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Flow structure and heat transfer characteristics behind a diaphragm in the presence of a diffusion flame

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Abstract—The characteristics of the separated flow behind a diaphragm over a burning surface are investigated experimentally. This complex problem of practical significance involving recirculation, blowing and combustion reactions is studied in a two-dimensional combustion tunnel. The flame structure, recirculation patterns and heat transfer to the surface are presented for a range of values of free stream and fuel injection velocities as well as for different heights of the diaphragm. The trends of heat transfer vs axial distance are shown to be similar to those resulting from a non-reactive heated stream with a diaphragm. Treating the case of a boundary layer diffusion flame as that corresponding to the zero height of the diaphragm, the heat transfer augmentation due to recirculation is estimated. It is found that at considerable downstream distances ($x/h > 3$), the heat transfer rates with diaphragm overtake the rates from a developing boundary layer case. Flow visualization studies with particle track photography show that there are many similarities between the reactive and the non-reactive cases.

1. INTRODUCTION

In many combustion problems of practical interest like propulsive devices, steps or diaphragms are introduced above the burning surfaces to enhance the stability of the flame, the regression rate of the fuel and/or the combustion efficiency. Also in many cases of fires over solid and liquid surfaces, obstructions to the air flow are inadvertently present in the form of rims and projections acting as flame holders. The blowing effect from the burning surface and the combustion reactions add to the complexity of the recirculating flow field downstream of the diaphragm. Indeed in some practical applications like hybrid rockets and solid fuel ramjets, diaphragms are introduced at such close intervals along the axis of the motor that the usually assumed model of boundary layer combustion becomes questionable. There appears to be no report in published literature wherein the problem is investigated in its entire complexity. One generally comes across either the effect of blowing or of a recirculation zone behind a step but rarely the combination of the two and rarer still those involving combustion.

One class of related studies having one or more features common to the present problem is that of flow and heat transfer in the vicinity of backward facing steps, blockages or orifices. Sparrow and co-workers [1–3], using water as the working fluid, have determined the effect of flow separation on heat transfer characteristics of turbulent pipe flow. The flow separation was induced by (i) an orifice, (ii) a segmental orifice plate causing unsymmetric blockage or (iii) a slat blockage at the inlet of the circular tube. For the first and third cases, measurements showed that the local heat transfer coefficients in the separated, reattached and redeveloped regions were several times as large as those of fully developed pipe flow. In the second case heat transfer coefficients were determined both around the circumference of the uniformly heated tube and along its length. A maximum was noted in the reattachment region of the separated flow.

Seki *et al.* [4] and Sinha *et al.* [5] investigated the reattachment lengths behind a step. They concluded that reattachment lengths vary linearly as a function of Reynolds number. Seki *et al.* [4] assumed the reattachment to take place at the maximum heat transfer point and correlated the reattachment length with step height. Sinha *et al.* [5] studied the variations of reattachment lengths with respect to the separating shear layer being laminar, transition or turbulent in the Reynolds number range of 100–12 500. Aung [6] investigated the laminar heat transfer downstream of the backward step. He reports that the flow and heat transfer conditions with the step deviate from those given by boundary layer theories on a flat plate. He observed that the reattachment point found by flow visualization does not lie at the maximum heat transfer location but is situated upstream from it. It was also shown that the local heat transfer rate monotonically increases across the reattachment point and is less than the flat plate value downstream.

Considering that the present problem involves a wake region destabilized by the blowing effect, it becomes relevant to take a look at the studies involving flow visualization and the vortex pattern in wake flows. Honji [7] and Batchelor [8], for instance studied the nature of vortices that are formed downstream of obstructions. Honji [7] introduced a right angled step like the present investigation and noted the number of vortices formed behind it in the Reynolds number range of 0–500. He located the presence of a main vortex and the formation of many secondary vortices at distinct Reynolds numbers.

The work of Richardson *et al.* [9] on flow studies behind a two-dimensional backward facing step with mass injection from the surface is nearest to the problem under investigation though the former does not involve chemical reactions. The major results were the appearance of a second recirculation zone with the introduction of blowing and that the primary recirculation zone size and strength diminished with blowing velocity.

All these studies deal with separated flow characteristics in terms of reattachment lengths, vortex formations, its mechanism in cold flow or heat transfer characteristics in the hot flow. No data have yet been reported with combustion and blowing present together. The main objective of the present work is to make a study on the heat transfer characteristics and recirculation patterns of the separated flow behind a diaphragm in the presence of a diffusion flame. A comparative study between the cold flow and combustion case with respect to the recirculation pattern has been made. The heat transfer characteristics of the boundary layer and heated stream case are compared with the reactive flow to bring about the distinctive features resulting from the introduction of the diaphragm.

2. EXPERIMENTAL SET-UP

The experimental set-up used in the present investigations is shown in Fig. 1. The subsonic combustion tunnel has provisions for heating the main stream and varying the N_2–O_2 concentration of the free stream. The blower can provide, at the rectangular test section, a velocity of up to 400 cm s^{-1} which is measured by the calibrated venturimeter connected to a projection manometer.

Gaseous fuel from the LPG tank is metered through a rotameter and is injected into the test section through the flat porous plate which also acts as the bottom surface of the test section. The fuel stream can also be diluted with N_2 to any desired extent. A thin diaphragm of adjustable height is located at the leading edge of the porous plate. When the diaphragm is retracted the flow assumes a boundary layer type of flow and when projected into the test section, the flow becomes a recirculating flow.

Flow visualization has been made using the particle track technique. For this, magnesium oxide particles of size range 5–20 μm are seeded into the free stream slightly ahead of the settling chamber. A chopped sheet of light through the mouth of the test section enables particle track photography which is carried

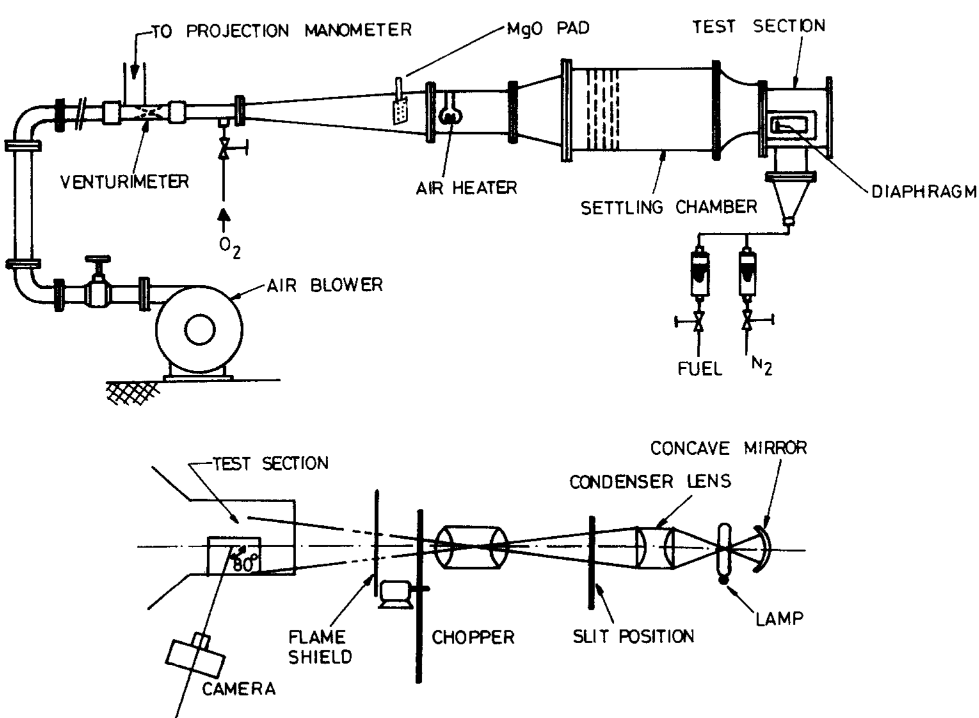


FIG. 1. Experimental set-up.

out with high-speed film. For the flow conditions of the present experiment, the strobing frequency is maintained at 200 Hz. Particle track lengths are measured from the photographs on a micro-film reader whenever the velocity estimations are required. Temperature measurements are made using 200 μm thermocouples of Pt–Pt/13% Rh or iron–constantan depending on the regions of measurement so as to obtain the best resolution. The traverse on which the thermocouple probe is mounted has finer graduation, but in view of the bead size a step of 0.5 mm is made use of for traversing in the y-direction.

2.1. *Data reduction*

While the velocity and temperature (T) could be obtained in a straightforward manner, the estimation of heat flux to the plate required greater care. Making use of the T vs Y data in a thin film near the surface—up to 2.5 mm—the gradient at the surface is obtained by linear regression. In all cases the correlation coefficient was found to be greater than 0.95 indicating that the obtained data predict an accurate temperature gradient at the surface. The value of the surface temperature is also obtained from the regression analysis. An average value of thermal conductivity which is representative of the range of surface temperatures and compositions has been utilized to compute the heat flux. It may be noted that the convective heat flux gauges are too big to make heat flux estimations at such close intervals as reported in the following section. Also, the introduction of heat flux gauges significantly alters the condition at the porous plate.

It is nevertheless necessary that a verification be made for the validity of the above method of estimating heat flux (q). For this purpose, the energy balance at the porous plate surface is made use of. The heat flux from the hot gases to the plate must, at steady state, be absorbed by the incoming cold fuel gas. This can be expressed as follows:

$$\rho_f V_w C_{pf}(T_w - T_{in}) = q'$$

where ρ_f is the density, C_{pf} the specific heat at constant pressure and T_{in} the initial temperature of the gaseous fuel. From this expression, one can estimate q' given the wall temperature, T_w. The values of T_w as obtained from regression analysis are used here to compute the heat fluxes. The specific heat of the fuel in the temperature range of interest is estimated by the standard polynomial expressions, data for which are available in ref. [10]. The heat fluxes obtained (q') agree with the values obtained by the method of surface temperature gradient (q) within 15% which is satisfactory for heat transfer measurements. Within this accuracy range, q' is consistently lower than q probably due to heat losses along and across the porous plate. Indeed q' itself can be used in place of q for all the following discussions since no qualitative change in the heat transfer profiles is noted. This feature is evident in Fig. 2.

3. RESULTS AND DISCUSSION

3.1. *General*

When a diaphragm obstructs the flow over a surface, the flow gets separated at a point upstream of the diaphragm and gets reattached further downstream. Consequently, there are two recirculation zones one in front of and the other behind the diaphragm. Figure 3, which is a photograph taken with a transparent diaphragm, is a good representation of such flows. The emphasis of the present investigation is on the nature and effects of the downstream recirculation and hence, the upstream vortex is not discussed in detail.

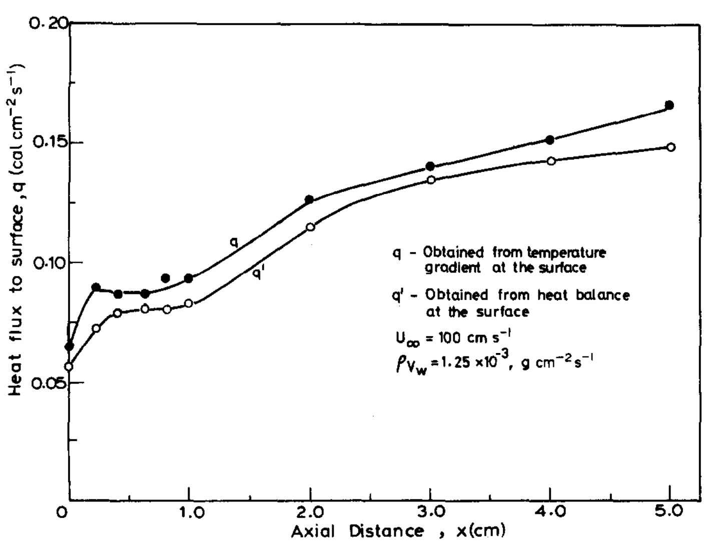


FIG. 2. Comparison between the two methods for heat flux estimation.

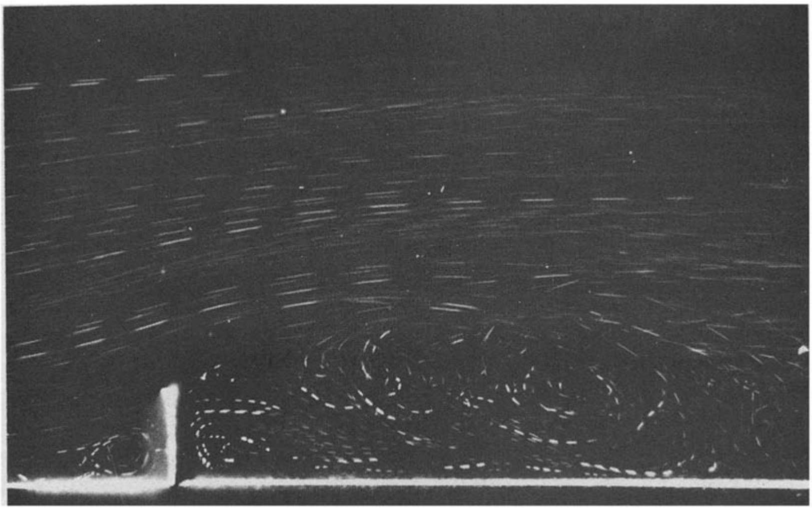


FIG. 3. General flow pattern including upstream vortex.

In spite of the strong recirculating region behind the diaphragm a sheet-like flame appeared anchored on the diaphragm as shown in Fig. 4. When the conditions are altered to see if any other flame structure is admissible, the flame only gets into an unstable condition tending to blow-off. The stable flame sheet does not start exactly from the edge of the diaphragm but after a noticeable gap. The dead space or the base quenching at the leading edge of the flame is attributable to the heat loss from the reaction zone to the diaphragm. The order of the quenching distance observed in the present series of experiments is in the range 2–3.5 mm. These values, measured from direct photographs are of the same order as those in other types of burners (see, e.g. Murthy [11]) and decrease with the extent of dilution. The leading part of the flame following the dead space is blue indicative of premixedness. But the part further downstream is yellowish which is more like a diffusion flame observed in boundary layer combustion.

It was earlier stated that an obstruction-introduced recirculation can support a flame at higher stream velocities than the boundary layer flow. For the present studies where a two-dimensional flow is investigated, it is essential to work with a stable two-dimensional flame structure as in Fig. 4. A stability margin was therefore obtained to describe this feature as well as to fix the range of velocities for the experiments. Ranges of free stream and injection velocities corresponding to stable, unstable and blow-off regimes are determined for different diaphragm heights beginning with $h = 0$. With non-zero h, the flow pattern is completely altered and so are the stability boundaries. It may be noted that the boundaries for the recirculating flow are not so marked as for the boundary layer flame. Also, the blow-off velocities for $h > 1$

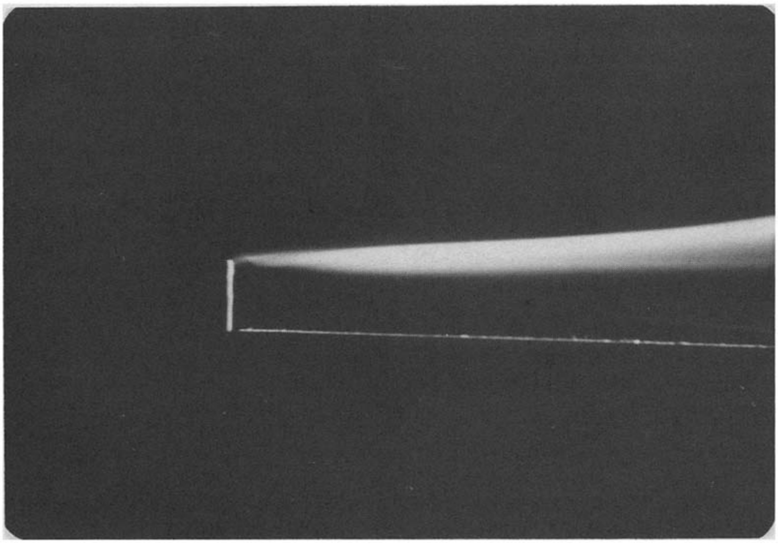


FIG. 4. Flame by injection of gaseous fuel into the recirculating air stream.

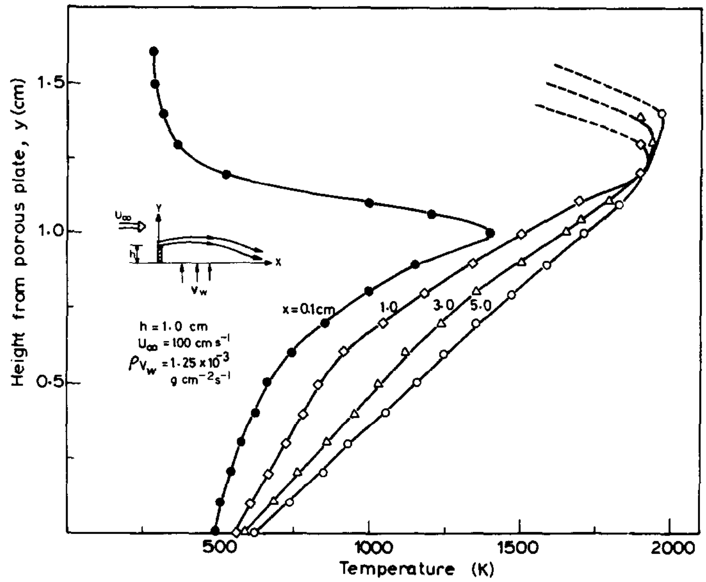


FIG. 5. Temperature profiles behind the diaphragm in the presence of the flame.

mm, were larger than 400 cm s^{-1} which could not be obtained from the present experimental set-up. While the blow-off limit gets shifted considerably towards high free-stream velocity, the boundary between stable and unstable regions shifts only marginally. In the unstable region the two-dimensionality of the flame is lost and oscillatory combustion begins. Therefore, it was decided to conduct further experiments in a velocity range of 0–200 cm s^{-1} wherein a two-dimensional, stable flame could be established. This corresponds to a Reynolds number range of 0–10^4 based on the hydraulic diameter of the test section.

3.2. *Heat transfer to the transpiring surface*

The heat transfer rates to the porous plate behind the diaphragm are obtained by the procedure described earlier beginning from the temperature profiles. Figure 5 shows the temperature profiles at a few axial stations. The profiles indicate only a weak variation of temperature with height close to the wall which is characteristic of wake type flows. The temperature gradient at the surface becomes steeper at downstream stations. Other features to be noted are the variations in flame temperature and the flame stand-off. The temperature profile upward of the flame gradually attaining a free stream value is again a feature common to most diffusion flames.

A plot of wall surface temperature (T_w) against the axial distance x is shown in Fig. 6 for a set of conditions $h = 1.0$ cm, $U_\infty = 100$ cm s^{-1} and $\rho_f V_w = 1.25 \times 10^{-3}$ g cm^{-2} s^{-1} treated as the base-set in the present investigation. Over a short distance

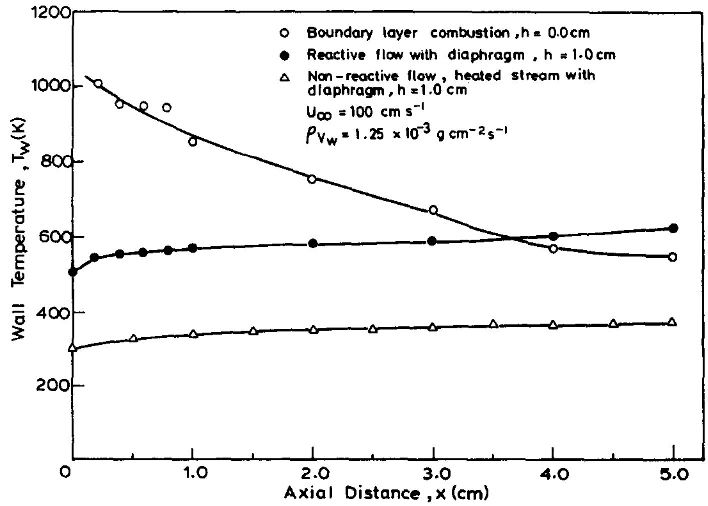


FIG. 6. Plate surface temperature variation in the flow direction—a comparative plot.

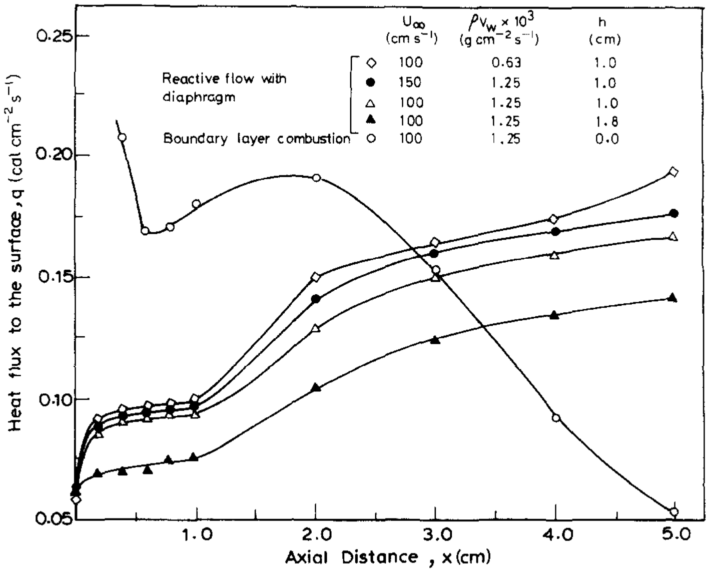


FIG. 7. Heat flux vs distance for a set of parameter variations (with combustion).

along the plate the surface temperature is nearly constant, but further downstream it rises. This is despite the increase in flame stand-off. Going by the logic used earlier for validation of heat flux estimation, when the injection is uniform the trend in T_w is indicative of the trend in heat transfer rates too, which will be discussed later.

At this stage, it is perhaps appropriate to bring in the relevance of boundary layer flow since a comparative curve of T_w vs x is shown in Fig. 6 for the boundary layer case. As mentioned in the introduction, just a small obstruction changes the boundary layer flow to a recirculating flow. Also, quite often a diaphragm is deliberately introduced in an otherwise boundary layer flow to enhance heat transfer to the surface. However, this is done in the developed boundary layer region, rather than in the developing region like the present case. In the following discussions both the regions of developing and fully developed regions are involved and hence appropriate comparisons can be made with the recirculating flow.

In the boundary layer case, T_w monotonically decreases with distance, which is explained by the fact that the flame gradually moves away from the surface just as the boundary layer thickness. On the other hand, as has already been noted, T_w increases with distance in the presence of a diaphragm or equivalently in the recirculating flow. Thus just by the trend of surface temperature, it is possible to conclude whether a given problem belongs to the class of boundary layer flow or a recirculation type of flow. Figure 6 also indicates that beyond $x = 3$ cm at the base conditions, T_w (boundary layer) < T_w (recirculation), though at an upstream station, say $x = 0.5$ cm, the former is twice as much as the latter. This difference nearer the leading edge is obviously due to the corresponding flame heights.

From a larger number of experimental runs, a representative set of heat flux variations is shown in Fig. 7. Some general features of heat flux vs distance in the presence of a diaphragm are as follows. In the immediate vicinity of the diaphragm ($0.2 < x < 1$ cm), there is a region of constant heat flux. Right at the foot of the diaphragm, the heat flux is significantly less. Further downstream, the heat flux monotonically increases with a tendency to attain a maximum. A maximum can be expected as the reattachment point is approached as in the case of flow behind a backward step [1–5]. Such a point does exist in the present case too, but beyond the porous plate where there is no injection of fuel.

The four different curves in Fig. 7 corresponding to recirculating flow are meant to describe the influence of parameters, namely free stream velocity (U_∞), injection velocity (V_w) and the height of the diaphragm (h). It has been observed that increasing U_∞ does not seem to change the appearance or temperature level of the flame significantly. Therefore, the observed increase in heat flux with U_∞ appears to be mainly due to the increased strength of the vortex and the consequent shift in the flame location. With V_w the blocking effect tends to reduce the heat transfer to the surface. The increased h lifts the flame further away from the porous plate resulting in a lower heat flux to the plate. An increase of h from 1.0 to 1.8 cm lowers the heat flux by more than 15% on most of the stations on the porous plate. A more significant result is the distinct trend of the boundary layer diffusion flame (also shown in Fig. 7, $h = 0$) compared to the profiles described above. Except in the region very close to the leading edge (this exceptional region is discussed elsewhere [12]), the heat flux from the boundary layer diffusion flame decreases monotonically with distance from the leading edge. The

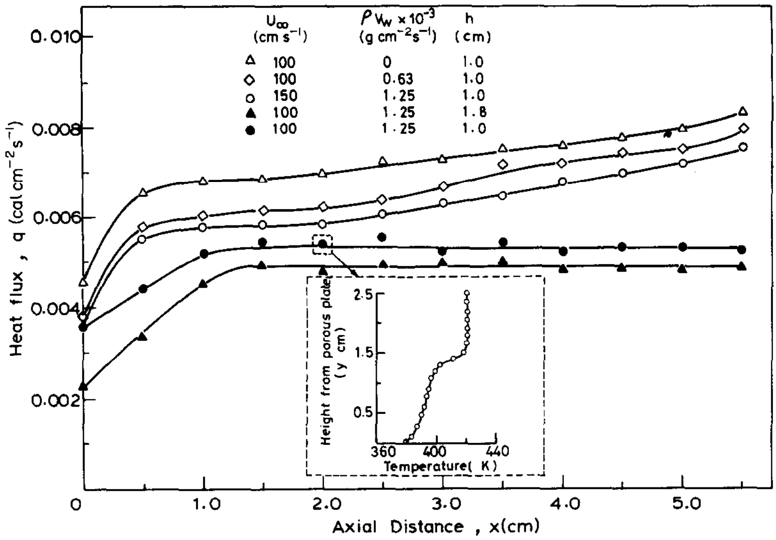


FIG. 8. Heat flux variation with the heated main stream without combustion. Inset: a typical temperature profile.

heat flux curve of the boundary layer flame and that of the flame with a diaphragm cross each other at a station, approximately $x = 3h$, beyond which the heat transfer rates from the latter are increasingly higher.

Since the region of interest involves recirculation with blowing and combustion, it is of interest to investigate whether the observed heat transfer patterns are due to the peculiarity of the flame structure discussed earlier or to the recirculating flow with blowing. Even in the literature, the information on heat transfer rates in recirculating flows with blowing is scanty. Hence, a series of experiments has been conducted with the approaching free stream heated up to a temperature of 120°C and with blowing effected by non-reactive nitrogen gas. The injectant mass flux ($\rho_f V_w$) is held at values corresponding to the combustion experiments described earlier. A set of results on heat transfer rates is shown in Fig. 8 wherein the parametric effects corresponding to U_∞, V_w and h can be inferred. These curves also exhibit similar qualitative variations as those in Fig. 7. A low heat flux at the base of the diaphragm, a region of near constant heat flux and finally a gradual rise are the common features. Shown in the inset of Fig. 8 is a typical temperature profile at a particular axial section which displays the well-stirred nature of the recirculating regions or wake flows. The top-most curve in Fig. 8 corresponds to the case of recirculating flow without blowing ($V_w = 0$) at a pseudo-steady state where the rate of rise of surface temperature is very small. On this curve the flat region is less pronounced.

The heat flux levels in the case of a non-reactive heated stream are an order of magnitude lower than those with combustion for the obvious reason of much lower temperature differences in the field. For this reason and also from the point of view of generalization, it is perhaps better to present the results in terms of Stanton number variation. As is well known, the Stanton number ($St = \alpha/\rho_\infty U_\infty C_p$) involves α, the heat transfer coefficient which takes account of the driving potential for heat transfer, namely, $(T_{max} - T_w)$. For the combustion case T_{max} is the flame temperature and for the heated stream, it is the free stream temperature. The Stanton number profiles are compared in Fig. 9 wherein the case of the boundary layer diffusion flame is also included. The curves with diaphragm are nearly flat and they do not give indications of the different regions of heat transfer which were evident on the heat flux profiles. The two cases of reactive and non-reactive flows result in the same order of Stanton number but the combustion case remains slightly higher. The behaviour of the Stanton number profile for the boundary layer case ($h = 0$) is quite distinct and is of steeply decreasing nature. It may be noted that these profiles of St can be used to estimate wall temperature and heat transfer rate at any station for a given set of operational conditions. However, slight variations in St are observed with changes in U_∞, V_w and h which have not been generalized here.

3.3. *Flow visualization*

It has been observed that the two regions of near constant and increasing heat flux are common to both the reactive and non-reactive cases. There are however dissimilarities when one looks at the transition points in the heat flux profile, i.e. the combustion case produces a narrower constant q region. To throw light on these features, flow visualization was necessary. Also, little information is available in the literature regarding the flow patterns behind diaphragms where blowing is involved let alone combustion. Yet another factor that prompted flow visualization study was the possibility of comparing cold flow with reactive flow

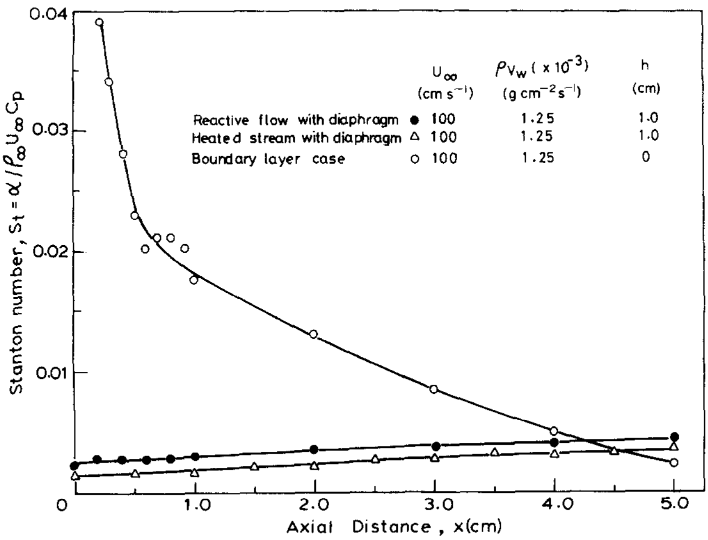


FIG. 9. Stanton number profiles for the three different cases.

the similarity of which is often assumed but seldom demonstrated.

The direct still photographs of particle tracks for a variety of conditions are shown in Figs. 10(a)–(e). A common feature that distinguishes the recirculation behind a diaphragm from that behind a backward facing step is that the recirculation bubble height is more than that of the obstruction. This is obviously due to the inclination of the incoming flow which is a consequence of flow separation upstream of the diaphragm. The cold flow without blowing (Fig. 10(a)) shows a large main, clockwise recirculation pattern with a slight unsteadiness as could also be identified in Fig. 3 earlier. At the foot of the diaphragm, a smaller secondary vortex with anti-clockwise rotation is located. With mild blowing (see Fig. 10(b)), the recirculation zone gets lifted and the eddy appears elongated. Nearer the diaphragm this eddy is so narrow that it tends to break-up into smaller ones if blowing is intensified. The secondary vortex also is lifted up but to a lesser extent and this region seems to consist of mainly the injectant mass and of the entrained mass partly from the free stream in the neighbourhood of the diaphragm and partly from the primary vortex. This secondary recirculation zone is probably responsible for the low constant heat flux zone in the heated stream experiments since the vortex would then have principally the low temperature, injectant gas. The primary vortex in clockwise motion produces reverse flow of heated mass adjacent to the porous plate surface. Both the oblong nature of the vortex and the gradual dilution and heat loss along the flow path, produce the monotonic variation of heat flux far downstream.

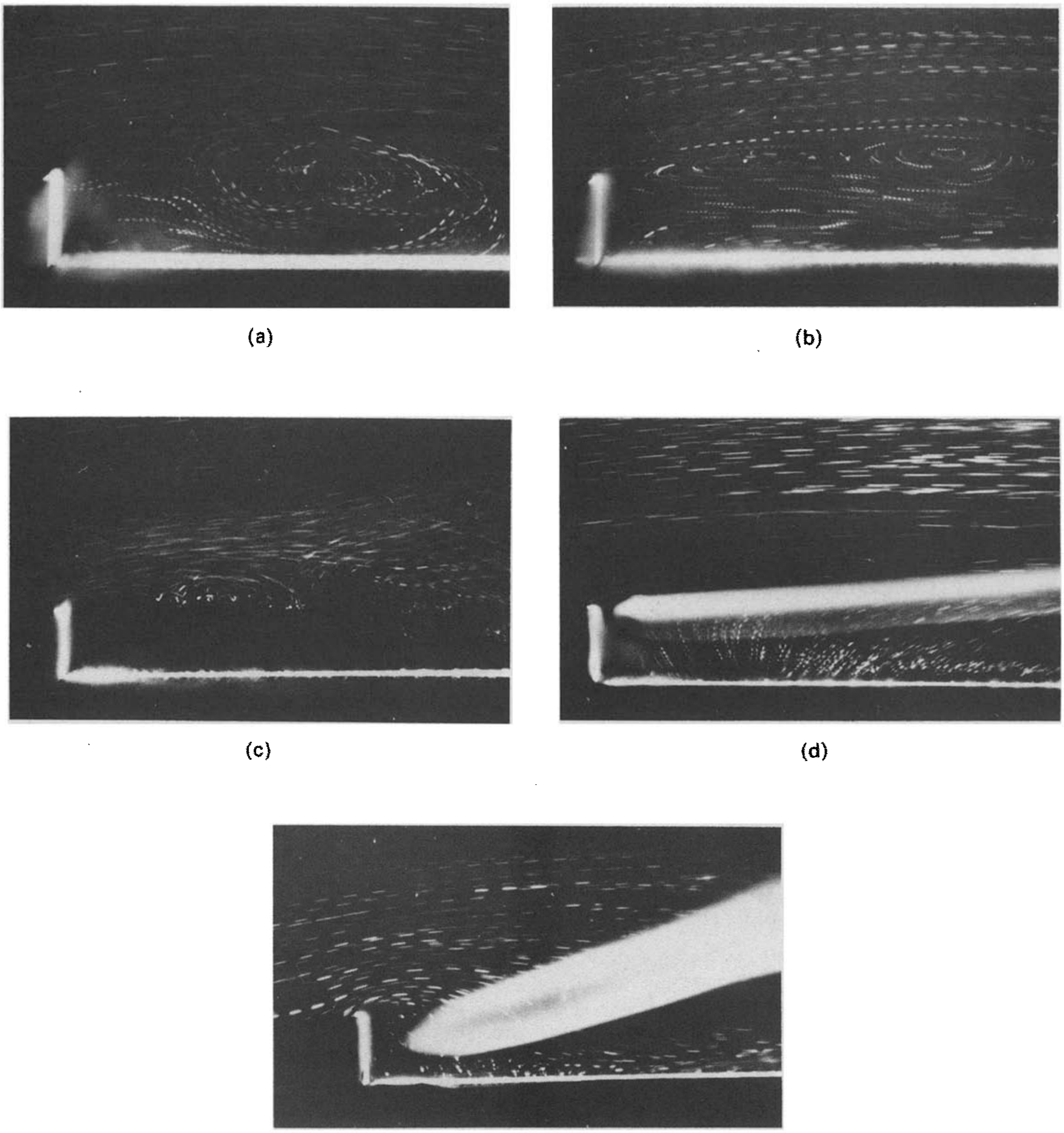
With moderate to intense blowing ($\rho_f V_w / \rho_\infty U_\infty > 0.01$), the recirculation pattern vanishes and a stratified shear flow results as can be seen in Fig. 10(c) (the absence of particles near the plate). Such a destabilized vortex can be expected to result in vortex shedding. This has been verified by an exclusive set of experiments conducted in a longer combustion chamber.

The particle track photographs with combustion posed difficulty in interpretation and many different views had to be obtained, two of which are shown in Figs. 10(d) and (e). The particles from the two sides of the two-dimensional flame sheet appear to enter into the flame zone. The pattern suggests that the flame itself is located near the shear layer formed between the free stream and the expanded primary vortex. The secondary vortex seems to have shrunk in size and continues to have a large component of the cold injectant mass. One other distinctive feature of this flow is that the recirculation bubble size and flame stand-off are less sensitive to the injection velocity of the fuel. The correspondence between the flow pattern and the heat flux profile is very much like the description given for the case of a non-reactive stream.

4. CONCLUDING REMARKS

The attempt to investigate the complex flow resulting from combustion of a fuel surface downstream of a diaphragm has led to some important results concerning the gross features like heat transfer rates to the surface as well as finer features of the flow pattern and temperature distribution. The recirculating flow consists of a large primary eddy and a secondary eddy of significant size at the foot of the diaphragm. Blowing or fuel injection through the porous plate tends to lift and stretch these eddies, but the two-vortex pattern is still discernible. With combustion, the flame is located at the shear layer and the primary eddy appears enlarged further.

Temperature profiles indicate the expected well-stirred type of regions behind the diaphragm with the



(a) (b) (c) (d) (e)

FIG. 10. Flow visualization studies: (a) recirculation behind a diaphragm without blowing; (b) with mild blowing, but no combustion; (c) intense blowing condition; (d) recirculation flow with blowing and combustion; (e) similar to (d) but from a different view.

surface temperature gradients gradually increasing along the flow direction. The heat flux to the surface shows a constant flux zone near the diaphragm followed by a monotonic rise. The two zones are attributable to the two different eddies visualized by particle track photographs. Experiments with a heated main stream with no combustion and the flow visualization in the cold flow lead to the conclusion that the flow pattern and heat transfer trends are similar with or without combustion reactions.

The presence of a diaphragm helps in postponing the blow-off of the flame in relation to the boundary layer diffusion flame. However, the stable flame zone marked by a perfect two-dimensional flame is only marginally widened. In the boundary layer case, due to the proximity of the flame, the heat transfer rates are high around the leading edge but sharply decrease along the flow direction. The diaphragm when placed at the leading edge moves the flame further from the plate. But the recirculation currents enhance the heat transfer rates considerably beyond about $x/h \simeq 3.0$.

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CARACTERISTIQUES DE STRUCTURE D'ECOULEMENT ET DE TRANSFERT THERMIQUE DERRIERE UN DIAPHRAGME EN PRESENCE D'UNE FLAMME DE DIFFUSION

Résumé—On étudie expérimentalement les caractéristiques de l'écoulement séparé derrière un diaphragme sur une surface en combustion. Ce problème complexe mais pratique concernant la recirculation, le soufflage et les réactions de combustion, est étudié dans un tunnel bidimentionnel de combustion. La structure de la flamme, les configurations de la recirculation et le transfert thermique à la surface sont présentés pour un domaine de valeurs des vitesses de l'écoulement libre et de l'injection, et pour différentes hauteurs du diaphragme. Les tendances du transfert thermique en suivant la distance axiale sont semblables à celles d'un écoulement chaud et non réactif avec un diaphragme. En traitant le cas d'une couche limite de flamme de diffusion comme celui d'un diaphragme sans épaisseur, on estime l'augmentation de transfert thermique due à la recirculation. On trouve qu'à des distances importantes en aval ($x/h > 3$) les flux thermiques avec diaphragme dépassent ceux du cas de la couche limite. Des études de visualisation avec des particules utilisées comme traceur montrent qu'il y a plusieurs similitudes entre les cas de reaction et ceux sans réaction.

STRÖMUNGSSTRUKTUR UND WÄRMEÜBERTRAGUNGSVERHALTEN HINTER EINER BLENDE IN GEGENWART EINER DIFFUSIONSFLAMME

Zusammenfassung—Das Verhalten der abgelösten Strömung hinter einer Blende über einer brennenden Fläche wird experimentell untersucht. Dieses komplexe Problem von praktischer Bedeutung, das Rückströmungs-, Einblas- und Verbrennungsvorgänge beinhaltet, wurde in einem zweidimensionalen Verbrennungsraum untersucht. Flammenstruktur, Verwirbelungsmuster und Wärmeübertragung zur Oberfläche werden sowohl für verschiedene Freistrahl- und Einspritzgeschwindigkeiten als auch für verschiedene Höhen der Blende dargestellt. Es wird gezeigt, daß die Verläufe der Wärmeübertragung über den axialen Abstand ähnlich den Verläufen sind, die aus einer nicht reagierenden beheizten Strömung mit Blende resultieren. Die Zunahme der Wärmeübertragung aufgrund von Verwirbelungen wird dadurch bestimmt, daß der Fall einer Grenzschicht-Diffusionsflamme so behandelt wird, als würde dieser mit der Höhe Null der Blende korrespondieren. Es wurde gefunden, daß die Wärmeübertragungsraten mit Blende bei großen Abständen in Strömungsrichtung ($x/h > 3$) die Werte des Falles bei ausgebildeter Grenzschicht annehmen. Studien zur Sichtbarmachung der Strömung mittels Partikelspurenfotografie zeigen, daß viele Ähnlichkeiten zwischen reaktiven und nicht-reaktiven Fällen bestehen.

СТРУКТУРА ПОТОКА И ХАРАКТЕРИСТИКИ ТЕПЛОПЕРЕНОСА ЗА ДИАФРАГМОЙ ПРИ ВОЗДЕЙСТВИИ ДИФФУЗИОННОГО ПЛАМЕНИ

Аннотация—Экспериментально исследуются характеристики отрывного течения за диафрагмой над горящей поверхностью. Эта сложная, практически важная задача, охватывающая проблемы рециркуляции, вдува и реакций горения, исследуется в двухмерной камере горения. Структура пламени, модели рециркуляции и теплоперенос к поверхности рассматриваются при различных значениях скоростей свободного потока и инжекции топлива, а также для различных высот диафрагмы. Показано, что тепловой поток в осевом направлении изменяется таким же образом, как и при обтекании диафрагмы нагретым потоком без реакции. На основе предположения, что диффузионное пламя пограничного слоя соответствует нулевой высоте диафрагмы, получена оценка интенсификации теплопереноса за счет рециркуляции. Найдено, что на значительных расстояниях по потоку ($x/h > 3$) интенсивность теплопереноса при наличии диафрагмы превышает соответствующие значения в случае развивающегося пограничного слоя. Визуальные наблюдения, а также фотографирование следа частиц выявляют большое сходство между химически активными и неактивными потоками.