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IGNITION OF FLAMMABLE VAPOURS, GASES AND
SHEET MATERIALS BY CATALYTIC HEATERS

by

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SUMMARY

The incendivity of catalytic beds was tested using propane, ethylene and various saturated paraffins including petrol and pieces of nylon and cellulosic cloth and paper.

It was possible to ignite all gases and vapours with the exception of petrol, when these impinged on the catalytic bed at sufficiently high velocities. When various saturated hydrocarbon liquids were sprayed on to the heated catalytic bed, none ignited. Ethyl ether ignited when a very small volume was sprayed.

It was difficult to ignite sheets of flammable materials. Only cellulosic materials ignited after prolonged direct contact with the catalytic bed.

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INTRODUCTION

Appliances producing heat by catalytic oxidation of various fuels have been in use in the UK for a number of years. This type of combustion can present specific fire and explosion hazards, some of which have been evaluated by the Fire Research Station; the results have been incorporated into a preliminary draft Standard applicable to portable domestic appliances¹.

Claims have been made that such appliances, both domestic and industrial, could be used in areas where flammable gases may be present, based on a report of work carried out in France of an investigation on some aspects of the ignition of flammable gases by industrial catalytic heaters², which states that, in use, catalytic heaters are unlikely to ignite most flammable gases and liquids, with the exception of hydrogen and ethyl ether, both of which were readily ignited. It was concluded that such appliances should not be used in workshops where ethyl ether vapour and hydrogen gas may be present, but it could be inferred that the use of such heaters in areas where other gases and vapours were present was permissible. However, only a limited range of industrial conditions was investigated.

The present programme was therefore carried out in order to clarify the situation. For these tests domestic appliances were used, but the difference between the catalytic beds of these and industrial heaters is not significant.

APPARATUS AND MATERIALS

Heaters

Three models of domestic catalytic heaters were investigated, using commercial butane as a fuel at a pressure of 28 cm of water. The output of the heater designated 'A', an unused model, could be varied in three stages up to a maximum of 2.8 kW. Combustion took place within the catalytic bed, which was constructed of platinised asbestos, and mounted in a stove enamelled case with a retaining wire mesh on the outer exposed surface of the catalytic bed. A combustion failure device was fitted, which comprised a sturdy thermocouple

with the junction near the surface of the bed which, when the bed was hot, energised a solenoid holding open a spring-loaded valve supplying fuel to the main control valve. Should the bed cool down, the solenoid was de-energised releasing the spring-loaded valve and stopping the supply of fuel. The heater was brought into use by pressing a button, which opened a spring-loaded by-pass port, admitting fuel to the bed and to the pilot jet. On igniting the pilot, the flame heated the thermocouple junction and warmed the catalytic bed locally, starting the oxidation of the fuel on the bed. When the thermocouple reached a sufficient temperature to hold the solenoid valve open, the press button was released; this action extinguished the pilot jet and shut down the by-pass valve admitting the fuel to the bed. From then onwards the fuel was supplied through the main solenoid valve only.

The heater designated 'B' was an unused model from another manufacturer. The principles of operation and the safety devices were similar to those of heater 'A'. The output could also be varied step-wise to a maximum of 3.5 kW. The catalytic bed was made from platinised silica fibre, but otherwise its construction was similar to heater 'A'.

Heater 'C' was a smaller model from the manufacturer of heater B, with a maximum output of 2.15 kW, which had been used for other work intermittently over a period of two years.

MEASUREMENTS

Temperature

The temperature of the catalytic bed was measured with T_1 and T_2 alloy thermocouples, 0.2 mm dia. The surface temperature of the catalytic bed during gas and vapour ignition tests was measured, using a disappearing filament pyrometer at the wavelength of 0.65μ . These readings were corrected, assuming from values given in the literature that the emissivities of asbestos and silica fibre were 0.95 and 0.85 respectively.

Velocity profiles of moving jets of gas

It was proposed to examine the ignition of vapours by directing them as jets on to the exposed surface of the heated catalytic bed, taking note of the velocity of projection. To obtain basic data on the velocity distribution, undisturbed by any combustion reactions, the behaviour of jets of air (mean molecular weight 29) were used to simulate ethylene (molecular weight 28), and of carbon dioxide (molecular weight 44) were used to simulate propane (molecular weight 44). Such non-combustible gases allowed a sensitive electronic hot-wire anemometer to be used, because of the absence of heat from combustion.

Figures 1 and 2 illustrate the velocity distribution at distances of 75, 100 and 125 mm from the orifice, of jets of air and carbon dioxide issuing from a 1.2 mm orifice at 3.5 l/min into free air, as a dimensionless velocity (the ratio of measured velocity to the maximum (axial) velocity, plotted against the distance at right angles of the point of measurement from the axis of the jet.

Figure 3 illustrates the effect of impingement of the jets of air, from orifices of different diameters placed 75 mm from a porous catalytic bed, on the velocity distribution across the face of the bed at the same flow rate, 3.5 l/min, as for Figs 1 and 2. Figure 4 shows a similar set of curves for air ejected at 10 l/min, the rate of flow used for tests with hydrogen.

Flammable gases, liquids and sheet materials

The heaters were fuelled with a commercial butane of the following composition:

- 10 per cent propane
- 35 per cent n-butane
- 55 per cent iso-butane

The fluids injected on to the heated catalytic beds were:

- Liquids: decane, hexane, ethyl ether, petroleum ether, boiling range 60-80°C and leaded petrol
- Gases: technical grade hydrogen, and ethylene; high purity industrial propane.

The sheet materials are listed in Table 1.

Table 1. Sheet materials

Material	Description	Name	Weight g/m ²
Cotton	Fabric	Winceyette	151
Cotton	Fabric	Plain cloth	114
Cellulose acetate	Fabric	Twill	95
Nylon	Fabric	Canvas	178
Cellulose (wood pulp)	Paper	Newsprint	44
Cellulose	Paper	Wiping tissue	31

Photographs

A 35 mm ciné film at 32 fps was made of some of the ignitions of vapours and gases.

Application of flammable liquids to catalytic beds

Two methods of application of liquids to the catalytic beds were used. In the first method, 0.01, 0.1, 0.5 and 1.0 ml of liquid were squirted on to the catalytic bed using a syringe of appropriate capacity fitted with a hypodermic needle. In the second method, 0.5 ml of the flammable liquid was squirted from a 20 ml volume syringe, without a hypodermic needle fitted, after which the plunger was repeatedly operated by pulling back and forth until ignition took place or all liquid and vapour had been expelled on to the surface of the catalytic bed. The bore of the needle mount of this syringe was 0.75 mm.

Application of flammable gases

Pure gases were metered at the rate of 3.5 l/min for propane and ethylene and 10 l/min for hydrogen through nozzles of 0.8, 1.2, 1.6 and 3.2 mm bore and directed on to the heated catalytic beds of the heaters. Table 2 gives the nozzle velocity for each nozzle and each gas.

Table 2. Nozzle velocity m/s

Gas	Nozzle diameter mm			
	0.8	1.2	1.6	3.2
Propane, ethylene	116.2	51.6	29.1	7.3
Hydrogen	332.0	147.5	87.9	20.7

Application of sheet material

200 mm wide strips of the materials were stretched from top to bottom of, and in contact with, the catalytic bed surfaces or guards of the heaters. The strips were kept on the surfaces of the beds for up to 7 min and on the guards of the heaters for up to 90 min.

RESULTS

All tests were carried out with the heaters operating at maximum heat output.

Ignition of liquids

Twenty tests were carried out with each of the four volumes of liquid squirted

from the syringe and hypodermic needle. Only one ignition was observed in the form of a flash; this occurred when 0.5 ml of ethyl ether was squirted on to the surface of heater 'A'. The smallest volume did not cause any visually detectable effects on the surface of the catalytic bed in any test. Larger volumes produced rapidly vaporising wet patches on the surface of the catalytic bed with a glowing ring surrounding the patch.

Twenty tests were also carried out with 0.5 ml of each liquid squirted by repeated pumping from the 20 ml syringe until either all liquid and vapour were expelled or an ignition was obtained. A certain amount of personal judgment was required to select a position for the syringe which would give an ignition. Ethyl ether, hexane and petroleum ether ignited on the catalytic surfaces of each heater in each test. The expelled liquid, vapour and air initially created a glowing circular hot spot on the catalytic beds, followed by a flash when vapour only was discharged at a later stage of the application. Only 100 octane leaded motor fuel failed to ignite, although this produced a hot spot. Figure 5 shows a sequence of ciné frames, showing ignition of ethyl ether on the catalytic bed of heater 'A'. The first frame shows the hot spot produced by the impinging jet of gases; in the second frame a faint luminescence can be seen, which developed into the luminous flame shown in frame 3. This flame increased in size as more vapour was expelled, until the end of the syringe stroke was reached and the vapour supply ceased, frame 6. In frame 7 this fluid had almost burnt away, but the second stroke of the syringe had provided a fresh supply of vapour which had ignited, beneath the hot spot from the first application, to start another ignition cycle, frame 8.

Figure 6 shows a similar sequence with heater 'B', but with a microbunsen burner supplied with unlit town gas near the catalytic bed. When the ethyl ether vapour flashed, it ignited the town gas resulting in a fully developed bunsen flame, frames 3 - 8. At this stage, almost all the ethyl ether had been consumed.

Ignition of gases

Jets of propane, ethylene and hydrogen were ejected from various diameter nozzles at a distance of between 50 and 150 mm on to the catalytic beds of each heater. As in the previous tests, personal judgment was used to select a position which would give an ignition. Table 3 summarises the results for heater 'A'.

Table 3. Ignition of propane, ethylene and hydrogen on catalytic bed of Heater 'A'

Flammable gas	Nozzle diameter mm			
	0.8	1.2	1.6	3.2
Propane	Flash	Flash	Flame	None
Ethylene	Flash	Flame	Flame	Flame
Hydrogen	Flame	Flame	Flame	Flame

In this and subsequent tables, 'flash' indicates that the flammable mixtures ignited and produced a stable flame on the surface of the catalytic bed only; 'flame' indicates that the flammable mixtures ignited as above but flashed to, and stabilised on, the nozzle. All jets of flammable gas ignited in either of these ways, with the exception of propane discharged from the 3.2 mm jet.

Figure 7 shows a sequence of cine frames of the ignition of propane flowing through a 0.8 mm dia nozzle and impinging on the surface of the catalytic bed of heater 'A'. In frame 1 only a hot spot on the surface of the catalytic bed has developed. In frame 2 faint luminosity has surrounded the hot spot; this then gradually developed into a flame which did not flash back to the nozzle.

Figure 8 shows the ignition of an ethylene jet discharged from a 3.2 mm dia nozzle on to the surface of the catalytic bed of heater 'A'. Frame 1 shows a hot spot only, but unlike that in Fig. 7, frame 1, the hot spot is not uniform but consists of many localised bright regions; these were seen to be established on asbestos fibres protruding above the general level of the bed. In frame 2 a faint luminescence has surrounded the uppermost glowing fibres, which in frame 3 has progressed to flame combustion. This flame flashed back to, and stabilised on, the nozzle, frame 4.

The flame has enlarged further in frames 5 and 6, but its appearance is blurred due both to over exposure of the film by the bright flame and to its motion.

Figure 9 shows the ignition of hydrogen discharged from a 3.2 mm dia nozzle on to the heated catalytic bed of heater 'A'. There was very little enhanced heating of the catalytic bed before ignition occurred, frames 1 to 3. Small hot spots, however, are just discernible. Because hydrogen flames are only slightly luminous the flames in frames 4 - 8 are very faint. Jets of hydrogen also ignited when directed on to a cold, unfuelled, catalytic bed.

Identical ignition tests were carried out with heaters 'B' and 'C'. The results are given in Tables 4 and 5.

Table 4. Ignition of propane, ethylene and hydrogen on the hot catalytic bed of Heater 'B'

Flammable gas	Nozzle diameter mm			
	0.8	1.2	1.6	3.2
Propane	None	None	None	None
Ethylene	Flash	Flame	None	None
Hydrogen	Flame	Flame	Flame	Flame

Table 5. Ignition of propane, ethylene and hydrogen on the hot catalytic bed of Heater 'C'

Flammable gas	Nozzle diameter mm			
	0.8	1.2	1.6	3.2
Propane	None	None	None	None
Ethylene	Flash	None	None	None
Hydrogen	Flame	Flame	Flame	Flame

Heaters 'B' and 'C' ignited the flammable gases less readily than heater 'A'. Otherwise the mode of ignition was very similar.

Temperature measurements

The maximum temperatures of the catalytic beds operating at the maximum heat output were measured with stainless steel sheathed thermocouples 0.8 mm diameter; this temperature was approximately 520°C for each heater. With all heaters the bottom part of the catalytic bed had the highest temperature.

The temperatures of the hot areas produced by the impinging gases, propane and ethylene, were measured with a disappearing filament pyrometer. It was not possible to measure the temperature of hot spots produced by hydrogen because the brief delay between the gas reaching the surface of the catalytic bed and the development of the flame was not enough to allow the adjustment of the pyrometer. Heater 'A' developed hot spots on protruding bundles of asbestos fibre against a

background heated to a lower, more uniform temperature. The average temperature within the catalytic bed during application of extra fuels was also measured by a 0.2 mm dia thermocouple inserted below the surface of the bed. The recorded temperatures for each heater for the four nozzle sizes are listed in Tables 6 and 7 for propane and ethylene respectively.

Table 6. Temperatures produced by propane jet before ignition, °C

Nozzle dia mm	Heater A	Heater B	Heater C
0.8	1) 850 2) 1145 3) -	1) 1060 2) 1090	1) 960 2) 1030
1.2	1) 760 2) 955 3) 1210	1) 900 2) 995	1) 890 2) 940
1.6	1) 720 2) 905 3) 1180	1) 830 2) 930	1) 810 2) 940
3.2	1) 670 2) 830 3) 930	1) 740 2) 880	1) 710 2) 785

Table 7. Temperatures produced by ethylene jet before ignition, °C

Nozzle dia mm	Heater A	Heater B	Heater C
0.8	1) 770 2) 960 3) 1065	1) 920 2) 990	1) 990 2) 1065
1.2	1) 720 2) 890 3) 1090	1) 900 2) 1030	1) 970 2) 910
1.6	1) 680 2) 900 3) 1070	1) 840 2) 960	1) 830 2) 880
3.2	1) 600 2) 885 3) 990	1) 720 2) 875	1) 710 2) 820

1. Temperature of beds by thermocouple
2. Temperature of hot spots by pyrometer
3. Temperature of raised hot spots by pyrometer (Heater A only)

On average, heater 'A' produced the highest surface temperatures (on the raised fibres 3) Tables 6 and 7) and heater 'C' the lowest. The temperatures indicated by buried thermocouples, 1), Tables 6 and 7, were higher with heaters 'B' and 'C' than with heater 'A' for each gas. When ignition did not occur, the temperature of the hot spots, 2), Tables 6 and 7, decreased as the diameter of the jet increased.

Table 8 indicates the lowest temperatures as measured by the pyrometer at which ignition of propane and ethylene occurred with various heaters.

Table 8. Lowest ignition temperature of the catalytic beds

Flammable gas	Temperature °C	Heater
Propane	1145	A
Ethylene	1065	A
Ethylene	990	B
Ethylene	1065	C

Note: Propane did not ignite on heaters B and C

Gas velocity for ignition

Table 9 shows the maximum velocities estimated from Figs 3 and 4 at the face of the catalytic bed for tests in which ignition occurred. Such maxima were always on the axis of the gas stream. From this data it is possible to estimate approximately the velocity of the stream required to ignite the gas on the catalytic bed. Thus, with heater 'A', propane did not ignite when the maximum velocity was 0.8 m/s but ignited at the velocity of 1.8 m/s; ethylene, on the other hand, ignited at 0.8 m/s. The tests carried out with hydrogen did not use sufficiently low velocities for a similar estimate to be made.

With heater 'B', propane did not ignite at any velocity up to the maximum of 4.5 m/s, and ethylene did not ignite at the velocity of 1.8 m/s, but ignition occurred at 3.4 m/s.

Heater 'C' also did not ignite propane at velocities up to the maximum of 4.5 m/s; it did, however, ignite ethylene at the velocity of 4.5 m/s.

The velocity profiles at which ethylene and propane ignited on heater 'B' are indicated in Figs 1 and 2. The differences in the velocity profiles for air (equivalent to ethylene) are very small for the three planes of measurement, but somewhat greater with carbon dioxide (equivalent to propane). However, there is a difference between the absolute values of the velocities.

Table 9. Maximum velocities of jets impinging on the catalytic bed in tests where ignition occurred
Velocity in m/s

Heater	Flammable gas	Nozzle diameter mm			
		0.8	1.2	1.6	3.2
A	Propane	4.5	3.4	1.8	NI
	Ethylene	4.5	2.8	2.1	0.8
	Hydrogen	11.0	4.5	3.3	3.1
B	Propane	NI	NI	NI	NI
	Ethylene	4.5	3.4	NI	NI
	Hydrogen	11.0	5.9	3.8	3.1
C	Propane	NI	NI	NI	NI
	Ethylene	4.5	NI	NI	NI
	Hydrogen	11.0	11.5	3.8	3.1

NI No ignition

Figures 3 and 4 show the velocity profiles of jets of air measured 2 mm above the surface of the catalytic bed of heater 'C' at the flow rates of 3.5 and 10 l/m. All these measurements were taken with the probe wire parallel to the surface of the catalytic bed. With all nozzles and both rates of flow the velocity fell rapidly as the distance from the axis of the jet increased and at 10 mm from the axis the velocity had fallen to 20 to 30 per cent of the value measured on the axis of the gas stream, after which the velocity fell at a much slower rate. The maximum velocities measured at the axis for 0.8 and 1.2 mm jets are compared with the maximum velocities obtained with free jets, where the flow was unimpeded by the catalytic bed, in Table 10, from which it can be seen that the maximum velocity was not significantly changed by the catalytic bed, in contrast to the substantial reduction outside the central area of the jet. This effect will be discussed later.

Table 10. Comparison of the maximum stream speeds m/s

Flow	Jet diameter	
	0.8 mm	1.2 mm
Free	4.5	3.7
Impeded	4.9	3.8

Ignition of solids

When sheet materials were placed on the hot, catalytic bed, only those which were made from cotton fibres or wood pulp ignited, and the mechanism of ignition was similar. Areas which were in closest contact with the catalytic bed were very quickly carbonised after the volatiles had been expelled, and the carbonaceous matter thus formed was ignited to smouldering combustion. Most of the carbonaceous matter smouldered at dull red heat and only small areas glowed to a bright yellow. Flame combustion was always initiated by these bright yellow surfaces igniting the volatiles emitted by charring material. These results are summarised in Table 11.

Table 11. Time for glowing and flame combustion of solids on catalytic beds min:s

Material	Heater A	Heater B	Heater C
Tissue	1) 1:05, 0:53, 1:40 2) 1:34, No, No	1) No, 2:10, 0:40 2) No, No, No	1) No, No, No 2) No, No, No
Newsprint	1) 1:00, 1:43, 1:08 2) 3:06, No, No	1) 0:55, 1:40, 0:55 2) No, 2:20, 1:35	1) No, No, No 2) No, No, No
Cotton	1) 0:35, 0:45, 0:34 2) 1:40, 2:32, No	1) 0:45, 0:50, 0:40 2) No, 2:00, No	1) 1:40 2) No
Flannelette	1) 0:50, 0:45, 0:44 2) 1:50, 1:08, 1:22	1) 1:35, 0:45, 1:10 2) No, No, No	1) No 2) No

- 1) Time for glowing
- 2) Time for flame combustion
- No = effect not observed

Cellulose acetate and nylon fabrics melted and were subsequently charred. These charred areas commenced to glow but they did not initiate flame.

None of the sheet materials ignited when they were placed on the guard and scorching was observed on the cellulosic materials only.

DISCUSSION

Ignition temperatures

Limiting safe temperatures for the hot surfaces of an electrical apparatus are often specified by reference to ignition temperatures of liquids or gases³. Ignition temperatures, sometimes called spontaneous or auto-ignition temperatures, may be measured in many ways⁴, and those measured in an open necked heated vessel are often required⁵. This method gives reproducible results, but these are dependent upon the volume and material of the vessel⁶, factors which may not be mentioned in reported values. Values from one reference are given in Table 12⁷.

Table 12. Auto-ignition temperatures for fluids

Vapour or gas	Auto-ignition temperature	
	°C	°F
Propane	466	871
Ethylene	450	842
Hydrogen	585	1085
Decane	208	406
Hexane	261	502
Ethyl ether	236	356
Petrol 100 octane	456	853
Petrol 50-60 octane	278	536

Of the methods for determining ignition temperature, the open necked vessel commonly yields the lowest values. A method more appropriate for comparison with the present tests is that of ignition of vapours by hot, flat surfaces⁴. In this method either static or moving gases are brought into contact with a heated surface and the lowest temperature of the surface which will result in combustion of the gas is designated as the ignition temperature.

Ignition temperatures determined in this way are higher than those produced in a vessel, and also the values for moving gases tend to be much higher than those for stagnant gases. The majority of hot surface ignition temperatures for hydrocarbons are greater than 1000°C but in all cases the lowest temperatures are obtained with lean mixtures. These values are very dependent upon experimental conditions.

Mechanism of ignition

The high temperature of the catalytic bed measured in areas where hot spots were formed indicates a greatly increased rate of reaction occurring to some depth in the catalytic bed. Thus, not only must a considerable volume of fuel be supplied to these areas of the bed, to maintain a high combustion rate, but also the combustion products must be speedily swept away.

Catalytic heaters operate by the gaseous fuel entering the rear of the porous structure of the catalytic bed under a small positive pressure and when it approaches the forward surface of the bed it mixes and reacts with the inward diffusing air. The rate of reaction is thus governed by the rate of supply of fuel and the rate of diffusion of air.

Other conditions apply when forceful flows of gaseous fuel and air are applied to the front surface of the catalytic bed. After leaving the nozzle the fuel rapidly entrains air and the premixed air and fuel strike the surface of the catalytic bed, where the flow pattern is changed (see Figs 3 and 4). The outer part of the flow decelerates rapidly, but the high rate of flow at the central part shown by the absence of a stagnation zone (zero velocity) at the centre of impact of the jet on the surface of the catalytic bed indicates penetration of the porous bed. The depth of the hot spot on the catalytic bed at this point confirms that gases penetrate the catalytic bed within the area of the hot spot.

The continuous flow of unburned gas ensures rapid removal of combustion products from this area and, as a result, a high rate of reaction can continue until the temperature of the catalytic bed or combustion products is high enough to produce flame within the moving stream of air and flammable gas. The velocity profiles plotted in Fig. 3 indicate that the gases must move with velocities greater than 0.75 m/s to ignite ethylene and greater than 1.5 m/s to ignite propane, these being the lowest velocities at which gases can penetrate the bed. Hydrogen is ignited much more readily than the hydrocarbon gases, and the high reactivity of hydrogen on the catalytic bed is indicated by the ignition of hydrogen on the cold, unfuelled catalytic surface.

When vapours only were expelled from the syringe the mechanism of ignition for volatile liquids was similar to that for gases. It was noted, however, that the flame zone was much closer to the syringe nozzle, probably because premixed air and vapour was expelled after air had been drawn inside the syringe on the return stroke.

When flammable gases were tested ignition did not occur until the temperature of the bed was raised to 1000°C or more. Such temperatures were achieved quickly with vapours of liquids, and visible flame was observed on the cine records at about 100 - 200 ms after the downward stroke of the syringe plunger began. The hot zone created by the impinging flammable mixture was deep, and in some cases the buried thermocouple registered temperatures equal to the surface temperatures measured by the pyrometer, Tables 6 and 7.

Flame combustion of propane was preceded by a faintly luminous reaction, spreading in some cases over an area much larger than that of the hot spot, which persisted for 30-50 ms before flame appeared. The asbestos-based catalytic bed of heater 'A' had protruding bundles of fibres which reached higher temperatures than the general surface of the catalytic bed. The preflame reaction occurred around these protrusions but spread over a considerable area, Figs 5 and 6.

The lowest temperatures at which the gases ignited were within the range of 990 - 1060°C. These are well above the auto-ignition temperatures of the vapours and gases used, Table 12, but are similar to the hot surface ignition temperatures for stagnant gases.

Ignition of liquids

When liquids are projected on to a catalytic bed they must be vaporised before flame combustion can occur. Thus, when a drop of liquid settles on the catalytic bed, the bed has to supply the heat necessary for vaporisation and local cooling of the fibre bed will occur. The vapours thus produced rise by convection and, with the exception of ethyl ether, any extra heat produced by their oxidation is not sufficient to ignite the mixture.

Ignition of sheet materials

Only cellulosic sheet materials could be ignited by the catalytic bed and then only when they were in direct contact with it. The mechanism of ignition appears to be different from that for vapours and liquids.

The charring sheet formed a barrier between the catalytic bed and the external air supply. It is thus likely that the function of the hot catalytic bed was to initiate smouldering combustion after which volatiles expelled from other areas of the material were ignited by this glowing source. The intensity of smouldering was observed to vary greatly with the movement of the surrounding air, causing different degrees of brightness of the glowing zone. Other experiments have shown how smouldering combustion can be affected by the velocity of air over the glowing surface, an increase in velocity eventually resulting in flame combustion⁸. The poor overall reproducibility noted in these tests can be perhaps related to varying air velocity.

Industrial use of catalytic heaters

The use of heating appliances in industrial areas is governed by Regulations issued under the Factories Act 1961. The publications of the British Standards Institution, CP 1003, Parts 1, 2 and 3, and BS 4683, recommend that in such areas the surface temperature of electrical apparatus must not exceed the auto-ignition temperature of vapours or gases which may be accidentally discharged. The catalytic heaters tested to not comply with such requirements. The surface temperature of the catalytic beds of the domestic heaters investigated exceeded 500°C, a temperature higher than the auto-ignition temperature of most flammable vapours or gases. Industrial catalytic heaters are not likely to differ from these. The above experiments with domestic models of catalytic heaters have shown that of 20 liquid spillages of ethyl ether, one was ignited but vapours of individual or mixed saturated gaseous hydrocarbons ignited in every test when projected on to the hot bed.

CONCLUSION

The experimental conditions used are considered to be a reasonable simulation of accidental splashes or accidental leaks of volatile flammable fluids that could occur in industrial conditions, and it is therefore concluded that catalytic heaters of the type reported here should not be used when these can possibly occur.

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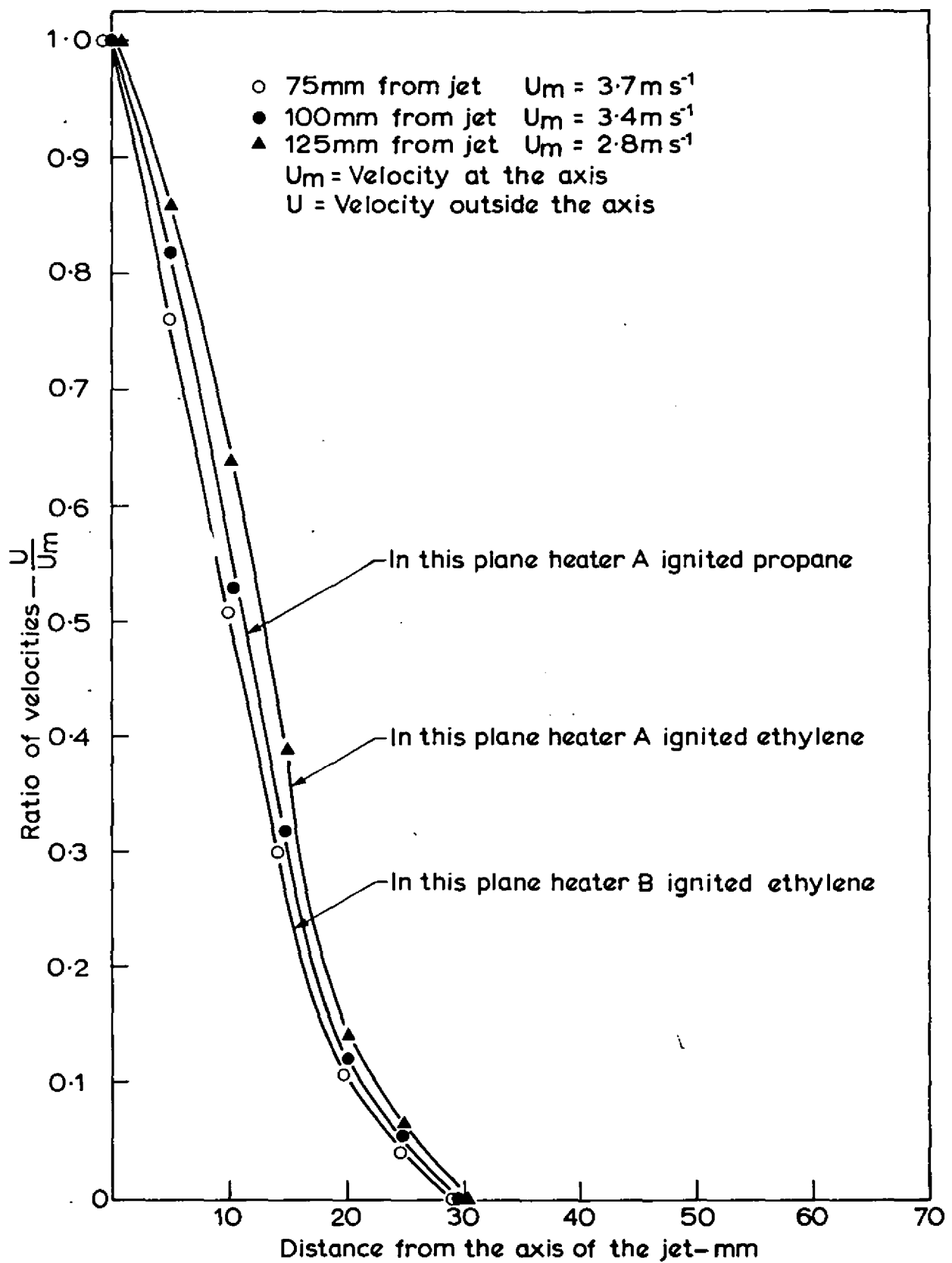


Figure 1 Velocity distribution for 1.2mm jet at 75,100,125mm with air - Rate of flow 3.5l/min
 Air temperature 20.5°C

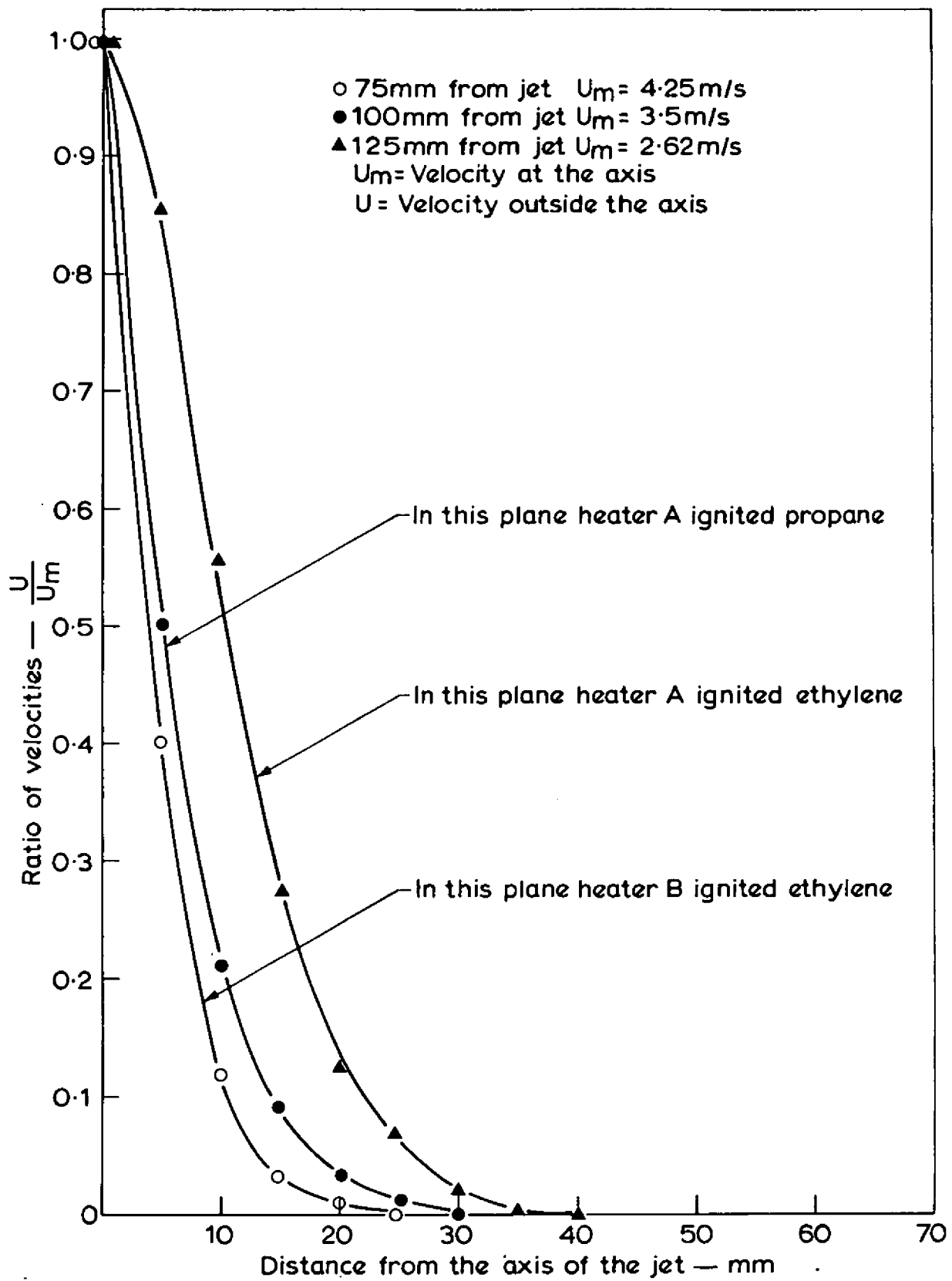


Figure 2 Velocity distribution for 1.2mm jet at 75, 100, 125mm with CO_2 – Rate of flow 3.5l/min
 Air temperature 23°C

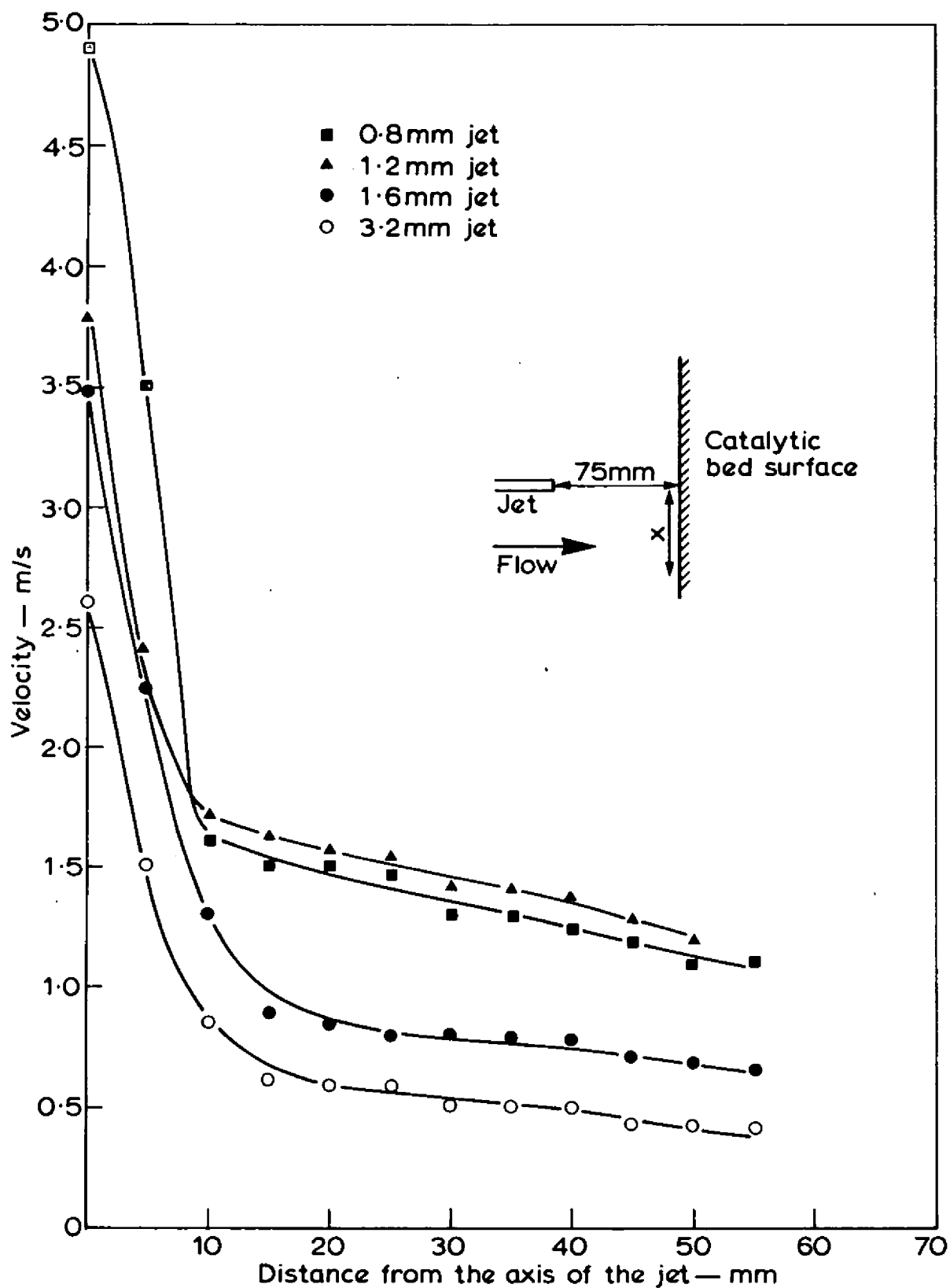


Figure 3 Velocity distribution on heater surface – Rate of flow 3.5l/min – Jet 75mm from surface with air Air temperature 20.5°C

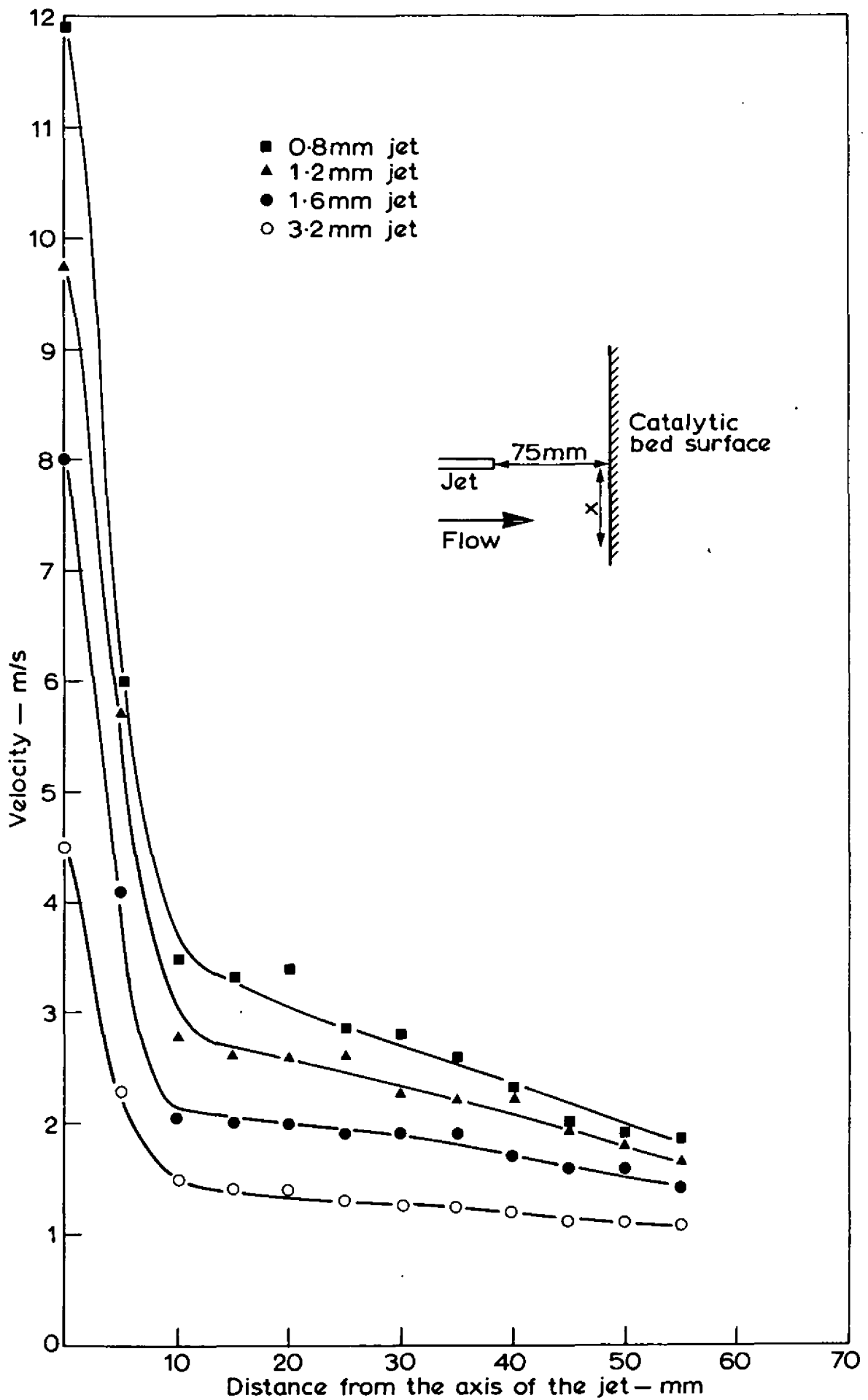


Figure 4 Velocity distribution on heater surface – Rate of flow 10l/min – Jet 75mm from surface with air Air temperature 20.5°C

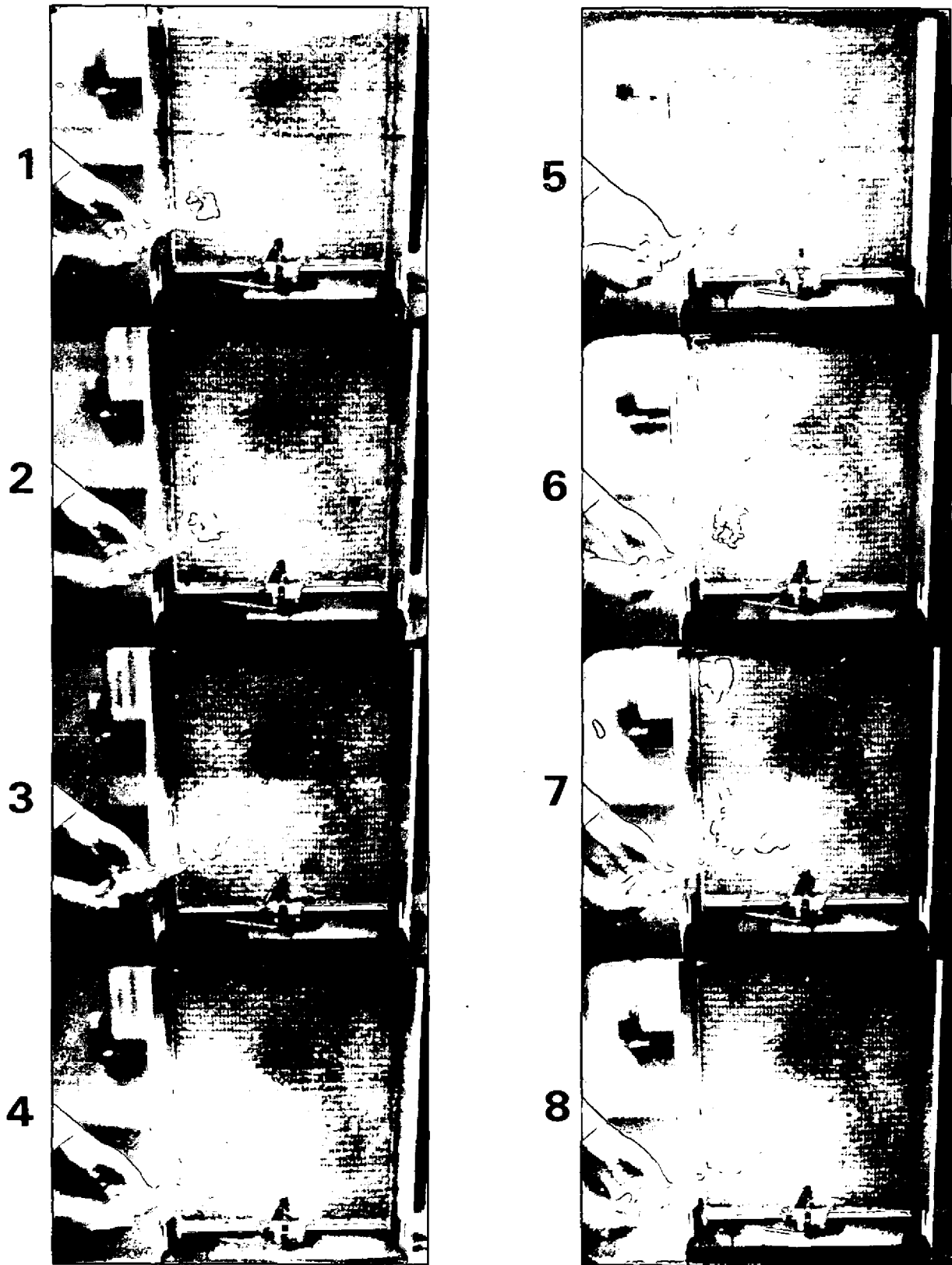


FIG. 5. IGNITION OF ETHYL ETHER ON CATALYTIC BED - HEATER 'A'

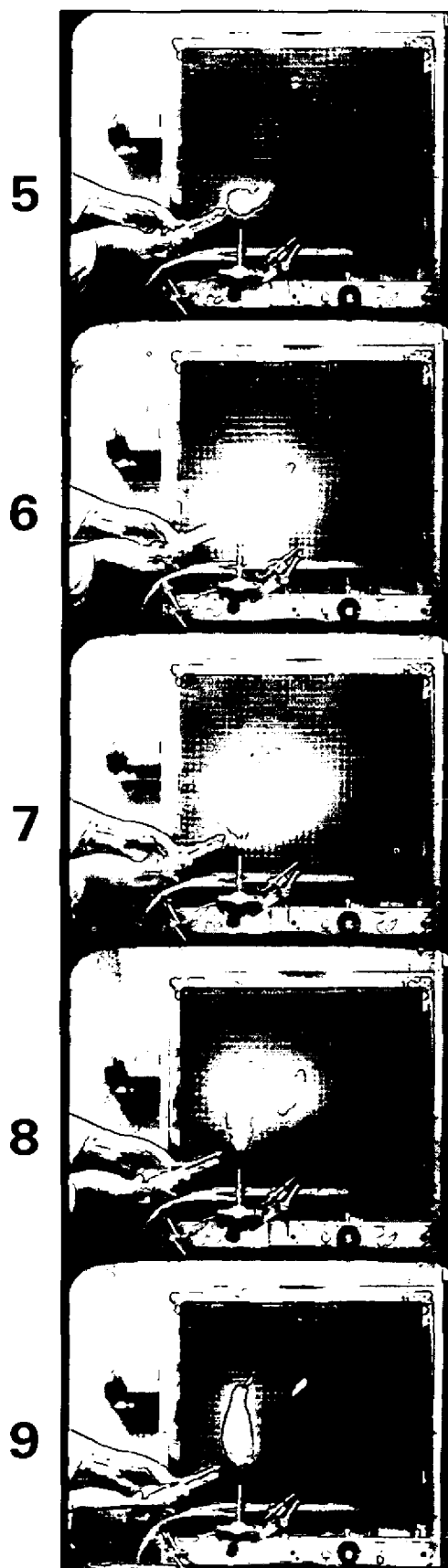
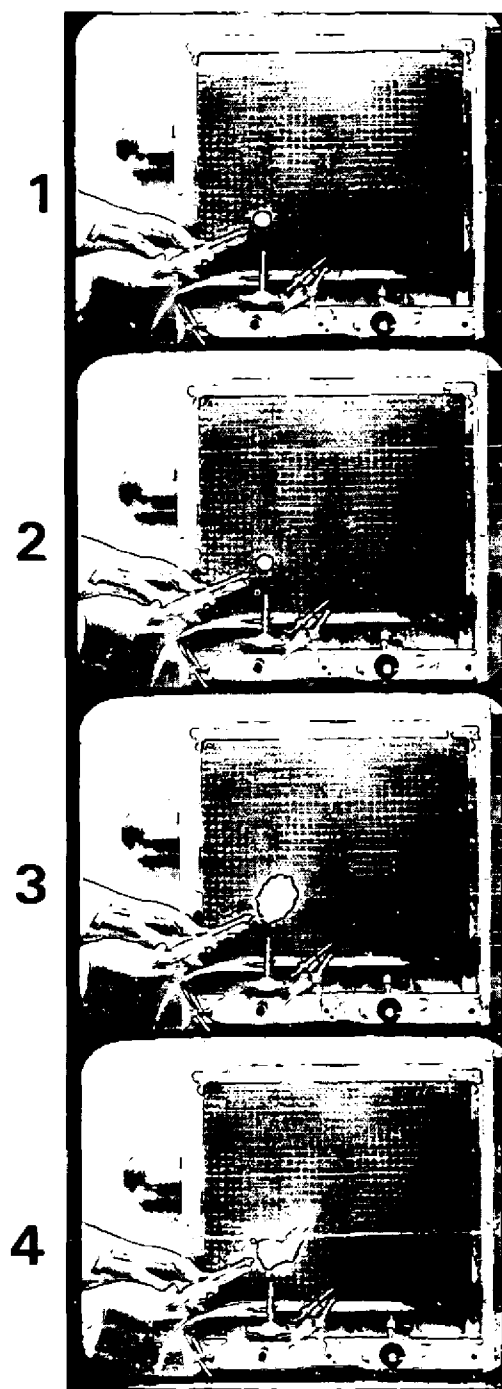


FIG. 6. IGNITION OF ETHYL ETHER FOLLOWED BY THE IGNITION OF A BUNSEN BURNER - HEATER 'B'

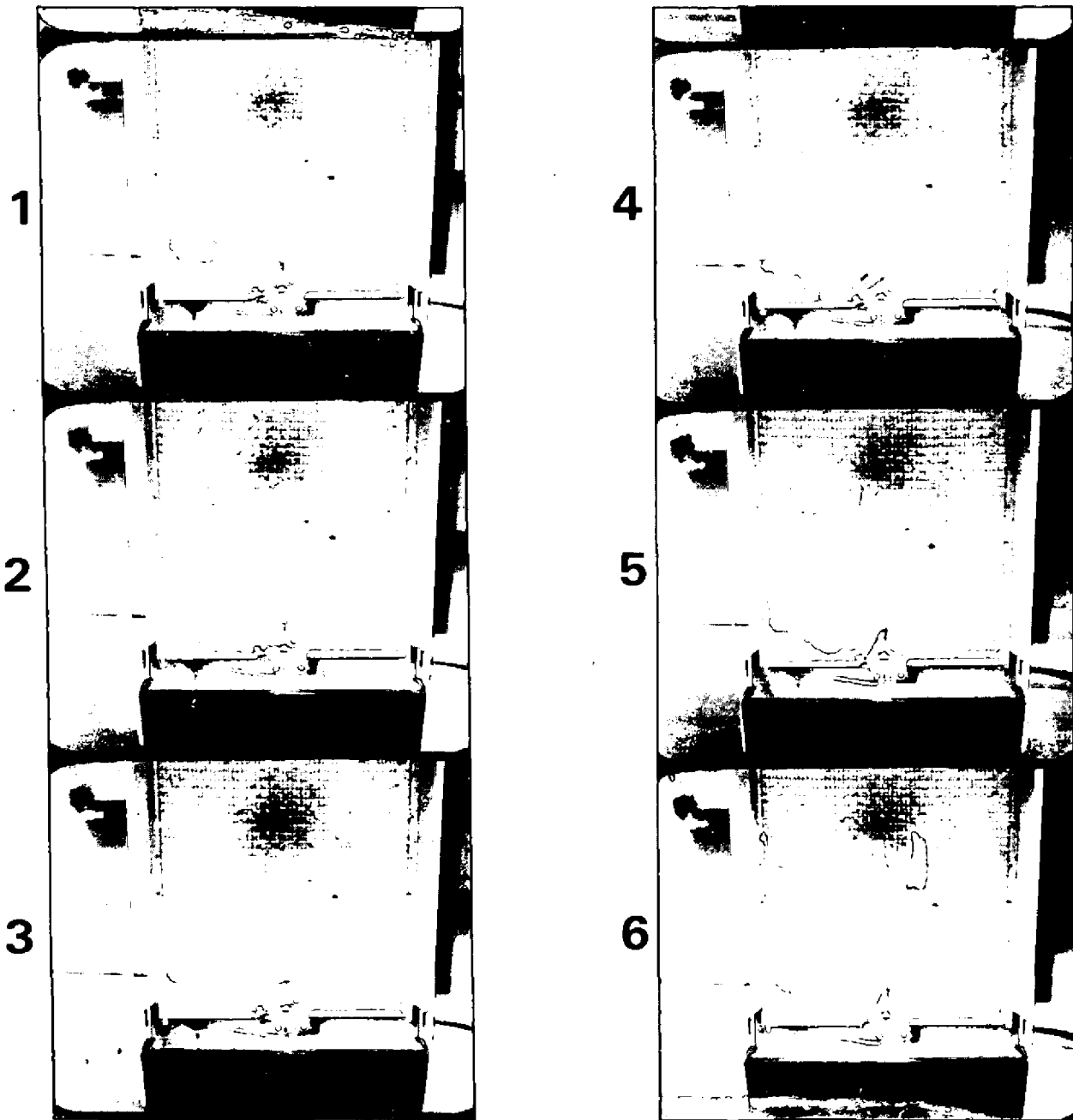


FIG.7. IGNITION OF PROPANE ON CATALYTIC BED
OF HEATER 'A' - 0.8 mm DIAMETER JET

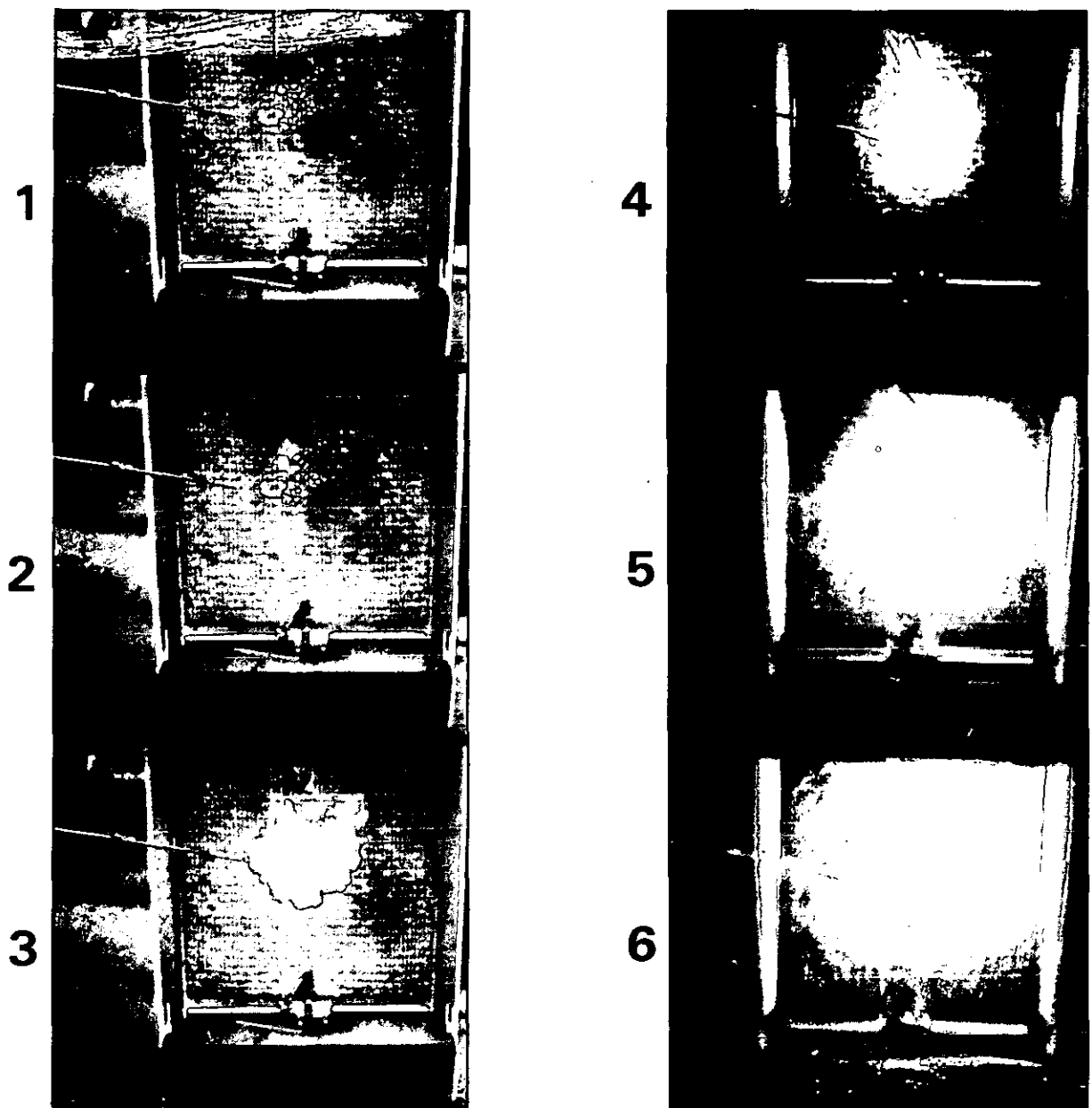


FIG. 8. IGNITION OF ETHYLENE ON CATALYTIC BED
OF HEATER 'A' - 3.2 mm DIAMETER JET

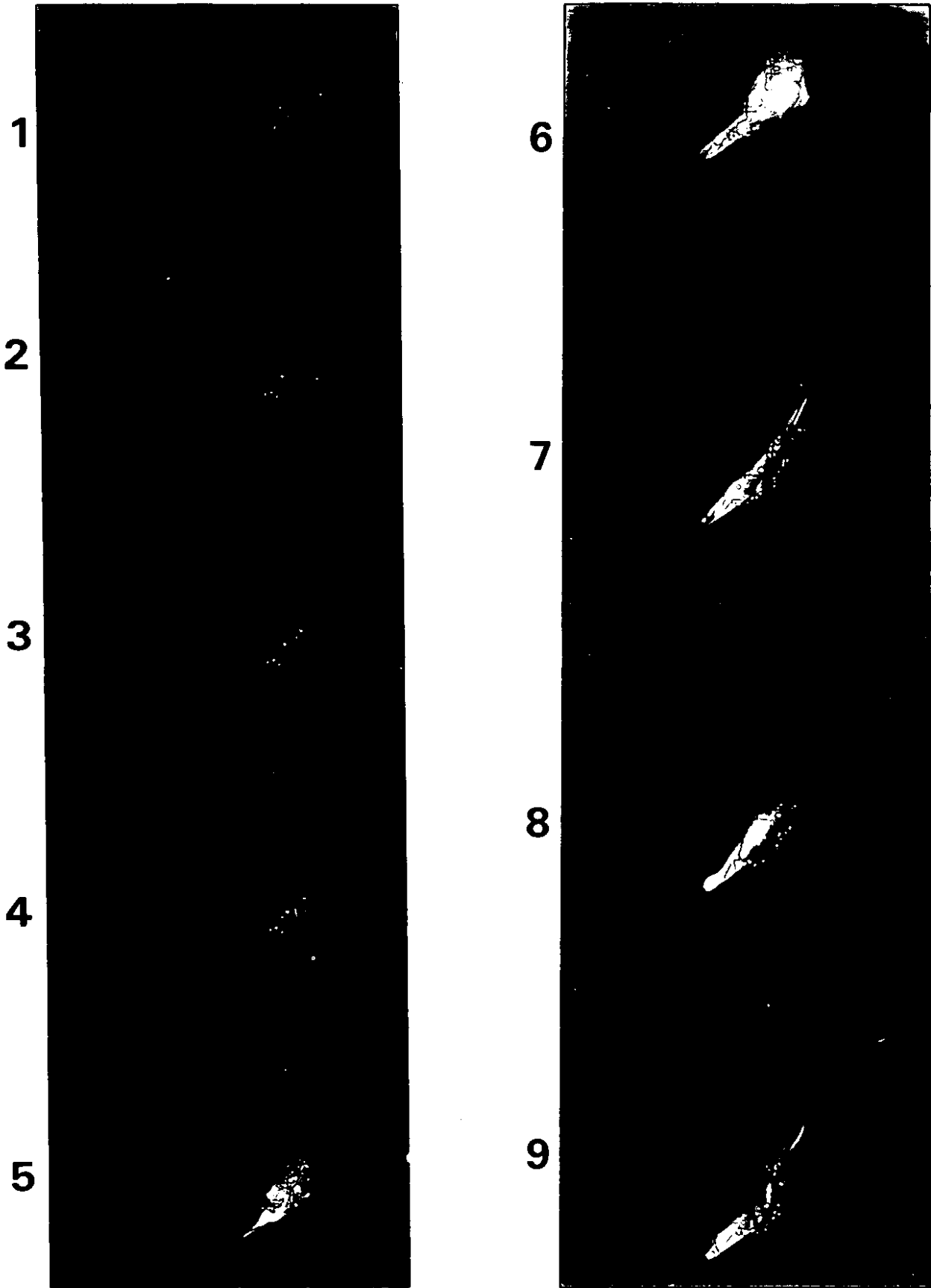


FIG. 9. IGNITION OF HYDROGEN ON
CATALYTIC BED OF HEATER 'A'