.990 40.020	2.700	.030	″	″	″	″	″	″	″	5	4.5	″	126	119	Yes	No	Do Do Do
799	42.720 42.750	2.700	.030	″	″	″	″	″	″	″	4.5	4.5	″	114	119	Yes	No	Do Do Do
800	45.450 45.480	2.700	.030	″	″	″	″	″	″	″	4.0	4.0	″	112	112	Yes	No	Do Do Do
801	48.180 48.210	2.700	.030	″	″	29.89	57	″	.5	″	7	6	″	153	139	Yes	No	Do Do Do
802	50.910 50.940	2.700	.030	″	Nil	″	″	″	″	″	5	4.5	″	126	119	Yes	No	Do Do Do
803	53.640 53.670	2.700	.030	″	″	″	″	″	″	″	4.5	4	″	119	112	Yes	Yes	
804	56.370 56.400	2.700	.030	″	″	″	″	″	″	″	4	3.5	″	112	105	Yes	Yes	

No	Gas Meter Reading	Gas in Cubic Ft. EC	Gas in Cubic Ft. S.B	Cutting Current in Amperes	Breadth of Flange	White Metal Bearing Diameter	White Metal Bearing Length	Shaft Diameter	Dia. of Bearing Minus Dia of Shaft	Ignition Internal	Ignition External	Remarks
805	67.000-67.550 71.550	5.000	.550	18	1.375	20"	2"	2"	.0015	Yes	No	External Mixture Explosive. Paper Window Burst by Internal Explosion
806	70.600 73.100	2.500	.550	"	"	"	"	"	"	Yes	No	Do Do Do
807	73.650 76.150	2.500	.550	"	"			"	"	Yes	No	Do Do Do
808	76.700 79.200	2.500	.550	"	"			"		Yes	No	Do Do Do
809	81.650-82.100 84.600	2.500	.450	"	"			1.996	.004	Yes	No	Do Do Do
810	85.050 87.550	2.500	.450					"	"	Yes	No	Do Do Do
811	88.000 90.500	2.500	.450	"	"			"	"	Yes	No	Do Do Do
812	90.950 93.450	2.500	.450	"	"			"	"	Yes	No	External Mixture Explosive. External stud withdrawn from shaft before experiment. After experiment shaft found inside switch box.
813	93.900 96.400	2.500	.450	"	"			"	"	Yes	No	Do Do Do Do
814	96.600-97.050 99.550	2.500	.450	"				1.965	.015	Yes	No	External Mixture Explosive
815	[illegible] 102.500	2.500	.450	"	"			"	"	Yes	No	Do Do
816	2.950 5.450	2.500	.450	"	"			"	"	Yes	No	Do Do
817	5.900 8.400	2.500	.450	"	"			"	"	Yes	No	Do Do Stud out of shaft. After experiment shaft found inside S.B.
818	8.850 11.350	2.500	.450	"	"			"	"	Yes	No	Do Do Do
819	11.500	—	.450	"	"			"	"	Yes	—	No flame at bearing. Short flame at flanges. Gap at flanges -01" (Average)
820	12.250	—	.450	"	"			"	"	Yes	—	Do Do
821	12.700	—	.450	"	"			"	"	Yes	—	Do Do
822	13.150	—	.450	"	"			"	"	Yes	—	Stud out shaft drawn in. No flame at bearing. Flanges oiled before experiment. Short red flame and smoke at flanges
823	13.600	—	.450	"	"			1.965	.035	Yes	—	Sparks at bearing. Shaft drawn in. Short flame at flanges
824	14.050	—	.450	"	"			"	"	Yes	—	Do Do Do
825	14.500	—	.450	"	"			"	"	Yes	—	Do Do Do
826	14.950	—	.450	"	"			"	"	Yes	—	Do Do Do
827	15.000-15.450	—	.450	"				"	"	Yes	—	Do Do Do
828	16.000	—	.550	"	"			"	"	Yes	—	Sparks at bearing. Also whitish ... (slightly luminous) extending about five inches beyond bearing
829	16.550	—	.550	"	"			"	"	Yes	—	Sparks at bearing. Temperature of shaft 80°F

No	Gas Meter Reading	Gas in Cubic Feet E.C	Gas in Cubic Feet S.B	Igniting Current in Amperes	Bearing at Flange	White Metal Bearing Diameter	White Metal Bearing Length	Shaft Diameter	Dia. of Bearing minus Dia of Shaft	Ignition Internal	Ignition External	Remarks
830	16·350 - 17·000	—	·550	18	1·375	2·0"	2·5"	1·965"	·035"	Yes	—	Sparks at Bearing. Temperature of Shaft 58°F. White Emanation extending beyond Bearing
831	17·650	—	·350	"	"	"	"	"	"	Yes	—	Do Do
832	18·000	—	·350	"	"	"	"	"	"	Yes	—	Do Do
833	19·050 - 19·510 21·000	2·500	·450	"	"	"	"	"	"	Yes	No	External Mixture Explosive
834	21·450 23·950	2·500	·450	"	"	"	"	"	"	Yes	No	Do
835	24·400 26·900	2·500	·450	"	"	"	"	"	"	Yes	No	Do
836	27·350 29·850	2·500	·450	"	"	"	"	"	"	Yes	No	Do White deposit (probably smoke) on side of Explosion Chamber nine inches from Bearing
837	30·300 32·650	2·300	·450	"	"	"	"	"	"	Yes	No	Do Do Stud out shaft drawn in
837	33·300 35·800	2·500	·450	"	"	"	"	"	"	Yes	No	Do Do Do
838	36·650 - 37·300	—	·450	"	"	"	"	1·955	·045	Yes	Nil	Numerous Sparks and short Flame at Bearing
839	37·750	—	·450	"	"	"	"	"	"	Yes	—	Brownish Flame extending one inch beyond Bearing
840	38·300	—	·550	"	"	"	"	"	"	Yes	—	Do Do
841	38·850	—	·550	"	"	"	"	"	"	Yes	—	Do Do
842	39·400	—	·550	"	"	"	"	"	"	Yes	—	Do Do
843	39·950	—	·550	"	"	"	"	"	"	Yes	—	Do Do
844	40·500	—	·550	"	"	"	"	"	"	Yes		Do Do Stud out, shaft drawn into S.B.
845	41·050	—	·550	"	"	"	"	"	"	Yes	—	Do Do Do Temp. of Shaft 90°F
846	41·400	—	·350	"	"	"	"	"	"	Yes	—	A few Sparks at Bearing. No Flame.
847	41·750	—	·350	"	"	"	"	"	"	Yes	—	Neither Flame nor Sparks at Bearing
848	42·100	—	·350	"	"	"	"	"	"	Yes	—	Do White Emanation at Bearing
849	42·500	—	·400	"	"	"	"	"	"	Yes	—	Short Bluish-White Flame at Bearing
850	42·900	—	·400	"	"	"	"	"	"	Yes	—	Do Do
851	43·500	—	·600	"	"	"	"	"	"	Yes	—	No Flame White Emanation at Bearing
852	44·200	—	·700	"	"	"	"	"	"	Yes	—	Weak internal explosion. Nothing seen at Bearing
853	44·750	—	·550	"	"	"	"	"	"	Yes	—	Red Flame extending two inches beyond Bearing

No	Gas Meter Reading	Gas in Cubic Feet E.C.	Gas in Cubic Feet S.B.	Ignition Current in Amperes	Breadth of Flange	Bearing Diameter	Bearing Length	Shaft Diameter	Dia. of Bearing minus Dia. of Shaft	Ignition Internal	Ignition External	Remarks
854	44·450-45·200	—	·450	18	1·375	2·0"	2·5"	1·955	·045	Yes	—	Red flame extending two inches beyond bearing
855	45·700	—	·500	"	"	"	"	"	"	Yes	—	Do Do Do
856	46·175	—	·475	"	"	"	"	"	"	Yes	—	Do Do Do Temp. of shaft 180°F
857	46·650	—	·475	"	"	"	"	—	"	Yes	—	Shaft, bearing and flanges oiled. Smoke at bearing and flame very short. Shaft outside bearing covered with globules of oil.
858	47·125	—	·475	"	"	"	"	"	"	Yes	—	Do Do Do
859	47·350-47·625 50·325	2·500	·475	"	"	"	"	"	"	Yes	No	External mixture explosive
860	50·800 53·300	2·500	·475	"	"	"	"	"	"	Yes	No	Do Do
861	53·775 56·275	2·500	·475	"	"	"	"	"	"	Yes	No	Do Do
862	56·750 59·550	2·800	·475	"	"	"	"	"	"	Yes	No	Do Do Stud out, shaft drawn inside switch box. Ext. mix. ignited immediately after int. ign. Flame drawn into S.B. thro' flanges
863	60·025 62·875	2·800	·475	"	"	"	"	"	"	Yes	No	Do Do Do Do. Whistling sound produced when flame drawn in between flanges and bearing
864	63·300 66·300	3·000	·475	"	"	"	"	"	"	Yes	No	Do Do Do
865	66·775 69·775	3·000	·475	"	"	"	"	"	"	Yes	No	Do Do Do
866	70·250 73·250	3·000	·475	"	"	"	"	"	"	Yes	No	Do Do Do
867	73·725 76·725	3·000	·475	"	"	"	"	"	"	Yes	No	Do Do Do
868	77·900 80·900	3·000	·475	"	"	"	"	"	"	Yes	No	Do Do Do
869	80·675 " "	—	·475	"		"	"	1·945	·055	Yes	—	Shower of white sparks at bearing
870	81·150	—	·475	"	"	"	"	"	"	Yes	—	White flame extending 2-3 inches beyond bearing
871	81·625	—	·475	"	"	"	"	"	"	Yes	—	Do Do Do Do Preceded by red sparks
872	82·100	—	·475	"	"		"	"	"	Yes	—	Do Do Do Do
873	82·575	—	·475	"			"	"	"	Yes	—	Do Do Do Do Stud out shaft drawn inside switch box
874	83·050	—	·475	"			"	"	"	Yes	—	Casing shattered by force of internal explosion.
875	83·080	—	·030	"	1·0"		1·625	·625	·001	Yes	—	Brass bearing. No flame
876	83·110	—	·030	"	"		"	"	"	Yes	—	Do Do
877	83·140	—	·030	"	"	"	"		"	Yes	—	Do Do
878	83·170	—	·030	"	"	·650	"		·025	Yes	—	Do Do

No	Gas Meter Reading	Gas in Cubic Feet EC	Gas in Cubic Feet SB	Igniting Current Amperes	Breadth of Flange	Bearing Diameter	Bearing Length	Shaft Diameter	Dia. of Bearing minus Dia. of Shaft	Ignition Internal	Ignition External	Remarks
879	53·170-53·200	—	·030	18	1·0	·650	1·625	·625	·025	Yes	—	Sparks at bearing
880	53·230	—	·030		"	·672	"	"	·047	Yes	—	Sparks and short blue flame
881	[illegible] 53·410	—	·030	"		·687	"	"	·062	Yes	—	Sparks and red flame extending approximately one inch beyond bearing
882	56·820-56·850 57·760	5400	·030	"	"	·687	"	"	"	Yes	No	External mixture explosive
883	57·790 90·690	2·400	·030	"	"	·687	"	"	"	Yes	No	Do Do
884	90·720 93·620	2·900	·030	"	"	"	"	"	"	Yes	No	Do Do
885	93·650	—	·030	"	"	·695	"	"	·070	Yes	—	Blue flame extending approximately two inches beyond bearing
886	 95·760	2700	·030	"	"	"	"	"	"	Yes	No	External mixture explosive
887	96·790 99·640	2·700	·030	"	"	"	"	"	"	Yes	No	Do Do
888	99·520 102·220	2·700	·030	"	"	"	"	"	"	Yes	No	Do Do Two reports heard
889	2·540	—	·030	"	"	·720	"	"	·095	Yes	—	Sparks followed by bluish-red flame extending approximately two inches beyond bearing
890	4·570	—	·030	"	"	"	"	"	"	Yes	—	Do Do
891	3·310 6·910	2600	·030	"	"	"	"	"	"	Yes	No	External mixture explosive
892	4·940 7·640	2·700	·030	"	"	"	"	"	"	Yes	No	Do Do Do
893	7·670 10·370	2·700	·030	"	"	"	"	"	"	Yes	No	Do Do Do Two reports heard
894	10·480	—	·030	"	"	·735	"	"	·110	Yes	—	Bluish-white flame extending 2-3 inches beyond bearing
895	10·630	—	·030		"	"	"	"	"	Yes	—	Green flame extending 2-3 inches beyond bearing (Copper fuse used)
896	10·500-10·530 13·230	2·700	·030	"	"	"	"	"	"	Yes	No	External mixture explosive
897	13·260 15·960	2·700	·030	"	"	"	"	"	"	Yes	No	Do Do
898	15·990	—	·030	"	"	·750	"	"	·125	Yes	—	Green flame extending approximately 3 inches beyond bearing (copper fuse used)
849	16·020	—	·030	"	"	·750	"	"	"	Yes	—	Do Do Do
900	16·050 16·650	2·600	·030	"	"	"	"	"	"	Yes	No	External mixture explosive
901	15·680 21·480	2·800	·030	"	"	"	"	"	"	Yes	No	Do Do Do
902	21·510 24·410	2·900	·030	"	"	"	"	"	"	Yes	Yes	
903	24·440 27·240	2·800	·030	"	"	"	"	"	"	Yes	Yes	

APPENDIX 1.

INTRODUCTION:

In 1927, the Committee of The Journal of the Royal Technical College, accepted for publication an account of part of the work. A copy of the reprint is herewith presented, together with a mathematical investigation given by way of extension to this paper. The author acknowledges his indebtedness to Professor James Muir, M.A., D.Sc., A.R.T.C., and Mr. Alex. D. Third, B.Sc., Ph.D., A.R.T.C., for assistance given in the mathematical investigation.

The drop in Temperature produced by the passage of Hot Gases through apertures.

The following rough calculations are given by way of extension to the paragraph at the foot of page 119 of the 4th. Number of the Journal of the Royal Technical College (Paper on Preventing Electrical Apparatus from starting Explosions).

The paragraph is as follows:- "The cooling of hot gases, by passing through a gap, may be regarded as being effected in two ways (i) naturally by the sudden expansion from high pressure to low, and (ii) by passing over the cold surfaces of the metal flanges. The heat absorbed by a cold metal surface from a hot gas passing over it, is proportional to the area of the surface, to the density of the gas, to the speed with which the gas sweeps over the surface and to the difference in temperature between the surface and the hot gas. When a 'gap' is short, deep and of small area the first cause of cooling probably predominates; with long narrow gaps cooling is possibly accomplished mainly by the large metal surface swept over."

In considering the passage of hot gases (such as steam) through nozzles, it is found that the passage of the gas may be regarded as being a "reversible adiabatic expansion". This may be a large assumption if applied to the passage of flames from an explosion but it will be made (combustion is not adiabatic). For the reversible adiabatic expansion of ideal gas, $pv^n = \text{Constant}$ and $pv = RT$, hence if the expansion through the gap be from P_1, T_1, to P_2, T_2, $T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$. Taking n (the ratio of the specific heats of the gas at constant pressure and constant volume) as 1.4 and $r = {}^{P_2}/P_1$, then $T_2 = T_1 r^{0.286}$. If the gap is a convergent or a parallel one the outlet pressure is always 0.53 of the initial pressure (if the final pressure is not above this). If the passage is divergent, fuel expansion can take place within its boundary.

Should/

Should the velocity of the stream at any point in the gap be required it is given by the equation,

$$r = \sqrt{\frac{2gn}{n-1} P_1 V_1 (1 - r^{\frac{n-1}{n}})}$$

where P_1 is in lbs/sq. ft.

V_1 the specific volume in cub.ft/Lb.

r the pressure ratio at the point (referred to P_1)

g the acceleration due to gravity,

or the flow is given by

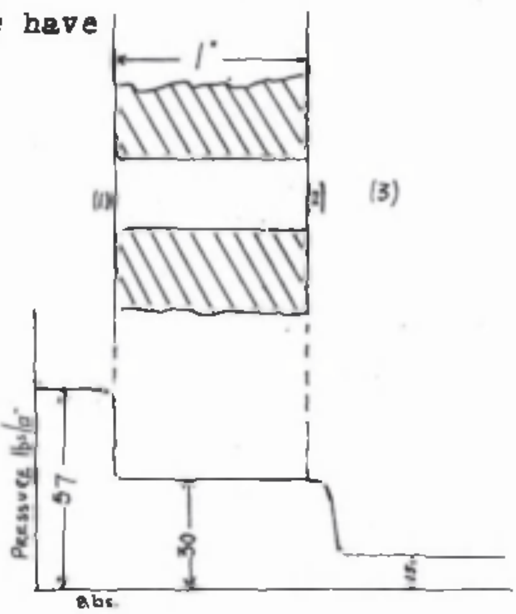
$$w = a \sqrt{\frac{2gn}{n-1} \frac{P_1}{V_1} (r^{\frac{2}{n}} - r^{1 + \frac{1}{n}})}$$

where w is the flow in lb. per sec.

and 'a' is the area to flow in sq. ft.

<u>CASE I.</u> <u>The extreme case of the gap $\frac{1}{10}$" x $\frac{3}{8}$" x 1".</u>

The form of the passage is of the same order as in nozzle work, the heat transference through the limited surface of metal is negligible when the quantity of gas flowing is considered; the expansion being regarded as adiabatic we have



$$T_2 = T_1 \, r^{0.286}$$

$$r = \frac{P_2}{P_1} = 0.53 \quad \text{so } T_2 = 0.83 T_1$$

If say $T_1 = 2000°F$ (absolute)

$T_2 = 1660°F$ a drop of $340°F$

but for this case Fig. 5 p 122 of the Journal paper gives a maximum Pressure $P_1 = 57$ lb/in.^{2} (abs).

So $P_2 = 0.53 \times 57 = 30$ lbs/in^2

$P_3 = 15$ lbs/in^2 (atmospheric.)

There is thus expansion from 30 lbs to 15 lbs/in^2 after leaving the gap. This expansion takes place very close to the gap and produces further cooling which is probably of importance.

CASE II. Another extreme case - the gap 0.03" x 29" x 1"

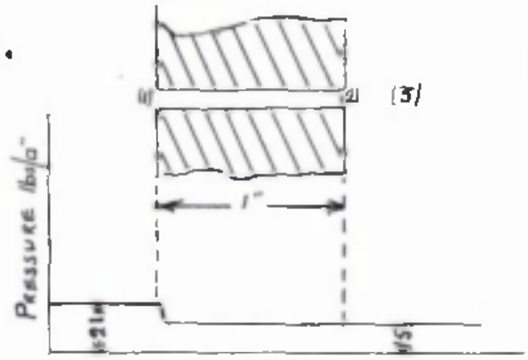


Fig. 5, p.122 gives $P_1 = 21$ lb/in^2 absol.

$P_2 = P_3 = 15$ lb/in^2 = (atmos).

Cooling due to adiabatic expansion.

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$= 0.91\ T_1$$

If $T_1 = 2000°F$ (absol) $T_2 = 1800°F$

A drop of 200°F.

Now consider the heat lost by transmission to the cold metal sides of the gap.

Reynolds' laws of heat transmission, stated in the paragraph quoted at the beginning of this note may be expressed by the equation.

$H = B\ \rho\ v\ t_m$ [$H = A + B\ \rho\ v\ t_m$ - the term A for gases at rest being negligible.]

where t_m is the mean temperature difference between hot gas and metal; v is the speed of gas, ρ the density, B a constant. H is the heat transmitted per unit area per second.

If w = total weight of gas passing per second and

a = cross-section area of flow, $w = a\ v\ \rho$ and

$H = \frac{w}{a} B\ t_m$ (Heat transmitted per sq. foot per sec.)

For ordinary transmission through boiler tubes $B \doteqdot \frac{1}{1200}$ to give B in B.T.U. per sq. ft. per sec., w being in lbs/sec, a in sq. ft., t_m in °F.

Now T_1 and T_2 being the temperatures of gas on entering and on leaving respectively, then (ignoring natural drop due to expansion) we have

Heat taken from gas = $w.S.(T_1 - T_2)$ where S is the spec. heat of the gas (pressure constant).

So $w.S.(T_1 - T_2) = \frac{w}{a}\ B\ A\ t_m$ where A = surface area of metal which is independent of flow of gas as experiments corroborate.

$$\therefore\ T_1 - T_2 = \frac{B.A.t_m}{S.a.}$$

Substituting numbers and taking $s = 0.24$ and the temperature of the hot gases somewhere over $1800^\circ F$ (absol.) and temperature of metal over $500^\circ F$ (abs.) so that $t_m = 1300^\circ F$, we get (A and a, both being put in sq. inches.)

$$T_1 - T_2 = \frac{29 \times 2 \times 1300}{1200 \times .24 \times .03 \times 29} \doteq 300^\circ F$$

The total drop in temperature might thus be about $500^\circ F$, - 200° due to natural cooling (expansion) and 300° due to transmission to the metal.

Of course the various assumptions made render the calculations of very doubtful value. The experiments might lead one to expect that the drop of $340^\circ F$ got in Case I should be more nearly equal to the $500^\circ F$ got in Case II (both gaps were flame-proof), but the further cooling in Case I just after the gas leaves the gap could reasonably be taken to account for this difference, without having regard to a possible difference in the internal temperatures (in one case pressure attained 51 lbs., in the other 21 lbs/in^2 abs.) But 500° seems too small a drop in temperature. If so, then it can only be suggested that calculations based on adiabatic expansion of ideal gases do not apply to gases in a state of combustion.

APPENDIX ii.

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