AN EXPERIMENTAL INVESTIGATION OF THE EVAPORATION AND COMBUSTION OF FUEL DROPLET ARRAYS

A THESIS

SUBMITTED TO THE MECHANICAL Engg. DEPARTMENT OF EAST PAKISTAN UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DACCA IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF M.Sc. IN MECHANICAL ENGINEERING.

By

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September , 1966

THIS IS TO CERTIFY THAT THIS WORK WAS DONE BY ME AND IT HAS NOT BEEN SUBMITTED ELSEWHERE FOR THE AWARD OF ANY DEGREE OR DIPLOMA OR FOR PUBLICATION.

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ACKNOWLEDGEMENT

THE AUTHOR EXPRESSES HIS SINCEREST GRATITUDE TO PROFESSOR VALENTINE GERALD DESA, FOR HIS VALUABLE SUGGESTIONS AND GUIDENCE IN CONDUCTING THE EXPERIMENT AND WRITING THE THESIS.

THE AUTHOR TAKES THE PLEASURE OF ACKNOWLEDGING THE KIND HELP AND CO-OPERATION RENDERED TO HIM BY THE PROFESSORS,COLLEGUES, MEMBERS OF MECHANICAL AND ALL OTHER DEPARTMENTS OF EAST PAKISTAN UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DACCA.

THANKS ARE ALSO DUE TO MR. BAMUNDAS BASU FOR DRAWING THE GRAPHS AND FIGURES PRESENTED IN THIS THESIS.

ABSTRACT

Experimental investigation was conducted on stationary fuel droplets in order to study the evaporation rate and combustion rate of fuel droplets at different temperature levels and the influence of neighbouring drops on the evaporation and combustion rate of fuel droplets, the distance between the droplets being 0.15 to 0.3 cm.

The experimental set up consisted mainly of an electric tube furnace , electronic stroboscope used in conjunction with a stationary film camera and quartz fibres for holding the fuel droplets.

Fuel droplets were suspended from quartz fibres and introduced into the hot electric furnace (ambient gas being quiescent air), and the rate of decrease of droplet diameter is recorded on the photographic film. From the silhouete of the droplet diameter the necessary calculation were made to determine the evaporation and combustion rates.

From the experimental investigations it has been found that for each of the droplets in single,double and triple droplet arrays the square of the droplet diameter varies linearly with time both during evaporation and combustion.Again for similar experimental conditions, the evaporation constant for each of the droplets in double and triple arrays has been found to be lower than that of the single droplet thus showing the influence of droplet interaction on the evaporation rate.It has also been observed that the droplet interaction modifies the burning rate of fuel droplets.

In this investigation only single,double and triple droplet arrays have been studied. Further extensive work is necessary with a variety of droplet arrangement in order to write usable formula for evaporating and burning fuel droplets.

TABLE OF CONTENTS

CHAPTER - I

Introduction

INTRODUCTION

1.0 This report encompasses the result of the experimental investigation conducted on single droplets and on arrays of fuel droplets in order to study the evaporation rate and combustion rate of fuel droplets at different temperature levels, and the influence of various droplet arrays on these evaporation and combustion rates. Along with this, attention has been focussed on topics related to the understanding of combustion process involving liquid fuel droplets.

1.1 In some internal combustion engines like the gas turbine, the diesel engine and the rocket, the fuel is sprayed into a combustion chamber in the form of fine droplets of varying diameter. The interplay between the droplets, gas motion, evaporation and combustion presents the basic problem which can be reduced to a problem of heat, mass and momentum transfer between the droplets and the surroundings.

1.2 It has been observed that the parameters like droplet size, distribution, penetration velocity of the droplet and their interrelated effect on the combustion process cannot be isolated and studied in an actual combustion chamber of the internal combustion engine. So for investigating the phenomena of combustion of droplets, the parameters are isolated and studied under the simulated conditions. This simulated approach has so far been adopted in the study of the evaporation rate , combustion rate and droplet life time. The results from the individual studies have yet to be integrated for predicting the behaviour of these parameters in an actual combustion chamber.

1.3 Extensive work has been done on the evaporation and combustion of single fuel droplets. Spalding (1) Godsave (28), Hottel (30) and

others developed theoretical equations for calculating the evaporation and burning rate of single fuel droplets. Their equations show that the square of the diameter of the droplet bears a linear relationship with time, i.e. D^2/t is constant. Spalding showed that the rate of evaporation and combustion of fuel droplet can be theoretically calculated with the help of a transfer number 'B' which may be thought of as a driving force for mass transfer. His equation for evaporation constant and burning rate is written as -

$$K = \left(\frac{8k}{\rho_l c} \right) \mathrm{Ln} \left(1 + B \right)$$

1.4 Though an array of fuel droplets simulates the condition of a spray system more appropriately than a single droplet, little work has been done with such multiple droplet arrays. Penner (20) appreciated the importance of this and conducted experiments with [redacted]-droplet arrays, the droplets in this configuration being placed side by side and were ignited by an external flame source. However, no useful theoretical equation applicable to an array of fuel droplet has been developed. From the concept of transfer number ' B ' it is evident that evaporation and combustion rate will depend on the relative distance between the droplets, number of droplets in a given volume and the temperature of the environment. Moreover the thermal donductivity ' k ' of the surrounding fuel vapour mixture makes it more difficult to write an equation for an array of fuel droplets and the main approach of study is the direct experimental investigation of the problem.

1.5 Experimenters have adopted different experimental set-ups in the study of the evaporation and combustion rate of fuel droplets. The fuel droplets can be studied either when stationary or when moving, under forced or natural convection. The droplet, in each case is introduced within a hot furnace and photographic technique is employed to record the rate of evaporation

and combustion of fuel droplets. The design of the experimental set-up chosen by the writer was largely influenced by the equipment and facilities available in the laboratory.

1.6 The present experimental investigation was conducted on stationary fuel droplets suspended from quartz fibres, which were introduced into a hot furnace, where the ambient gas, quiescent air, was at atmospheric pressure. A stationary film camera, fitted with an extra lens for magnification, was used in conjunction with an electronic stroboscopic flash lamp in order to record the rate of evaporation and combustion of fuel droplets. Single, double and triple droplet arrays of kerosene (Sp.Gr. 0.786) and diesel (Sp.Gr. 0.832) fuel were employed in this study. From the experimental investigation it has been found during evaporation that the square of the diameter of the droplet varies linearly with time for each of the droplets in single, double and triple droplet arrays. However, for similar experimental conditions, the evaporation constant for each of the droplets in double and triple droplet arrays was found to be lower than that of single droplet, thus showing that droplet interaction influences the magnitude of the evaporation constant. It was also observed that droplet interaction modifies the burning rate of the droplets and the flame structure.

1.7 In the subsequent chapters of this report, details of theory of evaporation and combustion of droplets, experimental arrangement, results and discussion have been presented.

C H A P T E R - II

Subject Matter

* Nature of the problem
* A review of the theoretical and experimental work.

2.1. NATURE OF THE PROBLEM:

In combustion engines like the gas turbine, the diesel engine and the rocket, the fuel is sprayed into the combustion chamber in the form of fine droplets of various diameters. The condition prevailing in the combustion chamber prior to the injection of fuel is a complex one. The combustion chamber contains highly compressed oxidizer diluted with nitrogen and residual products of combustion, all at a very high temperature. In the case of rockets there may also be a residual flame. The interplay between the droplets, gas, motion, evaporation and combustion presents the basis probelm, which can be reduced to a problem of heat, mass and momentum transfer between the droplets and the surrounding environment. Each droplet, as it traverses the combustion chamber, serves as a spherical reservoir of fuel which supplies the fuel vapour in all directions until it ignites or evaporates completely.

2.2. During the short tenure of the drop in the combustion chamber the following phenomena have been known to occur:

i) The drop receives heat from its surroundings.

ii) Thermal expansion of the drop commences and evaporation starts about the same times.

iii) The droplet surface temperature reaches the wet bulb temperature (not the boiling point temperature) corresponding to the ambient conditions. If the rate of heat transfer is very rapid then this may cause the droplet constituents to polymerize and crack.

iv) Then simultaneous mass transfer processes take place:

(a) The fuel vapour diffuses into the surrounding medium;

(b) Diffusion of liquid within the droplet.

v) The fuel vapour with the oxygen of the surrounding medium forms a fuel vapour mixture of strengths varying from very rich mixture near the droplet surface to a lean mixture away from the droplet surface. The stoichiometric mixture lies in between.

vi) The final step is the actual burning. The ignition often occurs in vapour phase with the production of a wake flame, which later becomes a diffusion flame enveloping the droplets.

2.3. The heat transfer to the burning droplet is increased due to the presence of the flame front surrounding it. At any time in the course of burning this heat serves both to evaporate the liquid and to heat the interior of the droplet. The ~~exact~~ degree of internal heating depends in a complicated way on droplet size, time, thermal properties of the liquid and burning rate. The process of heat transfer and diffusion sustains the droplet combustion.

2.4. It is, therefore, observed that a certain time elapses from the instant of spraying to the occurrence of actual ignition. This time is known as the ' ignition lag' or 'ignition delay' and is composed of two delays:

(i) Physical delay which can be stated as the time between the beginning of injection and the attainment of chemical reaction conditions;

(ii) Chemical delay in which the reaction first starts slowly and then accelerates until inflamation or ignition occurs.

No clear cut demarcation can be made between these two delays. Furthermore, it is not well understood which factor (physical or chemical) is the rate determining process in the ignition lag. Some chemical reaction may take place during evaporation.

2.5. It has been observed that the parameters like droplet size, distribution of drops, penetration velocity of the spray and their interrelated effect on the actual combustion process in the combustion chamber cannot be isolated and studied in an actual combustion chamber. Moreover, in the spray system sometimes coalition of the drops takes place thereby increasing the size of the drops and decreasing their number within the combustion chamber. Also the droplet is likely to meet wide variation in magnitude and direction of velocity, temperature and gas composition in its path from the injector to the point where the ignition starts and when the combustion is finally complete.

2.6. For investigating phenomena of combustion of droplets, the parameters are isolated and studied in the simulated conditions prevailing within the combustion chamber. The approaches made so far relate to:

a) The evaporation rate and constant for droplets.
b) The burning rate of droplets.
c) The droplet life time.

The results from the individual study have to be integrated for predicating approximately the behaviour of these parameters in the combustion chamber.

2.7. In the present investigation, the parameters notably evaporation rate and burning rates have been studied for single suspended droplets and an array of suspended droplets with predetermined arrangement.

Theoretical and Experimental Investigation Survey.

2.8. A brief review of the theoretical and experimental studies of both the non-fuel droplets and fuel droplets undertaken by different investigators is presented here. The subject itself has been intensively investigated in Russia, United States, Germany, United Kingdom and Japan due to its importance in designing the fuel spray combustion chambers.

2.9. The basis of the theory of evaporation of droplets in a gaseous medium was laid down by Maxwell (17). In an article written in the year 1877 on " The theory of wet bulb thermometer" he considered the simple case, that of the stationary evaporation of a spherical droplet. He assumed that vapour concentration at the surface of the drop was equal to its equilibrium concentration. Of course this assumption is true when the radius of the drop is significantly greater than the mean free path of the vapour molecules. Maxwell deduced the following equation

$$K = 4\pi R\mathfrak{D} (c_0 - c_\infty) \quad \ldots \quad \ldots \quad (2.9\text{-}1)$$

which indicates that the evaporation is purely diffusion control and the rate of evaporation of drop is proportional not to the surface area of the drop but to the radius of the drop.

2.10. Another pioneer in this field was Mr. Sreznevesky (35). He showed that the rate of evaporation of a droplet in gaseous medium is proportional to its linear dimensions.

$$R \frac{dh}{dt} = \text{Constant.} \quad \ldots \quad \ldots \quad (2.10\text{-}1)$$

2.11. Sreznevesky's experiment on the rate of evaporation of the droplet at different temperature showed that the rate is approximately proportional to the vapour pressure of the liquid. He however did not obtain the exact proportionality. In 1910, Morse (36) showed that the rate of evaporation is proportional to the radius of the sphere. Actually Maxwell, Stefan, Sreznevesky and Morse found theoretically and experimentally that at low temperature the mass rate of evaporation of a drop into still air as proportional to the first power of the drop diameter.

The direct measurements of the temperature of an evaporating drop suspended from the junction of a thermo couple was made by Frossling(37) Frossling in a comprehensive theoretical and experimental study extended the results to the case of a drop evaporating in a moving gas stream of similar temperature. Ranz and Marshall (38) measured the temperature of evaporating water drop suspended from glass capillaries with a manganin constantan thermocouple inserted into the drop from the side.

2.12. M.D. Apasheve and P.V. Malov (12) of the Laboratory of Engines of the Academy of Science USSR showed that Sreznevesky's conclusion that surface area of droplet (square of its diameter) varies linearly with

time is a special case of evaporation and cannot be applied to the case of a moving droplet. These authors established the following relation

$$\frac{d(D)^2}{dt} = -\frac{8 K_c C_g}{\rho_L}\left(1 + A R_c^n S_c^{0.33}\right) \quad \ldots \quad \ldots \quad (2.12\text{-}1)$$

In this relationship , when the droplet is stationary and no gas movement takes place then Re = 0 and the equation becomes

$$\frac{d(D)^2}{dt} = -\frac{8 K_c C_g}{\rho_L} = \text{Const.} \quad \ldots \quad \ldots \quad \ldots \quad (2.12.2)$$

when the relative movement between the gas and stream exists then Re varies so that $\frac{d D^2}{dt} \neq$ constant. They noted that the fractional distillation of fuels during the evaporation process has a significant influence on the evaporation kinematics of light fuels only and where the temperature of the medium is low.

2.13. In Japan, Yasusi Tanasawa and Kiyosi Kobayasi (//) adopted a different theoretical approach for studying the evaporation of droplets. They simplified the problem of evaporation by dividing the total evaporation time into two parts. First is the heating period during which the surface temperature of drops rises to a certain temperature T. They considered that during this time no decrease of the drop radius due to evaporation occurs. After this comes the second part, in which consideration is given to vaporization of the drop which results in the decrease of drop radius while the surface temperature remains at constant value.

2.14. Godsave (28) conducted experimental study on combustion of single fuel droplets and correlated the results with the equations based on these discussed by Tanford and Pease (39).

In rectilinear coordinates his equation can be written as

$$c\rho\left\{\frac{\partial T}{\partial t}+\frac{dx}{dt}\frac{\partial T}{\partial x}+\frac{dy}{dt}\frac{\partial T}{\partial y}+\frac{dz}{dt}\frac{\partial T}{\partial z}\right\}$$

$$=\left\{\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)\right\}+F \qquad (2.14\text{-}1)$$

F = heat supplied by local heat source per unit time per unit volume.

By putting this in spherical polar coordinates and introducing relevant boundary condition he solved for temperature T

$$T=\frac{T_2-T_1}{e^{-E/R_2}-e^{-E/R_1}}e^{-E/R}+\frac{T_1e^{-E/R_2}-T_2e^{-E/R_1}}{e^{-E/R_2}-e^{-E/R_1}} \qquad (2.14\text{-}2)$$

where $E=\left(\frac{dm}{dt}\right)c/4\pi K$.

Thus he showed that temperature distribution is a function of the mass rate of evaporation as given by E.

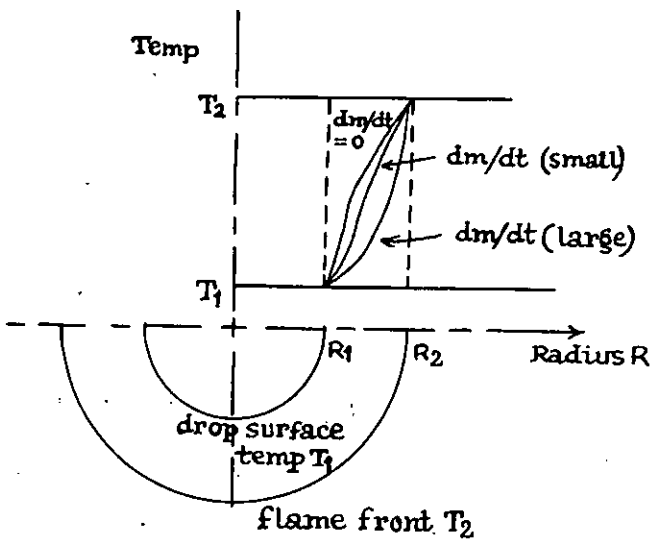

Fig. (2-1)

The expression derived by Godsave from heat transfer consideration is

$$\frac{dm}{dt} = \frac{\text{Log}_{10}\left[1 + \frac{C\Delta T}{\triangleleft H_{-a}}\right]}{\frac{.4343\,C}{2\pi k}\left[\frac{1}{D} - \frac{1}{D_f}\right]} \quad \ldots \quad (2.14\text{-}4)$$

Where all quantities except D & D_f are assumed constant.

C = average heat capacity of the air fuel vapour mixture between the droplet surface and the flame front.

k = average conductivity of the same mixture

$\triangle T$ = Temperature difference between the droplet surface and the flame front

D = Instantaneous diameter of the droplet.

D_f = Instantaneous diameter of the flame front.

The above equation gives the mass burning rate in terms of the geometry and the physical properties of the system.

The Eqn (2.14-4) can be rewritten as

$$\frac{d\,D^2}{dt} = \frac{\text{Log}_{10}\left[1 + \frac{C\Delta T}{\triangleleft H_{-a}}\right]}{\left(\frac{\pi}{4}\rho D\right)(.4343)\frac{C}{2\pi k}\,\frac{1}{D}\left(1 - \frac{D}{D_f}\right)} \quad \ldots \quad (2.14\text{-}5)$$

This shows that the ratio of the flame diameter to the droplet diameter is independent of droplet diameter provided the physical and chemical parameters remains unaltered.

Godsave suspended single droplets on silica fibre ignited them, and followed the progress of combustion photographically. On plotting graphs he found that

$$R_o^2 - R^2 = Kt \quad \ldots \quad \ldots \quad (2.14\text{-}6)$$

is the equation that satisfies the graph were 'K' is the evaporation constant. Godsave calculated 'K' in a very simple way. He considered the

droplet to be spherical of radius R and assumed steady radial heat transfer from the flame to the droplet against the outward diffusing fuel vapour. He concluded that heat transfer is the important factor in controlling the rate of burning.

2.15. C.A. Gregory JR. and H.F. Calcote (29) did experiment to examine the droplet vapour reactions. His technique provided facility for studying individual rate steps that would be expected to be of importance in any heterogeneous combustion system.

2.16. A.R. HALL and J. Diederichsen (40) studied free droplets burning in air at one atmosphere and 710° C and suspended drops at pressure upto 20 atm. They found that mass rate of burning of liquid paraffin bears a linear relation to the drop diameter. They indicated that evaporation constant is proportional to nth root of the atmospheric pressure, the effect being attributed to change in latent heat of the fuel associated with pressure change.

2.17. D.B. Spalding (1) concentrated much attention on the type of flame and its influence on the combustion of liquid droplets. He took the help of transfer number 'B' to proceed with the investigation.(The nature of this transfer number 'B' has been dealt at length in the third chapter). He showed that mass transfer rate of vaporization can be calculated in terms of the transfer number which may be thought of as a driving force for mass transfer. He investigated the combustion rate of droplets in natural convection and also in forced convection. He also studied the flame extinction velocity and its dependence on the droplet diameter which is very important in combustion process with forced convection. Spalding applied the boundary layer theory to predict burning of liquid fuel from some simple geometric shapes. His

theories predict that the mass rate of vaporization of a droplet is proportional to the square root of the Reynolds number. Spalding deduced an equation for mass transfer rate of fuel drops in an environment in which mass transfer occurs by diffusion only across a plane film of gas, which has zero velocity in directions parallel to the plane.

His equation is given by

$$\frac{\dot{m}_j'' D_o}{\mathfrak{D} \rho_g} = 2 \ln (1 + B) \quad \ldots \quad \ldots \quad (2.17\text{-}1)$$

His another equation for droplet life time is given by

$$\frac{t \mathfrak{D} \rho_g}{D_o^2 \rho_L} = \frac{1}{8 \ln (1 + B)} \quad \ldots \quad \ldots \quad (2.17\text{-}2)$$

OR

$$\frac{D_o^2}{t} = \frac{8k/c \ln (1 + B)}{\rho_L} \quad \ldots \quad \ldots \quad (2.17\text{-}3)$$

D.B. Spalding distinguished two types of flame configurations: envelope flame and wake flame. When the sphere is in moving air stream of sufficiently low velocity an envelope flame exists on the sphere i.e. the flame envelopes the leading half of the sphere. Spalding observed that if the air flow is gradually increased, a critical free stream velocity U_c is reached at which the flame suddenly change its form. The flame on the leading half of the sphere is extinguished and a small flame is stabilized within the wake. The envelope configuration is a diffusion flame while the wake configuration is a premixed type of burning with the sphere acting in the role of a bluff body stabilizer as well as the source of fuel vapours. The critical velocity of transition U_c is called the extinction velocity.

2.18 H.C. Hottel, G.C. Williams, (30) and H.C. Simpson studied the burning of droplets by projecting a stream of uniform droplets up into an electric furnace and allowing these droplets to follow their trajectories inside the furnace. Residence time of the droplets in the furnace was measured by recording photo electrically the instant at which the droplet entered and left the furnace. They suggested that a realistic theory of droplet combustion must include the effect of the motion of the main air stream past the droplet. The temperature pattern within the droplet dependence on at least nine diamensionless groups.

$$\theta = f(AB;\ C, \theta_s, B',\ J, Z, t) \qquad \ldots \qquad \ldots \qquad (2.18\text{-}1)$$

2.19. Seuchiro Kumagai and Hisoshi Isoda (31) investigated the combustion of fuel droplets in a vibrating air field at room temperature. The droplet was suspended from a silica filament and ignited by a burner. The driving unit of a dynamic speaker isused as the vibrator. They found that the relation between the diameter of a burning droplet D and time t is the same as combustion in quiescent air, namely

$$D_o^2 - D^2 = Kt \qquad \ldots \qquad \ldots \qquad (2.19\text{-}1)$$

When the amplitude of the diapharagm is increased keeping the frequency and the distance from the droplet constant, the value of K increases, reaches a maximum and then drops to zero. With smaller amplitude the flame boundary takes an oval shape much the same as in the combustion in still air.

2.20. Jack Lorell and Bernard J. Wood (32) studied the droplet combustion by simulating a non-vapour catalytic porous sphere to that of a liquid drop. Porous sphere was fed by liquid reactant at a rate determined by physical and chemical parameters of the system under study. Linear variation of mass burning rate m_f with droplet radius was found to apply equally well to droplets

as large 6000 μ in radius. They detected an increase in burning rate with rising weight fraction of gaseous oxidizer. In such case there is a gradual approach of the luminous region of the flame towards the liquid surface thereby increasing the heat transfer per unit area of the drop surface. They found that spherico-symmetrical model qualitatively predicts the variation of the burning rate of the liquid droplet as a function of the droplet radius and the chemical properties of the system.

2.21. Kiyosi Kobaysi (33) studied by means of motion picture recording the combustion mechanism of fuel droplet suspended from a quartz fibre. The surrounding temperature was 800°C. Rapid evaporation of fuel droplet took place culminating into spontaneous ignition. The relation between drop diameter D and time t was found to be given by

$$\frac{d(D^2)}{dt} = \text{Const.} \qquad \ldots \qquad \ldots \qquad (2.21\text{-}1)$$

This is similar to the equation of evaporation and the slope of the curve is greater after ignition than during evaporation. This increase in slope is due to increase in the amount of heat transferred to the droplet from the flame and is analogous to the increase of the temperature of the surrounding air in the case of evaporation. He, however, found that light oil and kerosene burn with liquid phase creacking at higher temperature but at lower air temperature there is only evaporation without liquid phase cracking.

2.22. Agestion, Wise and Willes A Rosser (8) studied the influence of hydrodynamic factors mainly the effect of forced convection and turbulence on droplet combustion. They also took the help of porous sphere to simulate liquid droplet. They found that near the extinction velocity of air the

consumption of liquid fuel is reduced to a great extent from the value measured with full flame envelope. Hence maximum gain in the rate of combustion of a droplet of a given dia as a result of forced convection is limited by the phenomena of flame extinction. They also observed that the combustion of a fuel cloud composed of small liquid particles more closely resembles that of a prevapourized premixed fuel oxidizer mixture.

2.23. E.G.Masdin and M. Thring (25) studied the influence of such variables as temperature gas composition, gas velocity and droplet size on fuel combustion. They observed that temperature and fuel type influences the ignition lag quite appreciably.

On conducting experiments on kerosene droplets in still air Masdin found that the following equation is obeyed.

$$D_0^2 - D^2 = K (t - t_0) \quad \ldots \quad \ldots \quad (2.23\text{-}1)$$

With heavy residual fuels, complications airse owing to the formation of cenosphere which can take up to 10 times as long to burn as do the volatiles from the same droplets.

2.24. Suchero Kumagai (26) sought to find out the influence of oxygen concentration with n-heptane and ethyl alcohol droplets burning at various O_2 and N_2 mixtures. It was found that burning rate increases with an increase of O_2 concentration which is in satisfactory agreement with the theoretically calculated value.

2.25. J.A. Bolt and M.A. SAAD (27) conducted experiments on combustion rates of freely falling drops in a hot atmosphere. Radiation effect was found to be small. His equation was

$$D_0^2 - D^2 = Kt \quad \ldots \quad \ldots \quad (2.25\text{-}1)$$

K is the coefficient of combustion and depends on the type of fuel, drop dia, relative velocity between falling drop and surrounding atmsphere.

2.26. D.G. Udelson (13) in his investigation of fuel burning as a single sphere found along with envelope flames and wake flames a third region of burning wherein a flame is stabilized in the boundary layer at the side of a liquid sphere. The angular position which the side flame assumes when measured from the forward stagnation point of the sphere is found to increase with free stream air velocity. He also showed that the angular position depends on the sphere size as well as on the orientation of the air flow with respect to the gravity force thus proving natural convection to be an important factor.

2.27. V.G. DeSa (2) studied the combustion of falling droplets inside an electric furnace. DeSa investigated the droplets of gas oil and observed that at about 808° C the first stage ignition occurs with a slight explosion. The flame diameter was found to be smaller than the diameter of the droplet and was nearly equal to the width of the vapour trail. The first stage ignition flame appeared weakly. At higher air temperature (830° C) a second stage ignition occured in the vapour sheath around the droplet. At temperature of 852°C he observed a flash back between the lifted flame in the vapour trail and the flame surrounding the droplet, and vapour burned sometime after the passage of the droplet.

A dark trail known as carbon tube was found to start from the immediate wake of the droplet and tapering in diameter to two thin bright lines. The carbon tube was gradually heated to incandescence by the surrounding burning vapour.

2.28. The case of two droplets burning in close proximity has been investigated in detail by Fuchs and Penner (20). It is interesting to note that the linear relation between the square of the droplet diameter and time applies also to this type of combustion of fuel droplets. In general average evaporation constant for two droplets takes a maximum value for a certain value of the initial minimum distance between adjacent drop surfaces. This attributed to a balance between two opposing factors viz. the decrease heat loss from the flame of one droplet because of the presence of other droplet which acts as a heat source and the decreased O_2 supply to the region between two droplets. Experiments were conducted with five and nine droplets. In the experiments with five droplets four of the droplets were placed at the corners of a square and the fifth in the centre of the square. The square of the diameter for the droplet surrounded by four other droplets was again found to decrease linearly with time with the value of K 20 % larger than for similar studies with two droplets. In the experiments with nine droplets 8 of the droplets were located at the edges of a cube and the ninth droplets was positioned at the cube centre. The square of all the diameters decrease linearly with time.

C H A P T E R - III

Theory of the Evaporation and Combustion of fuel droplets.

A. STATUS OF THEORY OF EVAPORATION OF FUEL DROPLETS

3.1. In discussing the history of a fuel droplet in the combustion chamber of any internal combustion engine first comes the heat-up period. In this heat-up period the drop receives the sensible heat from environment; diffusion within the droplet begins and the light ingredients come upto the droplet surface. Following this evaporation commences. This is defined as the changes of a substance from the liquid to the gaseous state which takes place at the surface of the liquid and at all temperatures. Evaporation is different from boiling.* ?

3.2. Evaporation as a whole may be divided into two parts:-(24)

a) Evaporation in which no chemical reaction takes place e.g.simple vaporising problems.

b) Evaporation associated with chemical reaction such as problems of combustion and reaction.

Again the droplets may vaporise under either of the two conditions:-

i) The droplets are far removed from each other and that there is no influence of one droplet on another or on air between them.

ii) It may happen that the droplets are very close to each other with a consequent large effect on both the temperature and the fuel vapour concentrations in the surrounding air.

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* Boiling can be stated as the rapid change of a substance from the liquid to the gaseous state which takes place throughout the mass of the liquid and at a definite temperature under given conditions for a particular liquid. The temperature remains constant throughout the process provided the pressure remains unchanged.

3.3. Evaporation of a single droplet without interaction with any other drops:

The temperature history diagram of the drop and the surrounding air is shown in Fig. (3.3-1) taken from the paper by Wakil, Myers & Uyehara.

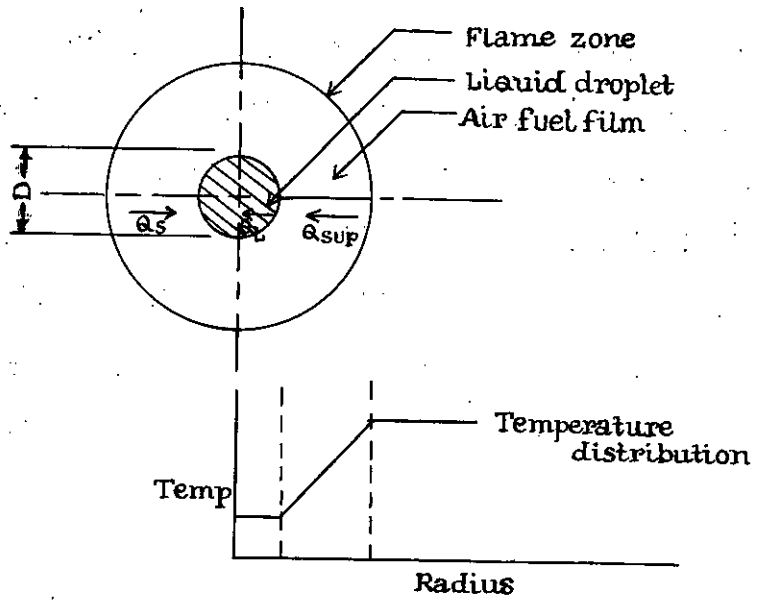


Fig. (3.3-1). Temperature and heat flow diagram of the drop.

Referring to figure (3.3-1) heat transfer from air to the droplet Q, may be divided into three parts (24).

a) Sensible heat Q_S to heat the liquid droplet.
b) Latent heat of vaporization Q_L
c) Super heat Q_{sup} to raise temperature of the diffusing vapour from that of the droplet itself T_S to the air or boundary temperature T_B.

Thus total heat transfer becomes:

$$Q = Q_S + Q_L + Q_{sup} \quad \ldots \quad \ldots \quad (3.3\text{-}1)$$

Heat Transferred to the liquid surface of the drop = $Q_S + Q_L$

3.4. During the unsteady state period, heat transferred from the air to supply sensible heat to the liquid fuel far exceeds the amount to supply latent heat of vaporization. The effect is more pronounced the lower the volatility of the fuel and its initial temperature (24).

3.5. Mr. Wakil, Myers & Uyehara (24) conducted experiment and found it impossible to boil a liquid droplet, when the droplet receives heat from the environment only. If the droplet boiled then the flow of fuel vapour away from the droplet surface becomes rapid and that no heat can be conducted into the droplet. Under these circumstances the droplet would cool down. This concept is of importance during the physical delay period, for it means that regardless of how hot the air is in the absence of radiation, the droplet temperature will always be below its boiling point temperature at the existing gas pressure. During heating, the heat transfer from the surrounding to the droplet makes the droplet temperature approach the boiling point temperature and the partial pressure of fuel vapour P_{fL} to the total pressure irrespective of fuel.

This indicates that the difference in fuel volatility will be less pronounced at higher air temperature than at lower air temperature.

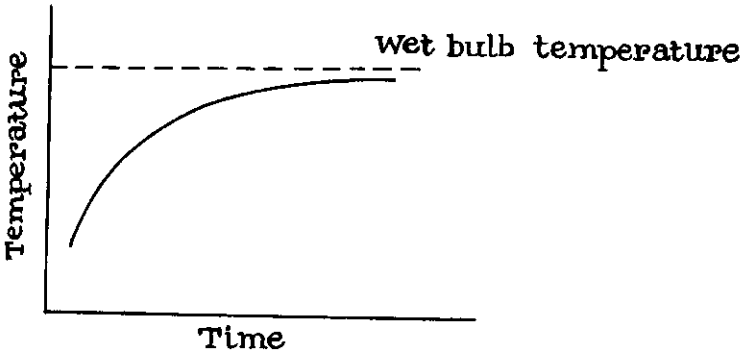


Fig. (3.5-1) – (24)

Now the temperature of each droplet rises rapidly and asymptotically approaches the wet bulb temperature corresponding to the particular fuel used and ambient air conditions. Under these conditions droplet temperature has reached a value where its vapour pressure and mass transfer are so high that latent heat of vaporization Q_L and vapour superheat Q_{sup} balance heat transfer from air. For this condition heat to the liquid Q_s

approaches zero and the droplet remains at its wet bulb condition until it vaporizes completely.(24). Hence the droplet has an unsteady state or time spent by the it in heating up to its wet bulb conditions until completely vaporized.

3.6. The following conclusions were drawn by [illegible] Wakil, Myers and Uyehara (24).

1. For any one fuel the higher the air temperature or pressure the higher the wet bulb temperature.
2. Higher the wet bulb temperature or lower the initial droplet temperature the greater the fraction of its life time the droplet spends in the heat up or unsteady state.
3. The more volatile the fuel the lower the wet bulb temperature and the shorter the droplets life time.
4. The higher the air temperature the smaller the differences between volatile and non-volatile fuel with respect to the droplet's life time.

3.7. From the discussion of history of the droplet itself it is obvious that T_{drop} and $P_{f\ drop}$ vary with time, and that temperature and partial pressure throughout the film vary with both distance from drop surface and time.

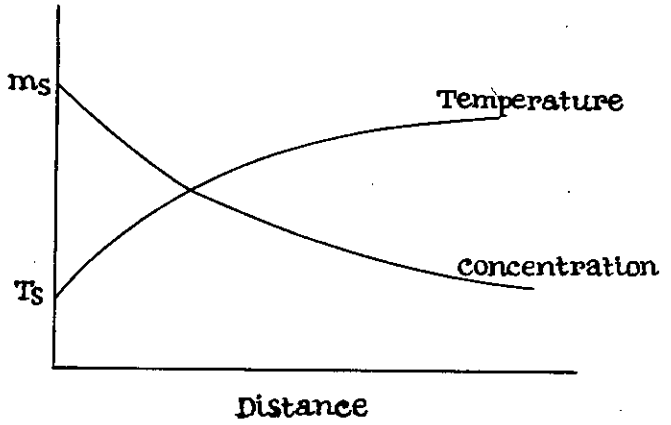


Fig. (3.7-1)

Shows the variation of temperature and vapour concentration from the droplet surface (1).

Considering the mass transfer without reaction, the following analysis has been made by Spalding.

Due to the concentration gradient, diffusion of species takes place. This diffusion process is governed by the Fick's first law of diffusion which states that species 'J' diffuses (moves relative to the mixture) in the direction of decreasing mass fraction of 'J', just as heat flows by conduction in the direction of decreasing temperature, i.e.

$$U_j = -\rho \mathcal{D}_j \nabla m_j \quad \ldots \quad \ldots \quad (3\cdot7\text{-}1)$$

U_j = Mass flux of species 'j' ($g\,cm^{-2}\,Sec^{-1}$)

ρ = mass density of solution (g/cm^3)

$\mathcal{D}_j$ = mass diffusivity

$m_j = \frac{\rho_j}{\rho}$ = mass fraction of 'j'

ρ_j = mass concentration of 'j' (g/cm^3)

3.8. Hence the differential equation for diffusion of fluid in a steady motion can be written from Spaldings theory (1) in the following manner :

$$\mathcal{D} \nabla^2 m_j - V \cdot \nabla m_j = 0 \quad \ldots \quad \ldots \quad (3\cdot8 - 1)$$

This equation states that the net rate of diffusion of the substance 'j' into unit volume is exactly equal to the net rate of a which 'j' is convected out.

In the equation (3·8-1) the variation of diffusion coefficient and density in space are neglected. This molecular diffusion coefficient '$\mathcal{D}$' is of the same order of magnitude as the thermal diffusivity. During turbulence just like 'α', '$\mathcal{D}$' is replaced by eddy diffusivity.

Now if flow pattern around the drop remains constant the mass transfer is directly proportional to concentration difference. In the mass transfer

process at the phase boundary there is a normal velocity which is proportional to the mass transfer rate itself.

Now v_s = normal velocity at the surface.

then $\rho_g v_s$ = mass transfer rate of the component 'j'

which is equal to the component of 'j' being transferred by convection and by diffusion. Writing the mass balance.

$$\rho_g v_s = \rho_g m_j v_s - \mathfrak{D} \rho_g \left(\frac{\partial m_j}{\partial y} \right)_s \quad \ldots \quad (3.8\text{-}2)$$

putting $b = \dfrac{m_j}{m_{js-1}}$ ... . (3.8 -3)

then equation (3.8 -2) reduces to

$$v_s = \mathfrak{D} \left(\frac{\partial b}{\partial y} \right)_s \quad \ldots \quad .... \quad (3.8\text{-}4)$$

3.9. Hence the differential equation for mass transfer in a steady flow may be written as from Spalding's work ( )

$$\mathfrak{D} \nabla^2 b - V . \nabla b = 0 \quad .... \quad (3.9 - 1)$$

This equation may be regarded as the equation governing the diffusion of some property 'b' in the fluid. Hence mass transfer rate depends on the difference in the values of the variable 'b' in the gas stream and the surface. This difference $b_g - b_s \equiv$ 'B' is known as the transfer number( )

The transfer number is the driving force in mass transfer in dimensionless form. When 'B' is positive, mass transfer is outward from the surface; when 'B' is negative, mass transfer is inward. From the above discussion it can be stated that when a component of a gas mixture is transferred between the gas and a solid or liquid surface, the rate of its transfer depends on

$$B = \frac{m_{j_g} - m_{j_s}}{m_{j_s} - 1} \quad \ldots \quad \ldots \quad (3.9\text{-}2)$$

3.10. In the evaporation of fuel droplets simultaneous heat and mass transfer takes place. Considering the mass transferred and heat balance the following equation can be written (|)

$$Q\rho_g v_s = k \left(\frac{\partial T}{\partial y}\right)_s \quad \ldots \quad \ldots \quad (3.10\text{-}1)$$

or $$\rho_g v_s = \frac{k}{Q} \left(\frac{\partial T}{\partial y}\right)_s \quad \ldots \quad \ldots \quad (3.10\text{-}2)$$

Q = heat conducted from gas for per unit mass vaporized.

$\left(\frac{\partial T}{\partial y}\right)_s$ = temperature gradient at and normal to the surface

k = thermal conductivity.

C = specific heat of gas at constant pressure and assumed constant.

writing $$\rho_g v_s = \frac{kC}{Q} \left(\frac{\partial T}{\partial y}\right)_s \quad \ldots \quad \ldots \quad (3.10\text{-}3)$$

and $$b = \frac{CT}{Q} \quad \ldots \quad \ldots \quad \ldots \quad (3.10\text{-}4)$$

$$v_s = \frac{k}{\rho_g C} \left(\frac{\partial b}{\partial y}\right)_s \quad \ldots \quad \ldots \quad \ldots \quad (3.10\text{-}5)$$

$$= \alpha \left(\frac{\partial b}{\partial y}\right)_s \quad \ldots \quad \ldots \quad \ldots \quad (3.10\text{-}6)$$

Where $\therefore \alpha = \phi$ $\quad \ldots \quad \ldots \quad \ldots \quad (3.10\text{-}6a)$

Hence the driving force for mass transfer

$$B_H = \frac{C(T_g - T_s)}{Q} \quad \ldots \quad \ldots \quad \ldots \quad (3.10\text{-}7)$$

Where B_H denotes derivation of driving force from heat balance.

3.11. Both forms of B are valid. The congruence of both forms may be demonstrated by observing that as unit mass of fluid changes temperature from T_s to T_g it gains an amount of heat $C(T_g - T_s)$. Since Q units of heat

are required to vaporize unit mass of the transferred substance, the amount of the transferred substance which may be vaporized is equal to

$$C\left(\frac{T_g - T_s}{Q}\right) \quad \ldots \quad \ldots \quad (3.11\text{-}1)$$

3.12. Now considering the case of a small sphere exchanging mass with an infinite reservoir and from Spalding's analysis ( ).

$$\mathfrak{D}\,\nabla^2 b - V \cdot \nabla b = 0$$

$$\text{and } \vartheta_s = \mathfrak{D}\left(\frac{db}{dy}\right)_s$$

Considering the specific direction 'y' with the diameter of the droplets 'D'

Taking 'v' to be constant

then, on integrating from zero to 'y' the following eq^n is obtained :

$$\mathfrak{D}\left[\frac{db}{dy} - \left(\frac{db}{dy}\right)_s\right] - \vartheta\,(b - b_s) = 0 \quad \ldots \quad \ldots\ (3.12\text{-}1)$$

Solving in the manner of a stagnation film exchanging mass with infinite reservoir, the following eq^n can be arrived at.

$$\frac{\dot{m}'' D}{\mathfrak{D}\rho_g} = 2\,\mathrm{Log}_e\,(1 + B)$$

Again starting from the relation of mass transfer rate and rate of change of radius 'r'

$$\dot{m}'' = -\rho_L\left(\frac{dr}{dt}\right)$$

and 't' is found to be given by

$$\frac{+\mathfrak{D}\rho_g}{D_o^2\rho_L} = \frac{1}{8\,\mathrm{Log}_e(1+B)} \quad \ldots \quad \ldots \quad (3.12\text{-}2)$$

D_o = initial diameter of sphere

ρ_g = density of gas assumed to be constant

ρ_L = density of the liquid sphere

$$D_o^2 = t\left[\left\{\frac{8\rho_g}{\rho_L}\right\}\left\{8\log_e(1+B)\right\}\right] \qquad (3.12\text{-}3)$$

Evaporation rate was found by Spalding and others as

$$K = \frac{D_o^2}{t}$$

In which case,

$$K = \frac{D_o^2}{t} = \left\{\frac{8\rho_g 8}{\rho_L}\right\}\left\{\log_e(1+B)\right\} \qquad \ldots \quad \ldots(3.12\text{-}3)$$

$$\text{or } K = \left(\frac{8k}{\rho_L c}\right)\left\{\log_e(1+B)\right\} \qquad \ldots \quad \ldots(3.12\text{-}4)$$

3.13. Here it is quite evident that the relation between 'K' and 'B' is exponential. Again B is affected by change of temperature and slightly by pressure for the rise in wet bulb temperature of the liquid. But due to this exponential relationship the net effect is not that much pronounced.

B. STATUS OF THEORY OF COMBUSTION OF FUEL DROPLETS

3.14. In the previous chapter attention has been focussed on the evaporation of fuel droplets without chemical reaction and combustion. In this chapter, evaporation of fuel droplets associated with chemical reaction and heterogeneous combustion has been taken up for study.

3.15. In order to study the heterogeneous combustion phenomena of a liquid fuel drop, a spherically symmetric model is usually employed with two concentric spheres. Interior sphere representing the fuel droplet and exterior sphere the flame zone.

3.16. Another important consideration in the droplet combustion system is the monppropellant reaction system and bipropellant reaction system. In the monopropellant reaction system the flame involves a single reactant system in which a single component evaporates from the liquid surface and then decomposes exothermally at a rate which is a function of temperature and composition.

3.17. In a bipropellant reaction system the flame requires the interaction of two reactants, fuel and oxidizer one of which evaporates from the droplet surface and diffuses into the gas phase containing the other reactant. Interdiffusion of reactants takes place and the flame is established at some distance from the droplet. It is the second case that has been considered in this study.

3.18. Theoretical Analysis:

In order to study the combustion process the model is employed as has been stated earlier. A source of one reactant is the liquid droplet and the

other is located in the gas phase at an infinite distance from the liquid sphere.

3.19. The following assumptions are taken (1,2) (3,9) (20) [redacted] .....

i) The combustion occurs under isobaric condition.

ii) The steady state condition prevails.

iii) The droplet and flame surfaces are represented by concentric spheres. There is no relative motion between the droplet and the surrounding medium.

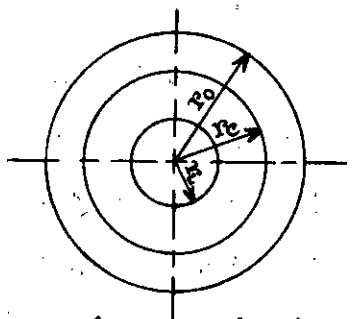
iv) The reaction yields product gases by exothermic reaction at a rate governed by the chemical kinatics.

v) The heat released by chemical reaction is removed by thermal conduction and mass transport.

vi) The effect of radiation has been neglected.

vii) In the spherosymmetrical model the convective effect due to thermal gradient has been neglected. Convective influence has been taken up as semi-empherical correction to this theoretical treatment(|) . [redacted] The interaction between the droplets has been neglected.

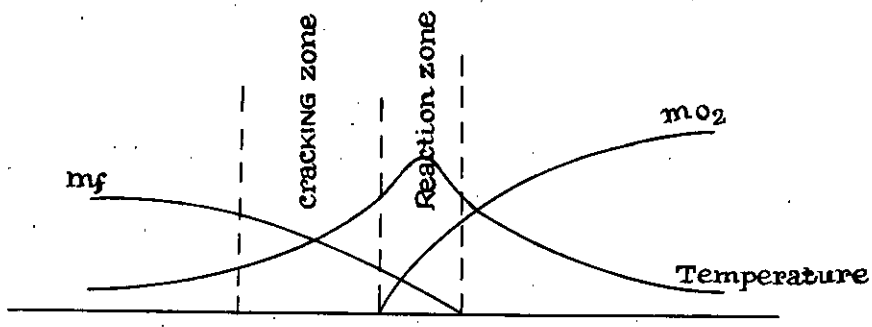
3.20. The schematic diagram of fuel droplet, flame zone and the outer boundary is shown by shematic diagram in the figure.



(Fig. 3.6-1)

r_o = radius of the outer boundary
r_c = radius of the reaction zone
r_L = radius of the liquid droplets.

3.21. The co-ordinate system is fixed with respect to the fuel droplet. The theoretical schematicc diagram of a diffusion flame is shown in the figure (|) :



(Fig: 3.7-1)

Temperature and concentration profiles of a diffusion flame:-

m_f = fuel vapour

m_{O_2} = mass of oxygen.

The fuel vaporizes from the liquid surface and flows towards the flame zone while oxydizer diffuses against the flow of products into the flame front.

Thus it is found that a material transfer of two reactants inter-diffuses from opposite directions and an exothermic chemical reaction is established to a region. In this analysis the approach of Spalding( ) has been taken up for analysing the fuel droplet combustion problems.

3.22. Some oxidizer diffuses to the liquid surface where the weight fraction of fuel is high, the extent of chemical reaction is very low in this region due to the low temperature prevailing in this region. On this fuel side it is quite likely for the hydro-carbon molecules to crack and polymerize forming on the one hand lighter molecules and on the other hand particles of carbon or tarry matter. Such effects have been neglected in this analysis.

The carbon and Tarry matters being very hot radiate the characteristic bright yellow light. This light often makes it difficult to recognize the blue emission, characteristic of the reaction zone itself.()

3.23. The combustion system of the type described is a four component system composed of fuel, oxidizer, products and inert gas (30). Four conservation of mass equations describes the mass rate of each component. The mass rate of inert gas is zero because no sink exists within the system for the species of molecules.

3.24. In the region ($r_L < r < r_c$) enclosed by the difussion flame interface, the fuel vapour is diluted by means of combustion product and inert gas (10,1,15). In this region, reaction may occur between carbon dioxide and fuel vapour resulting in carbon monoxide, which then diffuses to the reaction zone (7, 1). Hydrogen may be formed in a similar manner. At the liquid fuel surface there may be finite concentration of carbon dioxide and monoxide.

3.25. For a monopropellant liquid aerosol system the position of the flame front is located at a distance where the chemical reaction has practically gone to completion and the gas temperature has essentially attained the adiabatic-flame temperature (9).

3.26. The transfer number can be calculated for the burning fuel droplets with the help of enthalpy balance and mass balance. Unit mass of gas decreases from temperature T_g to T_s and the oxygen is consumed with fuel to carbon dioxide and water. The decrease of enthalpy is wirtten from Spalding's analysis (1) as $m_{og} \; H/r_s + C (T_g - T_s)$ ... ... (3.26-1)

H = Heat of combustion of the fuel in gaseous state.

m_{og} = Oxygen concentration.

r_s = Stoichiometric ratio.

If Q units of heat is required to vaporize unit mass of fuel the mass of fuel which can enter the vapour phase as a result of the decrease of enthalpy

$$B = \frac{m_{og}\ H/r_s + C\ (T_g - T_s)}{Q} \quad \ldots \quad \ldots\ (3.26\text{-}3)$$

3.27. All the terms contained in it are among the most practical problems except for T_s which can be roughly taken as equal to the boiling point of the fuel without serious error(|).

3.28. From the equation it becomes quite evident that reduction in oxygen effects the burning rate. Again the transfer number in pure warm air is of course somewhat greater than that of cold air by reason of the $C\ T_g$ term.

Now when the diameter of the liquid fuel drop is small and if forced convection becomes unimportant, then the time of burning t_b is given by

$$t_b = \frac{\rho_L\ D_b^2}{8k/C\ \mathrm{Log}_c\ (1 + B)} \quad \ldots \quad \ldots\ (3.28\text{-}1)$$

(From Spalding's work) (|)

Where 'ϕ' has been replaced by 'α' for simplicity since transfer number is based on the enthalpy.

3.29 Godsave's result (28) was expressed in terms of an evaporation constant 'K' defined as $K = \frac{D_o^2}{t_b}$ .... (3.29-1)

But it has been seen that 'K' must depend on the fuel and atmospheric properties since,

$$K = \frac{8k/C\ \mathrm{Log}_c\ (1 + B)}{\rho_L} \quad \ldots \quad (3.29\text{-}2)$$

which is not a constant of the fuel alone since the oxygen concentration and temperature of the atmosphere affect 'B'.

3.30. In actual spray combustion system the fuel droplets do not burn isolated but in clouds. So mutual droplet effect must be modified for taking into

Consideration the mutual interference effect on the burning rate.

So far few theoretical studies have been undertaken in this area; mainly the investigations are of emperical nature.

C H A P T E R - IV

Experimental Method

* Description of the experimental set-up.
* Procedure.

EXPERIMENTAL SET-UP AND PROCEDURE

4.0 In the combustion chamber of an internal combustion engine the fuel is sprayed in the form of fine droplets (Max. droplet diameter may be as large as 75 microns) into the compressed air having pressure and temperature about 400 psi and 1200 ^{o}F respectively. During the brief tenure of the droplets in the combustion chamber, the pressure may rise to 1000 psi and temperature to 4500^{o}F. The simultaneous presence of swirl and residual gases complicates the problem to a great extent. So under these complex conditions it is very difficult to study the effect of any particular parameter on the evaporation and combustion of fuel droplet. Hence as we have shown in chapter (II), the parameters are best isolated and studied in the simulated conditions prevailing in the combustion chamber, and the choice of these parameters dictates the design of the experimental set-up.

In the present study the influence of the parameters such as ambient temperature and neighbouring droplets on the rate of evaporation and combustion of fuel droplets has been taken up for investigation, the ambient pressure being atmospheric, gas quiescent air at atmospheric pressure, and the temperature controlled by means of an electric furnace. A brief description of the experimental apparatus and procedure adopted is given in the following paragraphs.

4.1. As has been described in chapter two, experimenters have adopted different set-ups in the study of the combustion of fuel droplets, each

of which has advantages and disadvantages and the design of the set-up chosen by the writer has been largely influenced by the equipment and facilities available in the laboratory.

4.2. The fuel droplets can be studied either when they are moving or when they are stationary. Though moving droplets simulate the conditions prevailing in the actual oil fired combustion chamber much more closely than the stationary droplets, however in this system, repetitive investigation of a consistent arrangement of fuel droplet arrays is difficult, since complications arise regarding the furnace design, photographic technique and drop formation. On the other hand, in the stationary fuel droplet system, the droplets can be formed either by using a hypodermic syringe through a hypodermic needle on to a quartz fiber or feeding fuel through a porous sphere. The porous sphere does not resamble a fuel drop in an actual combustion chamber since it maintains a definite shape and volume through out the process of investigation, the rate of evaporation and combustion being determined by the amount of fuel consumed at a definite interval of time, although, the formation of drop at the end of of a quartz fiber has the disadvantage that the quartz fiber distorts the shape of the fuel droplet and also interfers with the process of heat transfer to the droplet during evaporation and combustion, nevertheless, this technique has the practical advantages that the experimental set-up is simple in respect of the formation of drops, the furnace design, the photographic arrangement and the facility of repetitive study of a parti-

cular formation of drops.

4.3. The electric furnace, into which the quartz fiber with the droplet is introduced, can be laid out in two dispositions. In the first the furnace may be kept vertical and the drops introduced from the top. In the second the furnace is kept horizontal and the drops are inserted from the side. The natural convection currents are dominant with the vertical arrangement, and makes introduction of droplets from the top difficult to control. Hence, the horizontal arrangement of the electric furnace was chosen.

4.4. The manner of introducing the stationary fuel droplets on quartz fiber into the air at high temperature could be executed in any of the following ways. In the first, the quartz fiber with the droplet is kept stationary and the furnace mounted on a trolley is pushed forward so as to surround the droplets. The movement of the furnace disturbs the air near the mouth of the furnace, and induces small amount of forced convection currents inside the furnace. In the second method the furnace is kept stationary and the quartz fiber is attached to a trolley. In this case the trolley with the mounted quartz fiber and its droplets is pushed into the furnace. With this method small vibration is imposed on the quartz fiber during transportation and may cause the droplets to fall down from the quartz fiber. The first method has been chose as it has favourable advantages.

4.5. The life time of a droplet in the electric furnace is known to depend on the diameter of the droplet and furnace temperature. For droplet dia-

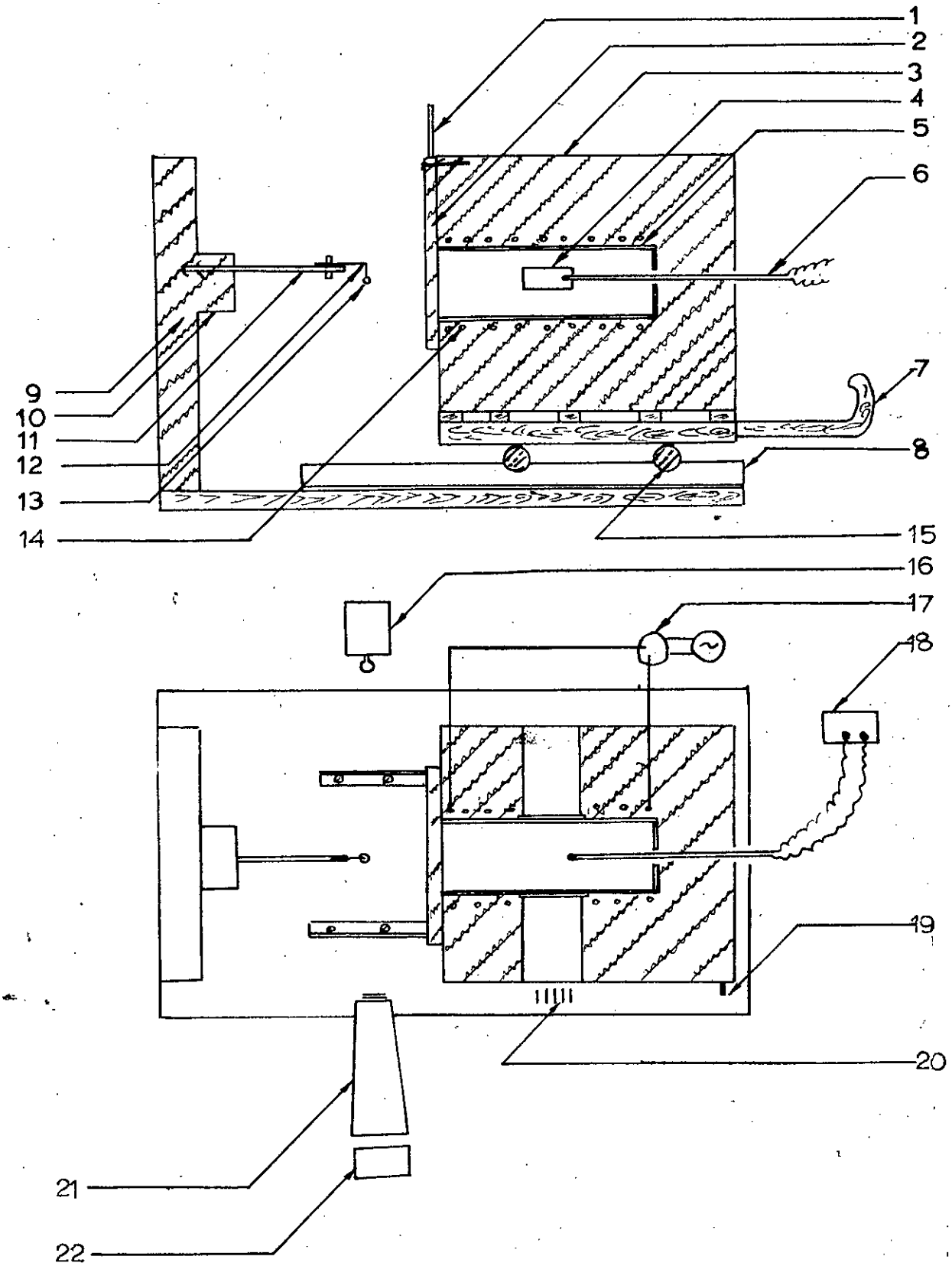
meter 0.11 cm(kerosene) furnace temperature 785°C , the life time is of the order of 1.1 sec. (33) . Hence a special high speed photographic arrangement is required to investigate the evaporation and combustion rate of fuel droplets. A high speed motion picture camera would have been the most appropriate apparatus in this investigation. However, in the absence of such an expensive piece of equipment the writer adopted another method, wherein a stationary film camera is used in conjunction with an electronic strobascope G.E.C. Strobalac, Type 1531 - A, 210-250 V,50-60 C, with frequency of flashes ranging from 110 to 25000 flashes/min,duration of each flash for low range is 3 microsecond. With this method, experiment had to be conducted in a dark room, since the shutter of the camera had to be open. The droplet is placed in between the stroboscope and the camera. Now whenever the stroboscope flashes the silhouette of the droplet is projected on the film.

4.6. The description of the experimental set-up (shown schematically in Fig. 4-1) is given below along with the procedure.

4.7. The experimental set-up is more or less similar to that used by Kiyosi Kobayasi (33) in his study of fuel droplets.

4.8. The electric tube furnace (5f)* censists of a stainless steel tube of diameter 3 inch and length 9 inch and is fitted with two quartz glass window (4f) of 2 x 1 x $\frac{1}{16}$ inch size through which the droplets are illuminated and photographed. Nickel chromie electric heating coil of 2 K.W. (14f), (wire diameter .036 inch and coil diameter .25 inch) is wound round the stainless steel tube over .25 inch layer of asbestos,

*f - indicates fig. 4-1



Fig(4-1). Experimental apparatus

the tube with the coil windings is encased in a chamber (3f) of size 11 x 11 x 13 inch and made of 1/16th inch M.S. sheet, the space in between the tube and the casing is insulated by 4" thick asbestos powder in radial direction. The heating coil is connected through on auto transformer (17f) to 220 V. A.C. line for controlling the current that is temperature of the furnace.

One end of the furnace is closed by an asbestos cement board and the open end is closed by an asbestos cement shutter (2f). The shutter can be swirled by the handle (1f). The furnace is also equiped with an iron-constantan thermocouple (6f) placed with its hot junction in the vicinity of the fuel drops, when the drops is introduced into the furnace. Now, the trolley (7f), on which the electric furnace is mounted, is fitted with wheels (15f) and rolls over rails (8f) made of one inch angle. The length of the rails were chosen 18 inch to provide enough traction track for the furnace.

4.9. The fuel drop is formed at the end of a hypodermic needle (No.18-20) with the help of a syringe and then transferred to the end of the quartz fiber (12f) of .2 to .35 mm in diameter. The fiber is bent 90° so that the drop may assume a spherical shape. The diameter of the droplet can be varied between 0.6 to 2.0 mm. by controlling the displacement of the plunzer of the hypodermic syringe. The position of the droplet in the furnace is determined by adjusting the position of the pointer (19f) on the markings (20f).

4.10. There is a projecting plug (10f) made of asbestos powder and attached to the stand (9f), which penetrates about ¼th inch into the furnace when the latter is pushed forward. This has been introduced to damp the convective flow.

4.11. The electric stroboscope is placed facing the camera, the fuel droplet remaining in between. The magnification of the droplet is obtained by means of a convex lens (focul length 13¼ mm) and fitted at the end of a bellows(21f). The degree of magnification used is 1°5 to 3.

4.12. The experimental procedure followed is described below.

The heating coils were first connected to the line with necessary adjustment of the auto transformer, so that after a definite time interval of about 3-4 hours the furnace attains the desired temperature. The rate of heating was kept low in order to avoid any ununiform distribution of heat flow in the furnace walls and also to prevent burn out of the coils.

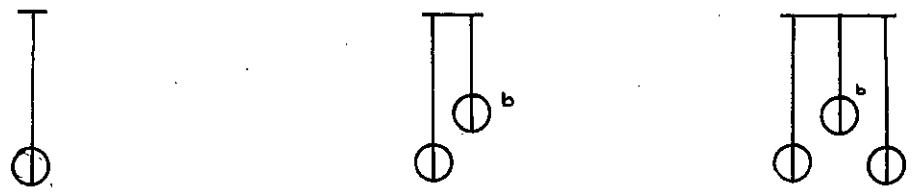
The frequency of the flash of the electronic stroboscope was next set at a value that depended on the temperature (120 flashes/min for 400°C, and higher flash frequency for higher temperature) and an empty quartz fiber introduced in the furnace was focussed on the ground glass screen of the camera. When the furnace attained the desired temperature, the droplet was formed at the end of a hypodermic needle and next transferred to the quartz fiber. The furnace with its mouth open is pushed forward until it reached the predetermined position (ascertained by the position of the pointer on the markings). The stroboscope flash was started simultaneously and the film winding knob of the camera was rotated. ~~in~~ ~~ex~~. A series of magnified silhouettes of the evaporating or burning droplets were thereby obtained on the film.

4.13. After developing the films, the negatives were projected with the help of an Epidioscope on to a graph paper serving as a screen. The droplet cross-section were read and tabulated against the time determined from electronic flash frequency[x]. The droplets were magnified twice, first

x Appendix - I

while taking the photographs and next while projecting the negatives on to the screen. The magnification factor in the first case is determined by photographing a standard diam. wire placed in the place of the quartz fiber. In the second case the magnification is determined by projecting an another graph on to the screen.

4.14. Diesel fuel droplet (Sp.Gr. .825) and kerosene fuel droplet(Sp.Gr. .779) were investigated for three arrangements of the arrays of droplets.



1.Single droplets 2.Double droplets 3. Triple droplets.

In double droplets the droplets are placed at different hights from any reference plane. This has been done to investigate whether the variation of the altitude produces an effect on evaporation. The triple droplet arrangement actually simulates the condition of a spray system in simplest form where the droplet " b " indicates the trailing droplet.

4.15. PRECAUTION: The precautions taken during the investigation were :-

(i) After each experiment the furnace is purged by air, in order to drive out the vapour from the voult of the furnace.

(ii)The fuel droplets is formed only and only just before starting the investigation in order to avoid the vapour concentration near the mouth of the furnace.

(iii)The millivolt reading is taken before starting the investigation and after the investigation and for calculation, the average is taken in order to minimize the effect of change of temperature during taking reading.

(iv) The focus of the camera is checked before each reading. Standard rod for finding the magnification was photographed in every reading.

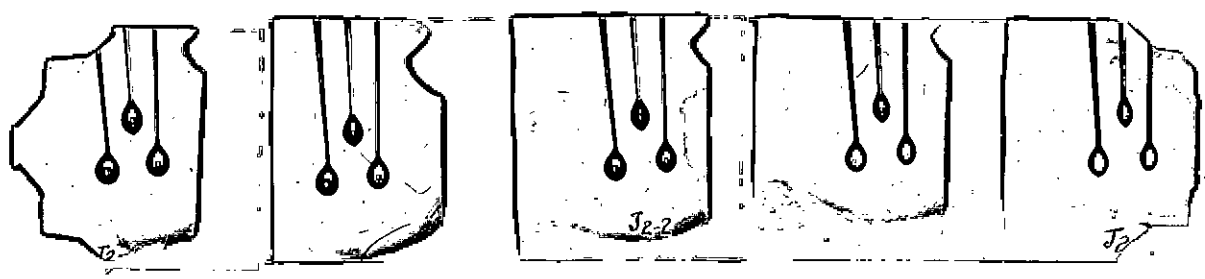
(v) Any circulation of air in the room should be avoided because of the draft effect on the formation of the drop, and on the temperature of the furnace.

C H A P T E R - V

Result

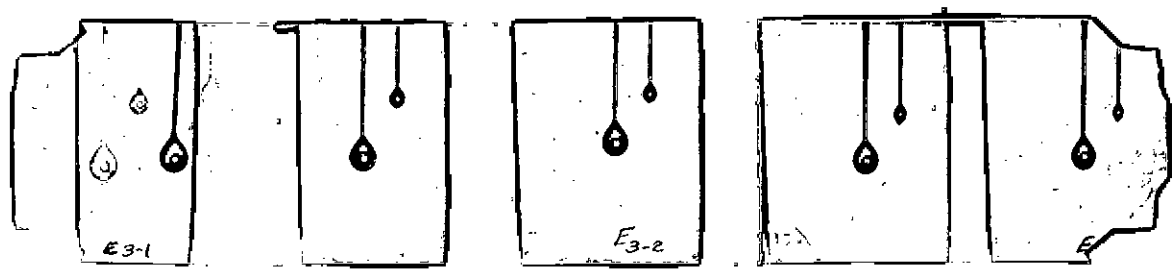
* Tabulated result
* Graphs
* Photographs

EVAPORATION



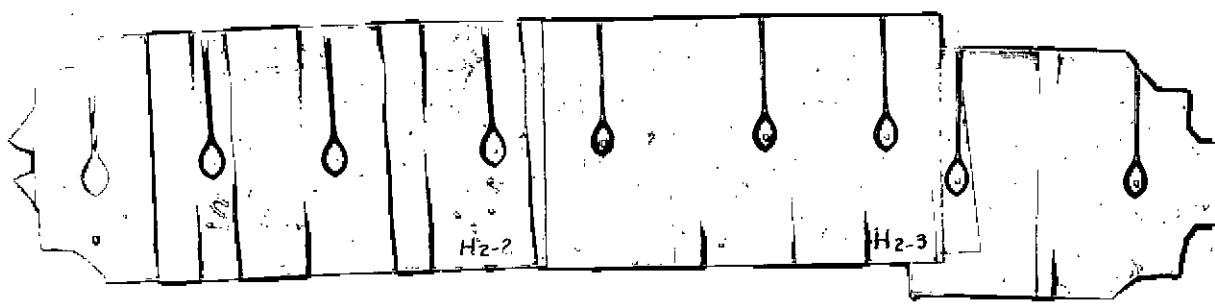
Kerosene droplet

T = 514°C ; Δt = 0·4 Secs.



Kerosene droplet

T = 400°C ; Δt = 0·5 Secs.



Diesel droplet

T = 221°C ; Δt = 1.5 Secs.

EVAPORATION CONSTANT
SINGLE DROPLET

(Temperature accuracy ± 5 °C)

Experimental method.	Ambient pressure	Ambient Gas	Fuel	Ambient Temp. °C	Evaporation constant(K) cm^2/ sec.	Code
			Diesel	221°C	.00103	H_2
Suspended Droplet	Atmos-pheric pressure	Air	Kero-sene	233°C	.00136	G_1
			Kero-sene	383°C	.00500	D_4
			Kero-sene	384°C	.00571	D_3
			Diesel	386°C	.00271	A_4
			Diesel	390°C	.00364	A_1
			Kero-sene	394°C	.00542	D_1
			Kero-sene	511°C	.00667	L_2
			Diesel	512°C	.00481	M_1
			Diesel	512°C	.00480	M_2
			Kero-sene	600°C	.00750	W_2
			Kerosene (burning)	717°C	.0155	A_c

EVAPORATION CONSTANT

DOUBLE DROPLET

(Temperature accuracy ± 5 °C)

Experimental method.	Ambient pressure	Ambient Gas	Fuel	Ambient Tem. °C.	Evaporation constant (K) $cm^2/sec.$ a		b		Code
Suspended Droplet	Atmospheric pressure	Air	Diesel	220°C		.00043		.00044	I_1
			Kerosene	243°C		.00137		.0037	F_2
			[redacted]	[redacted]		[redacted]		[redacted]	[redacted]
			Diesel	386°C		.00200		.00171	B_3
			Diesel	387°C		.00218		.00218	B_2
			Kerosene	400°C		.00334		.00334	E_3
			Kerosene	403°C		.00360		.00360	E_2
			Kerosene	511°C		.00595		.0062	L_1
			Diesel	512°C		.00421		.00421	N_1
			Kerosene	571°C	(1)	.00677	(1)	.00677	X_2
					(2)	.01297	(2)	.00879	
			Kerosene	591°C	(1)	.0069	(1)	.00610	X_1
					(2)	.0105	(2)	.00910	
			Kerosene (burning)	709°C		.0175		.0136	B_C

EVAPORATION CONSTANT

TRIPLE DROPLET

(Temperature accuracy ± 5 °C)

Experimental method	Ambient pressure	Ambient Gas	Fuel	Ambient Temp. °C		Evaporation constant (K) cm^2/ Sec. a	b	c	Code
Suspended Droplet	Atmospheric pressure	Air	Kerosene	382°C		.00341	.00333	.00341	R_2
			Diesel	389°C		.00215	.00215	.00215	Q_2
			Diesel	398°C		.00240	.00220	.00220	Q_1
			Kerosene	505°C		.00526	.00526	.00571	K_2
			Kerosene	511°C		.00444	.00600	.00600	J_2
			Diesel	512°C		.00349	.00349	.00349	P_2
			Kerosene	514°C		.0067	.00700	.00700	J_1
			Kerosene	601°C	(1)	.00831	.00810	.00672	U_2
					(2)	.00960	.00980	.01307	
			Kerosene	605°C	(1)	.00734	.00667	.00734	T_3
					(2)	.01169			

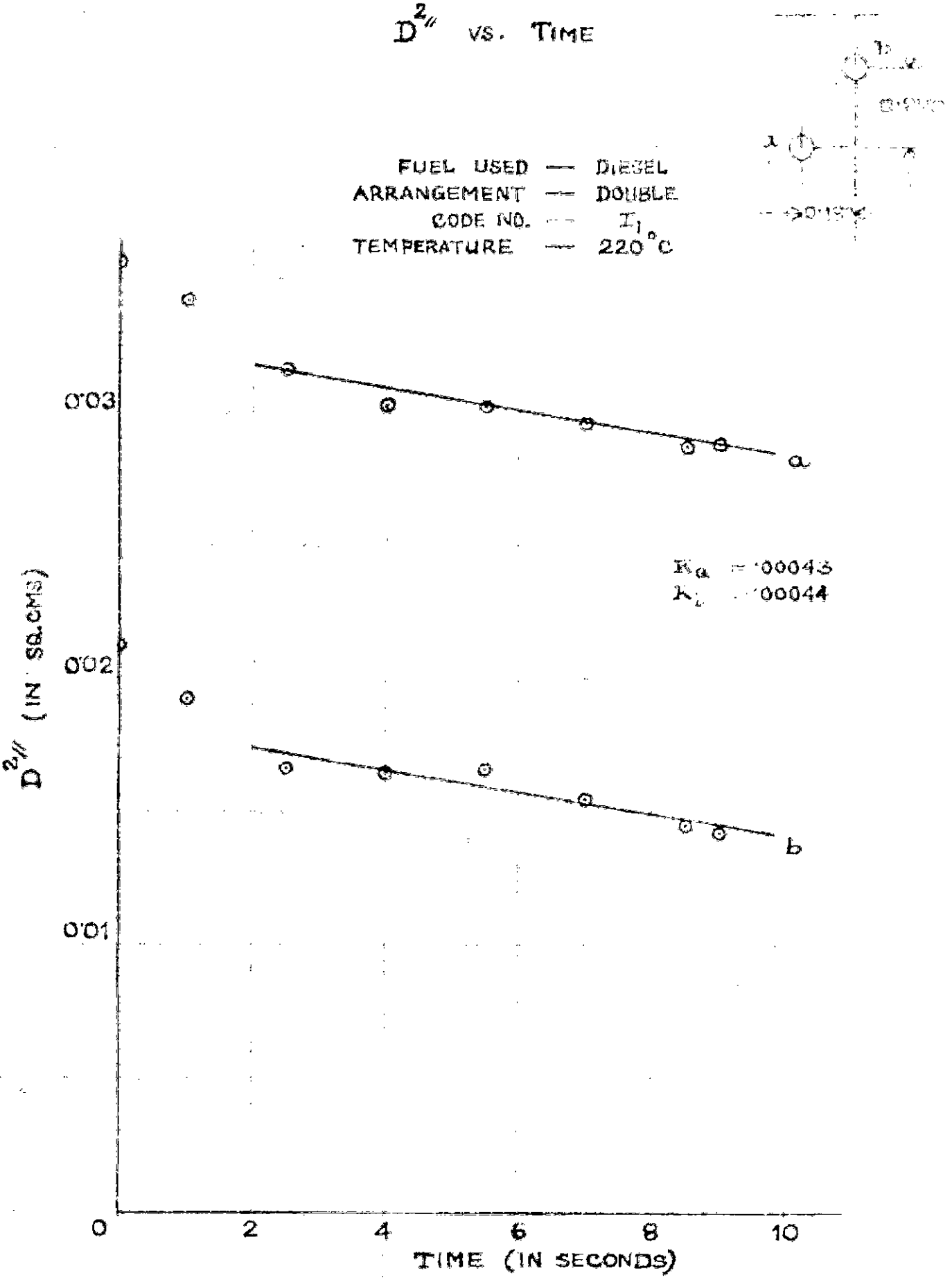


Fig . 5-1

Evaporation of Fuel Droplet .

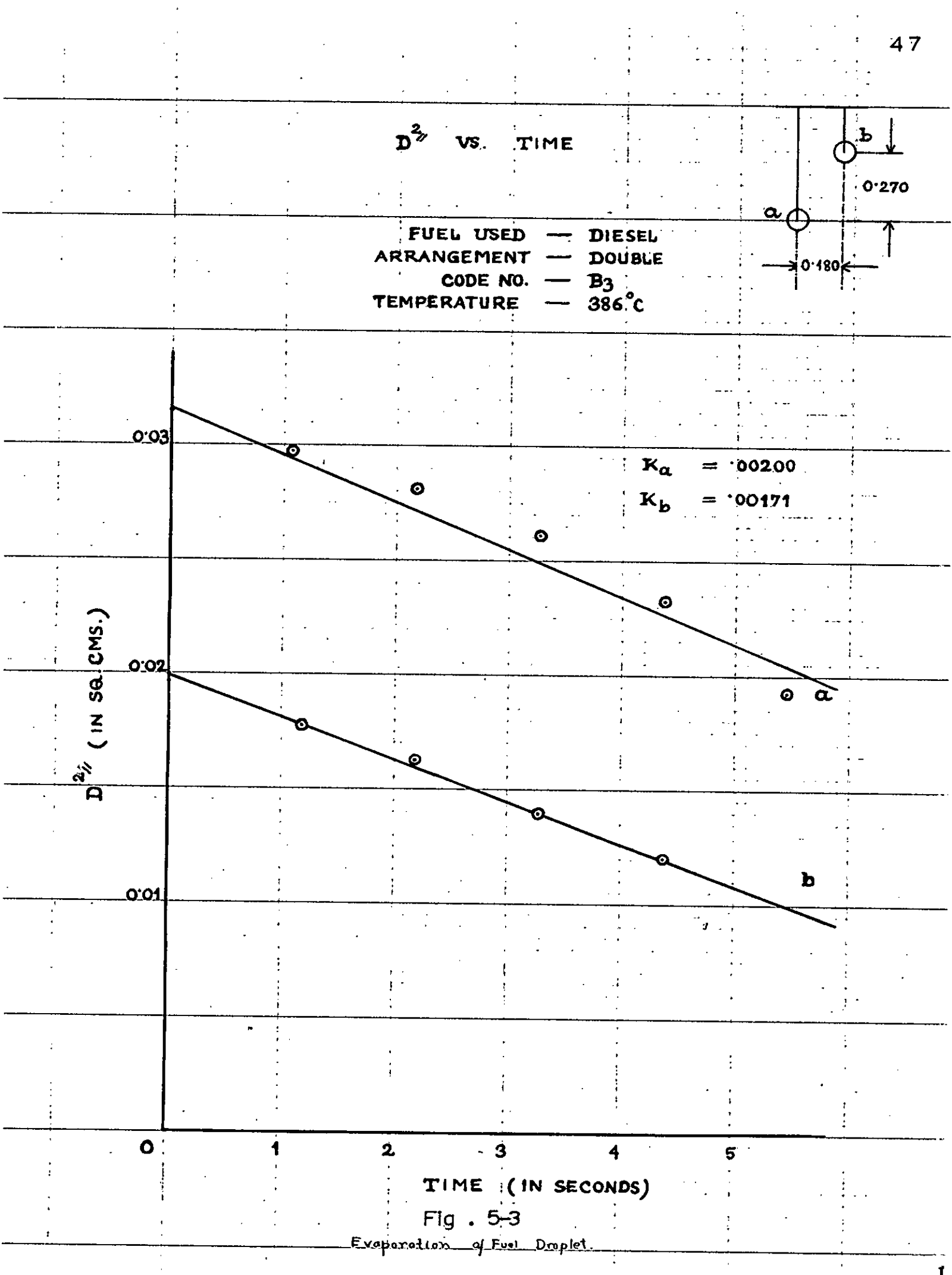


Fig . 5-3

Evaporation of Fuel Droplet

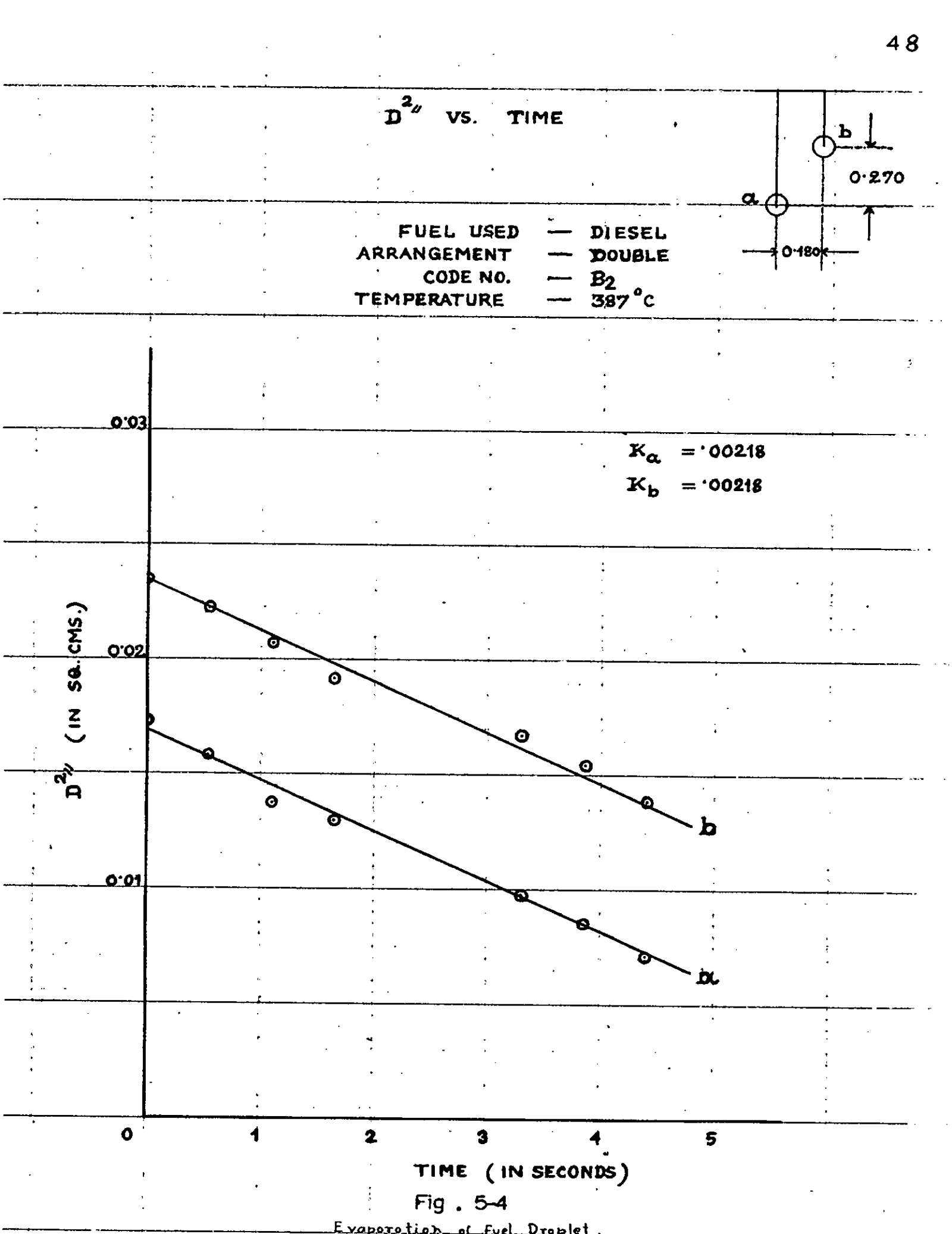


Fig . 5-4

Evaporation of Fuel Droplet

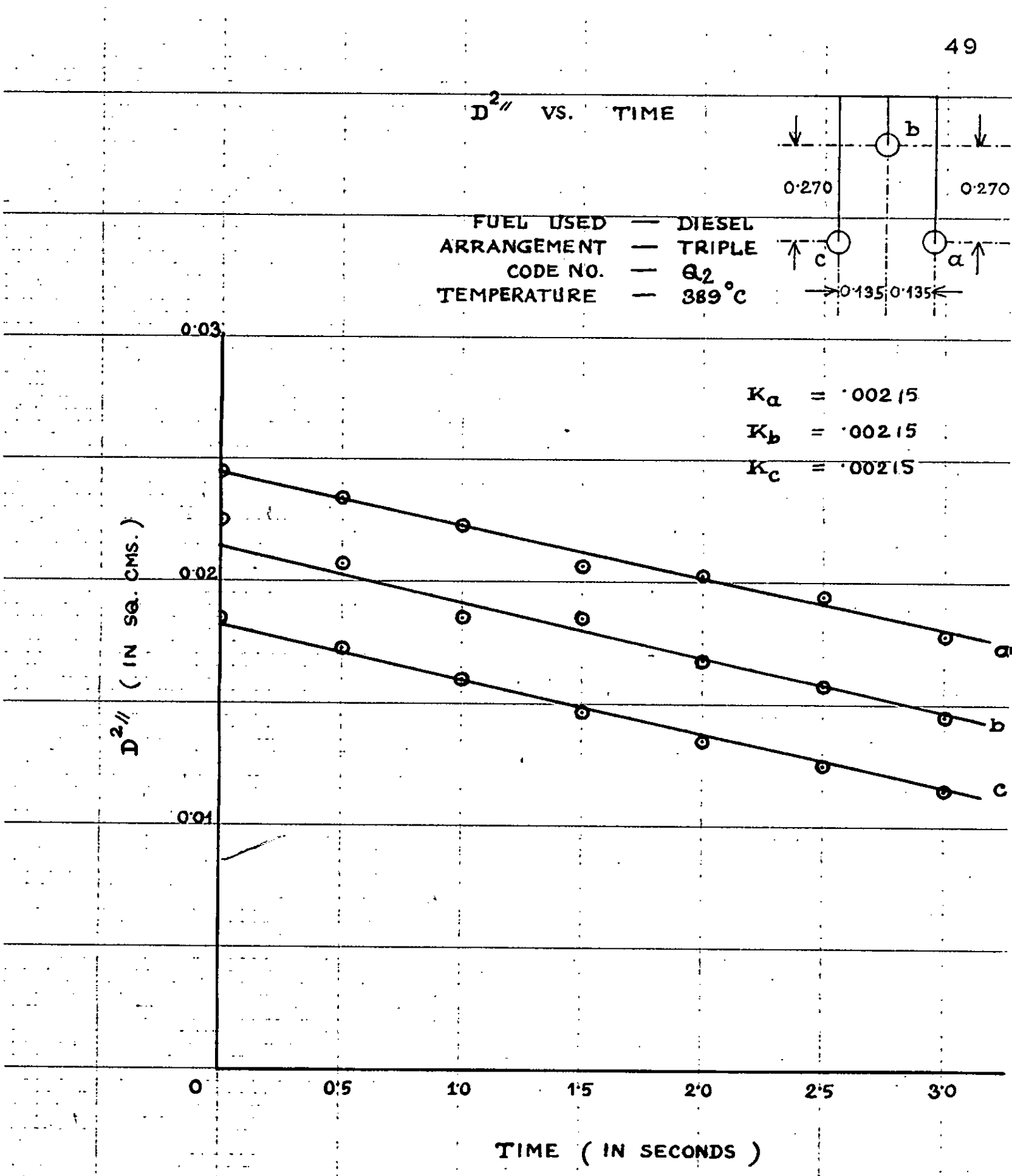


Fig. 5-5

Evaporation of Fuel Droplet

Fig . 5-6

Evaporation of Fuel Droplet

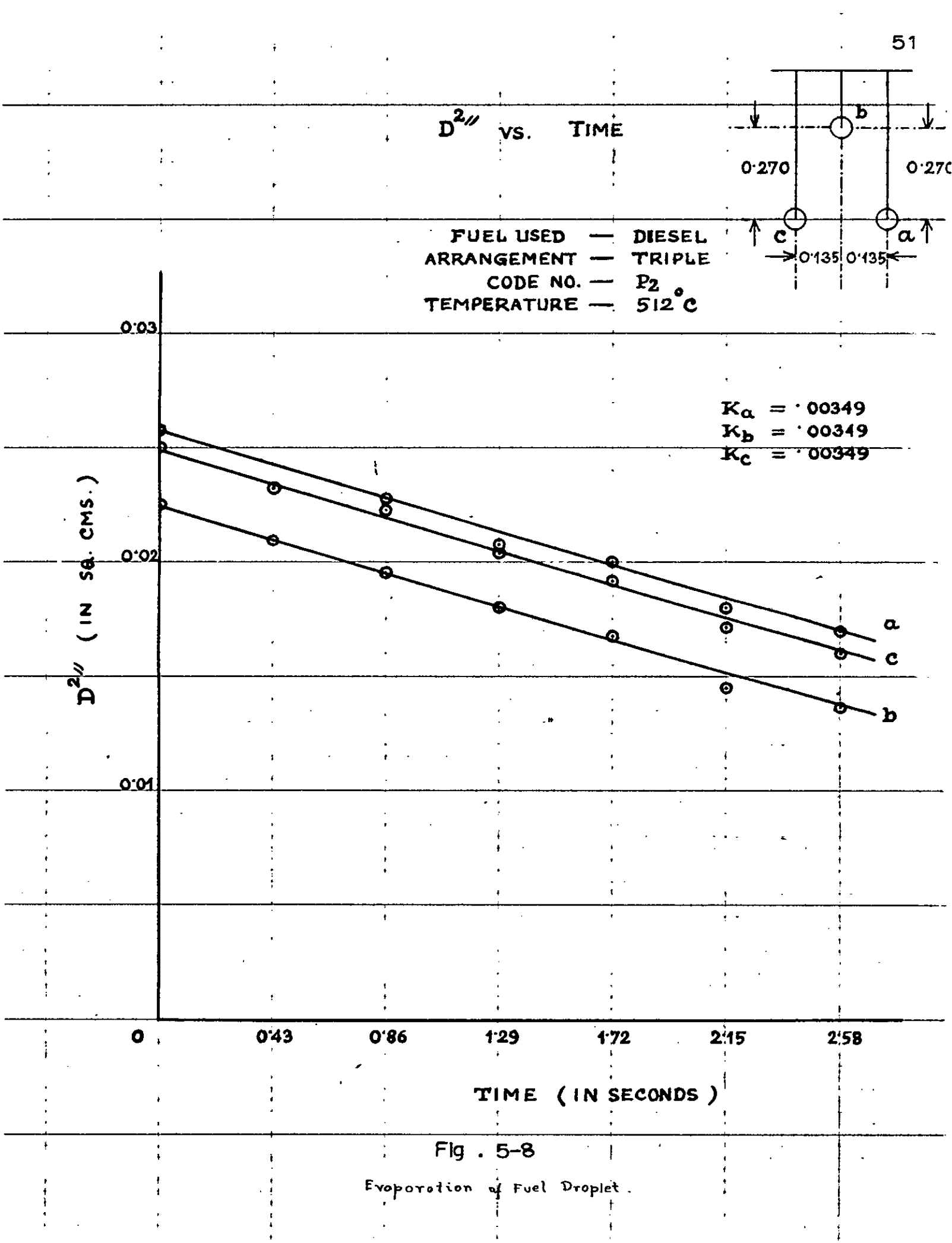


Fig . 5-8

Evoporation of Fuel Droplet .

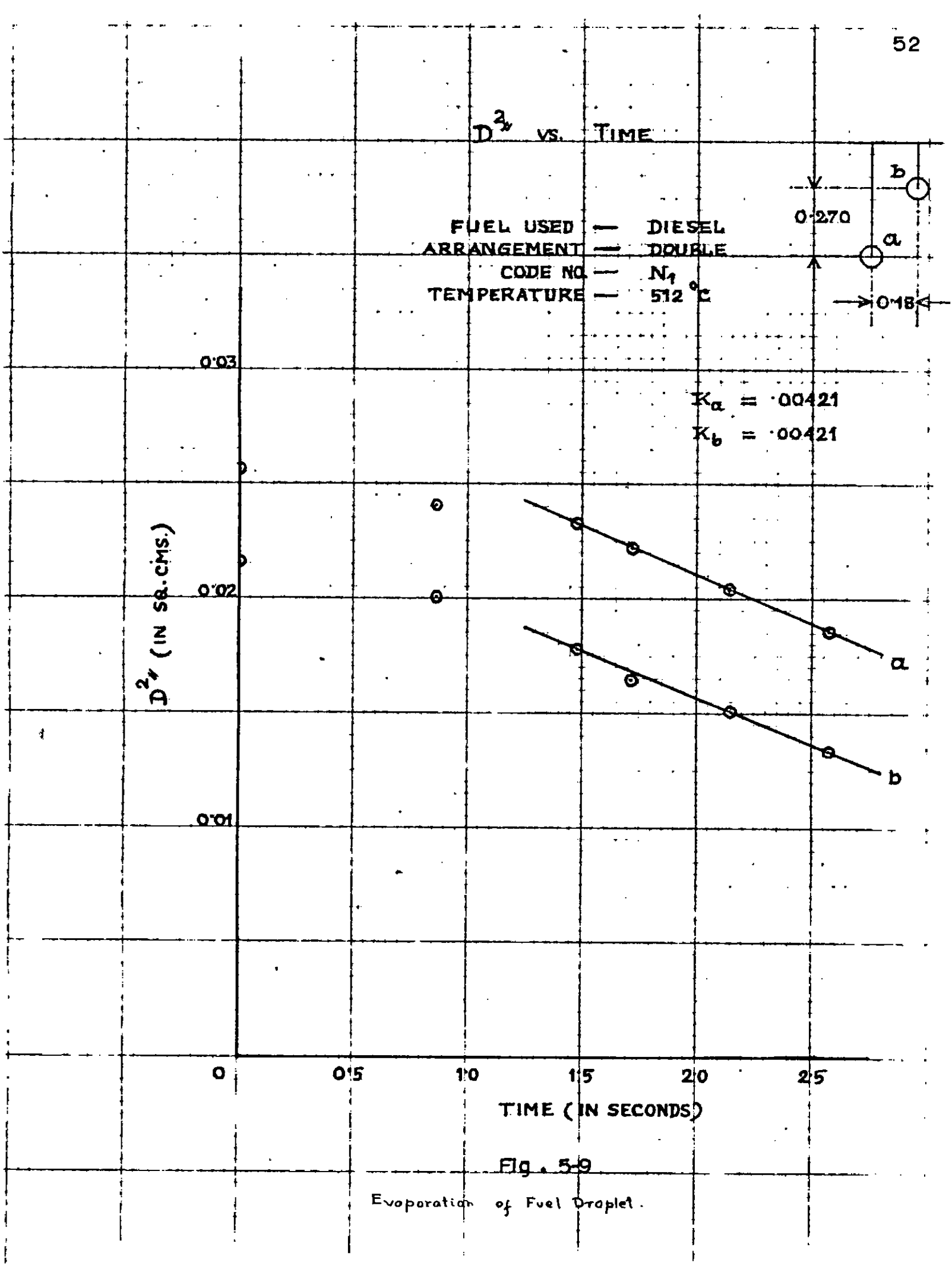


Fig. 5-9

Evaporation of Fuel Droplet.

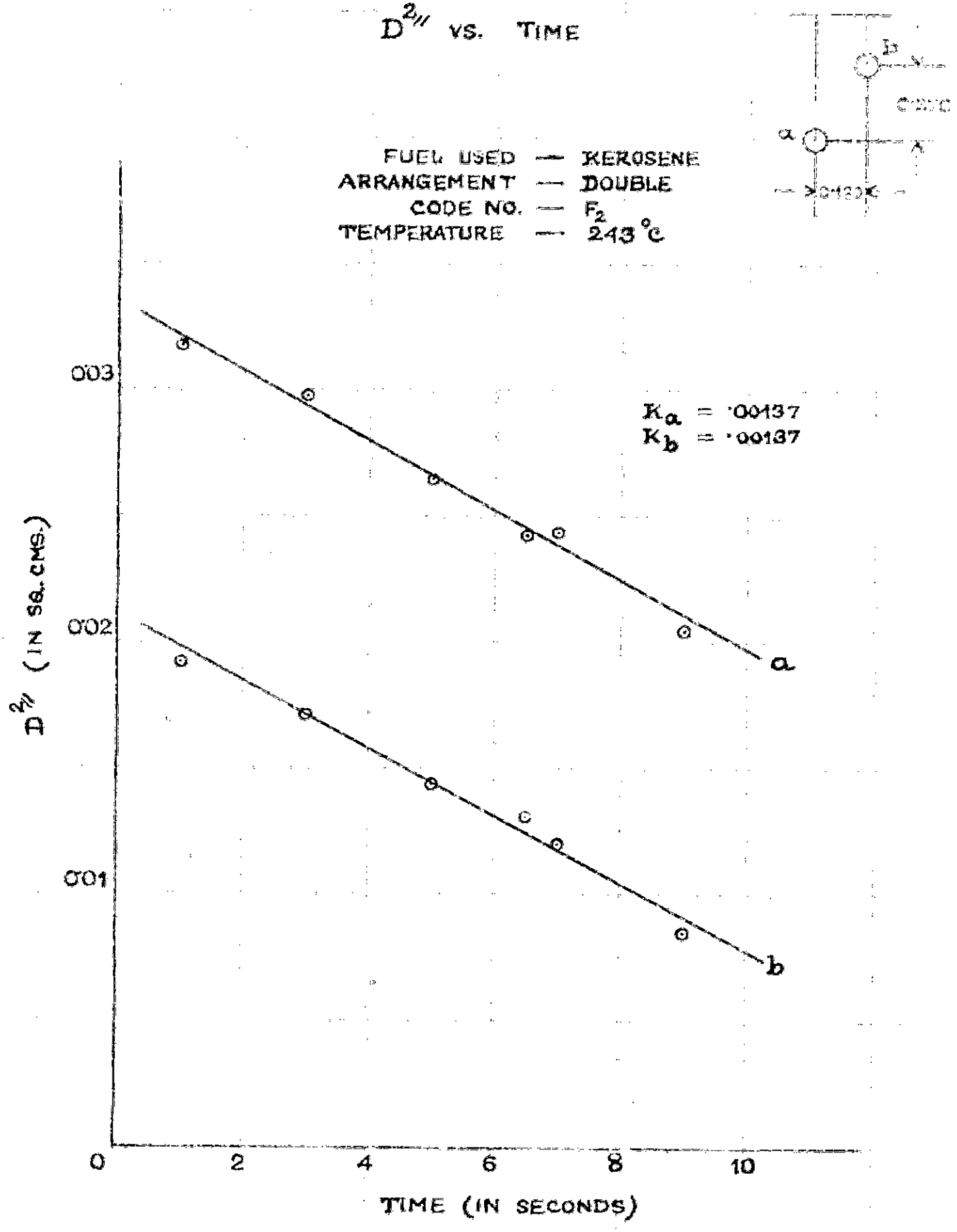


Fig. 5-10
Evaporation of Fuel Droplet.

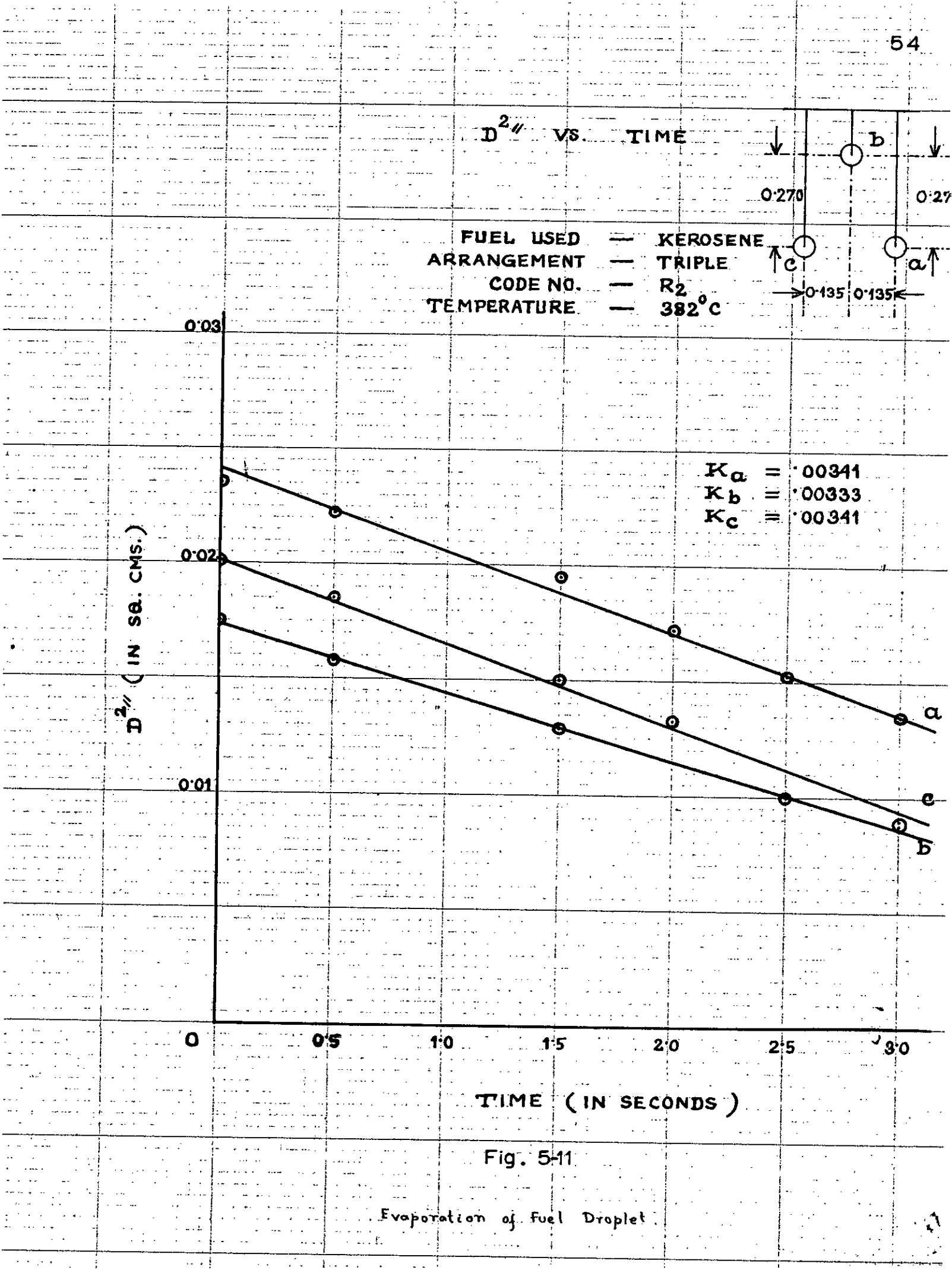

D²// VS. TIME
FUEL USED — KEROSENE
ARRANGEMENT — TRIPLE
CODE NO. — R2
TEMPERATURE — 382°C
b
0·270
0·27
c
a
0·135
0·135
Ka = ·00341
Kb = ·00333
Kc = ·00341
0·03
0·02
0·01
0
0·5
1·0
1·5
2·0
2·5
3·0
D²// (IN SQ. CMS.)
TIME (IN SECONDS)
a
c
b

Fig. 5-11

D^2 VS. TIME

FUEL USED — KEROSENE
ARRANGEMENT — DOUBLE
CODE NO. — E_3
TEMPERATURE — 400 °C.

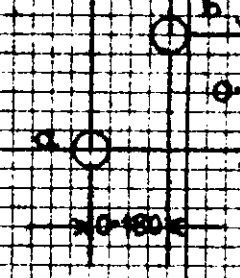


Fig. 5·13

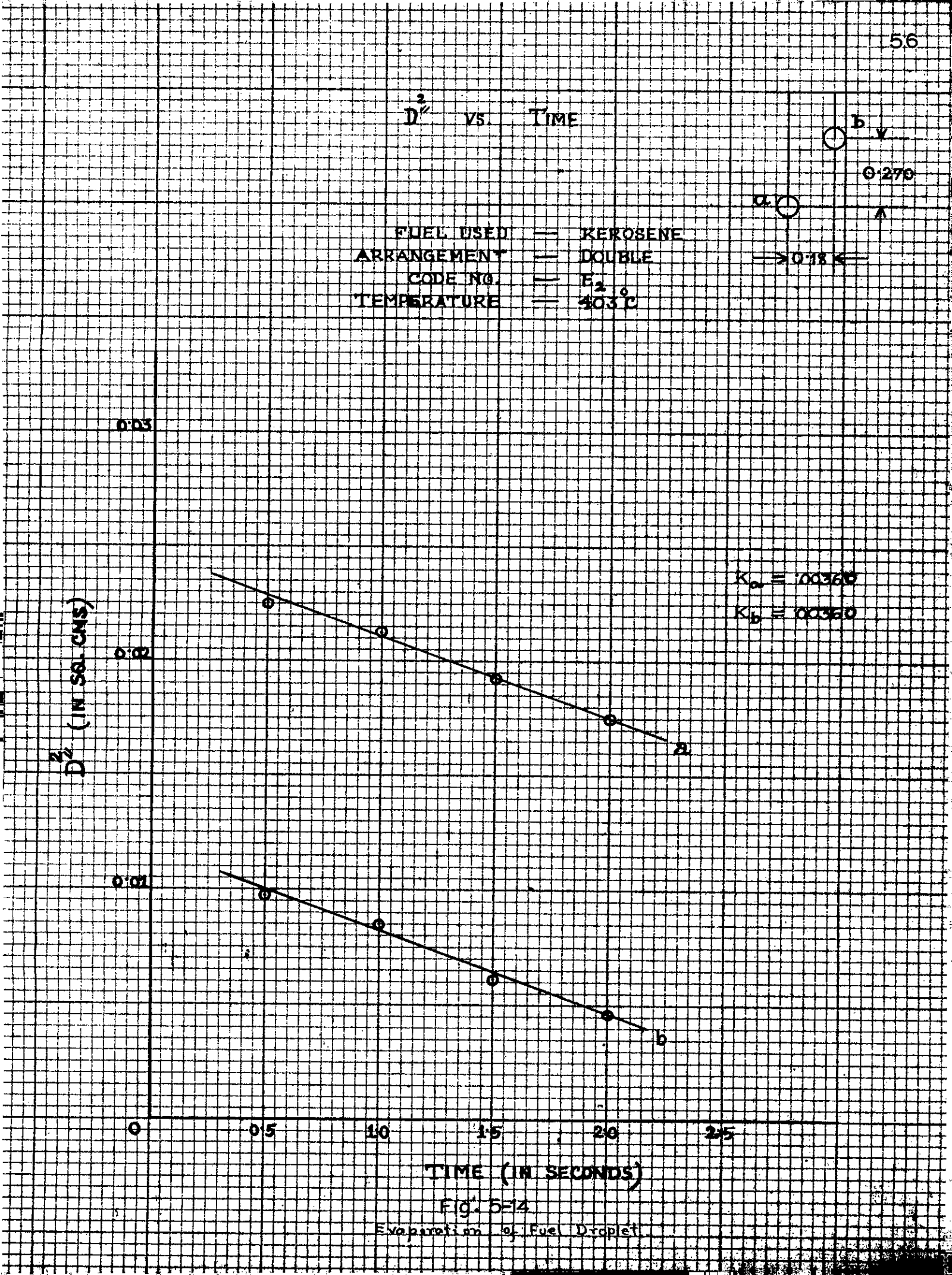


Fig. 5-14

Evaporation of Fuel Droplet

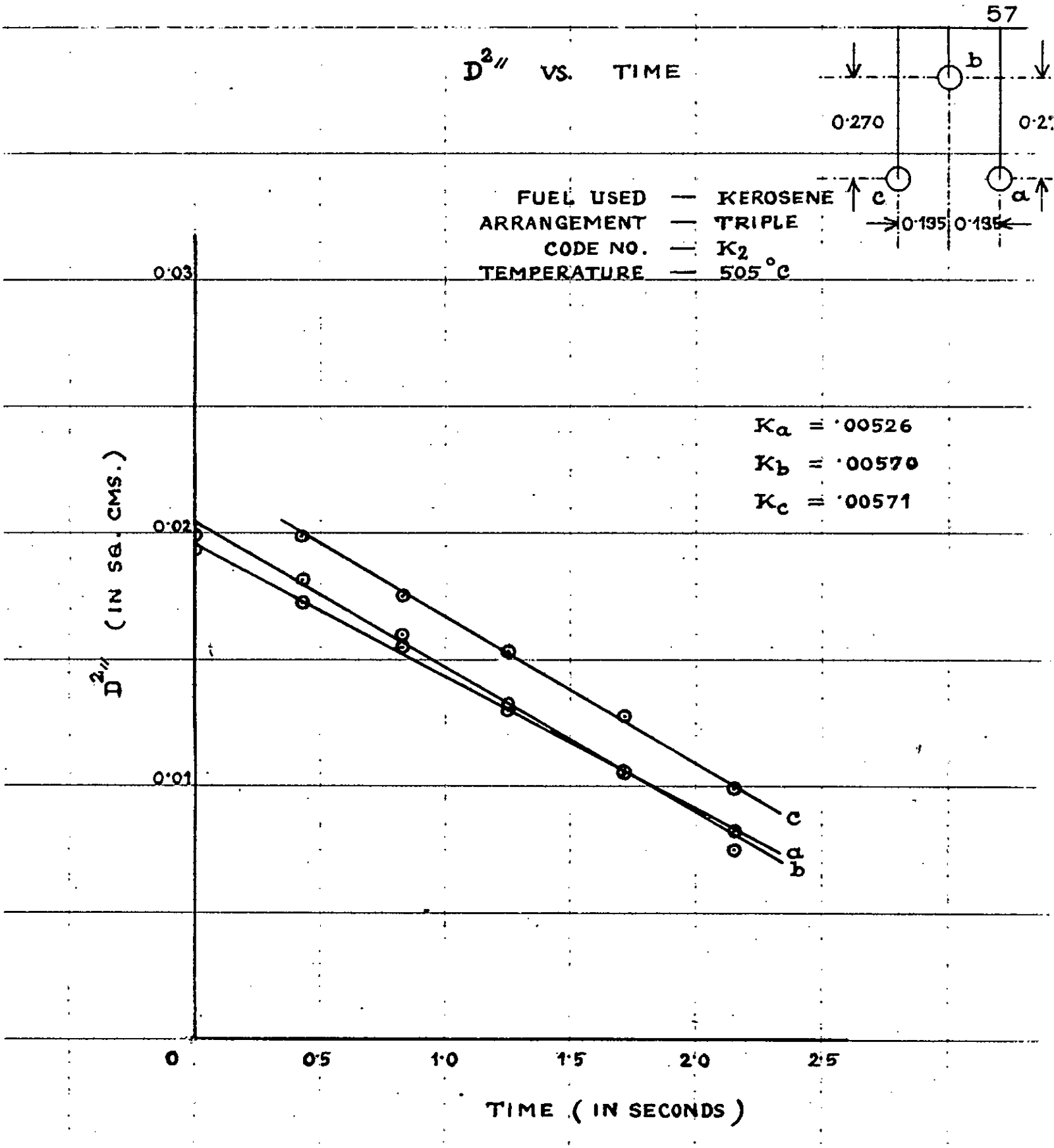

$D^{2//}$ VS. TIME
FUEL USED — KEROSENE
ARRANGEMENT — TRIPLE
CODE NO. — K_2
TEMPERATURE — 505 °C
b
0·270
c
a
0·135
0·135
K_a = ·00526
K_b = ·00570
K_c = ·00571
0·03
0·02
0·01
$D^{2//}$ (IN SQ. CMS.)
0
0·5
1·0
1·5
2·0
2·5
TIME (IN SECONDS)
c
a
b

Fig. 5-16

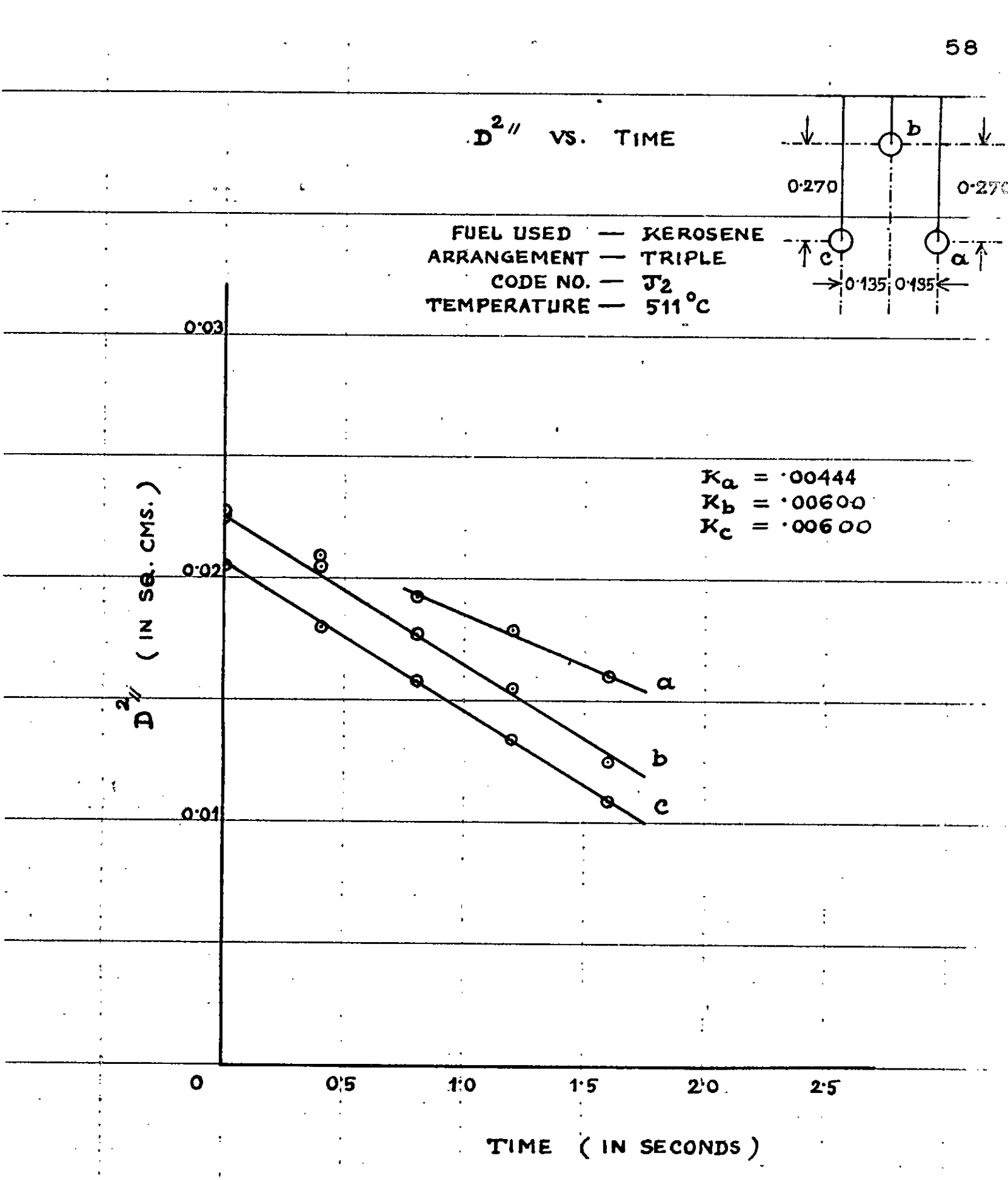
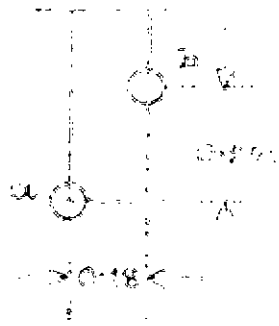

$D^{2}_{//}$ VS. TIME
FUEL USED — KEROSENE
ARRANGEMENT — TRIPLE
CODE NO. — J_2
TEMPERATURE — 511 °C
b
0·270
0·270
c
a
0·135
0·135
K_a = ·00444
K_b = ·00600
K_c = ·00600
0·03
0·02
0·01
$D^{2}_{//}$ (IN SQ. CMS.)
a
b
c
0
0·5
1·0
1·5
2·0
2·5
TIME (IN SECONDS)

Fig. 5-17

D^2 VS. TIME



FUEL USED — KEROSENE
ARRANGEMENT — DOUBLE
CODE NO. — L_1
TEMPERATURE — 511 °C

$K_a = \cdot 00595$
$K_b = \cdot 00520$

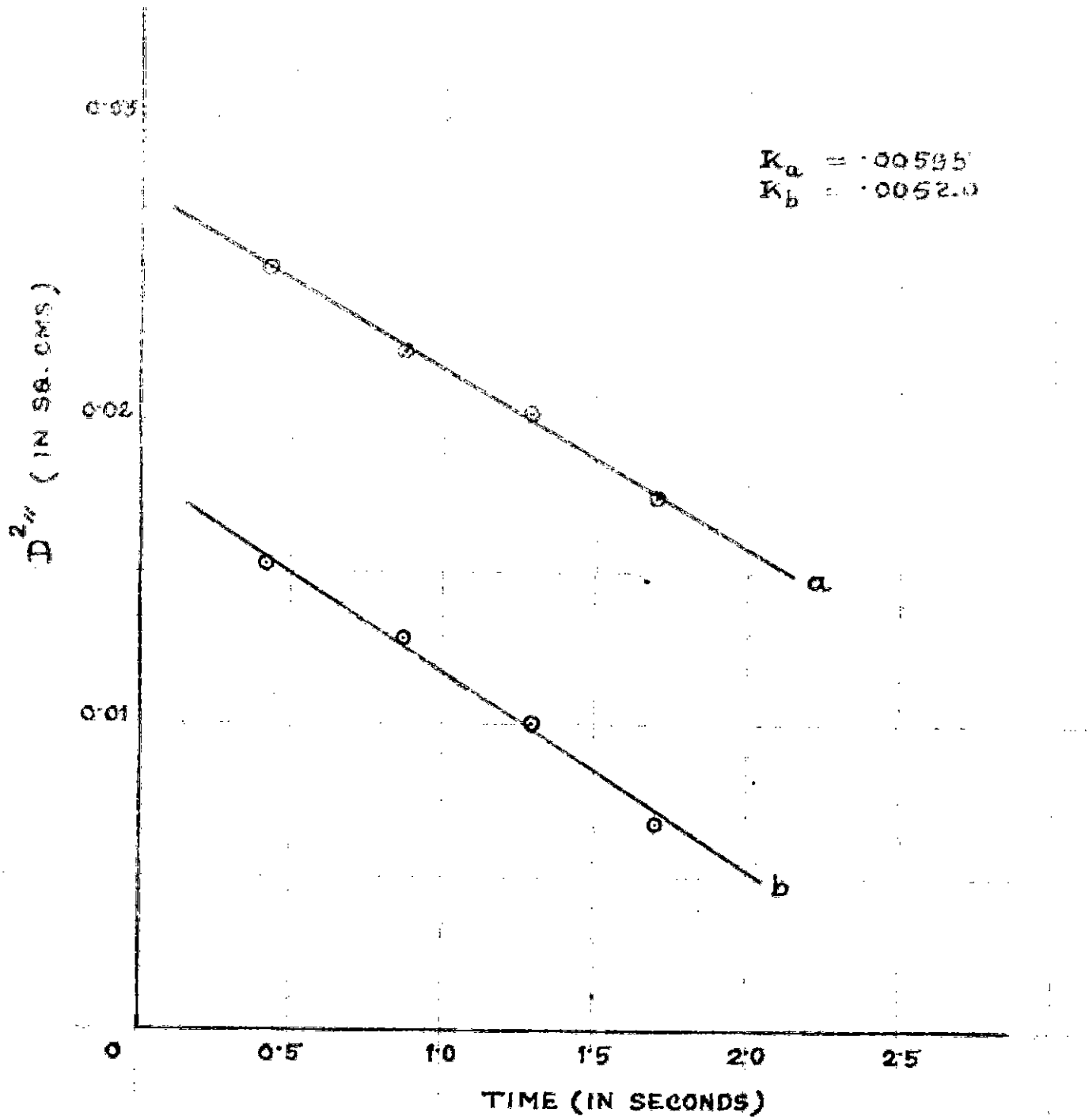
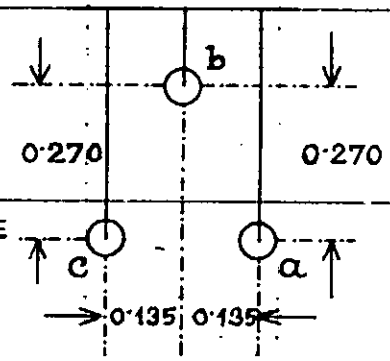


Fig. 5-18

Evaporation of Fuel Droplet.

D^{2} // VS. TIME

FUEL USED — KEROSENE
ARRANGEMENT — TRIPLE
CODE NO. — J_1
TEMPERATURE — 514 °C



K_a = ·00670
K_b = ·00700
K_c = ·00700

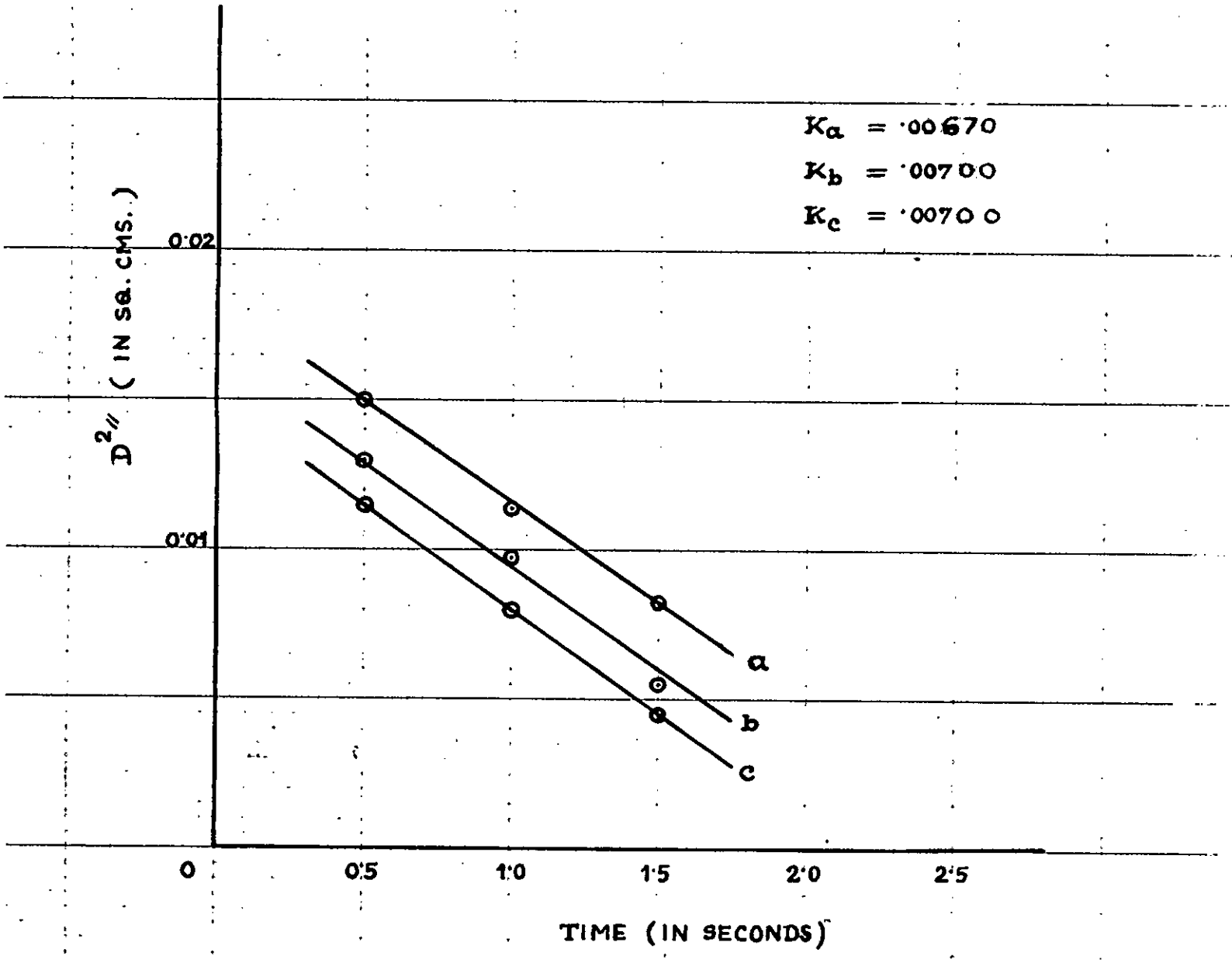
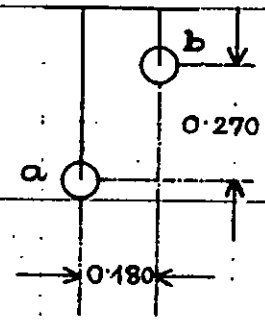


Fig. 5-19

D^2 VS. TIME



FUEL USED — KEROSENE
ARRANGEMENT — DOUBLE
CODE NO. — X_2
TEMPERATURE — 571 °C

$K_{a,1} = \cdot 00677$
$K_{a,2} = \cdot 01297$
$K_{b,1} = \cdot 00677$
$K_{b,2} = \cdot 00879$

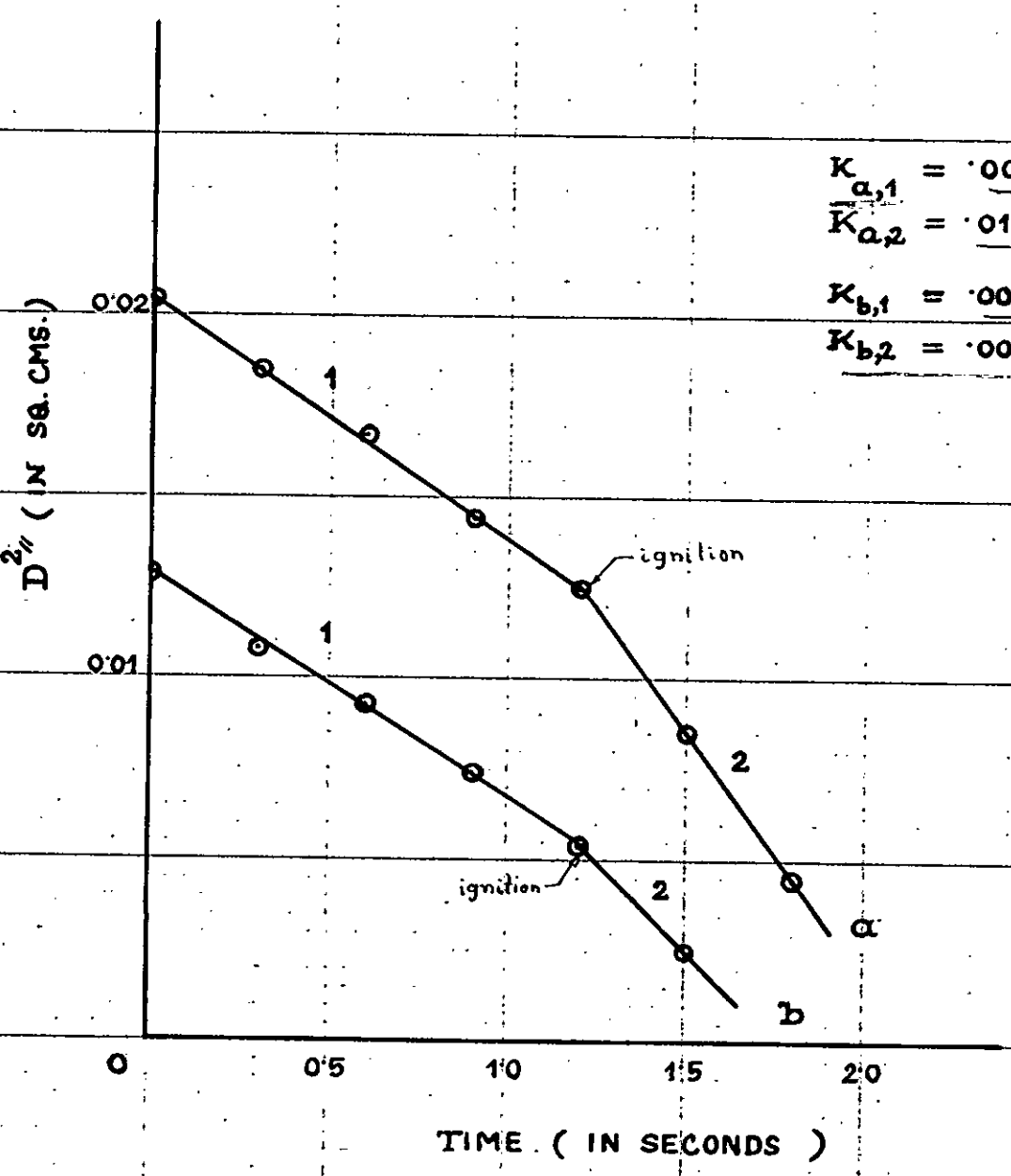
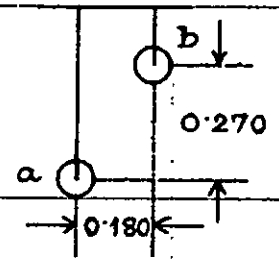


Fig. 5-20

D^{2} vs. Time



FUEL USED — KEROSENE
ARRANGEMENT — DOUBLE
CODE NO. — X1
TEMPERATURE — 591°C

$K_{a,1} = 0.00690$
$K_{a,2} = 0.01050$
$K_{b,1} = 0.00610$
$K_{b,2} = 0.00910$

4.5

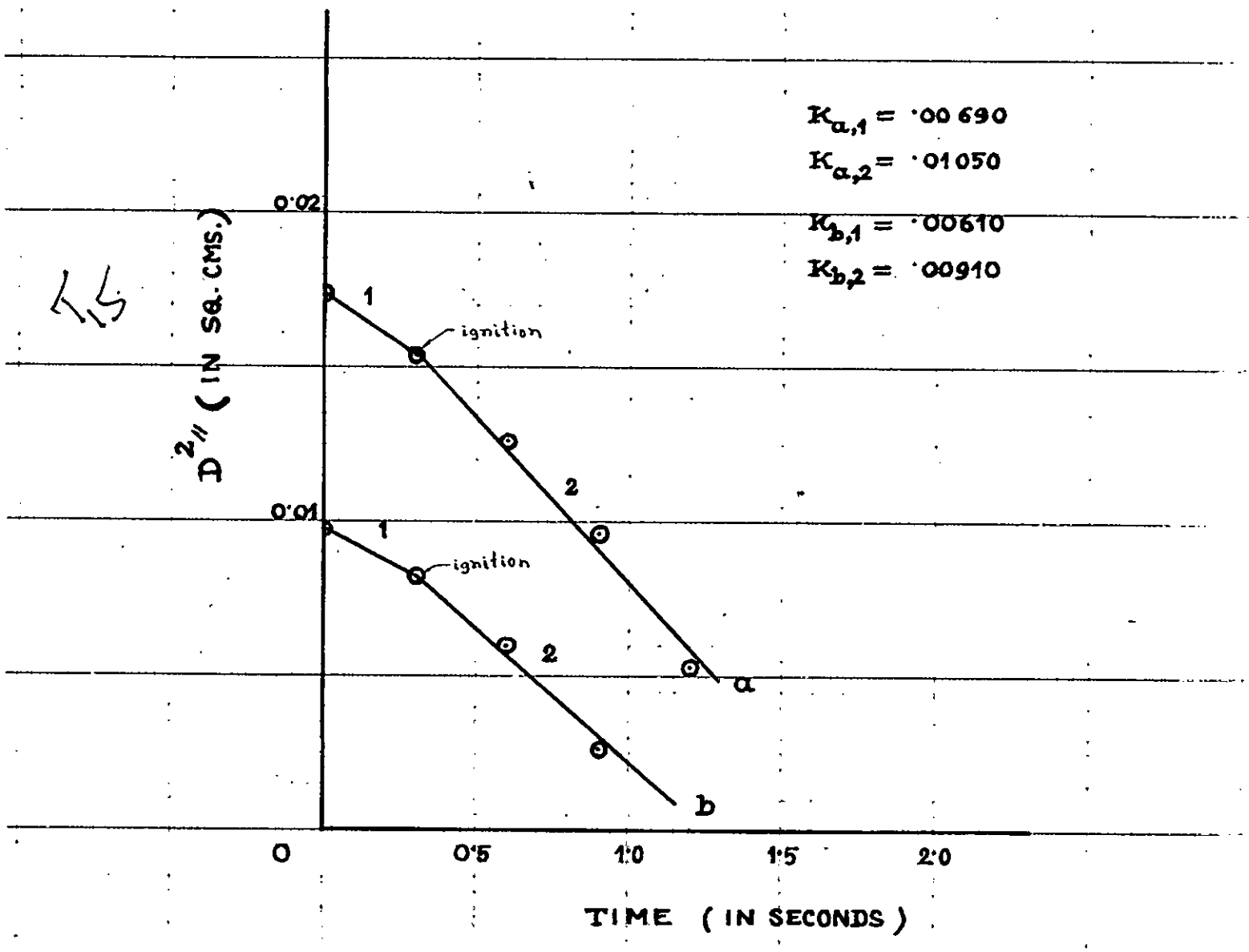
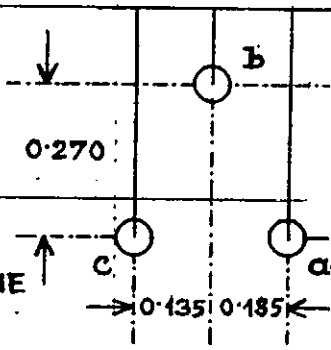


Fig : 5-21

D^{2} // VS. TIME



FUEL USED — KEROSENE
ARRANGEMENT — TRIPLE
CODE NO. — U_2
TEMPERATURE — 601 °C

$K_{a,1}$ = ·00831
$K_{a,2}$ = ·00960
$K_{b,1}$ = ·00810
$K_{b,2}$ = ·00980
$K_{c,1}$ = ·00672
$K_{c,2}$ = ·01307

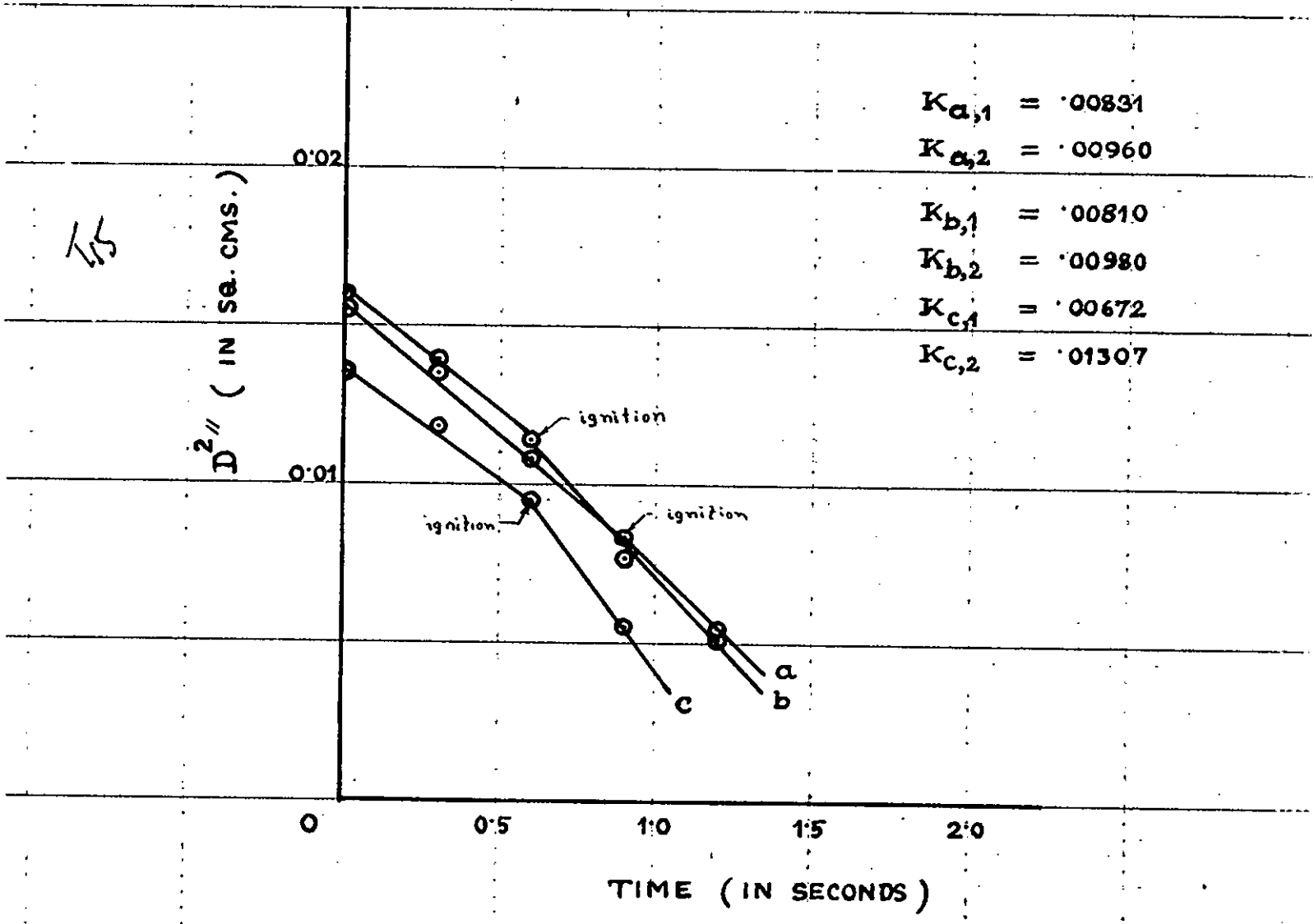


Fig. 5-22

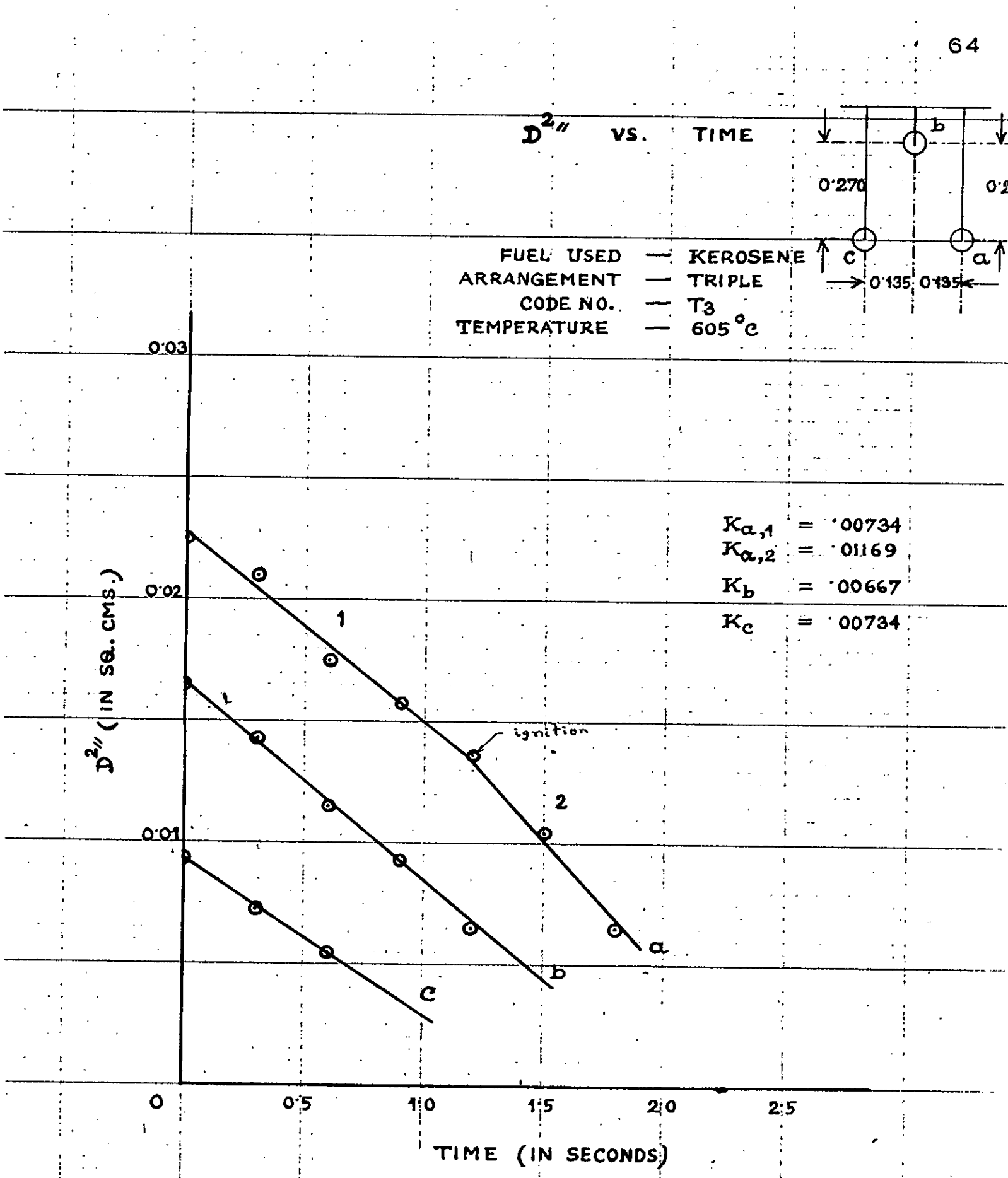

D^{2} VS. TIME
FUEL USED — KEROSENE
ARRANGEMENT — TRIPLE
CODE NO. — T3
TEMPERATURE — 605 °C
b
0·270
c
a
0·135
0·135
$K_{a,1}$ = ·00734
$K_{a,2}$ = ·01169
K_b = ·00667
K_c = ·00734
0·03
0·02
0·01
D^{2} (IN SQ. CMS.)
1
2
ignition
a
b
c
0
0·5
1·0
1·5
2·0
2·5
TIME (IN SECONDS)

Fig. 5-23

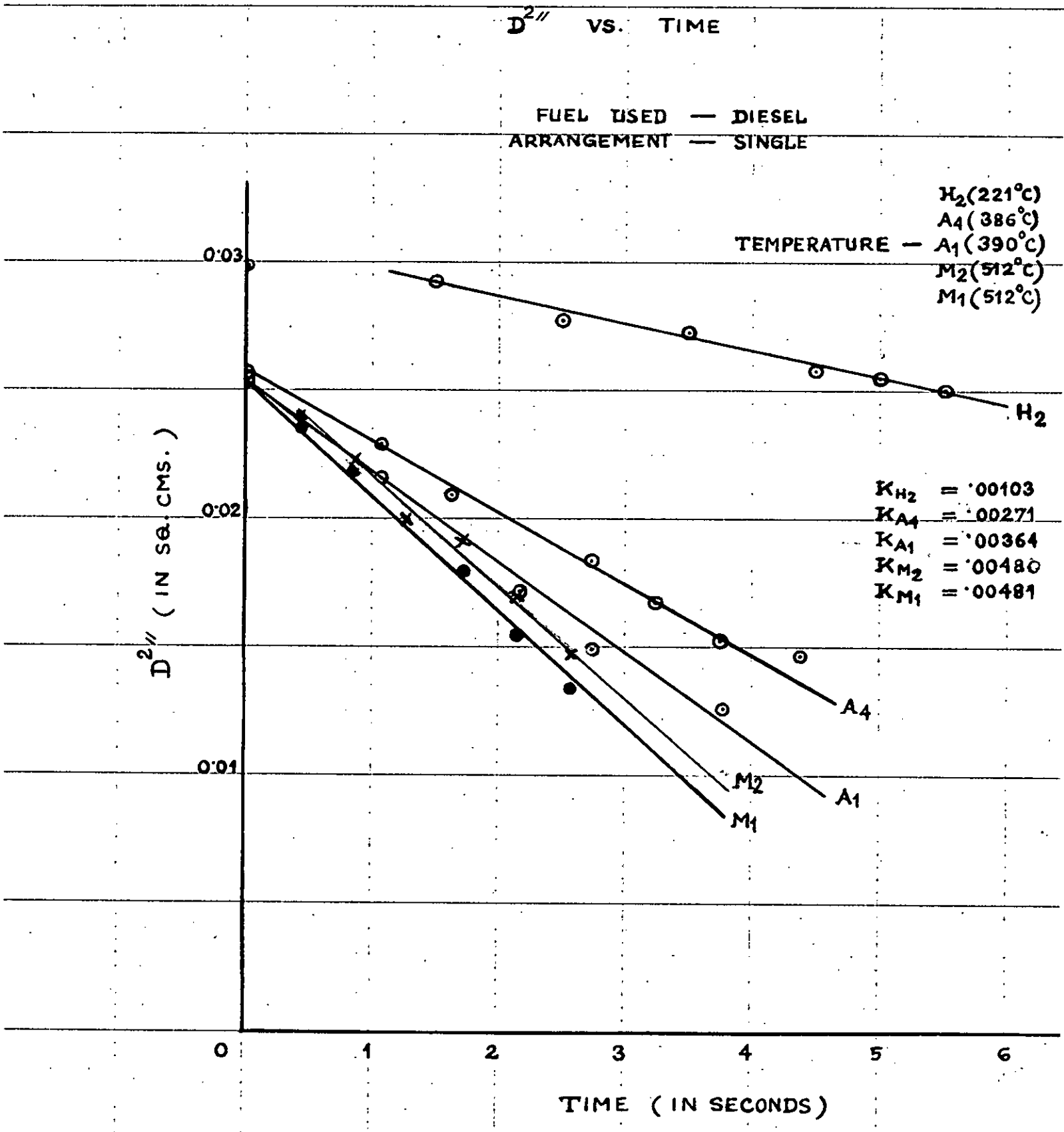


Fig . 5-24a

Evaporation [redacted] Fuel Droplet

$D^{2//}$ VS. TIME

Fig . 5-24b

Evaporation [redacted] of Fuel Droplet.

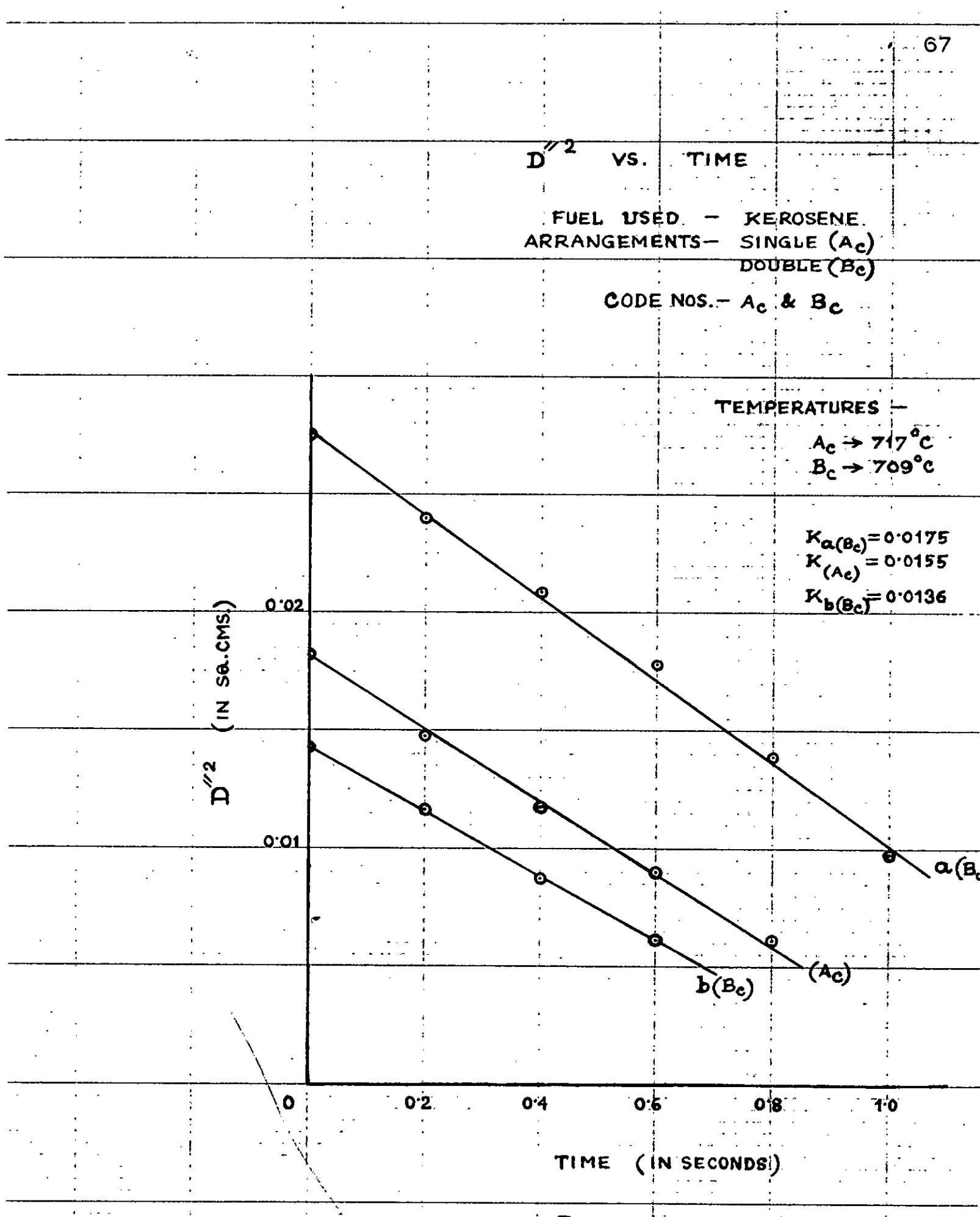


Fig. 5-25
combustion of Fuel Droplet.

X C - indicates burning

CHAPTER - VI

Discussion

DISCUSSION

6.0 In this chapter the discussion of the results of the present experimental investigation has been presented in three sections : I. The evaporation of fuel droplets, II. Combustion of fuel droplets, III. A general survey.

Section I

A study of the graphs Fig.(5-1) to Fig. (5-24) shows that the square of the diameter of the fuel drop varies linearly with time for the single, double and triple droplet arrangements. For single droplets, this linear variation of the square of the diameter with time has also been described by the earlier investigators (1,30) (33) (20) ; moreover the theoretical equation (3.12-4) prodicts such a linear variation.

However, no experimental data has earlier been published for evaporation constant of double and triple droplet arrays. In the present investigatiom , the writer found that for double and triple droplet arrays, the evaporation constant did not vary much. But for similar experimental conditions, the evaporation constant is found to be lower for double and triple droplet arrays when compared with that for a single droplet. This is due to the fact that multiple droplets form a vapour envelope of increased vapour concentration than do the single droplets thereby decreasing the driving force for mass transfer 'b' (eqn.3.9-1), which ultimately changes the transfer number 'B' of the equation(3.12-4).

It is inferred from this that the droplet interaction influences the evaporation constant, the degree of interaction will depend on the relative distances between the droplets.

The exact relationship between the orentation of the droplets , the distances between them and the evaporation constant is very difficult to predict theoretically. The approach is still an emperical one and extensive reswarch with different droplet arrangement is required for concluding an empirical formulaembracing these parameters. In the spray combustion engines the interaction between the droplets prevails both before and after the ignition of the droplets, and hence single droplet data cannot be applied directly in making vaporisation estimates in the oil fired systems. For such systems, the vaporisation data from droplet arrays simulate these conditions more appropriately.

6.2 From the graphical plots of Fig. (5-1) to Fig.(5-25) it is observed that for single, double and triple droplet arrangement for both kerosene and diesel fuel, the rate of evaporation increases with increase$ of temperature, the rate depends in a complicated way on the variation of the parameters 'k', 'C' 'B' , ' ρ_L' of the equation (3.12-4) with temperature. This can be shown by the help of the theoretical equation (3.12-4) and with the following two examples :

Example :

Theoretical equation $$K = \left(\frac{8k}{\rho_L C} \right) \mathrm{Ln} \left(1 + B \right)$$

		I	II
Environment temperature	T	870°F	620°F
Specific Heat	C	0.252	0.2465
Thermal conductivity	k	0.027	0.0243
Boiling point temp.	T_B	350°F	350°F
Density of fuel at	T_B	46	46
Latent heat	Q	98	98

Solving with the help of equation the following results are obtained

Problem I

Transfer number 'B' 1.34

Evaporation constant 'K' .0158 ft^2/hr or .00407 cm^2/sec

Problem II

Transfer number 'B' .68

Evaporation constant 'K' .0089 $ft^2/hr.$ or .00229 cm^2/sec

It is found from the above two examples that for any changes of temperature, the variation of the transfer number 'B' is much greater than the variation of the group $(\frac{8k}{\rho_L C})$ of equation (3.12-4). Hence the transfer number which is actually a measure of the driving force for mass transfer contributes major influence in the variation of the evaporation constant with temperature.

6.3 A study of the experimental data for droplets of kerosene and diesel fuel shows that for approximately the same temperature the evaporation constant for diesel fuel is lower than that of the kerosene fuel droplets, thereby indicating that the evaporation constant depends also on the characteristics of fuel. This is in confirmation with the theoretical prediction since that the evaporation constant is a function of the type of fuel as the properties like 'k' 'C' , ' ρ_L' 'T_B' are all different for different fuels, and that higher the boiling point temperature of the fuel, the lower will be the evaporation constant. This phenomena is important from the design consideration of any oil-fired combustion system.

In these calculations the properties of air has been taken for approximate calculation of the evaporation constant ; The mean temperature of the air has been taken for determing the properties.

6.4 The instances where theoretical predictions were not found to be substantiated were in the case of upper droplet in the three-drop arrays. From the theoretical equation (3.12-3) it is seen that evaporation constant 'K' is a function of the transfer number 'B' which is again a function of the driving force for mass transfer 'b' (eqn.3.9-1). Hence 'K' will be lowered when B ($\equiv b_g - b_s$) is lowered. There-fore it was expected that evaporation constant of the upper droplet in three-drop array would be lower than the neighbouring drops 'a', 'c' due to the increased mass supply from the neighbouring drops diminishing the value of the transfer number 'B'. Similar results were also expected for the droplet 'b' in two drop arrays (Fig.5-1). But experimental results does not show any marked difference between the evaporation constant of the droplets 'a', 'c' in both double and triple droplet dispositions, although the evaporation constant of all the droplets had been lowered. The writer is led to the conclusion that the vapour trails from the droplets coalesce into a single mass envelope around all the three droplets, affecting all the droplets simultaneously.

6.5 The effect of the droplet diameter on evaporation rate is clearly demonstrated from the results of the double and triple droplet arrangement, since all the droplets were simultaneously exposed to the same temperature. Examining the graphs Fig.(5-1) to Fig.(5-19) it is found that for such an array of droplets, the evaporation constant for a particular temperature is of same value for droplets of different diameter. Hence it is concluded that the evaporation constant is independent of droplet diameter when only the evaporation of fuel is considered. The drop diameter of-course determine the life time of the droplets since droplet life time is given by the relation D_o^2/K. So greater the initial diameter of the droplet greater will be its life time. This is a very important factor in designing the combustion chamber and nozzle of an oil fired engine.

Section II

6.6 In the attempt to investigate the burning rate of fuel droplets it was observed that at a temperature of 550° C Fig. (5·20) spontaneous ignition took place for kerosene droplets in double and triple droplet arrangements. But at that temperature ignition did not occur with single droplets. However, at a temperature of about 700°C , spontaneous combustion occured with single, double and triple droplets of both kerosene and diesel fuel.

The postulates for the occurrence of the spontaneous ignition of fuel droplet or droplets are that, a) there should be enough fuel vapour around the droplet or droplets, capable of forming stoichiometric ratio with the oxygen of the environment, b) this mixture concentration should survive a certain period of time during which pre-ignition chemical reaction takes place. The ignition delay period is thus dependent on the environmental conditions including temperature and characteristics of fuel and droplet diameters. However, the influence of vapour concentration on the occurrence of spontaneous ignition is minimized by raising the environmental temperature.

From these considerations, the writer concludes that at the lower temperature (e.g. 550°C) the fuel vapour from the single evaporating drop dissipates to the surrounding at a faster rate than the chain branching chemical pre-ignition reactions which contributes to ignition and, consequently, spontaneous ignition was inhibited ; however, with double and triple droplet arrays the build up of an increased mass of fuel vapour compensates for the dispersal of vapour into the surrounding air and as a result pre-ignition chemical reaction can occur in the residual fuel vapour which ultimately culminates in ignition.

6.7 Fig. (5-25) indicates that for each of the burning droplets, whether single or in arrays , the square of the droplet diameter varies linearly with time. Earlier investigators (33) also obtained similar results.

The rate of evaporation and the rate of combustion of fuel droplets can be examined simultaneously from the fig.(5.20-30) which shows that the rate of combustion is higher than the rate of evaporation. It is noted that this combustion rate is about 1.5 times the evaporation constant, the environment temperature being the same. This effect has also been observed by Kobayasi (33) and Niichi Nishiwaki (34). The change in slope in the curves Fig.(5.20-23) is due to the increased heat supply from the flame front around the droplets during burning and in agreement with the writers' observation of the influence of surrounding air temperatures on the evaporation rate.

6.8 Spalding (1), Penner (20) conducted experiments with single fuel droplets, and concluded that burning rate is independent of droplet diameter, a finding which they also predicted in their theoretical analysis.

However, in the present experimental investigation it was observed that for an array of burning droplets, the burning rate is essentially dependent on the orientation of the droplets. In an array of two and three droplets ,the rate of combustion for the lower droplet has been found to be higher than that for the upper droplets. Penner (20) reported similar results with two-drop arrays the droplets in this configuration being placed side by side and were ignited by a flame source.

The variation of burning constant of fuel droplets in an array is due to the fact that partly burned fuel vapour from the lower droplets fig.(5.20) ascends and surrounds the upper droplet or droplets, as a result fuel vapour ratio becomes rich in this upper region, and in consequence the burning rate

of the upper droplet or droplets decreases. The degree of this droplet interaction during burning depends upon the orientation of the droplets and the distance between them . A comparative study of the evaporation constant and burning rate obtained by different investigators is given on page. 75 .

6.9 Once the ignition of the droplets has been initiated , from the Fig.(Photo) the flames from the array of burning dropplets coalesce in a unified flame front enveloping the entire droplet dispositions[×]; the structure of this flame front depends on the type of arrangement of the droplets. Notwithstanding this, each droplet was found also to be surrounded but its own reaction zone. In an actual combustion chamber, this unified flame structure is expected to be present.

Section III

6.10 The total heat-up period of the droplet could be divided into two parts ; i) the unsteady state of heating, ii) steady state heating. The unsteady period consists of heating the droplet from the initial droplet temperature to the wet bulb temperature ; while in the steady state heating period the droplet maintains its wet bulb temperature. In the present study the unsteady heating period of the fuel droplets has not been considered in the [redacted] calculation of the evaporation constant, since in this transient period little evaporation takes place, and the chief function of the droplets in this period is to absorb sensible heat.

6.11 When the experiment was conducted with a single droplet at a temperature of about 500°C (where no ignition occured) a black residue was observed to stick to the quartz fibre after the complete evaporation of both kerosene and diesel fuel droplets. This carbon deposit arises from thermal decomposition of the fuel. The carbon formation indicates a diffusion process within the droplets and a selective vaporisation similar to the distillation process

× Prominent in negatives.

Comparative study of the Evaporation and burning Constant of single fuel droplets

	Fuel	Temperature	Evaporation Const. K $cm^2/sec.$
Godsave ( )	Kerosene Sp.Gr.at $60^oF/60^oF$ 0.8051	-	.0096
	Diesel Sp.Gr. 0.850	-	.0079
Kiyosi Kobayasi ( )	Kerosene (burning)	650^oC	.0103
	Diesel(burning)	628^oC	.0128
Masdin Ph.D. Thesis Sheffield 1960	Kerosene	Variation of K with temperature	.01 to .00445
Masdin Institute of Fuel June 1962	Aviation Turbine Kerosene in stagnant nitrogen	654^oC	.00685
		512^oC	.00465
		467^oC	.0044
		392^oC	.0035
		310^oC	.0021
Based on the theoretical eqn.(3?2-4)	Kerosene Sp.Gr. 0.786 at 60^oF	471^oC	.00407
		316^oC	.00229
Author	Kerosene Sp.Gr.0.786 at 60^oF	233^oC	.00136
		394^oC	.00542
		511^oC	.00667
		600^oC	.0075
		717^oC	.015
	Diesel Sp.Gr. 0.832 at 60^oF	221^oC	.00103
		386^oC	.00271
		512^oC	.0044

This formation ofcourse depends on the size of the fuel droplets, composition of the fuel and temperature of the environment. In multi-component fuel droplets due to this selective evaporation of fuel component, the transfer number 'B' and hence 'K' will vary during the entire evaporation or burning process. In the theoretical calculation no allowance was made for this variation in the fuel properties.

6.12 In the experimental study, the fuel drop and the thermo-couple were exposed not only to convective heat transfer but also to radiation heat transfer from the furnace walls, consequently, the temperature measured by the thermo-couple will be higher than the actual temperature of the surrounding air. However, radiation correction for the thermo-couple readings were made.

6.13 In summary, the writer has described in this report the results of his investigation of the evaporation and spontaneous combustion of fuel droplet arrays. This study has provided the information that the square of the diameter of the droplet varies linearly with time for each of the droplets in single, double and triple droplet arrays. However, for similar experimental conditions, evaporation constant for double and triple droplet is found to be lower than that of single droplet thus showing that droplet interaction influence the evaporation constant. Moreover, it has also been observed that droplet interaction modifies the burning rate of the droplets and the flame structure. The study on droplet arrays was limited and further extensive work is necessary with a variety of droplet arrangements in order to derive satisfactory empirical formulae for these arrays with multicomponent fuel droplets in evaporation and combustion processes.

APPENDIX - I

Experimental data and calculations

CALCULATION

This chapter devotes to a) finding out the diameter of the droplets at different time interval b) plotting the graph D''^2 Vs. Time and c) determining the evaporation constant K which is actually the slope of the curve of the above mentioned plot.

Since the droplet at the tip of the quartz fibre is not perfectly spherical and assumes an oval shape as the droplet evaporates, its shape should be corrected to an equivalent sphere. This has been done here by assuming that the shape of an actual droplet at the end of a quartz fibre is an ellipsoid and then equating its volume with an equivalent sphere (33).

Actual droplet Equivalent droplet

Volume of a sphere ... $= 1/6\pi D^3$

Volume of an ellipsoid $= 1/6\pi L_1 L_2^2$

Hence $D = \sqrt[3]{L_1 L_2^2}$

Let D'' = Diameter of the actual droplet

L_1'' = Major axis of the actual droplet

L_2'' = Minor axis of the actual droplet

D' = Magnified droplet diameter on the film

L_1' = Magnified major axis on the film

L_2' = Magnified minor axis on the film

m_2 = Magnification of the actual droplet on the film

D = Magnified droplet diameter as projected on the screen.

L_1 = Magnified major axis as projected on the Screen

L_2 = Magnified minor axis as projected on the Screen.

m_1 = Magnification of the droplet on the film and the droplet on the Screen

$$D = \sqrt[3]{L_1 L_2^2}$$

$$= \sqrt[3]{m_1 L_1' m_1^2 L_2'^2}$$

$$= m_1 \sqrt[3]{L_1' L_2'^2} = m_1 \sqrt[3]{m_2 L''_2 m_2^2 L_2''^2}$$

$$= m_1 m_2 \sqrt[3]{L_1'' L_2''^2}$$

$$= m_1 m_2 D''$$

$$D'' = \frac{D}{m_1 m_2}$$

' D ' was measured in inches. Writing the value in centimeter D'' can be written as :

$$D'' = \frac{2.54\ D}{m_1 m_2} \text{ cm}$$

When $m_1 = 6$

$m_2 = 2.5$

$$D'' = \left(\frac{2.54}{6 \times 2.5}\right)(D) = (D)(0.169) \text{ cm.}$$

When $m_1 = 6$

$m_2 = 2.32$

$$D'' = \left(\frac{2.54}{6 \times 2.32}\right)(D) = (D)(0.1825) \text{ cm.}$$

When $m_1 = 6$

$m_2 = 1.67$

$D'' = (D)\ (0.253)$

When $m_1 = 5.5$

$m_2 = 1.67$

$D'' = (D)\ (0.2765)$

Evaporation constant is determined by the following equation:-

$$K = \frac{(D_1''^2 - D_2''^2)}{(t_1 - t_2)} = -\frac{\Delta D''^2}{\Delta t}$$

t_1 = time corresponding to D_1''

t_2 = time corresponding to D_2''

× The negative sign indicates that the diameter of the droplet decreases with time. In this thesis the absolute value of the evaporation constant ' K ' has been considered.

× The specific gravity of the kerosene and diesel fuel were determined by Westphal Balance.

Fuel	Oil Temp.	Sp.Gr. of oil at _____	Sp.Gr. of oil at 60°F
Diesel	26°C	0.829	0.832
Kerosene	26°C	0.78	0.786

× The thermocouple was calibrated with the help of a Electric muffle furnace.(Appendix A). The temperature variation was found to vary within ± 5°C maximum. Personal error in reading the negatives ± 2 /.

EXPERIMENTAL DATA ON EVAPORATION AND COMBUSTION
OF
FUEL DROPLETS

Date	Room Temperature	Flash arrangement i.e. No. of flashes/min.	Fuel used	Type of arrangement of droplets.	No.of experiment conducted on each.	mV_1 (reading 1)	mV_2 (reading RI)	Code No.
13.4.66	36.7°C	110	Diesel	Single droplet	1	19.5	19.0	A
					4	19.0	19.0	
				Double droplet	2	19.2	19.0	B
					3	19.0	19.0	
					4	19.0	18.5	
23.4.66	34.5°c	120	Kerosene	Double droplet	2	20.4	20.0	C
					4	19.5	19.2	
				Single droplet	1	19.9	19.2	D
					3	19.0	19.0	
					4	19.0	18.9	
24.4.66	34.5°C	120	Kerosene	Double droplet	2	20.1	20.0	E
					3	19.9	19.9	
26.4.66	33.9°C	120	Kerosene	Double droplet	2	11.4	11.2	F
				Single droplet	1	11.0	10.5	G
26.4.66	33.3°C	120	Diesel	Single droplet	2	10.2	10.0	H
				Double droplet	1	10.1	10.0	I

EXPERIMENTAL DATA ON EVAPORATION AND COMBUSTION
OF
FUEL DROPLETS

Date	Room temperature	Flash arrangement i.e. No.of flashes/min.	Fuel used	Type of arrangement of droplets.	No.of experiment conducted on each.	mV_1 (reading I)	mV_2 (reading II)	Code No.
17.5.55	37.2°C	120	Kerosene	Triple	1	26.2	26.0	J
		150			2	26.0	25.8	
		130	Kerosene	Triple	1	25.0	25.0	K
		140			2	25.7	25.4	
		140	Kerosene	Double	1	26.0	25.8	L
				Single	2	26.0	25.8	
17.5.66	36.7°C	140	Diesel	Single	1	26.0	26.0	M
					2	26.0	26.0	
				Double	1	26.0	26.0	N
					2	25.8	25.8	
				Triple	2	26.0	26.0	P
23.5.66	35.6°C	120	Diesel	Triple	1	20.0	19.5	Q
					2	19.5	19.0	
			Kerosene	Triple	2	19.0	18.7	R
25.5.66	35.6°C	200	Kerosene	Triple	3	31.5	31.2	T
				Triple	2	31.3	31.0	U
				Single	2	31.2	31.0	W
				Double	1	31.1	30.0	X
					2	29.8	29.0	

CALCULATION SHEET

Date	Room temperature °C	No.of observation on each	mV_1	mV_2	Average mV	°C	Actual temperature.	Code No.
	36.7°c	1	19.5	19.0	19.25	353.5	390.0°c	A
		2	19.0	19.0	19.0	349.0	386.0°C	
13.4.66								
		2	19.2	19.0	19.1	350.7	387 °C	
	36.7°C	3	19.0	19.0	19.0	349.0	386 °C	B
		4	19.0	18.5	18.75	344.3	381 °C	
		2	20.4	20.0	20.2	370.7	405°C	C
	34.5°C	4	19.5	19.2	19.35	355.3	390°C	
23.4.66								
		1	19.9	19.2	19.55	359.0	394°C	
	34.5°C	3	19.0	19.0	19.0	349.0	384°C	D
		4	19.0	18.9	18.95	348.0	383°C	
24.4.66	34.5°C	2	20.1	20.0	20.05	368.0	403°C	E
		3	19.9	19.9	19.9	365.3	400°C	
	33.9°C	2	11.4	11.2	11.3	209.5	243°C	F
26.4.66								
	33.9°C	1	11.0	10.5	10.75	199.5	233°C	G
	33.3°C	2	10.2	10.0	10.1	187.7	221°C	H
26.4.66								
	33.3°C	1	10.1	10.0	10.05	186.7	220°C	I
	37.2°C	1	26.2	26.0	26.1	477.0	514°C	J
		2	26.0	25.8	25.9	473.5	511°C	
17.5.66	37.2°C	1	25.0	25.0	25.0	457.5	495°C	K
		2	25.7	25.4	25.55	467.3	505°C	
	37.2°C	1	26.0	25.8	25.9	473.5	511°C	L
		2	26.0	25.8	25.9	473.5	511°C	

CALCULATION SHEET

Date	Room temp. °C	No.of observation on each	mV_1	mV_2	Average mV	°C	Actual temperature	Code No.
17.5.66	36.7°C	1	26.0	26.0	26.0	475.3	512°C	M
		2	26.0	26.0	26.0	475.3	512°C	
	36.7°C	1	26.0	26.0	26.0	475.3	512°C	N
		2	25.8	25.8	25.8	459.0	496°C	
	36.7°C	2	26.0	26.0	26.0	475.3	512°C	P
23.5.66	35.6°C	1	20.0	19.5	19.75	362.5	398°C	Q
		2	19.5	19.0	19.25	353.5	389°C	
	35.6°C	2	19.0	18.7	18.85	346.1	382°C	R
25.5.66	35.6°C	3	31.5	31.2	31.35	569.0	605°C	T
	35.6°C	2	31.3	31.0	31.15	565.5	601°C	U
	35.6°C	2	31.2	31.0	31.10	564.7	600°C	W
	35.6°C	1	31.1	30.0	30.55	555.3	591°C	X
		2	29.8	29.0	29.40	535.0	571°C	

Fuel - Diesel
Droplet arrangement - Single
Code - A_1
$m_1 = 6$; $m_2 = 2.32$

	1	2	3	4	5	6	7	8
L_1	1.16	1.12	.9	.88	.86	.85	.84	
L_2	.75	.67	.63	.52	.51	.49	.45	
L_2^2	.56	.449	.396	.27	.26	.24	.202	
$L_1L_2^2$	.65	.504	.356	.238	.224	.204	.171	
D in.	.865	.796	.71	.66	.606	.588	.555	
D" cm.	.16	.147	.1315	.122	.112	.1085	.1025	
$D"^2$ cm.^{2}	.0255	.0215	.0172	.0149	.0126	.0118	.0105	
Time in Sec.	0	1.09	2.18	2.725	3.815	4.360	4.905	

Fuel - Diesel
Droplet arrangement - Single
Code No. A_4
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
L_1	1.10	1.08	1.07	1.03	1.04	1.02	1.02	
L_2	.77	.72	.67	.62	.58	.55	.53	
L_2^2	.591	.52	.45	.385	.335	.305	.28	
$L_1L_2^2$	.651	.562	.482	.397	.349	.307	.285	
D in.	.868	.821	.785	.735	.705	.675	.659	
D" cm.	.1605	.152	.145	.136	.132	.1245	.1215	
$D"^2$ cm.^{2}	.0257	.023	.021	.0184	.0169	.0155	.0148	
Time in Sec.	0	1.09	1.635	2.725	3.27	3.815	4.37	

Fuel - Diesel
Droplet arrangement - Double
Code No. - B_2
m_1 - 6 ; M_2 - 2.32

	1	2	3	4	5	6	7	8
La_1	.96	.92	.87	.84	.77	.75	.75	
La_2	.63	.6	.56	.54	.46	.41	.36	
La_2^2	.396	.36	.314	.291	.212	.168	.13	
$La_1L^2_{a_2}$	.37	.331	.273	.244	.163	.126	.0975	
Da in	.7179	.692	.6487	.6249	.5463	.5013	.4603	
D^n_a cm	.131	.1264	.1181	.114	.099	.0915	.084	
D^{n2}_a cm^2	.01716	.01598	.01396	.013	.0098	.00837	.0706	
Lb_1	1.05	1.05	1.00	.97	.94	.9	.9	
Lb_2	.75	.72	.70	.67	.62	.59	.55	
L_{b2}^2	.561	.52	.49	.45	.385	.348	.304	
$Lb_1L^2_{b_2}$	.59	.545	.49	.436	.362	.314	.274	
Db in	.8387	.8168	.7884	.7583	.7127	.6797	.6495	
$D^n b$ cm	.153	.49	.1439	.1382	.13	.124	.1183	
$D^n b^2$ cm^2	.02341	.0222	.02071	.0191	.01699	.01538	.01399	
Time in Sec.	0	.55	1.10	1.65	3.30	3.85	4.40	

Fuel - Diesel
Droplet arrangmenet - Double
Code No. B_3
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.1	1.1	1.1	1.05	1.00	.95		
La_2	.9	.85	.83	.8	.75	.67		
La_2^2	.81	.72	.69	.64	.56	.449		
$La_1La_2^2$	.89	.793	.757	.672	.56	.425		
Da in.	.964	.926	.91	.877	.825	.752		
Da* cm.	.178	.173	.168	.162	.1521	.139		
Da^{*2} $cm.^2$	.0316	.0299	.0283	.0262	.0232	.0194		
Lb_1	.9	.9	.87	.85	.82	.76		
Lb_2	.70	.65	.62	.55	.5	.45		
Lb_2^2	.49	.432	.384	.304	.25	.203		
$Lb_1Lb_2^2$	.44	.38	.334	.258	.205	.155		
Db in.	.76	.725	.694	.636	.59	.538		
Db* cm.	.1408	.134	.128	.1178	.109	.0995		
Db^{*2} $cm.^2$	.0198	.0178	.0164	.0138	.012	.0099		
Time in sec.	0	1.09	2.18	3.27	4.36	5.45		

Fuel - Kerosene
Droplet arrangement - Double
Code No. C_4
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.00	.98	.90					
La_2	.62	.60	.57					
La_2^2	.385	.36	.325					
$La_1La_2^2$	.385	.3525	.292					
Da in.	.7275	.706	.6634					
D''_a cm.	.133	.1291	.121					
Da''^2 cm.^{2}	.0169	.01667	.01464					
Lb_1	.92	.92	.92					
Lb_2	.66	.63	.59					
Lb_2^2	.436	.397	.349					
$Lb_1Lb_2^2$	.401	.366	.322					
Db in.	.7368	.7153	.6854					
Bb'' cm.	.1349	.131	.1254					
Db''^2 cm.^{2}	.0182	.01716	.01573					
Time in Sec.	0	.5	1					

Fuel - ~~Single~~ Kerosene
Droplet arrangement - Single
Code No. D_1
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
L_1	1.2	1.2	1.15	1.12	1.07	1.05		
L_2	.75	.7	.65	.6	.53	.47		
L_2^2	.56	.49	.42	.36	.28	.22		
$L_1L_2^2$	.67	.59	.483	.403	.3	.23		
D in.	.875	.84	.785	.739	.67	.613		
D" cm.	.1618	.155	.145	.1361	.124	.113		
D''^2 cm.^{2}	.026	.024	.021	.0186	.0154	.0128		
Time in Sec.	0	.5	1.0	1.5	2.0	2.5		

Fuel - Kerosene
Droplet arrangement - Single
Code No. - D_3
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
L_1	1.16	1.16	1.14	1.1	1.04			
L_2	.75	.72	.66	.55	.47			
L_2^2	.561	.52	.435	.302	.225			
$L_1L_2^2$	.651	.604	.496	.332	.234			
D in.	.8667	.8455	.7916	.6924	.6162			
D" cm.	.1582	.1543	.1444	.1264	.1124			
$D"^2$ cm.^{2}	.02503	.02381	.02085	.01598	.0127			
Time in Sec.	0	.5	1	2	2.5			

Fuel - Kerosene
Droplet arrangement - Single
Code No. D_4
$m_1 = 6$; $m_2 = 2.32$

	1	2	3	4	5	6	7	8
L_1	1.20	1.15	1.13	1.10	1.10	1.08	1.06	
L_2	0.88	0.84	0.8	0.75	0.7	0.65	0.61	
L_2^2	.775	.705	.64	.561	.49	.423	.372	
$L_1L_2^2$	.9	.81	.725	.619	.54	.457	.394	
D in.	.9655	.9322	.8984	.8522	.8143	.7703	.7331	
D" cm.	.1765	.1703	.165	.1559	.1484	.141	.1339	
$D"^2$ cm.^{2}	.0311	.029	.02722	0.2412	.02202	.01988	.01793	
Time in Sec.	0	1	1.5	2	2.5	3	3.5	

Fuel - Kerosene
Droplet arrangement - Double
Code No. - E_2
$n_1 - 6$; $n_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.00	1.00	1.00	.98	.95			
La_2	.77	.75	.71	.67	.64			
La_2^2	.591	.561	.504	.45	.41			
$La_1La_2^2$	.591	.561	.504	.44	.389			
Da in	.8392	.8248	.7958	.7606	.73			
Da" cm.	.153	.1503	.1454	.139	.1333			
$Da"^2$ $cm.^2$	.02341	.02259	.02114	.01932	.01777			
Lb_1	.72	.65	.62	.55	.50			
Lb_2	.55	.50	.46	.40	.34			
Lb_2^2	.3025	.25	.2116	.16	.1156			
$Lb_1Lb_2^2$	.218	.1625	.131	.083	.0583			
Db in.	.6019	.5457	.5079	.4362	.3878			
Db" cm.	.11	.0995	.09255	.0796	.0765			
$Db"^2$ $cm.^2$	.01210	.0099	.00856	0.006336	.00498			
Time in Sec.	0	.5	1	1.5	2			

Fuel - Kerosene
Droplet arrangement- Double
Code No. E_3
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.1	1.0%	1.04	1.00	1.00			
La_2	.86	.85	.8	.78	.75			
La_2^2	.7396	.7225	.64	.5929	.5625			
$La_1La_2^2$	.813	.76	.686	.5929	.5625			
Da in.	.9333	.9126	.8819	.8399	.8255			
Da" cm.	.1704	.1667	.161	.153	.151			
$Da"^2$ cm.^{2}	.02904	.02779	.0259	.02341	.0228			
Lb_1	.75	.65	.6	.52	.50			
Lb_2	.54	.50	.45	.4	.35			
Lb_2^2	.2916	.25	.2025	.16	.1225			
$Lb_1Lb_2^2$	.2182	.1625	.1215	.0834	.0612			
Db in.	.6020	.5457	.4953	.4369	.3941			
Db" cm.	.11	.0996	.0905	.0798	.072			
$Db"^2$ cm.^{2}	.0121	.0099	.00819	.00637	.00518			
Time in Sec.	0	.5	1	1.5	2.0			

Fuel - Kerosene
Droplet arrangement - Double
Code No. - F_2
$m_1 = 6$; $m_2 = 2.32$

	1	2	3	4	5	6	7	8
La_1	1.20	1.16	1.15	1.12	1.10	1.11	1.06	
La_2	0.90	0.90	0.86	0.80	0.75	0.75	0.67	
La_2^2	.81	.81	.7396	.64	.5625	.5625	.4489	
$La_1La_2^2$	.97	.94	.845	.716	.62	.625	.475	
Da in.	.9899	.9796	.9454	.8946	.8527	.855	.7803	
Da'' cm.	.1805	.1785	.1729	.163	.1559	.156	.1429	
Da''^2 cm.^{2}	.0323	.03186	.02989	.02657	.0243	.0244	0.204	
Lb_1	.86	.85	.82	.75	.73	.73	.62	
Lb_2	.73	.72	.67	.62	.58	.55	.46	
Lb_2^2	.5329	.5184	.4489	.3844	.3346	.3029	.2116	
$Lb_1Lb_2^2$	.458	.44	.368	.288	.246	.221	.131	
Db in.	.7708	.7606	.7166	.6604	.6266	.6046	.5079	
Db'' cm.	.141	.139	.1309	.1207	.1143	.11	.0929	
Db''^2 cm.^{2}	.01988	.01932	.01723	0.1457	.01706	.0129	.008575	
Time in Sec.	0	1	3.0	5.0	6.5	7.0	8.9	

Fuel - Kerosene
Droplet arrangement - Single
Code No. G_1
$m_1 = 6$; $m_2 = 2.32$

	1	2	3	4	5	6	7	8
L_1	1.25	1.17	1.14	1.15	1.15	1.15	1.15	1.15
L_2	.9	.86	.83	.79	.72	.7	.68	.66
L_2^2	.81	.7396	.6889	.621	.52	.49	.462	.435
$L_1L_2^2$	1.01	.865	.785	.715	.599	.565	.532	.5
D in.	1.003	.9528	.9225	.8942	.843	.826	.811	.795
D" cm.	.1828	.174	.1685	.163	.1539	.151	.148	.145
$D"^2$ cm.^{2}	.03342	.0303	.02839	.02657	.0236	.0228	.022	.021
Time in Sec.	0	1.5	3.0	4.5	6.5	7.5	8.0	8.5

Fuel - Diesel
Droplet arrangement - Single
Code No. H_2
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
L_1	1.21	1.21	1.17	1.15	1.13	1.12	1.12	1.12
L_2	.84	.83	.81	.80	.78	.77	.76	.74
L_2^2	.7056	.6889	.6561	.64	.609	.5929	.5776	.5476
$L_1 L_2^2$	.855	.83	.769	.735	.6865	.665	.654	.614
D in.	.9491	.9398	.9162	.9025	.881	.8729	.8680	.8499
D" cm.	.173	.171	.1673	.165	.161	.1593	.1583	.155
D''^2 $cm.^2$	.02993	.02924	.02799	.02722	.02594	.02538	.02506	.02402
Time in sec.	0	1.5	2.5	3.5	4.5	5.0	5.5	6.0

Fuel - Diesel
Droplet arrangement - Double
Code No. - I_1
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.25	1.20	1.17	1.12	1.15	1.15	1.12	1.1
La_2	.94	.93	.89	.88	.87	.86	.85	.85
La_2^2	.8836	.8649	.7921	.7744	.7569	.7396	.7225	.7225
$La_1La_2^2$	1.105	1.04	.926	.866	.87	.845	.81	.795
Da in.	1.0338	1.0132	.9747	.9532	.9546	.9454	.9322	.9264
Da" cm.	.189	.185	.1779	.174	.1742	.1729	.1702	.1692
$Da"^2$ cm.^{2}	.03572	.03422	.03165	.03028	.03035	.02988	.02897	.02863
Lb_1	.88	.85	.8	.8	.82	.80	.76	.76
Lb_2	.76	.72	.67	.66	.65	.63	.61	.6
Lb_2^2	.5776	.5184	.4489	.4356	.4225	.3969	.3721	.36
$Lb_1Lb_2^2$	.508	.44	.359	.348	.346	.318	.282	.284
Db in.	.7979	.7606	.6107	.7034	.7020	.6826	.6588	.6495
Db" cm.	.1458	.139	.13	.1282	.1281	.1246	.12	.1185
$Db"^2$ cm.^{2}	.02126	.01932	.0169	.01644	.01641	.01553	.0144	.01404
Time in Sec.	0	1	2.5	4.0	5.5	7.0	8.5	9.0

Fuel - Kerosene
Droplet arrangement- Triple
Code No. J_1

$n_1 - 6$; $n_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	.9	.85	.77	.67				
La_2	.63	.58	.5	.42				
La_2^2	.3969	.3964	.25	.1564				
$La_1La_2^2$	.357	.303	.1925	.118				
Da in.	.71	.6717	.5774	.4905				
Da" cm.	.1298	.1227	.1055	.0896				
$Da"^2$ cm.^{2}	.0168	.01506	.0113	.00803				
Lb_1	.98	.9	.8	.75				
Lb_2	.57	.52	.45	.30				
Lb_2^2	.3249	.2704	.2025	.09				
$Lb_1Lb_2^2$	.3155	.2435	.162	.0675				
Db in.	.6808	.6245	.5451	.407				
Db" cm.	.1242	.114	.0995	.07448				
$Db"^2$ cm.^{2}	.01543	.013	.0099	.00552				
Lc_1	.88	.82	.72	.55				
Lc_2	.56	.50	.4	.28				
Lc_2^2	.3136	.25	.16	.0784				
$Lc_1Lc_2^2$	.276	.205	.1155	.0432				
Dc in.	.6511	.5896	.4870	.3509				
Dc" cm.	.119	.1075	.089	.0641				
$Dc"^2$ cm.^{2}	.01416	.01156	.00792	.004109				
Time in Sec.	0	.5	.9	1.5				

Fuel - Kerosene
Droplet arrangement - Triple
Code No. J_2
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	.95	.92	.90	.88	.87			
La_2	.77	.73	.7	.67	.62			
La_2^2	.5930	.5329	.49	.4490	.3840			
$La_1La_2^2$	.564	.49	.441	.394	.334			
Da in.	.8262	.7884	.7612	.7331	.6938			
Da" cm.	.151	.1439	.139	.1338	.1265			
$Da"^2$ cm.^{2}	.0228	.0207	.01933	.01791	.016			
Lb_1	1.01	.95	.91	.89	.89			
Lb_2	.69	.65	.6	.54	.46			
Lb_2^2	.476	.4225	.36	.2916	.2116			
$Lb_1Lb_2^2$	.48	.401	.328	.259	.188			
Db in.	.7830	.8774	.6896	.6374	.5729			
Db" cm.	.143	.1345	.1258	.1163	.1045			
$Db"^2$ cm.^{2}	.0205	.01809	.01583	.01353	.01092			
Lc_1	1.0	.95	.92	.87	.85			
Lc_2	.75	.72	.65	.60	.52			
Lc_2^2	.5625	.5184	.4225	.36	.2704			
$Lc_1Lc_2^2$	.5625	.492	.388	.3138	.23			
Dc in	.8255	.7894	.7294	.6796	.6127			
Dc" cm.	.1509	.144	.133	.1239	.1119			
$Dc"^2$ cm.^{2}	.02278	.02074	.01769	.01535	.01253			
Time in sec.	0	.4	.8	1.2	1.6			

Fuel - Kerosene
Droplet arrangement - Triple
Code No. K_1
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.00	1.00	.96	.93	.86			
La_2	.8	.76	.7	.65	.59			
La_2^2	.64	.5776	.49	.4225	.3481			
$La_1La_2^2$	.64	.5776	.471	.393	.3			
Da in.	.8618	.8323	.7781	.7325	.6694			
Da" cm.	.1575	.1502	.1421	.1339	.1222			
$Da"^2$ cm."	.02481	.02256	.02019	.01793	.01488			
Lb_1	1.00	.100	.100	.92	.86			
Lb_2	.74	.7	.64	.57	.50			
Lb_2^2	.5476	.49	.4096	.3249	.25			
$Lb_1Lb_2^2$	.5476	.49	.388	.305	.215			
Db in.	.8181	.7884	.7294	.674	.6			
Db" cm.	.1494	.144	.1331	.123	.109			
$Db"^2$ cm.^{2}	.0223	.0207	.0177	.01512	.012			
Lc_1	.9	.87	.8	.75	.64			
Lc_2	.62	.56	.49	.4	.35			
Lc_2^2	.3844	.3136	.24	.16	.1225			
$Lc_1Lc_2^2$	.346	.272	.192	.12	.0785			
Dc in.	.702	.6479	.576	.494	.429			
Dc" cm.	.128	.1181	.1051	.09	.0782			
$Dc"^2$ cm.^{2}	.01638	.01395	.01105	.0081	.0061			
Time in Second	0	.46	.92	1.38	1.84			

Fuel - Kerosene
Droplet arrangement - Triple
Code No. K_2
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	.95	.9	.9	.82	.80	.7		
La_2	.68	.65	.60	.55	.48	.40		
La_2^2	.4624	.4225	.36	.3025	.2304	.16		
$La_1La_2^2$	.44	.371	.325	.248	.1845	.119		
Da in.	.7606	.7186	.6868	.6283	.5693	.4919		
Da" cm.	.139	.131	.1254	.1145	.1039	.0912		
Da''^2 cm.^{2}	.0193	.01716	.01573	.01311	.0108	.008317		
Lb_1	.98	.98	.92	.9	.85	.75		
Lb_2	.68	.64	.59	.52	.46	.36		
Lb_2^2	.4624	.4096	.3481	.2704	.2116	.1296		
$Lb_1Lb_2^2$	.454	.401	.3205	.2438	.18	.0972		
Db in.	.7686	.7374	.6884	.6247	.5646	.4598		
Db" cm.	.14	.1345	.1246	.114	.103	.08382		
Db''^2cm.^{2}	.0196	.01890	.0156	.013	.0106	.0702		
Lc_1	1.00	1.00	.95	.90	.85	.80		
Lc_2	.83	.68	.64	.60	.53	.43		
Lc_2^2	.5329	.4624	.4096	.36	.28	.203		
$Lc_1Lc_2^2$	.5229	.4624	.388	.324	.238	.163		
Dc in.	.8107	.7733	.7294	.686	.62	.546		
Dc" cm.	.1474	.141	.133	.1252	.1130	.0995		
Dc''^2 cm.^{2}	.02173	.0199	.0177	.0157	.0127	.0099		
Time in sec.	0	.43	.86	1.29	1.72	2.15		

Fuel - Diesel
Droplet arrangement - Triple
Code No. [redacted] L_1

$n_1 - 6$; $n_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.05	1.02	.95	.95	.9			
La_2	.84	.83	.76	.7	.65			
La_2^2	.7056	.64	.653	.49	.4225			
$La_1La_2^2$	.741	.654	.545	.466	.38			
Da in.	.9049	.8680	.8168	.7753	.7243			
Da" cm.	.165	.1583	.1492	.1419	.132			
$Da"^2$ cm.^{2}	.02722	.02506	.02226	.02014	.01742			
Lb_1	.88	.87	.82	.82	.75			
Lb_2	.62	.6	.52	.45	.35			
Lb_2^2	.3844	.36	.2704	.2025	.1225			
$Lb_1Lb_2^2$	.338	.313	.222	.166	.0915			
Db in.	.6966	.6790	.6055	.5490	.4506			
Db" cm.	.1272	.1239	.1108	.1005	.0834			
$Db"^2$ cm.^{2}	.01618	.01535	.01228	.01	.00692			
Time in Sec.	0	.43	.86	1.29	1.72			

Fuel - Kerosene
Droplet arrangement - Single
Code No. - L_2
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
L_1	1.17	1.16	1.07	1.06	1.04			
L_2	.78	.74	.67	.6	.5			
L_2^2	.6080	.5475	.4480	.36	.25			
$L_1L_2^2$	.711	.635	.48	.3815	.26			
D in.	.8925	.8595	.7830	.7253	.6383			
D" cm.	.163	.1569	.143	.1325	.1248			
$D"^2$ cm.^{2}	.02657	.02462	.02045	.01756	.01558			
Time in Sec.	0	.43	.86	1.29	1.72			

Fuel - Diesel
Droplet arrangement - Single
Code No. - M_1
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
L_1	1.05	1.02	1.00	.96	.93	.9	.88	
L_2	.8	.76	.73	.69	.65	.59	.53	
L_2^2	.64	.5775	.533	.475	.422	.348	.2811	
$L_1L_2^2$	.672	.59	.533	.456	.3925	.3132	.2471	
D in.	.8759	.8387	.8108	.7697	.7322	.6791	.6275	
D* cm.	.16	.152	.1481	.1404	.1339	.124	.1145	
D^{n^2} cm.^{n}	.0256	0.02341	.02193	.01972	.01793	.01538	.01311	
Time in Sec.	0	.43	.86	1.29	1.72	2.15	2.58	

Fuel = Diesel
Droplet arrengement= single
Code No. = M_2
m_1=6 ;m_2 = 2.32

	1	2	3	4	5	6	7	8
L_1	1.05	1.03	1.00	.97	.97	.95	.92	.96
L_2	.79	.77	.74	.7	.67	.62	.56	.51
L_2^2	.6241	.593	.55	.49	.449	.384	.32	.26
$L_1L_2^2$	.655	.61	.55	.475	.437	.365	.294	.224
D in	.8685	.8481	.8193	.7803	.7577	.7147	.6649	.6073
D" cm	.1585	.1549	.1495	.1425	.383	.303	.1212	.111
$D^{"2}cm^2$	.0251	.024	.02235	.02031	.01913	.01698	.01469	.01232
Time in Sec.	0	.43	.86	1.29	1.72	2.15	2.58	3.01

Fuel - Diesel
Droplet arrangement - Si Double
Code No. - N_{1a} & N_{1b}
$m_1 - 6$; $m2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.03	1.03	1.03	1.01	.98	.95	.92	.86
La_2	.82	.77	.75	.73	.7	.66	.62	.57
La_2^2	.6720	.5930	.5625	.533	.49	.435	.3848	.3249
$La_1La_2^2$	.625	.61	.58	.539	.48	.4105	.354	.2797
Da in	.8761	.8481	.834	.8138	.7830	.7432	.7074	.6540
Da" cm.	.16	.1549	.1521	.1485	.143	.1358	.1291	.1192
$Da"^2$ cm.^{2}	.0256	.02402	.02314	.02204	.02045	0.01844	.01667	.01421
Lb_1	1.01	.95	.92	.87	.85	.82	.80	.75
Lb_2	.72	.67	.65	.63	.60	.55	.50	.4
Lb_2^2	.5180	.4498	.4225	.3963	.36	.3025	.25	.16
$Lb_1Lb_2^2$	.523	.474	.388	.347	.306	.248	.2	.12
Db in.	.8057	.7797	.7299	.7027	.6739	.6283	.5848	.4932
Db" cm.	.1471	.1422	.1331	.1282	.123	.1148	.1067	.09
$Db"^2$ cm.^{2}	.02164	.02022	.01772	.01643	.01513	.01318	.01138	.0081
Time in Sec.	0	.86	1.49	1.72	2.15	2.58	3.01	3.44

Fuel - Diesel
Droplet arrangement - Double
Code No. N_2
$m_1 = 6$; $m_2 = 2.32$

	1	2	3	4	5	6	7	8
La_1	1.07	1.05	1.05	1.05				
La_2	.83	.79	.76	.75				
La_2^2	.689	.624	.5776	.5625				
$La_1La_2^2$	.736	.655	.606	.59				
Da in.	.9029	.8685	.8462	.8387				
Da" cm.	.1649	.1582	.1547	.153				
Da''^2 cm.^{2}	.0272	.025	.02393	.0234				
Lb_1	1.06	1.05	1.04	1.02				
Lb_2	.85	.82	.8	.78				
Lb_2^2	.722	.6720	.64	.6065				
$Lb_1Lb_2^2$	.765	.706	.666	.6195				
Db in.	.9146	.89	.8733	.8524				
Db" cm.	.1669	.1622	.1592	.1558				
Db''^2 cm.^{2}	.02785	.02631	.02534	.02427				
Time in Sec.	0	.43	.86	1.29				

Fuel - Diesel
Droplet arrangement - Triple
Code No. P_2
m_1 -6 ; m_2 - 2.32

	1	2	3	4	5	6	7	8	9
La_1	1.08	1.00	1.00	.95	.95	.90	.85	.85	.8
La_2	.79	.76	.75	.72	.70	.67	.66	.63	.56
La_2^2	.624	.5776	.5625	.5184	.49	.4489	.4225	.3969	.3136
$La_1La_2^2$	.675	.5776	.5625	.4925	.465	.404	.349	.337	.2535
Da in.	.8772	.8328	.8255	.7897	.7757	.739	.704	.6959	.6329
Da* cm.	.1604	.1521	.151	.144	.1413	.1349	.1282	.1272	.1157
Da^{*2} cm.^{2}	.02573	.02313	.0228	.02074	.01997	.0181	.0169	.01618	.01339
Lb_1	1.1	1.05	1.00	.95	.95	.95	.9	.87	.82
Lb_2	.71	.68	.67	.65	.62	.56	.55	.51	.46
Lb_2^2	.5041	.4624	.4491	.422	.385	.314	.3023	.25	.203
$Lb_1Lb_2^2$	.554	.4851	.449	.401	.366	.298	.272	.2124	.1582
Db in.	.8213	.7857	.766	.738	.709	.662	.64	.59	.546
Db* cm.	.15	.1438	.14	.1348	.1294	.121	.117	.108	.0976
Db^{*2} cm.^{2}	.0225	.0207	0196	.0181	.167	.01462	.0137	.01168	.0095
Lc_1	1.10	1.05	1.03	.95	1.00	.95	.93	.90	.85
Lc_2	.77	.75	.73	.71	.66	.62	.60	.56	.49
Lc_2^2	.5929	.5625	.532	.506	.435	.385	.36	.314	.2301
$Lc_1Lc_2^2$	.651	.59	.548	.481	.429	.366	.334	.282	.204
Dc in	.8667	.8387	.8184	.789	.758	.715	.695	.656	.589
Dc* cm.	.1583	.153	.1492	.143	.1383	.13	.127	.12	.1075
Dc^{*2} cm.^{2}	.0250	.0234	.0223	.0205	.0192	.0171	.161	.144	.01175
Time in Sec.	0	.43	.86	1.29	1.72	2.15	2.58	3.01	3.44

Fuel - Diesel
Droplet arrangement - Triple
Code No. Q_1
$m_1 = 6$; $m_2 = 2.32$

	1	2	3	4	5	6	7	8
La_1	.97	.95	.93	.90	.88			
La_2	.96	.74	.72	.69	.66			
La_2^2	.58	.5476	.52	.476	.4356			
$La_1La_2^2$	.561	.52	.479	.428	.384			
Da in.	.825	.8042	.783	.754	.7269			
Da" cm.	.1508	.1465	.143	.1375	.1328			
$Da"^2$ cm.^{2}	.0226	.02146	.0204	.0189	.0176			
Lb_1	1.00	.95	.97	.90	.82			
Lb_2	.58	.53	.49	.47	.43			
Lb_2^2	.3364	.2809	.2401	.2209	.1849			
$Lb_1Lb_2^2$	.3364	.267	.233	.199	.1513			
Db in.	.6955	.6439	.6153	.5838	.5329			
Db" cm.	.127	.1173	.11245	.1063	.0974			
$Db"^2$ cm.^{2}	.01613	.01376	.01266	.01130	.00945			
Lc_1	.9	.82	.81	.82	.80			
Lc_2	.57	.52	.50	.46	.42			
Lc_2^2	.3249	.2704	.25	.2116	.1764			
$Lc_1Lc_2^2$	.2922	.222	.2028	.1734	.1411			
Dc in	.6636	.6055	.5875	.5576	.5206			
Dc" cm.	.121	.1108	.1072	.1018	.095			
$Dc"^2$ cm.^{2}	.01468	.01228	.01149	.01036	.00903			
Time in Sec.	0	.5	1.00	1.5	2.0			

Fuel - Diesel
Droplet arrangement - Triple
Code No. O_2
$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.01	1.00	.95	.92	.93	.92	.9	.88
La_2	.79	.77	.76	.73	.71	.69	.66	.64
La_2^2	.6241	.5929	.5776	.5329	.5041	.4761	.4356	.4096
$La_1La_2^2$	.629	.5929	.549	.49	.468	.4395	.392	.36
Da in.	.8568	.8401	.8188	.7884	.7764	.7602	.7319	.7114
Da" cm.	.1564	.1535	.1494	.1439	.1419	.1391	.1338	.13
$Da"^2$ cm.^{2}	.0245	.0235	.0223	.0207	.02014	.01935	.0179	.0169
Lb_1	1.05	1.02	.96	1.02	1.00	1.00	.98	.98
Lb_2	.72	.69	.66	.64	.60	.57	.53	.50
Lb_2^2	.5184	.4761	.4356	.4096	.36	.3249	.2809	.25
$Lb_1Lb_2^2$	.545	.486	.418	.417	.36	.3249	.2754	.2448
Db in.	.8168	.7862	.7477	.7471	.7114	.6875	.6506	.6256
Bb" cm.	.1491	.1439	.1365	.1362	.13	.1255	.119	.1142
$Db"^2$ cm.^{2}	.0229	.0207	.0186	.01855	.0169	.0157	.01416	.01304
R								
Lc_1	.95	.94	.92	.9	.88	.85	.85	.86
Lc_2	.666	.63	.60	.57	.55	.52	.49	.45
Lc_2^2	.4356	.3969	.36	.3249	.3025	.2704	.2401	.2025
$Lc_1Lc_2^2$	.4149	.3735	.3319	.292	.266	.23	.204	.174
Dc in.	.7458	.7202	.6924	.6634	.6431	.6127	.5887	.5583
Dc" cm.	.1361	.1318	.1265	.121	.1172	.1119	.1072	.102
$Dc"^2$ cm.^{2}	.01852	.01737	0.16	.01464	0.1374	201252	.01149	.0104
Time in Sec.	0	.5	1.0	1.5	2.0	2.5	3.0	3.5

Fuel - Kerosene
Droplet arrangement - Triple
Code No. R_2

$m_1 - 6$; $m_2 - 2.32$

	1	2	3	4	5	6	7	8
La_1	1.00	.98	.93	.91	.87	.86		
La_2	.77	.75	.67	.64	.60	.55		
La_2^2	.5929	.5625	.4489	.4029	.36	.3025		
$La_1La_2^2$	.5929	.545	.4165	.372	.31	.26		
Da in.	.8401	.8168	.7468	.7191	.6768	.6383		
Da" cm.	.1535	.1491	.14	.1311	.1239	.1165		
$Da"^2$ cm.^{2}	.02356	.0223	.0196	.01719	.01535	.01357		
Lb_1	1.00	.98	.95	.92	.42			
Lb_2	.62	.58	.52	.42				
Lb_2^2	.3844	.3364	.25	.176				
$Lb_1Lb_2^2$	.3844	.329	.237	.162				
Db in.	.7271	.69	.62	.545				
Db" cm.	.1329	.126	.113	.955				
$Db"^2$ cm.^{2}	.01766	.01585	.0128	.0099				
Lc_1	.98	.97	.92	.87	.82	.77		
Lc_2	.69	.66	.57	.54	.47	.42		
Lc_2	.4761	.4356	.3249	.2916	.2209	.1764		
$Lc_1Lc_2^2$	.467	.423	.2988	.2536	.161	.136		
Dc in.	.7758	.7507	.6685	.6330	.5657	.5143		
Dc" cm.	.142	.137	.122	.1155	.10304	.0936		
$Dc"^2$ cm.^{2}	.02016	.01877	.015	.01334	.0107	.00876		
Time in sec.	0	.5	1.5	2.0	2.5	3.0		

Fuel - Kerosene
Droplet arrangement - Triple
Code No. - T_3
$m_1 = 6$; $m_2 = 2.5$

	1	2	3	4	5	6	7	8
La_1	1.00	.97	.92	.88	.86	.75	.65	
La_2	.82	.77	.73	.69	.62	.53	.42	
La_2^2	.6724	.5929	.5329	.4767	.3844	.2809	.1764	
$La_1La_2^2$	.6724	.58	.491	.42	.3308	.2105	.1148	
Da in.	.8760	.8340	.7889	.7489	.6916	.5949	.4846	
D_a" cm.	.15	.1449	.1331	.1264	.117	.1003	.0817	
$D_a"^2$ cm.^{2}	.0225	.021	.01772	.01598	.01369	.01006	.00667	
Lb_1	.9	.82	.77					
Lb_2	.46	.39	.32					
Lb_2^2	.2116	.1521	.1024					
$Lb_1Lb_2^2$	.19	.125	.079					
Db in.	.5749	.5	.4291					
Db" cm.	.097	.0845	.07245					
$Db"^2$ cm.^{2}	.0094	.00714	.00525					
Lc_1	.92	.90	.85	.75	.70			
Lc_2	.68	.62	.56	.49	.40			
Lc_2^2	.4624	.3844	.3136	.2401	.16			
$Lc_1Lc_2^2$	.425	.346	.266	.1805	.112			
Dc in.	.7519	.7020	.6431	.5651	.4820			
Dc" cm.	.127	.1189	.1086	.0956	.0815			
$Dc"^2$ cm.^{2}	.01613	.01414	.01179	0.00913	.00664			
Time in Sec.	0	.3	.6	.9	1.2	.15	1.8	

Fuel - Kerosene
Droplet arrangment - Triple
Code No. - U_2
$m_1 = 6$; $m_2 = 2.5$

	1	2	3	4	5	6	7	8
La_1	.92	.85	.81	.75	.65			
La_2	.67	.62	.54	.46	.36			
La_2^2	.4489	.3844	.2916	.2116	.1296			
$La_1La_2^2$	.413	.327	.236	.1586	.0843			
Da in.	.7447	.6889	.6180	.5413	.4385			
Da" cm.	.1259	.1162	.1045	.0915	.0741			
$Da"^2$ cm.^{2}	.01585	.0135	.01092	0.00837	.00549			
Lb_1	.95	.92	.89	.77	.67			
Lb_2	.66	.60	.52	.43	.34			
Lb_2^2	.4356	.36	.2704	.1849	.1156			
$Lb_1Lb_2^2$	.415	.3313	.2408	.142	.0775			
Db in.	.7459	.6920	.6221	.5217	.4264			
Db" cm.	.1262	.117	.1052	.0881	.0721			
$Db"^2$ cm.^{2}	.01593	.01369	.01107	.00776	.00519			
Lc_1	.85	.85	.80	.67				
Lc_2	.62	.56	.49	.36				
Lc_2^2	.3844	.3136	.2401	.1296				
$Lc_1Lc_2^2$	.327	.266	.1923	.0868				
Dc in	.6889	.6431	.5772	.4428				
Dc" cm.	.1163	.1088	.0975	.0747				
$Dc"^2$ cm.^{2}	.01353	.01184	.0095	.00558				
Time in Sec.	0	.3	.6	.9	1.2			

Fuel - Kerosene
Droplet arrangement - Single
Code No. - W_2
$m_1 - 6$; $m_2 - 2.5$

	1	2	3	4	5	6	7	8
L_1	.97	.95	.95	.94	.88	.85		
L_2	.75	.68	.62	.57	.50	.41		
L_2^2	.5625	.4624	.3844	.3249	.25	.1681		
$L_1L_2^2$	.545	.44	.366	.305	.22	.143		
D in.	.8168	.7606	.6153	.6731	.6031	.5229		
D^n cm.	.1382	.1288	.121	.1138	.102	.0884		
D^{n2} cm.^{2}	.0191	.01659	.01464	.01295	.0104	.0007815		
Time in Sec.	0	.3	.6	.9	1.2	1.5		

Fuel - Kerosene
Droplet arrangement - Double
Code No. - X_2
$m_1 - 6$; $m_2 - 2.5$

	1	2	3	4	5	6	7	8
La_1	1.06	1.03	1.00	196	.95	.82	.65	
La_2	.76	.71	.66	.61	.55	.45	.32	
La_2^2	.5776	.5041	.4489	.3721	.3025	.2025	.1024	
$La_1La_2^2$	.612	.518	.4489	.358	.2872	.166	.0666	
Da in.	.8490	.8031	.7652	.71	.6597	.5496	.405	
Da" cm.	.1432	.1359	.1295	.12	.1112	.9929	.0685	
$Da"^2$ cm.^{2}	.0205	.01847	.01677	0.0144	.01237	.00863	.00469	
Lb_1	.75	.72	.66	.62	.56	.40		
Lb_2	.64	.57	.52	.46	.38	.27		
Lb_2^2	.4096	.3249	.2704	.2116	.1444	.0729		
$Lb_1Lb_2^2$	.3061	.234	.1785	.131	.0809	.0291		
Db in.	.6739	.6162	.5630	.5079	.4325	.3076		
Db" cm.	.1138	.1042	.095	.086	.073	.0519		
$Db"^2$ cm.^{2}	.01295	.01086	.00902	.00739	.00533	.002694		
Time in Sec.	0	.3	.6	.9	1.2	1.5	1.8	

Fuel - Kerosene
Droplet arrangement - Double
Code No. - X_1
$m_1 - 6$; $m_2 - 2.5$

	1	2	3	4	5	6	7	8
La_1	1.03	1.03	1.00	.85	.70			
La_2	.68	.62	.55	.48	.33			
La_2^2	.4624	.3844	.3025	.2304	.1089			
$La_1La_2^2$	.476	.396	.3025	.196	.0761			
Da in.	.7808	.7343	.6713	.5899	.4238			
Da" cm.	.132	.1239	.1134	.098	.0715			
$Da"^2$ cm.^{2}	.01742	.01534	.01286	.0096	.005112			
Lb_1	.72	.62	.55	.42				
Lb_2	.53	.49	.42	.27				
Lb_2^2	.2809	.2401	.1764	.0729				
$Lb_1Lb_2^2$	.2025	.149	.097	.0306				
Db in.	.5872	.5302	.4595	.3128				
Db" cm.	.0993	.0896	.0775	.0529				
$Db"^2$ cm.^{2}	.00986	.008028	.006	.002798				
Time in Sec.	0	.3	.6	.9	1.2			

Fuel - Kerosene
(combustion)
Signle droplet
Code - Ac

$m_1 = 6$; $m_2 = 1.67$ $T = 717\ ^{o}C$

	1	2	3	4	5	6
L_1	.67	.61	.55	.52	.47	
L_2	.47	.43	.38	.32	.25	
L_2^2	.2205	.184	.144	.102	.0625	
$L_1 L_2^2$	.151	.112	.0792	.053	.0274	
D in	.533	.482	.43	.376	.3082	
D cm	.135	.122	.1088	.095	.078	
D^2 cm	.0182	.0148	.0118	.00902	.0061	
Time in sec.	0	.2	.4	.6	.8	

Kerosene

Code - Bc

(combustion)

Double droplet

$T = 709^{\circ}C$

$m_1 = 5.5$; $m_2 = 1.67$

	1	2	3	4	5	6	7
La_1	.72	.70	.67	.63	.60	.55	.50
La_2	.55	.50	.46	.42	.36	.30	.25
La_2^2	.302	.25	.212	.176	.1295	.09	.0625
$La_1La_2^2$	.216	.175	.142	.111	.0777	.0495	.0312
D in	.6	.56	.522	.481	.426	.368	.315
D cm	.166	.155	.1445	.1332	.118	.099	.0872
D^2cm	.0275	.024	.0209	.0178	.0139	.0098	.0076
Lb_1	.5	.45	.43	.36			
Lb_2	.4	.36	.30	.25			
Lb_2^2	.16	.1295	.09	.0625			
$Lb_1Lb_2^2$	.08	.0582	.0387	.0224			
D in	.431	.388	.338	.282			
D cm	.1198	.1075	.0935	.078			
D^2 cm	.0143	.0116	.00875	.0061			
Time in sec.	0	.2	.4	.6	.8	1.0	1.2

A P P E N D I X - II

* Specification of the fuel
* Nomenclature
* Bibliography.

Specification of the Fuel

Test	Kerosene	Diesel
Specific gravity at 60°F	0.786	0.832
ASTM Distillation		
10% point	302°F	356°F
90% point	422°F	630°F
Viscosity at 100°F Saybolt second	—	46
Carbon residue %	—	0.05

NOMENCLATURE

A	= Convection effect
B	= Transfer number
C	= Specific heat
C_o	= Concentration of vapour in equilibrium with the droplet.
C_∞	= Concentration of vapour of infinite distance from the droplet.
D	= Diameter of the droplet.
δ	= Diffusion co-efficient.
k	= Thermal conductivity.
K	= Evaporation constant.
m	= Mass fraction concentration
mj	= Mass fraction of component 'j'
Pf	= Partial pressure
R	= Radius of the drop
Re	= Reynolds number
Sc	= Schmidt criterion
t	= Time
T	= Temperature
U	= Velocity of flow in ' y ' direction
V	= Stream velocity
Kc	= Coefficient of vapour diffusion into the surrounding medium
h	= Height of the spherical segment
ρ_L	= Density of the liquid drop
ρ_g	= Density of gas
a	= Amount of radient heat absorbed per unit mass of fuel evaporated
ΔH	= Total amount of heat necessary to evaporate the fuel
J	= A function of heat absorption and temperature
B'	= Radiation effect
C_1	= Absorption of heat
Z	= Function of the radius
ζ	= A function of thermal conductivity and specific heat.
V_s	= normal velocity of the surface.
θ	= $\frac{T - T_o}{T_g - T_o}$ fractional accompolished temperature
$\dot{m}''$	= Mass of component j transferred across unit area in unit time.

Subscripts

b	= burning time
B	= boiling point of the fuel.
g	= In the gas phase
s	= at the drop surface
0	= Initia state.

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