ANALYSES OF THE COMBUSTION PROCESSES IN GAS TURBINES*

* Paper presented at the IV International Congress of Combustion Processes, Zurich 1957

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Combustion of a hydrocarbon requires the previous evaporation and mixture with oxygen. In a combustion chamber of a turbine combustion may take place in many diverse ways.

If the hydrocarbon vapors form an almost homogeneous mixture with air before combustion, combustion may be effected by a flame laminar or turbulent according to the circumstances across the mixture.

The propagation of flames laminar as well as turbulent has been the subject of intense studies in the last years, particularly because of its great interest in aviation propulsion systems. There exists an extensive bibliography in both the intrensic properties in the establishment of such flames in the rapid currents that obtain in combustion chambers of turbines and after burners. Typical examples of the bibliography are given in references (1) and (2) indicating theoretical and experimental studies of laminar flames of hydrocarbons and references (3) and (4) for turbulent flames and (5) and (6) on studies of the problem of establishing one or the other in rapid currents. In each one of the references found in the bibliography are found a complementary bibliography on these questions, knowledge of which is rudimentary because of the complication of the problem. The velocity of propagation of a laminar flame across a mixture of combustible vapors and air is independent of the pressure and is of the order centimeters per second. (1) That of a turbulent flame may be several times higher but at the most of some meters per second. This presents grave needs for space in order to burn such mixtures, particularly if the limitations imposed by the mentioned phenomenon of stabilization are taken into account and by those of the thermal blockade. (7)

When combustion is produced in a very intense turbulent zone the mixture between reactants and products makes the concept of a flame front disappear, a combustion almost homogeneous of the mixture obtains. The ideal limit of such type of combustion corresponds to the so-called perfectly mixed homogeneous reactor studied theoretically by Avery and Hart (8) and by DeZuboy (9) and whose practical realization was approximated in the spherical burner of Longwell (10). The homogeneous combustion chamber determines the maximum energy that may be liberated per unit volume in a combustion chamber. Longwell in his spherical combustion chamber reached rates of the order of 4×10^9 Kcal/m^3 per hour at ambient pressure with a stoichiometric mixture compared with the 2×10^6 Kcal/m^3 per hour which is characteristic of combustion chambers of industrial gas turbines.

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When the combustible penetrates in the liquid state into the zone of combustion of the chamber, evaporation, mixing of the vapors with the air and combustion are going on simultaneously starting some of the following types of combustion according to the circumstances.

a. Propagation of a flame of similar characteristics similar to the premixtures mentioned in the No. 1 across the cloud formed by the suspension of small droplets of the combustible in the air.

b. Formation of individual flames around or in the wake of the drops.

The first type of combustion is produced when the size of the drops is so small that they are able to evaporate in the heated zone of a premixed flame. This occurs with drops with a diameter of the order of 5 microns or less. Experiments made by Browning Krall (11) with clouds formed by drops of propane or kerosene with drop diameters less than 1 micron indicate that the characteristics of such flames are very similar to the premixed flames of the same fuel. For example, the velocity of the laminar flame is slightly less caused without doubt by the heat of vaporization of the drops. These flames of carbon dust and other solid fuels present characteristics similar to the foregoing. One essential difference rests without doubt in the prepondurate influence of the heat transmitted by radiation in the dust flames which makes the velocity of flame across dust mixtures dependent not only on the air/fuel relation but also and very considerably by the size of the particles of combustible and by the geometry of the flame (12 to 14). The study of such flames has great practical interest because of the possible employment of coal dust in the combustion chambers of industrial turbines.

The second type of combustion is that which is produced when the size of the drop exceeds several microns and it is that which is going to be considered in the following with considerable detail from the theoretical point of view as well as experimental.

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The combustion of a drop of combustible is a very complicated phenomena in which concurrently occur processes of heat transmission by radiation and convection in the atmosphere that surrounds the drop and at the same time the evaporation of the drop, the diffusion and mixing of the vapors and gases and finally the ignition and chemical reaction all of which is taking place in an environment which is not stationary. In studying the process the principal object of analysis consists of determining the conditions under which combustion may exist and the time required in burning a drop of a given size, that is to say, the life duration. One or the other depends on the physical chemical properties of the combustible and the atmosphere around it and of the state of movement relative to both. S. S. Penner (15) in a simplified dimensional study of the phenomenon enumerated 23 distinct dimensionless parameters. This constitutes an indication of the complication of the process.

Nevertheless, in the most simple case of combustion of an isolated drop in the ___________ atmosphere of a cavity in which is formed a flame of diffusion surrounding the drop it is possible to make a schematic model of the phenomenon which represents the model very approximately to the real case and is susceptible to theoretical study. Such a model is based on the following two considerations:

a. That combustion is effected in the vapor phase and the density of the liquid is much greater than the former for that reason combustion once initiated may be treated as a phenomon almost stationary.

b. The mixture of oxygen and vapors is effected by laminar diffusion of reaction at the high temperature that prevails in the flame and which permits the elimination of the chemical kenetics applying the classical method of Burke and Schumann (16) to the flame diffusion that forms around the drop. With such a hypothesis and if moreover the influence of free convection due to the heating of the gases is disregarded the model of combustion that appears in schematic form in Figure 1 is obtained.

Surrounding the drop is the form of a flame of very small thickness diagrammed by a spherical surface whose radius is several times larger than the radius of the drop. Toward the flame are diffusing the vapors of the combustible from the interior and oxygen from the exterior. The

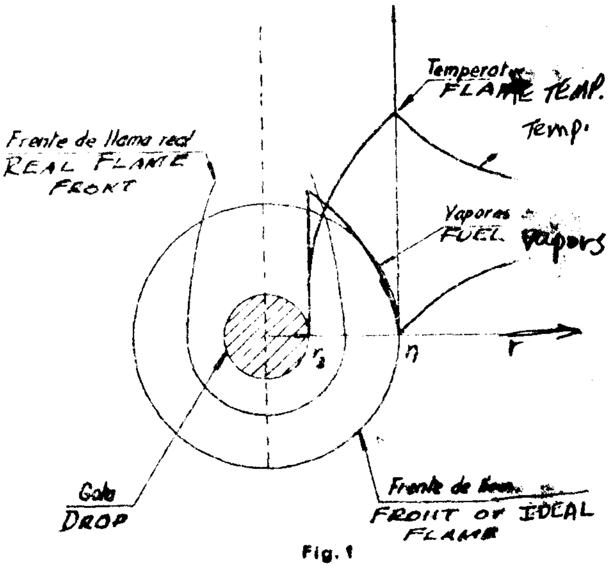

Fig. 1

diffusion is produced across an atmosphere of inert gases and products. These in their turn diffuse from the flame toward the exterior. The flame supplies the heat necessary for the evaporation of the combustible. The concentration of the vapors of the combustible and of oxygen in the flame are practically nil because both are consumed almost instantaneously on arriving at the flame because of its elevated temperature. This model was proposed by Godsave (17). A theoretical study completing the process based on the model may be found in reference (18).

Letting P_c signify the density of the liquid combustible, d the instantaneous diameter of the drop, m the mass of the combustible burned in unit time at each instant a simple calculation gives

$$\frac{m}{d} = -4\pi . P_c \frac{d(d^2)}{dt} \qquad (1)$$

$$\frac{m}{d} = -4\pi . \rho_c \frac{d(d^2)}{dt}$$

The fundamental result of the analysis is that d^2 is a linear function of the time t of combustion of the form.

$$d^2 = d_i^2 - Kt$$

$$d^2 = d_i^2 - Kt \qquad (2)$$

in which K is a constant of evaporation which depends only on the physical chemical characteristics of the process, d; the diameter of the drop at the instant combustion is initiated and t the time measured starting from this instant.

The previous result has been obtained from the hypothesis that the heat that the drop receives by radiation originates from the flame or from the walls of the combustion chamber is insignificant.

Calculations by Godsave (17) and by Hottel and his collaborators (19) show that such heat is small compared to that which the drop receives by convection, in all cases of practical ~~e~~interest.

From the equations of (1) and (2) there results

$$m = 4 \pi P_c Kd \qquad (3)$$

$$m = 4 \pi \rho_c Kd \qquad (3)$$

This shows that the mass burned per unit time is not proportional to the surface of the drop.

This is due to the approach of the flame front to the surface which hastens the evaporation. This attribute~~s~~ emphasises the interest in good atomization. In effect diminishing the size of the drops from the jet stream hastens combustion not only because the available liquid surface is increased but also the combustion per unit surface is more rapid.

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Numerous experimental measurements have been made under conditions that tend to reproduce Figure 1. Three of the techniques utilized with diverse methods are

a. Combustion of drops that fall freely or are thrown through the atmosphere (19). This method is appropriate to drop sizes comparable to those which are obtained in a combustion chamber but the results appear to be masked by the influence of the forced convection, owning to the movement of the drop to which reference has been made previously.

b. Combustion of drops suspended from a fine filament of silicon or quartz (17) with which are eliminated the inconvenience of the forced convection but the drops must be relatively large ($d \geqq 1$ mm) in order to eliminate the influence of the filament.

c. The employment of metallic spheres fed by the combustible by various procedures (20). With this method are obtained constant diameters and a really stationary and easy to control but must be used with very large diameters.

All of the experimental results confirm the lineal law of equation 2. Figure 2 shows some experimental results obtained in the combustion laboratory of INTA or taken from reference (21). It may be verified moreover that the experimental values of the constant of evaporation coincide very closely with the theoretical values. This may be seen in Table 1 (18) in which they are compared for some typical fuels.

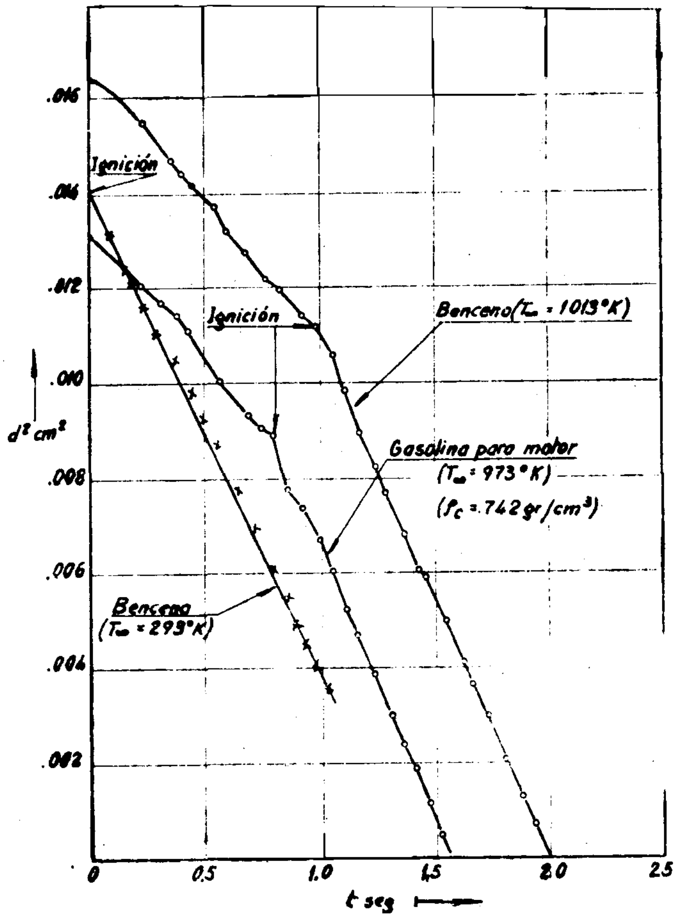

Fig 2

TABLA I

Combustible	K. cm²/seg. Teórico	 Exper.
n-Heptano	0.86×10^{-2}	0.97×10^{-2}
Benceno	1.00×10^{-2}	0.97×10^{-2}
Tolueno	0.87×10^{-2}	0.66×10^{-2}

Table 2 gives the values of K for a large variety of combustibles both simple and compound including the temperatures in which it was measured.

TABLA II

Combustible	K. cm²/seg.	T°K
Alcohol metilico	1.60×10^{-2}	1073
Alcohol etilico	0.99×10^{-2}	973
n-Heptano	1.16×10^{-2}	973
Isoctano	0.90×10^{-2}	973
Benceno.	1.00×10^{-2}	1000
Tolueno	0.91×10^{-2}	1000
Cetano	1.44×10^{-2}	973
Cicloexano.	1.02×10^{-2}	973
Metilnaftaleno	1.04×10^{-2}	973
Nitrobenceno.	1.02×10^{-2}	973
Gasolina motor	1.10×10^{-2}	973
Keroseno	1.12×10^{-2}	973
Aceite Diesel.	1.11×10^{-2}	973
Aceite pesado (ρ_c=0.918 gr/cm³) . . .	$1.05\times10^{-}$	968
Aceite pesado (ρ_c=0.864 gr/cm³) . . .	0.93×10^{-2}	973

The formula (2) gives the time of life t_v of a drop of initially of diameter d_i

$$t_v = \frac{d_i^2}{K} \qquad (4)$$

In Figure 3 are given the life span of drops of diameters between 10 and 200 microns for some of the fuels given in Tables 1 and 2. In the calculations the experimental values of the constants given in these two tables have been used.

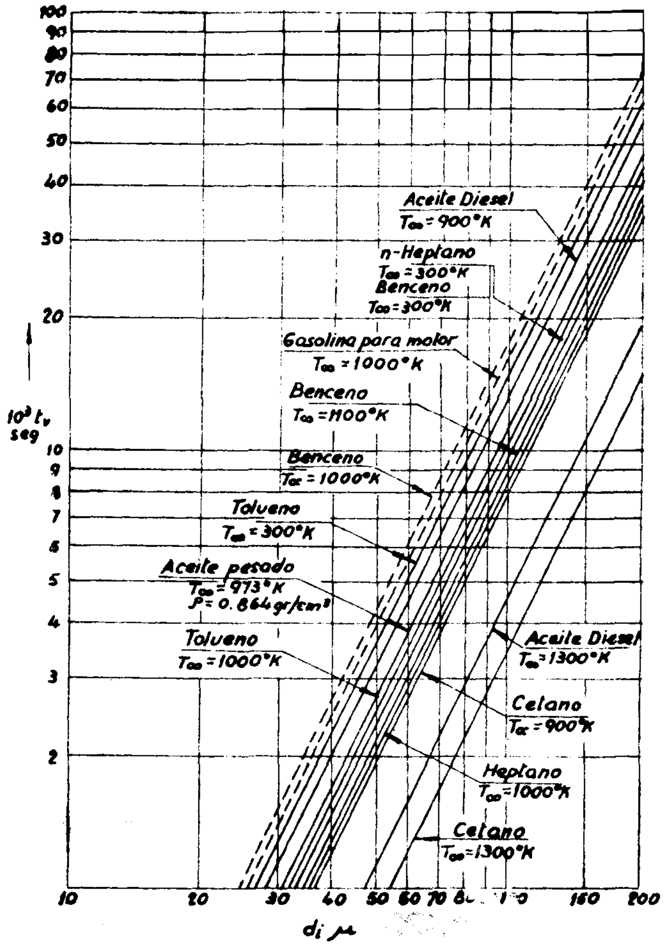

Fig. 3

If the fuel evaporates without combustion the lineal law 2 applies but the value of the constant of evaporation is less, which prolongs the time of life of the drop. At a temperature of the order of 1000°K the constant of evaporation without combustion is approximately 1/2 that of evaporation with combustion. At lower temperatures it is several times less. In Figure 3 have been included lines for drop lives that evaporate without combustion for typical fuels. These lines have practical interest because it may occur that the drops may not be able to maintain a surrounding flame in spite of the fact that the temperature of the atmosphere that surrounds them is higher than that required for combustion perhaps for lack of oxygen or because the drop is moving sufficiently rapidly across the atmosphere. (See paragraph 14 following)

When a drop of fuel penetrates into an oxidizing atmosphere heated to a temperature to that required for ignition of the drop there exists a transition period before the initiation of combustion which is composed of 2 parts. First the drop is heated expanding itself until its surface reaches a temperature near that of ebollution. In this phase the evaporation is very small but the diameter increase. When the temperature of the drop approximates the temperature of evollution intense evaporation is produced but without combustion. Both phases appear clearly in the higher curves of Figure 2. The transitory effects increase the life span of the drop by a fraction that lies between 15% for light fuels to 50% for more heavy fuels, at a temperature of the order of 1000°F.

In compound and heavy fuels the formation of interior bubbles of vapor and cracking can mask the lineal law 2 giving place to curves of d^2vst or irregular form like that shown in Figure 4 taken from reference 21. Nevertheless the life of a drop approximates being proportioned to the square of its diamater and one may continue to apply the law 4 in which K will be in this case an apparent constant of evaporation for the drop.

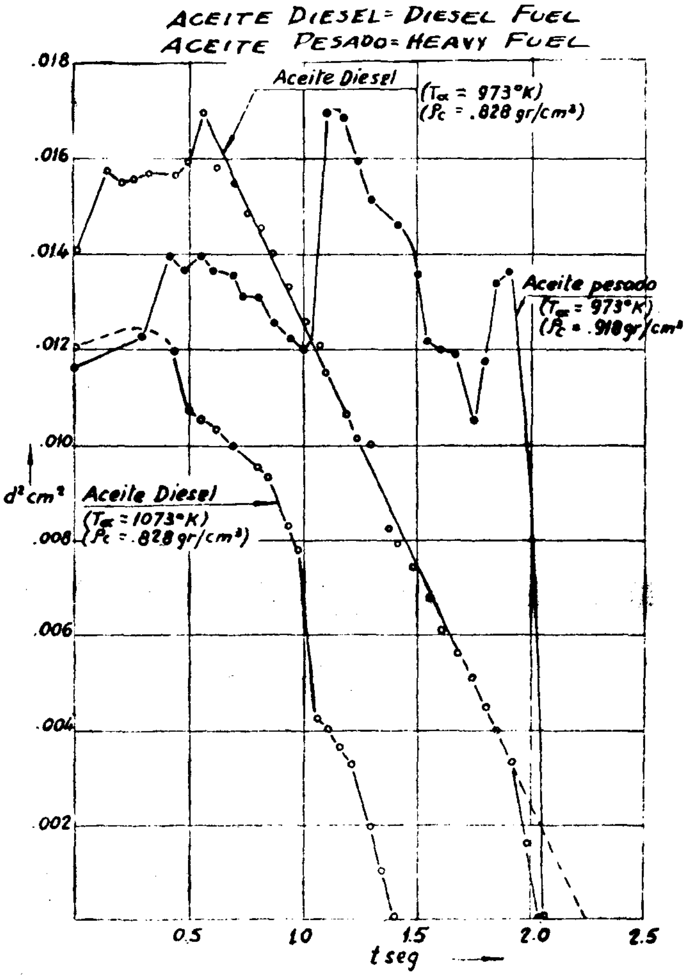

Fig. 4

The values of Tables 1 and 2 show that the constant of evaporation varies relatively little between fuels particularly if the enormous difference between the volatilities of the fuels is considered. As the quantities of air necessary for combustion of these fuels differ also by small quantities the result is that the system of combustion is particularly suitable to burn any class of fuel and for this reason is more adequate in industrial applications in which economy plays an important role.

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Figure 5 (Ref. 21) shows the influence of temperature of the atmosphere that surrounds the drop on the constant of evaporation. The abrupt fall that is observed at temperatures higher than 1000° corresponds to the influence of disassociation when the temperature of the flame is in that zone will be above 3000°K. The influence of the ambient temperature on the value of K in the zone of interest is somewhat less than the influence of said temperature on the velocity of propagation of a premixed flame.

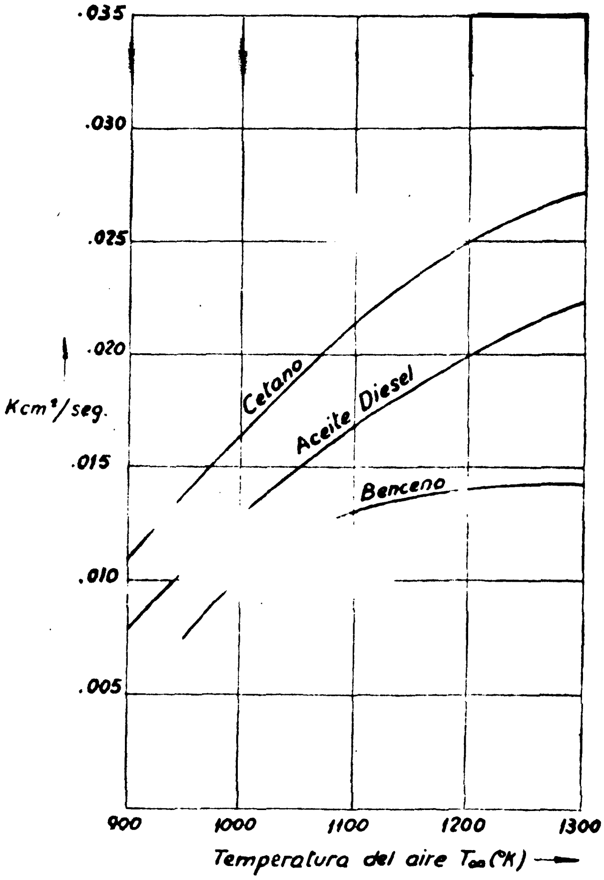

Fig. 5.

The value of K increases from 15 to 20% for each 100°C rise in temperature.

The volume V of air required by a drop of diameter d for combustion is

$$V = 4/3 \pi d^3 v \frac{P_c}{P_a} \quad \text{in which}$$

v is the weight of air per unit weight of fuel in a stoichiometric mixture and P_a is the __________ of the air. Since the mass m burned in unit time is given by (3) the heat liberated per unit volume per unit time is

$$\frac{qm}{V} = \frac{3q\,K\,P_a}{vd^2} \qquad (5)$$

$$\frac{q\,m}{V} = \frac{3q\,K\rho_a}{v\,d^2} \qquad (5)$$

in which q is the heating value of the fuel per unit of mass. This says that the heat liberated is directly proportional to the density of the air and inversely proportional to the square of the drop diameter which again shown the great importance of good atomization and the convenience of burning under pressure in order to hasten combustion.

Using typical values of this physical chemical constant there is obtained from (5) burning rate of the order of 10^8Kcal/m^3 per hour when the temperature of the air is some 1000°K for drops of 100 microns in diameter. This value is some 40 times less than that which may be obtained in a homogeneous ideal burner but it demonstrates the efficacy of the system of small drops and is some 50 times larger than the value obtained in an industrial turbine.

Theoretical results indicate that K as well as the relation between the radius of the flame and of the drops are practically independent of the pressure (22). There exists little experimental information about the influence of pressure on the combustion of a drop. The most complete work about this point is that by Hall and Diederichen (23) who tested with drops suspended and pressures in the range of 1 to 20 atmospheres showing that the constant of evaporation increased approximately as the 1/4 power of the pressure. This effect has been attributed to various causes (18) but especially to the influence of free convection that is produced because of the heating of the gases around the drop. This combustion hastens the combustion because the flame draws near the drop, as is shown in the schematic of Figure 1.

The quantative study of the possible influence of free convection is of interest to judge the value of the experimental results since if this influence is considerable the coincidence between theoretical and experimental values may be accidental. The question is very complicated and its technical interest limited for that reason we have limited only indicated in the bibliography (19) and (24) advice that the only experimental information concerns measurements in the absence of free convection (24) appears to indicate that its effect is considerable.

Major technical interest is found in the study of the influence of forced convection because in all technical applications the drops are in movement.

Frössling (25) proposed a semiemperical formula to calculate the influence of forced convection in the evaporation without combustion of a drop. Letting m^1 be the mass evaporated per unit time under the influence of forced convection and m that which would be evaporated without convection

The formula of Frössling gives $\frac{m'}{m} = (1 + 0\,3\; Sc^{1/3}\, Re^{1/2})$. (6)

$$\frac{m^1}{m} = (1 + 03 S_c R_e^{1/2})$$ expresión, $Sc = \frac{\mu}{\rho D C_p}$ y $Re = \frac{\rho_a v d}{\mu}$

in this expression $S_c = \frac{u}{PDC_p}$ and $R_e = \frac{P_a vd}{\_\_\_\_}$

and are respectively the Schmidt number and the Reynolds number of the phenomenon. ___ is the coefficient of viscosity of the atmosphere that surrounds the drop, D the coefficient of diffusion between the vapors of the fuel and air. C_p speciric heat at constant pressure V = velocity of the drop with respect to the atmosphere that surrounds it.

Easily it may be understood that (6) may also be written in the form

$$-\frac{d(d^2)}{dt} = K^1 = K(1+0.3S_c^{1/3}R_e^{1/2}) \qquad (7)$$

in which K^1 is a constant of evaporation with convection and K the corresponding constant without convection. Since K^1 depends on the diameter of the drop through R_e the results of (7) is that in this case the lineal law (2) does not obtain yet when the solutions of (7) draw very near to it for normal values of R_e.

It has been suggested that the rule (7) of Frössling is also applicable to the study of the influence of forced convection in the combustion of a drop when S_c and R_e are assigned these values corresponding to the temperatures prevailing between the atmosphere that surrounds the drop and the flame. This cannot be put down until the presentation of sufficient experimental information in order to decide the question but the information existing (27) suggests the validity of this rule or other similar ones, such as proposed by Spalding (28) and by Ingebo (29).

In INTA a program of theoretical and experimental work on this question has been finished. (30) (31) (This program has been partially ~~particularly~~ subsidized by the European Office ARDC. USAF through its contract No. A.F.61 514-734C with INTA).

Figure 6 taken from Ref. 26 reproduces some of the results obtained with toluene. In it the traces of the curve that correspond to the rule of Frossling have been represented. The measurements made could not be extended higher than the zone explored because of the extinction of the flame, which will be shown later. Figure 6 shows that the forced convection is somewhat effective in hastening the combustion of a drop but if the phenomena of extinction is taken into consideration the time of life of a drop may not be reduced probably more than 30% to 40% as a maximum.

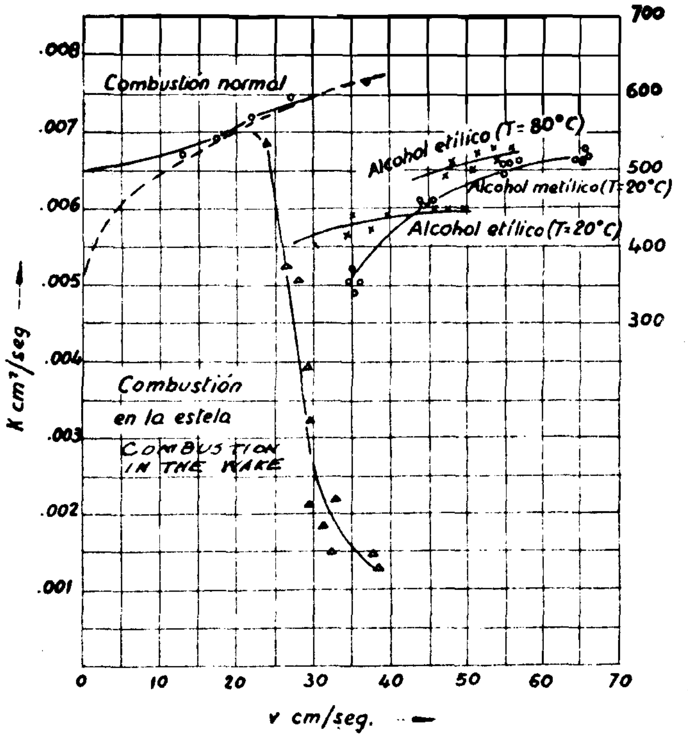

Fig. 6

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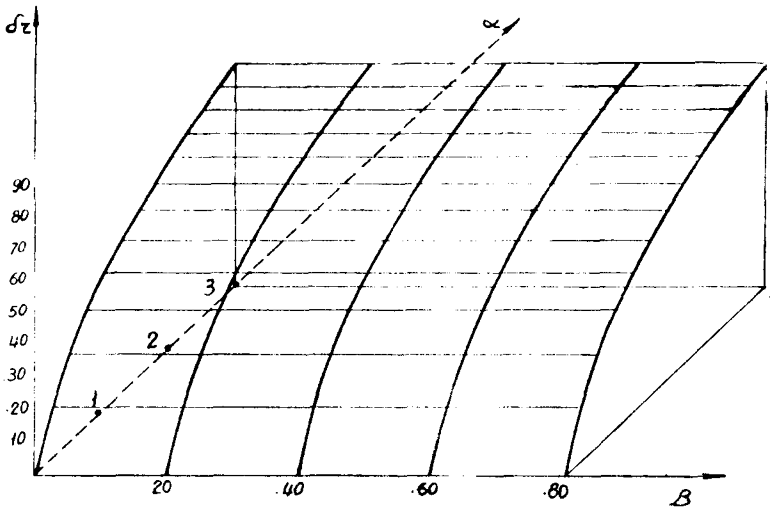
A problem of great practical interest in the combustion of a drop is the determination of the distance of travel or its penetration and of its life time when it moves across an atmosphere of definite characteristics with a certain initial velocity V_1 and it evaporates with or without combustion along its path. The difficulty of the problem rests on the fact the velocity varies because of its aerodynamic resistance. Problems of this type have been studied theoretically and experimentally by others among thom are Miesse (32) (33) and El Wakil and collaborators (34) (In the reference indicated may be found an abundant bibliography on the question). Taking as a base these studies and supposing that the formula of Frossling is applicable the reduction in life time and the penetration has been calculated for a drop that moves under the conditions indicated. (The authors take pleasure in expressing gratitude to Sr. Da Riva for his valued cooperation in making the calculations) The coefficient of resistance of the drop is inversely proportional to the Reynolds number of the movement for the interval of Reynolds numbers of practical interest. In this case equation 7 may be integrated in explicit form and starting this solution the life span of the drop may be calculated. The fundamental result is condensed in Figure 7. In this figure St is the reduction of the life span of the drop taking as unity the life span in a quiet atmosphere, α and B are two parameters defined by the following expressions.



$$\alpha = .3 S_c{}^{1/3} Re_i{}^{1/2}$$

$$\beta = 9 \frac{\mu}{K \rho_c}$$

$$\alpha = 0.3\ Sc^{1/3}\ Re_i{}^{1/2}, \qquad (8)$$

$$\beta = 9 \frac{\mu}{K \rho_c} \qquad (9)$$

in which R_{ei} is the initial Reynolds number and the rest of the parameters have previously been defined.

Figure 7 shows that the fundamental variable in the life is the parameter α while the influence of B is very small. The Schmidt number varies little from one fuel to another and has values of about 2. For this reason the important variable is the Reynolds number.

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The foregoing conclusions are valid as has been said if evaporation is produced with or without combustion.

If the evaporation is without combustion the life span is increased doubling itself for temperatures of the order of 1000°K. This problem is interesting for if the velocity exceeds a certain value the flame front is extinguished. Then the combustion of the drop takes place in the wake which reduces considerably the value of the constant of evaporation as is shown in Fig 7, or it may be totally extinguished in which case the drop is evaporated without combustion. Spalding (28) has pointed out that the fundamental variable for extinction is the relation $\frac{v}{d}$ between the velocity of the movement and the diameter of the drop. Fig 6 gives also such an example, some experimental values that we have obtained in this relation. The measurements were made at or near ambient temperature and the indications are that the value of $\frac{v}{d}$ corresponding to extinction increases considerably with the temperature.______________________________ for drop whose diameters are of the order of 100 microns or less extinction is produced at velocities of some centimeters per second. This signifies that ~~[illegible]~~ evaporation is produced without combustion in most cases of practical interest, the vapors burning later on mixing with air in one of the modes indicated at the beginning. Nevertheless the problem is not sufficiently clear.

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Another important question is the influence of the proximity of other drops on the velocity of combustion of each. There exist some preliminary experimental studies on this question (36) (37) and (38) which demonstrate that the interaction is small unless the drops are very close to each other and are very numerous. Fig 8 shows the results of two cases of interaction (37) and (38)

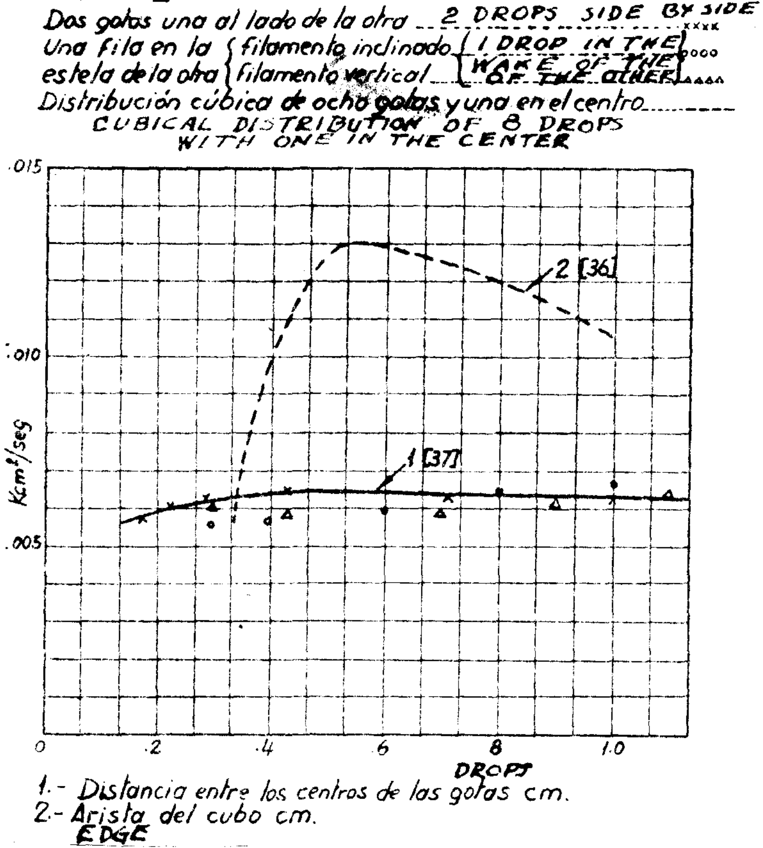

Fig. 8

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The preceding analysis furnishes the basic information to attempt a study of major practical interest, that of combustion of a jet of fuel. It turns out to be difficult, nevertheless, to know how such information ought to be used in the attempt such study and logically the answer ought to depend on the particular characteristics of each burner, the configuration of the currents in the primary zone of the chamber which vary widely from one to the other.

During the last years there has been great activity in accumulating information principally experimental about the combustion of streams of fuel. Frequently such information has referred only to partial aspects of the problem, most easy to study like the statistical characteristics of the streams (39) (40) their dynamics (41) (42) and (43) the diffusion and mixture of the drops with the atmosphere that surrounds them (44) and (45) its evaporation without combustion (41) (42) and (46) and finally the combustion (47) (48) (49) (50) (51) ~~has been observed~~

Some of such experiments have been made with ideal streams in which all the drops are of the same size.

The measurements made have referred generally to the gross characteristics of the stream, although in some cases the behavior of individual drops has been observed. Such observations have shown that to attempt to generalize the results obtained with isolated drops with those of streams difficulties appear concerning the values that should be assigned to characteristic parameters which are not well determined.

Various works of review principally directed toward the burner for reaction motors were presented in the two meetings for A. G. A. R. D. in 1954 (52) (53) (54)

The methods that have been followed for the study of combustion of streams may be put in three groups.

a. Methods based on the extension of the results obtained in studying the combustion of isolated drops. The take off point for such studies is established in the theoretical work of Probert (47).

Graves and Gerstein (53) have calculated some examples of the application of this method to determine the efficiency of combustion and the influence of parameters such as the value of the constant of evaporation or the concentration of oxygen. Another example may be found in Ref (51). The comparison between the experimental results and those redicted by this method are not conclusive making it necessary to continue the theoretical work as well as experimental in this direction.

b. Extension of methods employed in the study of turbulent flames, diffusion of gases, of heterogeneous combustion of jet streams. An example of this method is found in Ref (50). The problem consists of determining the geometrical location of the points in which fuel and oxygen are mixed in stoichiometric proportions.

c. Finally methods based on the study of the influence of some characteristic parameters of the stream and of the atmosphere in which it burns, in the characteristics of the combustion and the efficiency of combustion. Examples of the applicatian of this method are found in Ref (52) and (53). Thus when emperical information is secured by this method of great value nevertheless the results have limited application because they depend considerably on the configuration utilized. For this reason it would be advisable to accumulate preliminary information concerning the influence of some fundamental parameters that may be varied in a systematic way in simple and well defined configuration as has been done for example by Woodward (57).

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We have done (57) some theoretical work on the application of Probert's method in which has been considered both the stationary functiong region and transitory that corresponds to the beginning of combustion of the stream the alternate corresponding to periodic combustion.

In this work it has been supposed that all of the drops have the same constant of evaporation. How ligitimate this hypothesis is and the value that ought to be assigned to this constant if it is valid depends on the results of experimental measurements now in preparation. In these the size distribution function of drops of Mugele-Evans has been used and considered preferable to that of Rosin-Rammler and Nukiyama-Tanasawa because it permitted a prediction with close approximation and moreover limited the maximum size of the drops. Let F be the fraction of volume of the stream formed by drops whose diameter is less than d. The formula of Mugele-Evans gives for F the following expression

$$F = \tfrac{1}{2}\left[1 + \Phi\left(\varepsilon \ln \frac{\Theta d}{d_{max} - d}\right)\right]$$

$$F = \frac{1}{2}\left[1 + \Phi\left(\varepsilon \ln \frac{\Theta \, d}{d_{max} - d}\right)\right]$$

In this expression Φ is the integral error d_{max} is the maximum diameter of the drops ε and Φ are two characteristic parameters of the distribution. Fig 9 gives some distributions corresponding to typical values of these paramsters. In this figure it is seen that increasing ε increases the uniformity of the stream while increasing Φ diminishes the mean size of the drops.

If G is the volume of fuel injected in the burner per unit time and g the volume of the drops that exist in the chamber. g is expressed as a function of G by means of the formula

$$g = \frac{\varepsilon I}{\sqrt{\pi}} \cdot G t_v \qquad (10)$$

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in which I is given by the expression

$$I = \int_0^1 x^4 dx \int_0^{1-x} \frac{\exp\left[-\left(\varepsilon \ln \frac{\sqrt{x^2+y}}{1-\sqrt{x^2+y}}\right)^2\right]}{(x^2+y^2)^{3/2}\left(1-\sqrt{x^2+y}\right)} dy \qquad (11)$$

$$I = \int_0^1 x^4 dx \int_0^{1-x} \frac{\exp\left[-\left(\varepsilon \ln \frac{\sqrt{x^2+y}}{1-\sqrt{x^2+y}}\right)^2\right]}{(x^2+y^2)^{3/2}\left(1-\sqrt{x^2+y}\right)} dy \qquad (11)$$

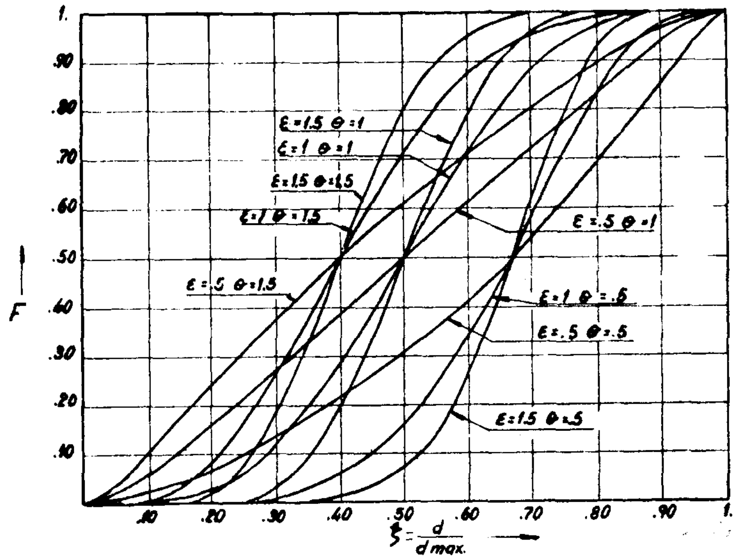
t_v is the time of combustion of the drops of maximum diameter in the stream.

The magnitude of 10 is of interest because the intensity of combustion of the burner should be inversely proportional to it.

As may be seen to increase ε that is to increase the uniformity of the stream diminish the volume of fuel in the chamber. In consequence it is of advantage to operate with streams of the highest possible uniformity in order to diminish the volume of the burner.

Combustion distorts the distribution of the drops in size conserving naturally the largest size. Fig 10 shows the functions of distribution in the flame corresponding to the three cases calculated.

For comparison there has been included in this figure the corresponding distribution in the stream. In Table III have been included the diameters from Sauter corresponding to the stream and the flame.



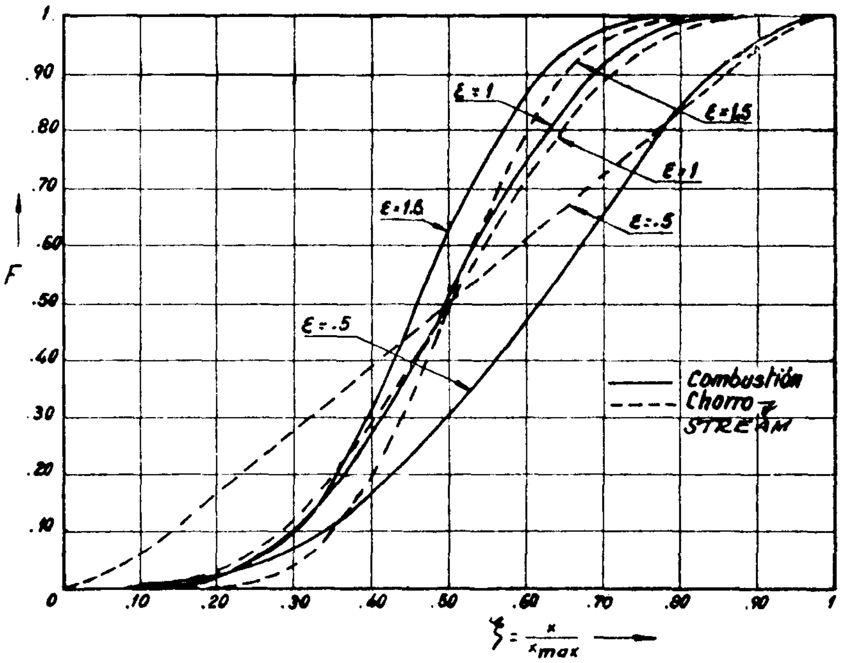


Fig. 10

TABLA III

ε =	0.5	1	1.5
$\frac{g}{G t_v}$ =	0.129	0.110	0.105
$\left(\frac{d_s}{d_{m\acute{a}x}}\right)_{chorro}$ - STREAM =	0.269	0.438	0.895
$\left(\frac{d_s}{d_{m\acute{a}x}}\right)_{llama}$ - FLAME =	0.517	0.454	0.401

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