Combustion of animal fat and its implications for the consumption of human bodies in fires

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This paper describes experiments in which the combustion of animal tissue (pork) was measured under a variety of conditions that may be encountered in fire scenes. Combustion depends on substantial preheating of the tissue by an external heat source and the availability of a porous wick (such as charred cellulosic material). Combustion of moderate-size samples can proceed at a moderate rate of 1–3 g/s (3.6–10.8 kg/hr) if provided with an adequate wick and results in only a small fire of 30–50 kW. In the final test, combustion of 26 kg of fat and skin created a fire of 120–130 kW. Such a fire is more likely to cause fire spread to other combustibles nearby. The presence of other, less efficient fuels (like skin and muscle) and the absence of large fuel masses (such as in the very lean pig carcasses used here) results in significantly smaller fires of 40–50 kW. Such fires are more typical of burning human remains when there are minimal contributions from other fuels.

Cette article décrit une expérimentation de la mesure de la combustion de tissus animal (cochon) dans des conditions diverses qui peuvent être observées lors d'incendies. La combustion dépend d'un chauffage préalable substantiel du tissus par une source de chaleur externe et la présence d'une mèche poreuse (telle que de la matière cellulosique carbonisée). La combustion d'échantillons de tailles moyennes peut se développer à une vitesse modérée de 1–3 g/s (3,6–10,8 kg/h) s'il y a une mèche adéquate et résulter en un petit feu de 30–50 kW. Dans le test final, la combustion de 26 kn de graisse et de peau a permis de créer un feu de 120–130kW. Un tel feu est plus probablement la cause d'une propagation à du combustible à proximité. La présence d'autres combustibles, moins efficaces (comme la peau ou le muscle) et l'absence de grandes masses de combustible (telles que les carcasses de cochon très maigres utilisées ici) provoque des feux singulièrement plus petits de 40–50 kW. De tels feux sont plus typiques de restes humains brûlants, lorsqu'il n'y a que des contributions minimes d'autres combustibles.

Es werden Versuche beschrieben bei denen die Verbrennung von tierischem Gewebe (Schwein) unter einer Reihe von Bedingungen gemessen wurde, wie sie bei Brandereignissen eintreten können. Die Verbrennung hängt ganz wesentlich vom Vorheizen des Gewebes mit einer externen Heizquelle ab und von der Verfügbarkeit eines porösen Dochtmaterials (wie z.B. verkohltes cellulosisches Material). Die Verbrennung kann sich mit einer mäßigen Rate von 1–3 g/s (3.6–10.8 kg/hr) fortsetzen, wenn geeignetes Dochtmaterial zur Verfügung steht. Daraus ergibt sich allerdings nur ein kleines Feuer von 30–50 kW. Der Brandversuch mit 26 kg Fett und Haut ergab ein Feuer mit 120–130 kW. Ein derartiges Feuer ist eher geignet, andere brennbare Materialien in der Nähe zu entzünden. Die Gegenwart anderer, weniger geeigneter Brennstoffe (wie Haut und Muskelfleisch) und die Abwesenheit von großen Mengen von brennbaren Materialien (wie bei dem hier verwendeten mageren Schweinekadaver) führt zu signifikant kleineren Feuern mit 40–50 kW. Dieses Brandverhalten ist eher typisch für die Verbrennung menschlicher Körperteile, wenn der Anteil anderer Brennstoffe gering ist.

Este trabajo describe experimentos en los que se quema tejido animal (cerdo) bajo diferentes condiciones que pueden darse en escenarios de incendios. La combustión depende del precalentamiento sustancial del tejido por la fuente externa de calor y la disponibilidad de mecha porosa (tal como material celulósico carbonizado). La combustión puede proceder a una velocidad moderada de 1–3 g/s (3,6–10,8 kg/hr) si se dispone de una mecha adecuada y resulta en un pequeño fuego de 30–50 kw. En el test de combustión final de 26 kg de grasa y piel se creó un fuego de 120–130 kw. Tal fuego es fácilmente extensible a otros combustibles cercanos. La presencia de otros combustibles menos eficientes (como piel y músculo) y la ausencia de grandes masas combustibles (tales como la carcasa de cerdos magros) se traduce en fuegos pequeños de 40–50 kw. Este tipo de fuegos son más típicos de la combustión de restos humanos en los que la contribución de otros combustibles es mínima.

Key Words: Forensic science; Fire investigation; Arson; Spontaneous combustion; Fat; Body consumption.

Introduction

Body tissue, muscle and fat, whether animal or human, are often involved in fires. Their involvement is usually limited to surface scorching and charring with limited penetration. Occasionally these materials constitute a significant percentage of the fuel load of a fire and investigators may be faced with a scene involving significant destruction of an animal carcass or human body where the surrounding fuel bears little fire damage or, when burned, seems to be incapable of generating sufficient external heat to cremate the remains effectively. Thus, the mythology of 'spontaneous human combustion' has arisen. In an attempt to understand the role of animal tissue in fires, it would be useful to establish the basic properties of such tissues as fuels. There appears to be little in the way of published data regarding these fire and fuel properties other than a citation in the National Fire Protection Association (NFPA) Handbook that animal fat has a heat of combustion (ΔH_C) of 39.8 kJ/g [1]. It was decided that some systematic examination of the fuel properties of animal tissue was needed. It was clear from case reports involving burned human bodies that a significant external ignition source was required to begin the process and that some sort of rigid porous wick was needed to sustain combustion in most instances [2,3]. It was thought that an external fire could begin the rendering of fat to a more readily combustible liquid and char nearby cellulosic materials (such as cotton clothing, upholstery or carpet) that in time, could serve as a rigid, carbonaceous wick. This paper, then, will explore the combustion of animal (pork) tissue (predominantly subcutaneous fat) under a variety of conditions that may be encountered in fire scenes.

Experimental

The room calorimeter at the California Department of Consumer Affairs – Bureau of Home Furnishings (BHF) provided the basic experimental requirements for the tests conducted. The room, 3 m x 3.6 m x 2.5 m, has a single door opening 2.2 m high x 0.9 m that is fitted with an exhaust hood that allows the entire room to function as an oxygen depletion calorimeter.

TABLE 1 Gasoline pan tests.

Test	*Size Pool (m)*	*Quantity (L)*
G1	0.43 x 0.43 x 0.1	1
G2	0.43 x 0.43 x 0.1	1

The tests generally progressed from simple, single fuel scenarios to several tests involving whole carcasses of slaughtered pigs purchased from a local meat-packing plant. All room test data (temperatures at three points in the room, CO, CO_2, smoke, heat release) were recorded on the BHF computer 12 times per minute. All tests were videotaped for later evaluation.

Since all of the tests would be initiated using 1 L of fresh automotive gasoline, the first two tests involved the combustion of 1 L of gasoline in a flat, stainless steel pan (Table 1). Ignition was by open flame. Tests were allowed to run to self-extinguishment.

The second series of tests involved the ignition of the same quantity of gasoline poured on a substrate of carpet and pad. A quantity of synthetic pile (1.5 cm deep) carpet (polypropylene and nylon yarns, polypropylene backing) was laid over 1.2 cm thick polyurethane rebond pad with no integral vapour barrier. The edges of the carpet were held down by angle iron and steel framing to prevent curling. Two of the tests were conducted directly on the concrete floor of the test room; all subsequent tests (Table 2) were conducted on a 200 kg capacity load cell (± 0.06 kg) by placing a suitably sized sheet of gypsum board centrally on the load cell and then the pad and carpet on top of it (Figure 1). Extinguishment, when needed, was by CO_2 extinguisher, hand-held, or very small quantities of water splashed onto residual flames.

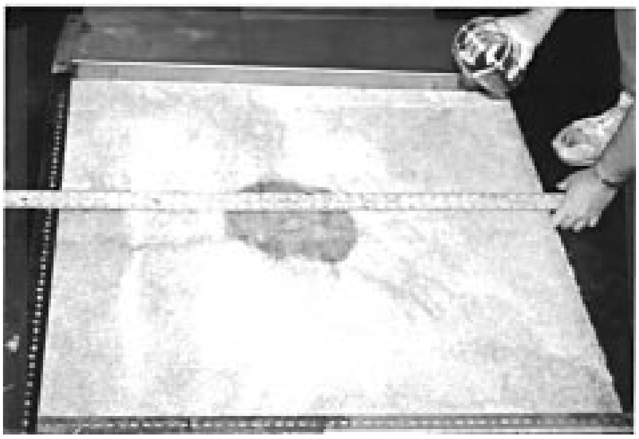

FIGURE 1 Typical carpet/pad fat test. 1 m^3 carpet over rebond pad on gypsum board base on load cell. Edges secured to prevent curling. One litre of gasoline poured in centre (d=0.25 m).

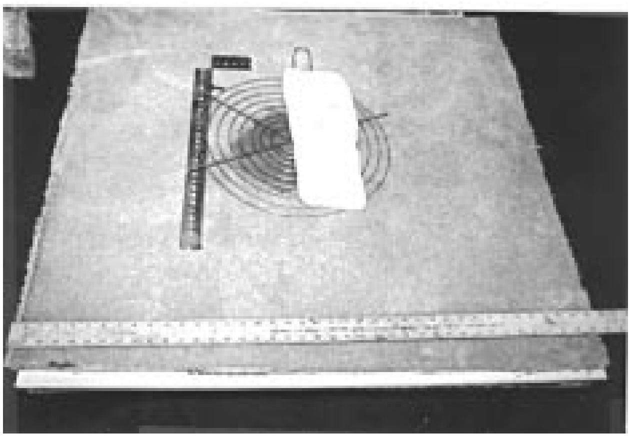

FIGURE 2 Typical pork fat test. Fat wrapped in cotton towel and supported on wire grille ~2–3 cm above carpet. Gasoline poured on cloth and on carpet.

Once a baseline of expected fire behaviour was established, quantities of fresh, refrigerated (not frozen) pork subcutaneous fat (with skin and some underlying muscle tissue included) were wrapped in cotton towel material and burned on the carpet, ignited with 1 L gasoline in the same manner as the carpet tests (Table 3, Figure 2). Extinguishment was by hand-held CO_2 extinguisher.

After each fire cooled, the remains of the pork fat mass and charred towel were removed and weighed.

TABLE 2 Carpet and pad tests.

Test	*Carpet (m²)*	*Gasoline (L)*	*Area of Pour (m diameter)*	*Substrate*
CP1	1	1	0.25	Concrete
CP2	1	1	0.25	Concrete
CP3	2	1	0.5 x 0.7	Gypsum board

TABLE 3 Pork fat tests.

Test	*Size of sample (cm)*	*Starting weight (kg)*	*Presentation*
P1	25 x 12 x 2.5	0.86	Wrapped in cotton towel. Supported on wire grille, tilted above carpet.
P2	35 x 15 x 3.5	1.44	Wrapped in cotton towel. Supported on wire grille, tilted above carpet.
P3	53 x 18 x 2.5	1.69	Wrapped in cotton cloth, placed directly on carpet.
P4	51 x 14 x 1	0.87	Wrapped in polyester/cotton cloth. Supported on wire grille.

FIGURE 3 Typical carcass test. Metal scale (1.2m) supported by wire just above carpet. Thermocouple placed in neck area of carcass.

A final series of tests was then carried out using the same carpet and pad over gypsum board with 1 L of gasoline as the igniter but using dressed carcasses of fresh, refrigerated (not frozen), pigs of various weights, as in Table 4.

Since human bodies often have some clothing items associated, a cotton/polyester blend shirt was put over the shoulders and forelegs of each carcass as in Figure 3. The gasoline was poured over this shirt and shoulders of the carcass. A final test (PC4) was not of a complete carcass but of a very large quantity (26.0 kg) of pork fat slabs covered with cutaneous (skin/fat) segments, wrapped in a cotton/polyester cloth robe.

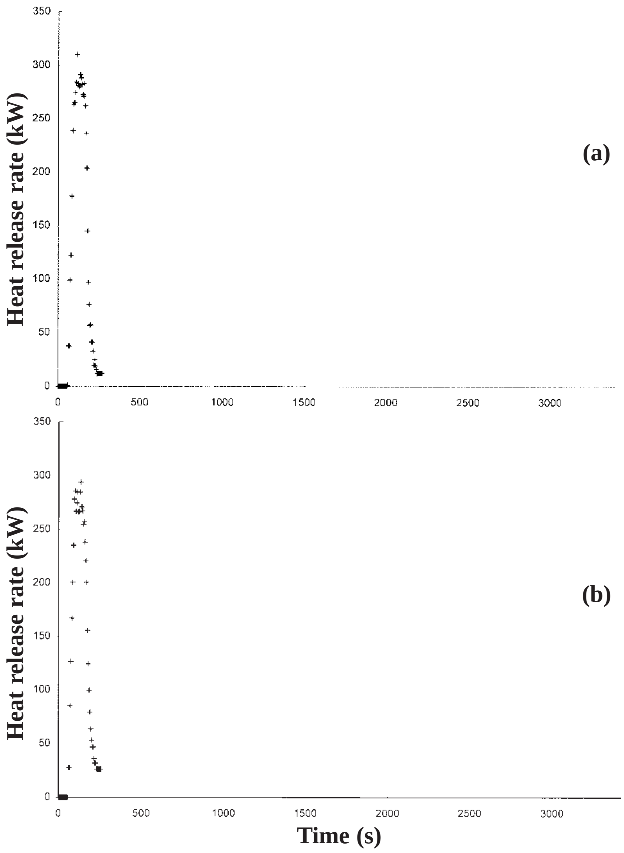

FIGURE 4 Gasoline pan test results for Table 1. Ignition at 60s. (a) Test G1 (b) Test G2.

TABLE 4 Pig carcass tests. Ignition by 1 litre of gasoline with flame.

	Starting weight (kg)	*Carpet area (m)*
PC1	53.3 (dressed, with intestines)	1.2 x 2.5
PC2	49.3 (dressed, no internal organs)	1.2 x 2.5
PC3	51.2 (dressed, no internal organs)	1.2 x 2.5
PC4	26.0 (pork fat, skin, dressed)	1.2 x 1.2

TABLE 5 Gasoline Tests.

Test	*Δm (kg)*	*Total burn time (min:s) observed*	*Peak heat release rate (HRR) (kW)*	*Time at Peak* (min:s)*	*Plume height (est.)(m)*	*Total heat release (MJ)*
G1	0.77	2:22	310	1:50**	1.2	30.8
G2	0.71	2:35	294	2:17**	1.2	30.2

*Ignition was at 1:00
**High heat release rate sustained for 90–170s

TABLE 6 Carpet and Pad Tests. NR = not recorded.

Test	*Δm (kg)*	*Total burn time (h:min:s)*	*Peak HRR (gasoline) (kW)*	*Time (min:s) (ignition at 1:00 min)*	*Peak HRR Carpet (kW)*	*Time (min:s)*	*Total heat release (MJ)*
CP1	NR	0:37:00*	139	2:21	157	3:29	50.2
CP2	NR	2:43:00**	129	2:04	169	5:28	59.1
CP3	32.16	0:26:00*	305	1:37	444	4:51	168.5

*Observed self-extinguishment
**Residual flames in carpet extinguished with water after 2:43:00

Radiant Heat Ignition (Cone Calorimeter) Tests

A Stanton-Redcroft Oxygen Depletion Cone Calorimeter (Polymer Laboratories, Epson, Surrey, UK) was used in an attempt to determine the heat of combustion of pork fat as used in these tests. A 10 cm x 10 cm x 3 cm aluminium foil tray was filled with segments of fresh, refrigerated pork fat and skin. The tray was then exposed to radiant heat flux of 35 kW/m^2 while a high voltage arc source was energized to provide an ignition source. A second tray was prepared in a similar manner but a small piece of cotton cloth was wrapped around the pork fat and skin. The wrapped pork was then exposed to the same radiant heat flux of 35 kW/m^2 with a high voltage arc ignition source. During one preliminary test the oxygen depletion data system was inoperative, so the ignition and flame behaviour of the two samples were observed directly and results recorded manually. A second series of tests yielded heat release rate (HRR) and estimated heat of combustion data for incident heat fluxes of 35 and 50 kW/m^2.

Results

Plots of HRR v. time for G1 and G2 are shown in Figure 4. The data are summarized in Table 5.

The basic data from the carpet and pad tests are shown in Table 6. In each test, the rapidly developing plume of the gasoline fire could be distinguished (visually and by data plot) from the plume from the carpet and pad. (Plots of heat release rate v. time for CP1–CP3 are shown in Figure 5). The larger HRR in CP3 was the result of scattering the gasoline over a larger area of carpet than the single pool created in CP1 and CP2. A larger area of carpet was involved immediately resulting in a much higher HRR and total heat release for this test as well.

It was observed that the carpet used could be ignited very readily and the carpet and pad could self-sustain combustion for long periods of time, displaying small (5–8 cm) flames where HRR was too low to be measured.

Pork Fat Tests

In each of these tests, three phases of burning were observed visually and could be distinguished in the HRR data. First was a sharp peak resulting from the gasoline, typically 140–150 kW peaking near 120 s (60 s after ignition) then quickly dropping off near 200 s (1:40 after ignition). Next was a broader peak resulting from the rapid involvement of the carpet, falling gradually after 500 s. Finally, the contribution of the pork fat could be seen as a shoulder or a separate peak on the HRR plot at 750–800 s. This could be correlated to observation of the video that demonstrated that by this time, the carpet was contributing very little (as evidenced by the very small isolated flames at the perimeter of the burned area while the charred area around the pork fat was burning much more energetically). The plots of HRR v. time for these tests are shown in Figure 6 and the results summarized in Table 7.

Pig Carcass Tests

The observations of fire behaviour in each of these tests were similar to those in the pork fat tests: a brief, energetic plume from the gasoline, followed by a more sustained, equally energetic plume from the carpet; finally a prolonged, low energy fire from the rendering and combustion of the fat and tissues of the carcass. Plots of heat release v. time for three pig carcass tests are shown in Figure 7. The results of the three carcass tests and one of a mass of fat (scraps) are summarized in Table 8. The HRR data for the fat scrap test (P4) are shown in Figure 8. (The weight of the

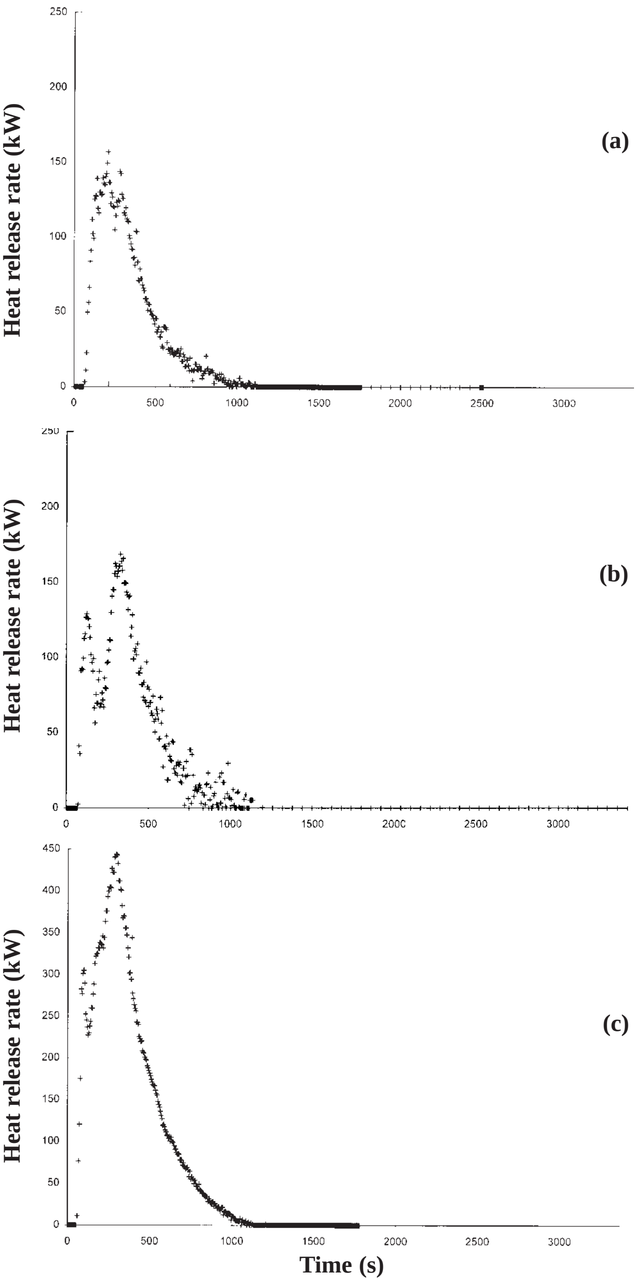

FIGURE 5 Carpet/Pad test results for Table 6. (a) Test CP1. (b) Test CP2 and (c) Test CP3. Note separate peaks for gasoline and carpet.

residues on the load cell were recorded manually as components were removed.)

Radiant Heat Ignition Test Results

Upon exposure to the 35 kW/m^2 heat flux, the top layer of pork skin dried, scorched and curled within one minute. Liquid fat could be seen rendering from the top layer to accumulate in the bottom of the aluminium foil tray. After four minutes, the top of the exposed fat had charred and occasional flames could be seen above the tray. After five minutes, there was a weak, apparently sustained flame on top of the pork. When the ignition source arc was turned off, the flames self-extinguished.

Exposing the cotton-wrapped pork fat to 35 kW/m^2 heat flux caused the cotton cloth to scorch and char in less than one minute. Within seconds of that charring, a flame was ignited as the pork fat rendered and saturated the charred cotton, which now acted as a wick. When the ignition arc was turned off, the combustion was sustained and a steady flame plume could be seen to extend from the charred cotton wick to well above the top of the radiant heater cone. The flames were extinguished by smothering after the sample tray was removed from the calorimeter. The charred cotton cloth was found to be still flexible in some areas, while others were charred and brittle. Maximum estimated heat of combustion of ~27 kJ/g (with an incident radiant heat flux of 35 kW/m^2) and ~32 kJ/g (with an incident radiant heat flux of 50 kW/m^2) was measured (Figure 9). Both estimates are ±5 kJ/g due to boiling of the liquefied fat under the cotton cloth wick. A maximum flame temperature of 911˚C was measured by a handheld thermocouple probe during these tests.

Mass Loss Rate

The mass loss rates for the gasoline pool tests calculated directly from the mass (load cell) data and are shown in Table 9.

TABLE 7 Results of pork fat tests.

	Δm_{fat} (kg)	Δm_{carpet} (kg)	*Total burn time (min:s)*	*Peak HRR (gasoline)(kW)*	*Time* (min:s)*	*Peak HRR (carpet)(kW)*	*Time (min:s)*	*HRR Max (pork)/time*	*Total HR (MJ)*
P1	0.45	2.93	37:00	147	1:20	139	3:50	600–1200s	70.8
P2	0.81	2.92	30:00	135	1:54	187	3:26	500–1100s 92 kW @11:02	106.2
P3	1.53	3.23	30:00	181	1:33	163	3:36	500–1200s 99 kW @12:49	117.1
P4	0.79	2.66	30:00	227	1:28	178	3:34	500–1100s 71 kW @10:36	90.5

*Ignition at 1:00

TABLE 8 Results of pig carcass tests.

	Δm_{total} *(kg)*	Δm_{carpet} *(kg)*	Δm_{fat} *(kg)*	*Total burn time (hrs:min)*	*Peak HRR (gasoline) (kW)*	*Time (min:s)*	*Peak HRR (carpet) (kW)*	*Time (min:s)*	*Peak HRR carcass (kW)*	*Total HR (MJ)*
PC1	7.8	NR	NR	3:57	231	1:24	153	6:33	43	391.2
PC2	6.2	2.8	2.9	1:00**	218	1:24	245	6:06	53	152.0
PC3	9.3	4.9	3.9	1:45**	310	1:19	201	5:18	50	227.7
PC4	13	2.1	11.2	1:08***	318	1:13	40	8:17	131	323.7

*Ignition at 1:00 min
**Residual fire in carpet extinguished with water
***Substantial fire in fat extinguished with CO_2

TABLE 9 Mass loss rates for gasoline fires over time period.

	Peak Loss Rate @ time (s)	*Average Loss Rate*
G1	10 g/s @ 93s (33s after ignition)	5–7 g/s (47–167s)
G2	10 g/s @ 102s (42s after ignition)	5–7 g/s (46–166s)

TABLE 10 Mass loss rates (g/s) for carpet/pad fires on test CP3.

	Gasoline (max)	*Carpet (max)*	*Carpet at 1000s*
Peak Loss Rate (at time s)	10 (90)	20 (265)	
Average Loss Rate (at time s)	8–9 46–169	17–18 (230–357)	1 (981–1041)

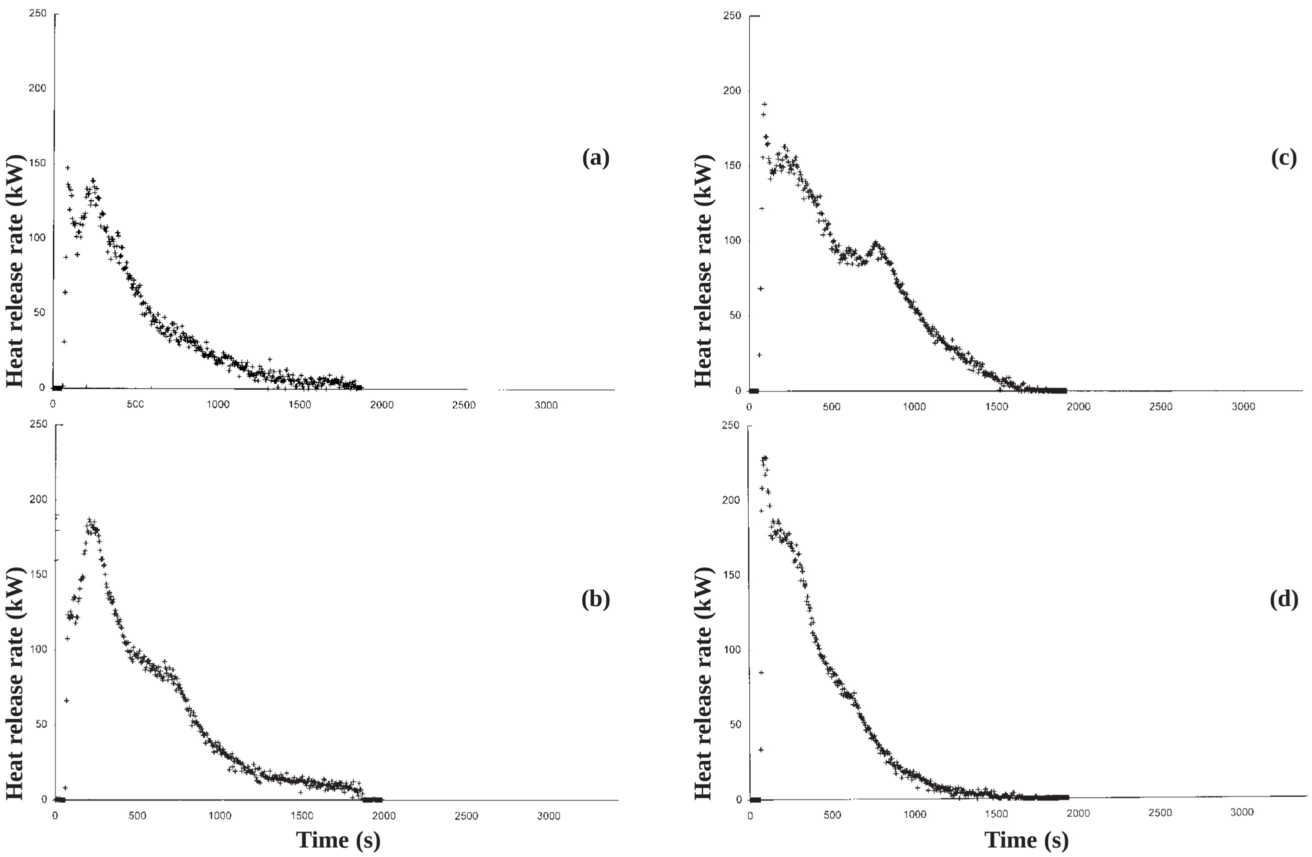

FIGURE 6 Pork fat tests (a) P1 (b) P2 (c) P3 (d) P4.

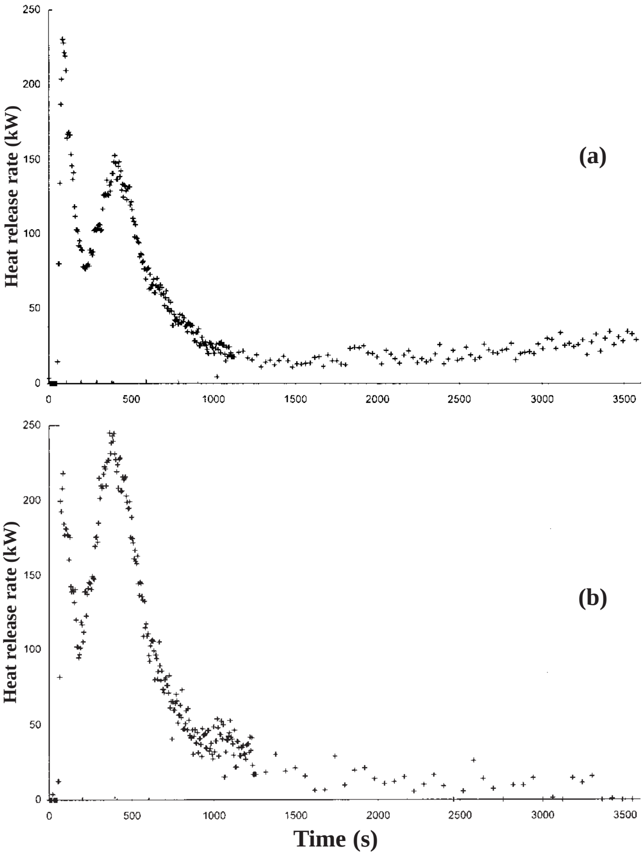

FIGURE 7A Carcass test results. (a) Test PC1 (b) Test PC2.

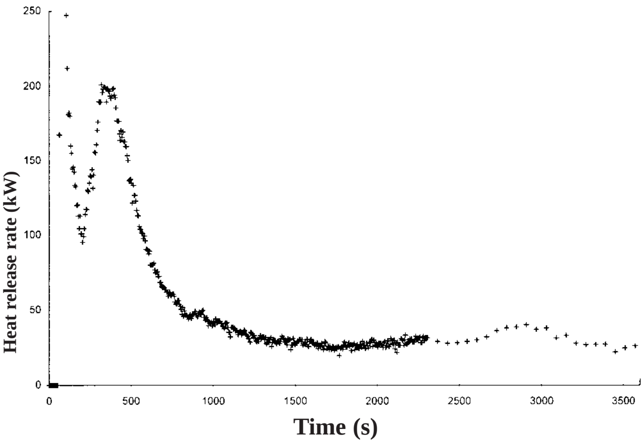

FIGURE 7B Carcass test results for test PC3.

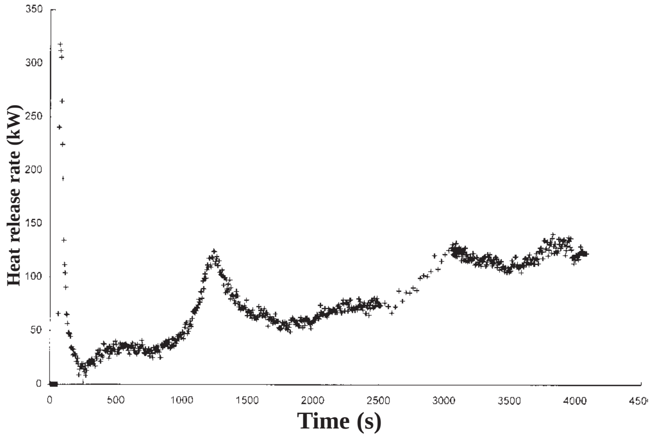

FIGURE 8 Carcass test results for test PC4.

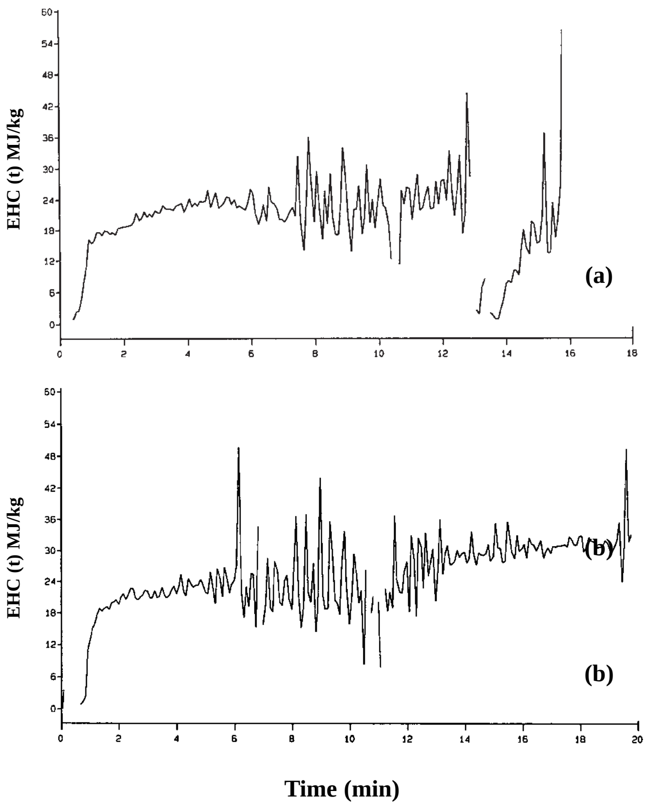

FIGURE 9 Effective heat of combustion of pork fat burning in the Cone Calorimeter (with a cotton cloth wick). Incident heat flux of (a) 35 kW/m^2 (b) 50 kW/m^2.

The mass loss rates for the gasoline/carpet tests with load cell data were calculated directly from the mass (load cell) data at three points, shown in Table 10.

The mass loss rates for the gasoline/carpet/pork fat tests were calculated manually at four points for test P1. Those for the remaining tests were calculated using Excel™ spreadsheet operations. Since these mass loss rates were close to the limit of sensitivity (0.06 kg) for the 200 kg load cell used, the resulting data are in the form of ‘steps’ from zero to two or three times the detection limit. At very low mass loss rates, five or more time intervals may pass before any mass loss is recorded. As a result, the data is best presented as a trend line, reflecting the average recorded over 12 time intervals (1 min). The peak and average loss rates in Table 11 were then estimated from these plots. The mass loss rates for these tests are shown in Figures 10–12.

The mass loss rates for the pig carcass tests PC1–PC4 were also calculated from the weights recorded by the load cell during each test using Excel™ spreadsheet operations. The plots are shown in Figures 13–16 and the data are summarized in Table 12.

TABLE 11 Mass loss rates (g/s) for pork fat on carpet. (Ignited with gasoline).

Test	*Loss rate: (g/s)*	*Gasoline max (at time s)*	*Carpet max (at time s)*	*Total at 800s*	*Total at 1000s*
P1					
	Peak	12 (83)			
	Average	7.5 (41–162)	4–5 (226–289)	2 (798–859)	1
P2					
	Peak	4 (83)	6 (250)		
	Average	4 (40–161)	5–6 (100–320)	2	1
P3					
	Peak	12 (100)	5 (250)		
	Average	5 (62–185)	4–5 (280–400)	3	2
P4					
	Peak	12 (88)	7 (500)		
	Average	6–7 (62–184)	5–6 (280–400)	2	1

TABLE 12 Mass loss rates (g/s) for pig carcass tests.

Test	*Loss rate: (g/s)*	*Gasoline max (at time s)*	*Carpet max (at time s)*	*Total at time 800s*	*Total at time 1000s*
PC1					
	Peak	18 (120)	14 (300)		
	Average	5 (100–280)	4–6 (200–700)	2–3	1–2
PC2					
	Peak	10(120)	12(350)		
	Average	5–7 (160–200)	5–10 (300–600)	2–3	1–2
PC3					
	Peak	12 (120)	10 (400)		
	Average	5–7 (100–200)	6–7 (250–600)	2–3	2–3
PC4					
	Peak	10 (120)		5–6(1200–1400s)	5–6(3100–3400s)
	Average	5–7 (100–200)	2–3 (400–600)		

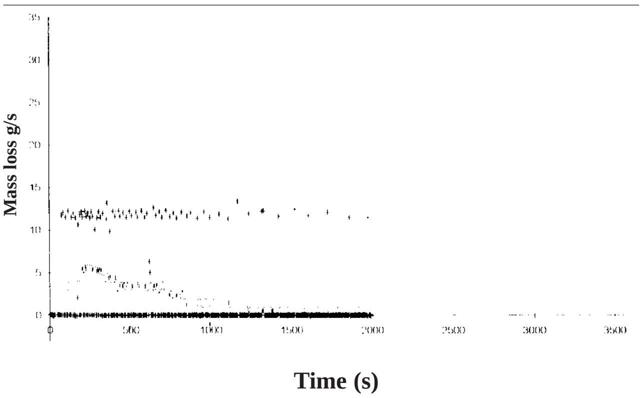

FIGURE 10 Mass loss rate for test P2 with trend line (average of value over previous 12 intervals). 0.8 kg of fat consumed.

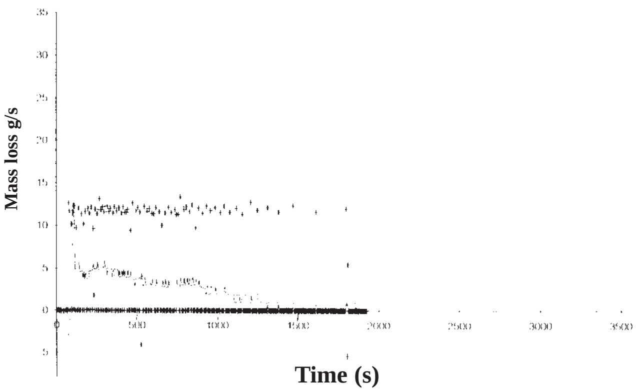

FIGURE 11 Mass loss rate for test P3 with trend line (average of value over previous 12 intervals). 1.53 kg of fat consumed.

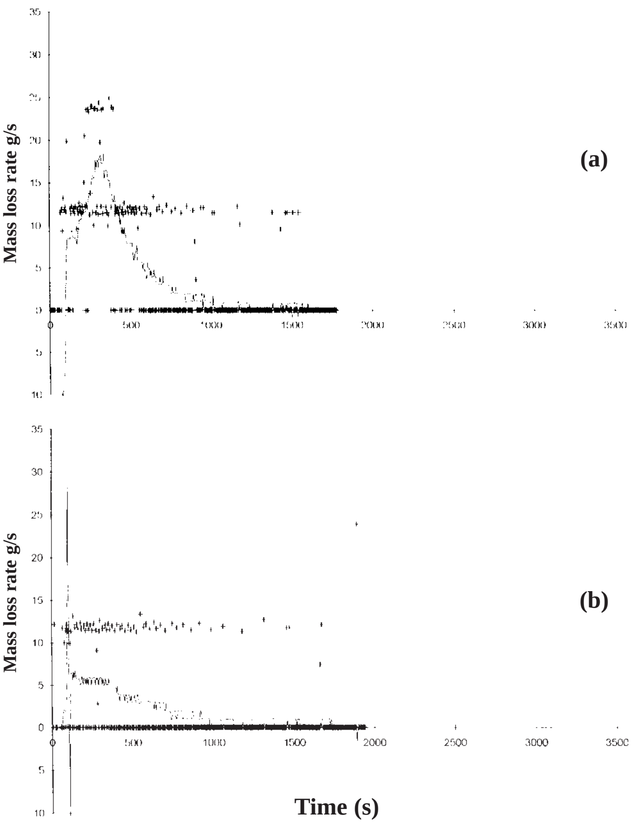

FIGURE 12 (a) Mass loss rate for test CP3, carpet/pad with 1 L gasoline scattered. (b) Mass loss rate for P4, carpet/pad/pork fat.

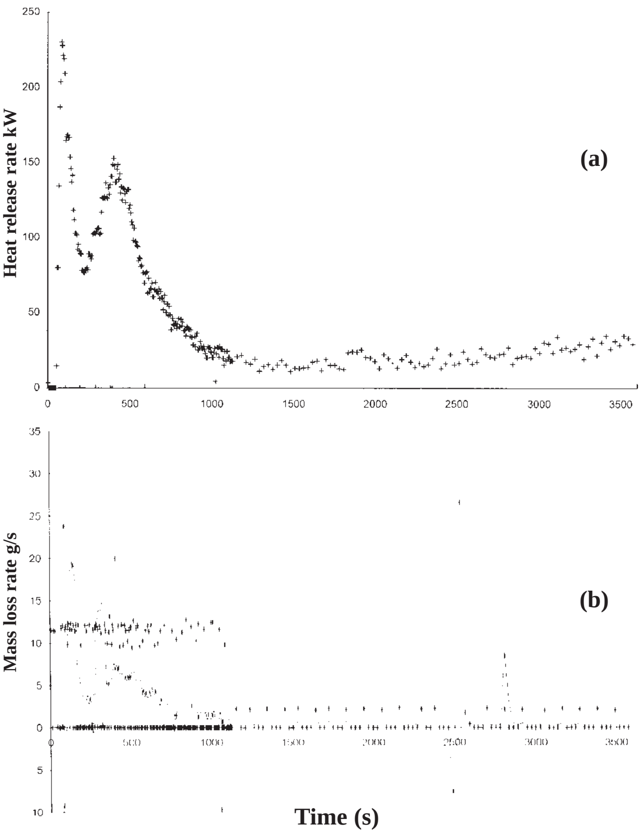

FIGURE 13 (a) Heat release rate and (b) mass loss rate for carcass test PC1. Sustained consumption after 600s.

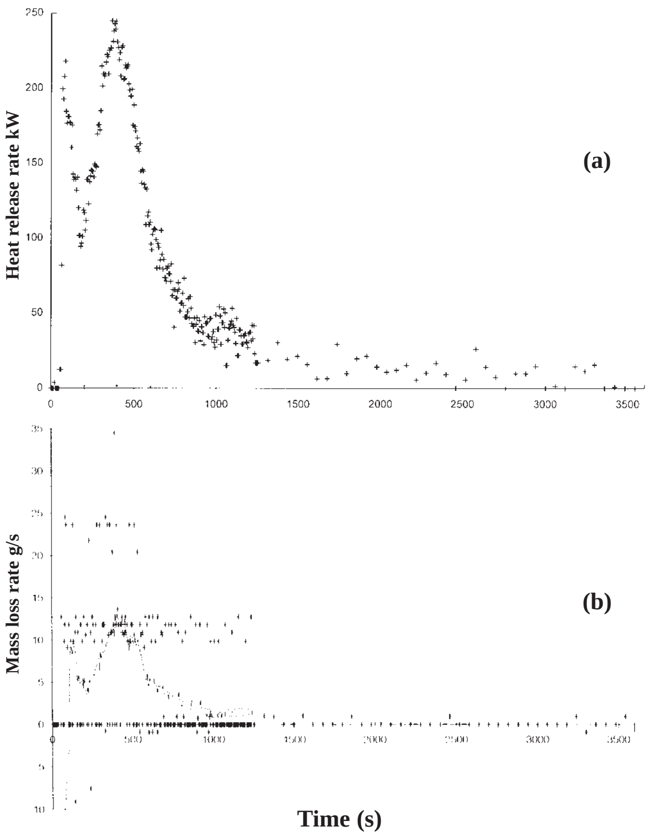

FIGURE 14 (a) Heat release rate and (b) mass loss rate for carcass test PC2. Sustained consumption after 600s.

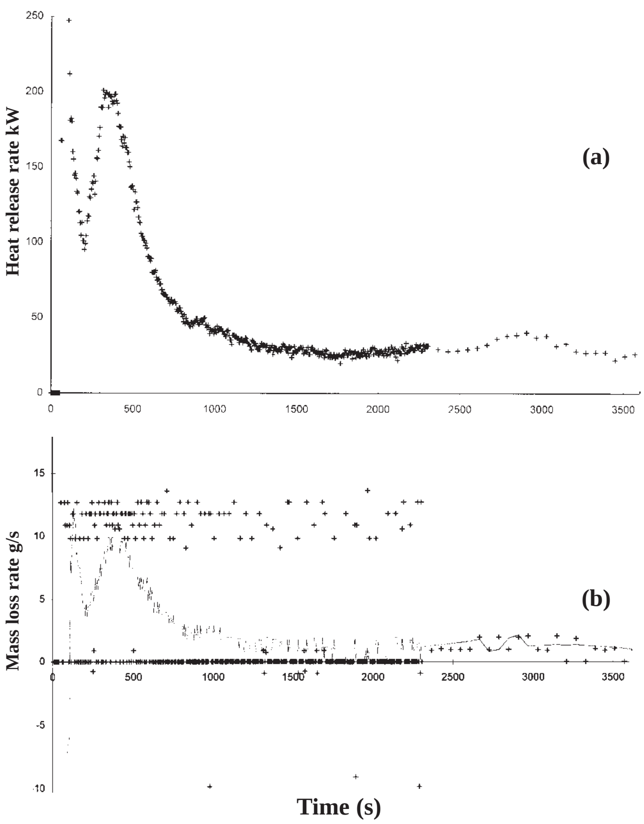

FIGURE 15 (a) Heat release rate and (b) mass loss rate for carcass test PC3. Sustained consumption and heat release after 600s.

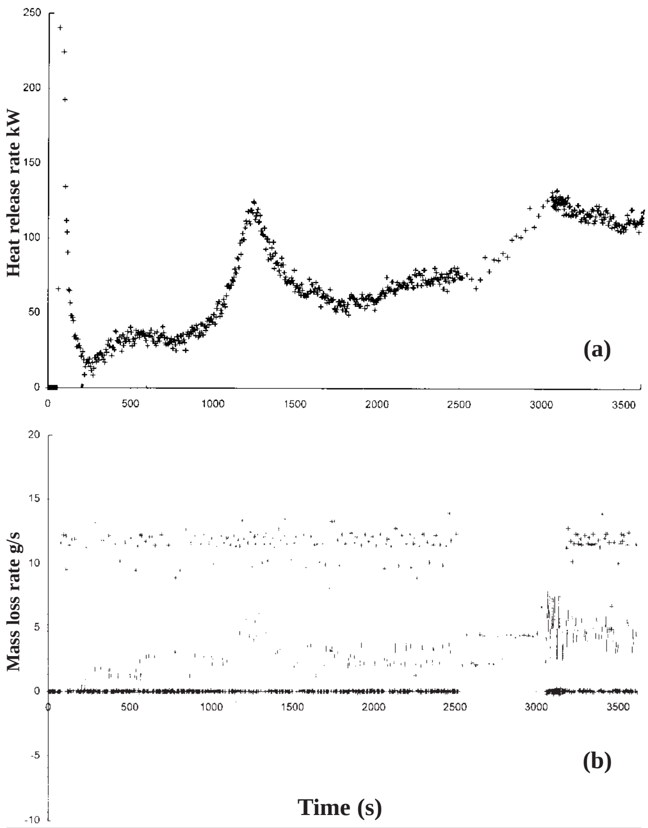

FIGURE 16 (a) Heat release rate and (b) mass loss rate for carcass test PC4 (26 kg of fat skin, scraps). Large peaks in HRR (120–130 kW) accompanied by peaks in mass loss rate of 5 g/s (at 1250s, 3100s).

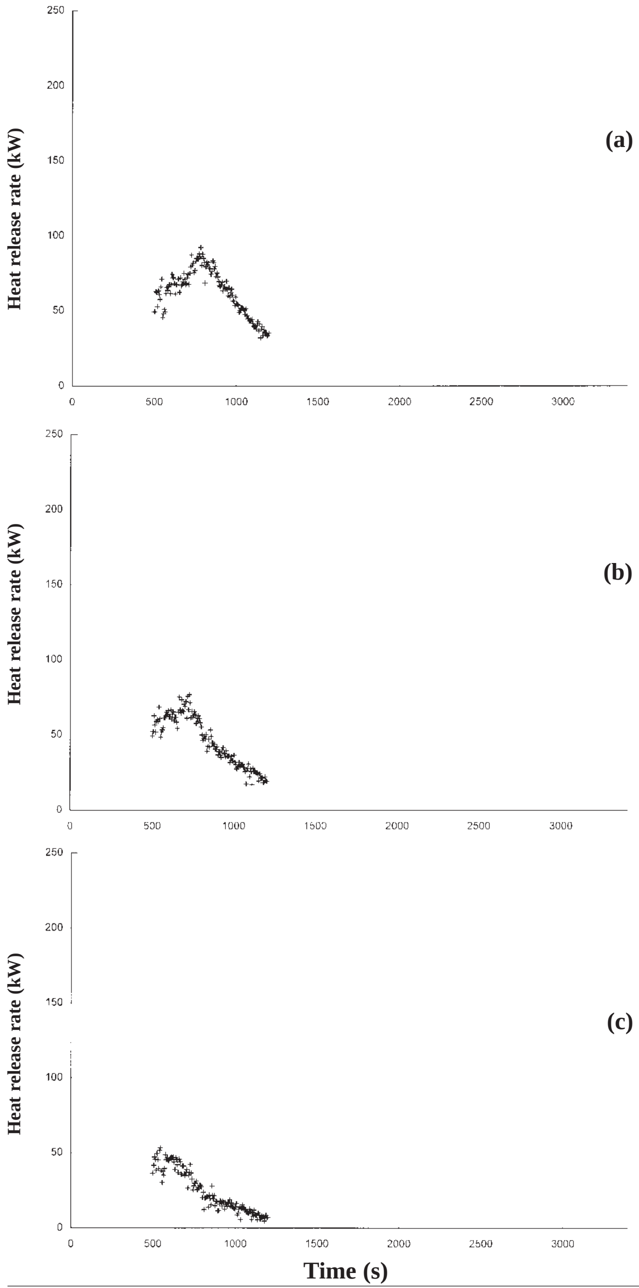

FIGURE 17 Heat release rates by subtraction (test CP1 used as baseline); (a) test P2 (b) test P3 and (c) test P4.

Discussion

The combustion of gasoline as a liquid pool has been studied extensively. The combustion of gasoline when it is absorbed into a porous substrate has not been explored as thoroughly. It is recognized that the larger the surface area of the exposed 'pool' the faster the loss rate (although the relationship is neither linear nor simple). The regression rate varies with pool size, being higher for very small diameter pools reaching a minimum (2 mm/min) for pools of about 0.1 m diameter, and levelling off at 3mm/min for pools >1 m in diameter [4]. One litre of fuel would form a pool with a depth of 5.3 mm in a pan of the dimensions used in these tests (43 cm x 43 cm). The pan used here did not have a level base, and the depth of the pre-fire pool varied from 2–8 mm (average depth 5.3 mm).

The observed mass loss rate of 5–7 g/s observed in these pan tests corresponds well to the 300–310 kW fires observed (at a ΔH_c for gasoline of 44 kJ/g). The regression rate (5.3 mm to zero in 2.5 min) also corresponds to the expected values for pool fires of this diameter despite the high rim of the pan which would be expected to throttle the combustion rate somewhat.

The areas of gasoline poured on the carpet would be expected to produce smaller diameter pools, as were observed (0.25 m), due to the penetration into carpet and pad. A smaller pool would be expected to produce a smaller heat release rate, but the capillary action of a porous substrate supplements the evaporation rate [5]. The observed peak HRR (of 129–139 kW) in tests CP1 and CP2 are in accord with the straight pool tests. The peak HRR occurred later than in the pool tests and the combustion was more prolonged. Unfortunately, only CP3 was accompanied by mass loss data. These data reflected an average of 8–9 g/s (including carpet). This same test had the gasoline spread across a larger surface of the carpet than a single pool, so its high peak HRR (305 kW) and fast development (37s after ignition v. 64–81s for straight pours) are not unexpected. This larger area of ignition prompted a vastly higher peak

HRR (444 kW) for the carpet. This also resulted in substantial destruction of a large portion of the carpet and pad (6.7 kg of 8.7 kg) before self-extinguishment in 26 minutes.

The pork fat tests revealed that some time was needed before the burning fat contributed measurably to the fire (only being measurable after 500 s). The formation of a rigid, carbonaceous char was seen in the cone calorimeter tests to be essential to the establishment of a sustained fire. The fat renders out upon modest heating but forms a pool of liquid with a high enough flash point so as not to ignite unless a porous char is present to act as a wick and thereby increase the effective vapour pressure of the liquefied fat fuel. While the elevation of the pork fat (Tests P1, P2) was useful in allowing observation of the rendering/combustion process, the mass loss rate for Test P3 (in which the fat was laid directly on the carpet) is not substantially different from the other tests in which the fat was supported on a wire grille. Observations showed that the charred cotton wrapping was the primary wick as flames could be seen supported across nearly the entire exposed surface. Thus, the larger the wick, the higher would be the expected mass loss rate (and higher the HRR) while the larger the mass, the longer the time the flames could be maintained.

In all these tests, the gasoline produced a single, brief energetic plume followed by a substantial plume supported by the combustion of the carpet and pad ignited by the gasoline flame. It is clear that the unusually flammable nature of this polypropylene/nylon pile carpet contributed to the ease of its ignition and to its tendency to burn for prolonged periods of time (up to four hours). Other carpets would not necessarily behave in this same manner, although the combustion of the pork fat would not be expected to be affected.

In carcass test PC1, the same brief peak heat release rate was seen as the gasoline burned off, followed by a more prolonged peak as the carpet was largely consumed. These initial fires initiated burning of the carcass under the throat and forelegs that continued for many minutes. The fire progressed down the left side and small (4–6 cm) flames were sustained continuously under that side of the carcass. Corresponding to a mass loss rate of 1–2 g/s, these flames were briefly visible above the carcass at 107 minutes, accompanied by an increase in smoke production. These flames correlate to a measured heat release rate of 35–40 kW in that time interval and the flames in the carpet were small but persistent. After 115 minutes, all flaming combustion in the carcass appeared to cease and the carpet continued to burn until the remaining residual flames were extinguished at 240 minutes.

In test PC2, the gasoline and carpet fires resulted in a very energetic fire in the head and fore-leg area of the carcass being sustained for some nine minutes (540 s) after which the fat in the neck, chest and shoulders sustained an energetic fire in that area for 10–20 minutes. This corresponds to the heat release rate ‘shoulder’ at 600–1200 s and a mass loss rate of 5 g/s decreasing to 2 g/s. After 20 minutes (1200 s) only small flames were visible under the chest and foreleg of the carcass. The carcass and carpet fires both self-extinguished by about 55 minutes.

In test PC3, the sharp peak at 100 s reveals a mass loss rate of 12 g/s as the gasoline burns away, and a broader peak of 10 g/s at 400 s corresponding to the maximum combustion rate of the carpet and pad. A rate of 2–3 g/s (600–1000 s) corresponds to the observed major combustion of fat and tissue from under the chest of the carcass and the 1 g/s rate after 1300 s was observed to be the carpet maintaining its slow continuous combustion and a slow progression of small flames along the haunches of the carcass. After about 45 minutes, the carcass seemed to have self-extinguished but the carpet continued to burn until nearly all its exposed area (2.8m^2) was consumed by extinguishment at 1hr 45 min.

In test PC4, the same sharp peak of 11 g/s is observed at 100 s corresponding to the gasoline burn-off but the large peak at 400 s is absent because the gasoline was poured directly on the large pile of pork scrap (with a cloth garment wrap), and resulting involvement of the carpet was limited to a slowly growing fire around the perimeter of the pile. Instead, a peak of 5 g/s is observed at 1250 s that correlates to a large portion of the pile surface becoming involved (and corresponds to a HRR peak of 120 kW as in Figure 16). There is an increasing loss rate from 2–5 g/s over the time 2200 to 3100 s, which corresponds to an increase in HRR to a peak of 130 kW at 3100 s. A sustained mass loss rate of 4 g/s after that time (to extinguishment) corresponds to a HRR rate of 120–130 kW). These mass loss rates and heat release rates equate to a heat of combustion of 24–31 kJ/g for the fat constituting the major fuel involved.

To explore the contributions of fat to such fires, the heat release rates of fat were calculated by subtracting the heat release rate generated by a typical carpet/pad/gasoline fire (CP1) from each HRR plot of a fat-fuelled fire (Figure 17). For Test P1, there is a difference of about 25 kW between the fat-fuelled fire and the equivalent carpet/pad fire over the time interval 500–1000s, with a maximum of about 30kW at 750 s. Test P1 involved the combustion of only 0.4 kg of fat. Tests P2–P4 demonstrated larger, more prominent peaks in the differential HRR and larger mass loss rates. Those data and the calculated heats of combustion are shown in Table 13.

These calculations are only approximate due to the uncertainty of mass loss measurements at such low levels and the uncertainty of the contribution the carpet might be making both in mass loss and HRR. The one large scale test where the fat was known to be the major fuel involved was PC4.

TABLE 13 Calculated heat of combustion.

Test	*Peak heat release rate kW (at time s)*	*Mass Loss Rate (g/s) +1 g/s carpet*	*ΔH_c kJ/g*	*Δm_{fat} kg*
P1	30 (750)	1	30	0.45
P2	75 (760)	2	37	0.81
P3	90 (800)	2	45	1.53
P4	50 (600)	2	25	0.79
PC1	50 (600)	3	17	N R
PC2	50 (1000)	2	25	2.9
PC3	50 (700)	2	25	3.9
PC4	120 (1250)*	4	30	11.2
PC4	130 (3100)*	4	32	
PC4	125–130 (>3100s)* to end	3	40	

*By direct measurement

In that test, a total loss rate of 4–5 g/s was observed and the carpet was seen to be a minor contributor during the fire. At one stage, enough liquefied fat was being generated that a pool of it leaked from the margins of the carpet test panel onto the plywood backing sheet to support a small pool fire. The calculated ΔH_c of 30–40 kJ/g from that test is in agreement with the small-scale tests conducted here and in concert with the literature value of 39.8 kJ/g given the inefficiency of the wick-supported combustion seen here. Oxygen-depletion cone calorimetry (using the Stanton-Redcroft calorimeter described previously) yielded a maximum estimated heat of combustion of ~27 kJ/g with a radiant heat flux of 35 kW/m^2 and a maximum rate of ~32 kJ/g with a radiant heat flux of 50 kW/m^2. Both estimates are ±5 kJ/g due to boiling of the liquefied fat under the cotton cloth wick. A maximum flame temperature of 911˚C was measured by hand held thermocouple probe during these tests.

Conclusion

It is clear that animal fat (and by extension human body fat, which is said to be very similar to the subcutaneous pork fat used here) can contribute to the fuel of a compartment fire. Its combustion depends on substantial preheating by an external heat source and the availability of a porous wick (such as charred cellulosic material). Its combustion can proceed at a moderate rate of 1–3 g/s (3.6–10.8 kg/hr) if provided with an adequate wick. Due to its heat of combustion (and losses due to the heat of vaporization of water in the tissue), such a mass loss rate is likely to produce only a small fire of 30–50 kW unless a very large surface area of fuel (and the commensurate large mass) is involved, such as the 26 kg of fat and skin in Test PC4. In such cases a fire of 120–130 kW might be expected. Such a fire is more likely to cause fire to spread to other combustibles nearby than a very small fire of 30–50 kW. The presence of other, less efficient fuels (like skin and muscle) and the absence of large fuel masses (such as in the very lean pig carcasses used in Tests PC1–PC3) would result in significantly smaller fires of 40–50 kW. Such fires would be more typical of burning human remains when there are minimal contributions from other fuels.

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