Characterization of Textiles Used in Chefs’ Uniforms for Protection Against Thermal Hazards Encountered in the Kitchen Environment

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ABSTRACT

Within the kitchen the potential for burn injuries arising from contact with hot surfaces, flames, hot liquid, and steam hazards is high. The chef’s uniform can potentially offer some protection against such burns by providing a protective barrier between the skin and the thermal hazard, although the extent to which can provide some protection is unknown. The purpose of this study was to examine whether fabrics used in chefs’ uniforms were able to provide some protection against thermal hazards encountered in the kitchen. Fabrics from chefs’ jackets and aprons were selected. Flammability of single- and multiple-layered fabrics was measured. Effect of jacket type, apron and number of layers on hot surface, hot water, and steam exposure was also measured. Findings showed that all of the jacket and apron fabrics rapidly ignited when exposed to a flame. Thermal protection against hot surfaces increased as layers increased due to more insulation. Protection against steam and hot water improved with an impermeable apron in the system. For wet thermal hazards increasing the number of permeable layers can decrease the level of protection due to stored thermal energy. As the hands and arms are most at risk of burn injury increased insulation and water-impermeable barrier in the sleeves would improve thermal protection with minimal compromise to overall thermal comfort.

KEYWORDS: burn injury; chef’s clothing; flammability; hot surface contact; hot water; low-pressure steam

INTRODUCTION

Due to the nature of cooking, with the proximity to hot surfaces, boiling water, hot oil, and flames, the risk of chefs sustaining a burn injury is high. Burns are the third most common type of injury among kitchen workers after strains/sprains and cuts/lacerations (Pearsonick, 1991; Gleeson, 2001; Cann et al., 2008). Cooks and food preparation workers reportedly have one of the highest rates of burn injuries of all occupational groups (Islam et al., 2000; Walters, 2009). Fatigue and heat strain related to working in a hot environment is also a risk. Cooking equipment and
hot food/liquids that pose a burn hazard also generate a hot humid workplace, with many commercial kitchens nearing or exceeding 30°C during service (Maguire and Howard, 2001; Haruyama et al., 2010). Working at a fast pace to meet customers needs also increases metabolic heat production further increasing the risk of overexertion and heat strain.

Despite injury prevention measures being taken in many kitchens (e.g. health and safety training, removal or modification of hazardous equipment) burn injuries still occur, as complete removal of thermal hazards is not possible. Therefore, use of personal protective equipment and protective clothing may then be used to prevent or reduce the severity of burn injuries that may occur. Chef’s clothing is not considered to be ‘protective clothing’ per se, but as a barrier between the skin and the hazard it could potentially provide some level of protection against burn injuries. Within the kitchen, potholder pads and oven mitts are used to prevent burns due to handling hot equipment. However, they are only used intermittently when a conscious choice to handle hot equipment is made. Rarely do they protect against accidentally touching hot surfaces, which in some reports has accounted for half the hot-surface contact burn injuries (Halpin et al., 2008).

The chef’s uniform is typically composed of a chef’s hat, double-breasted jacket, neckerchief, checked pants, apron, towels, and clogs (Culinary Institute of America, 2001; Ehnes et al., 2012; Robinson, 2013). The double-breasted design of the chef’s jacket, although designed so it can be quickly reversed to hide food soils when needed, has been reported as providing protection against the kitchen heat (Culinary Institute of America, 2001). The sleeves also reportedly protect forearms and wrists from burns if a spill or splash occurs (Culinary Institute of America, 2001). Whereas, the apron is primarily intended to protect the rest of the clothing from food-borne soils (Culinary Institute of America, 2001), rather than providing personal protection against injury.

Despite these references to protective properties of various items of the chef’s uniform, there is limited empirical evidence showing its effectiveness in reducing or preventing burn injuries. Correct sizing and fit of jackets are necessary to provide adequate protection but this does not always occur. Culinary arts students have reported frequently needing to roll up their sleeves, therefore exposing their forearms, because they were too long (Ehnes et al., 2012). Some protection provided through covering the arms with the sleeves of the jacket is important as the hands, wrists, and arms have the highest rate of burn injuries of all anatomical sites (Islam et al., 2000; Cann et al., 2008). Although garment design and fit are important for protection, the thermal performance properties of the materials from which garments are made play a major role in protecting against thermal hazards.

Fabrics used to make chef’s jackets tend to be woven and composed of 100% cotton or blend of polyester and cotton. The reported benefits of incorporating a higher proportion of polyester into the jacket has been to increase durability to laundering, and stain and wrinkle resistance, while also lowering the cost compared with 100% cotton (Chefwear, 2012). Fabric weights are described as lightweight (135–190 g m⁻²), mid-weight (200–255 g m⁻²), and heavyweight (>270 g m⁻²) (Chefwear, 2012). The majority of chef’s jackets are twill weave while the more informal shirts tend to be plain-weave fabrics. A twill fabric is often preferred due to greater durability and stain repellency (although rarely do fabrics in commercial use differ in weave type alone). Finishes may be used to enhance stain repellency and wrinkle resistance, but can also include antimicrobial and wicking treatments (Chefwear, 2012).

The chemical and physical properties of a fabric influence the burning behavior of the finished product, such as generic fibre, finishes, fabric weight, and construction (Tesoro and Meiser, 1970). Cotton fabrics tend to ignite easily and burn more rapidly than polyester. Polyester fabrics can be harder to ignite and tend to melt and drip away from the flame, potentially self-extinguishing if removed from the ignition source. In a blended fabric, however, the burning behavior of polyester and cotton cannot be easily predicted, as cotton/polyester fabrics may burn more rapidly than 100% polyester or cotton (Tesoro and Meiser, 1970). Lightweight fabrics tend to burn more rapidly than heavier weight fabrics of the same fibre content and construction (Miller and Meiser, 1970). Fabric finishes can also influence burning behavior. Flame retardant (FR) finishes applied to cotton and other flammable fabrics are common in specific industrial occupations where a risk of clothing becoming ignited is possible (e.g. electricians,
petroleum workers). However, FR fabrics are rarely found in chef’s wear.

The thermal resistance of a fabric relates to the insulation provided by the fabric and/or garment system. Thicker fabrics typically provide greater thermal insulation with a lower density fabric being more insulating than a higher density fabric of the same thickness (Bajaj and Sengupta, 1992). A thicker fabric or multiple layers can provide greater protection against many potential burn hazards but they also provide a greater barrier for heat transfer from the body to the environment, adding to the heat strain experienced by the wearer. This dilemma is widely acknowledged within the field of protective clothing research (e.g. Holmér, 1995; Havenith, 1999; McLellan and Selkirk, 2004).

Although under some circumstances moisture may improve insulation (Lee and Barker, 1986; Lawson et al., 2004), more often moisture greatly compromises insulation as water conducts heat better than air, and if clothing is permeable to air and moisture then rapid wetting of the clothing system occurs as heat energy is directly transferred via convection and mass transfer of hot liquids (Mell and Lawson, 2000). A water resistant barrier, such as a membrane or coating, is often required to keep insulating layers dry (Mell and Lawson, 2000; Jalbani et al., 2012). Such a layer if used throughout the entire garment would hinder evaporative heat loss. With the exception of a water-proof apron, chef’s clothing is permeable to both air and moisture. Therefore, the ability of the clothing to protect against a large spill of hot liquid may be inadequate. An impermeable apron can provide protection to the torso against wet thermal hazards and due to its limited coverage of the body is unlikely to increase the thermal strain of the wearer.

The focus of this study was to examine whether fabrics used in chefs’ jackets, worn with aprons, were able to provide some protection against a range of thermal hazards likely to be encountered in the kitchen (i.e. flame, hot surfaces, hot water, and steam), as well as to characterize selected thermal comfort properties (e.g. air permeability and thermal resistance). Two fabrics obtained from chefs’ jackets (light-weight and heavy-weight) were compared as various fabric systems (i.e. single, double, and four layers of fabrics in both uncovered or covered configurations with two types of apron fabrics). As there is limited information about the thermal protection provided by fabrics commonly used to make up clothing worn by chefs in commercial kitchens, this research will fill the gap in understanding whether the current clothing options for chef’s can provide some protection against burn injury.

MATERIALS AND METHODS

Fabrics and fabric preparation

Seven fabrics were selected for this study (Table 1). Four fabrics came from different types of chef’s jackets, two were 65% polyester/35% cotton (Unisync Group Ltd, Mississauga, ON), the other two were 100% cotton (The Happy Chef, Butler, NJ). Two of the fabrics were cut from aprons, one a permeable apron composed of 65% polyester/35% cotton (Mark’s, Welland, ON) and the other an impermeable nylon polyurethane (PU) coated apron (The Happy Chef). In order to compare the level of protection against a fabric intended for use where performance standards for FR clothing exist (e.g. CAN/CGSB-155.20-2000) one FR 100% cotton fabric was also selected (Cedro, Belo Horizonte, Brazil). Jacket fabrics were selected based on differences in fibre content and weight, and represent common types of chef’s jackets available on the market. All garments/fabrics except Apron-2 were laundered five times in accordance with CAN/CGSB-4.2 No. 58-2004. Apron-2 was not prewashed to prevent the laminated structure being degraded by laundering.

Fabric specimens were cut from the garments and FR fabric with no specimens containing the same warp or weft yarns. Specimens were conditioned for 24 h in standard atmospheric conditions (20±1°C; 65±2% relative humidity).

Experimental design

A 2×3×3 factorial design was carried out using the polyester/cotton jacket fabrics against hot surface contact, hot liquid and steam exposure (related to thermal protective properties). In this three-way factorial design the independent variables consisted of two fabrics (P-J1, P-J2), three apron treatments (none, Apron-1, Apron-2) and three layer configurations (1L, 2L, 4L). Air permeability and thermal insulation (related to thermal comfort) was also measured in single and layered fabric configurations, with apron fabrics over the single layer of jacket fabrics only. All
<table>
<thead>
<tr>
<th>Fabric code</th>
<th>Fibre content</th>
<th>Fabric count (warp x weft yarns cm(^{-1})) (^a)</th>
<th>Mass (g m(^{-2})) (^b)</th>
<th>Thickness (mm) (^c)</th>
<th>Air permeability (cm(^3) cm(^{-2}) s(^{-1})) (^d)</th>
<th>Thermal resistance (m(^2) K W(^{-1})) (^e)</th>
<th>Evaporative resistance (m(^2) Pa W(^{-1})) (^e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-J1</td>
<td>Plain weave, 65% polyester/35% cotton</td>
<td>37 x 20</td>
<td>193</td>
<td>0.53</td>
<td>6.49</td>
<td>0.073</td>
<td>11.34</td>
</tr>
<tr>
<td>P-J2</td>
<td>Twill weave, 65% polyester/35% cotton</td>
<td>50 x 24</td>
<td>261</td>
<td>0.63</td>
<td>7.81</td>
<td>0.073</td>
<td>11.34</td>
</tr>
<tr>
<td>C-J1</td>
<td>Twill weave, 100% cotton</td>
<td>61 x 44</td>
<td>167</td>
<td>0.49</td>
<td>2.59</td>
<td>0.071</td>
<td>11.34</td>
</tr>
<tr>
<td>C-J2</td>
<td>Twill weave, 100% cotton</td>
<td>42 x 22</td>
<td>311</td>
<td>0.79</td>
<td>5.00</td>
<td>0.071</td>
<td>10.83</td>
</tr>
<tr>
<td>FRC</td>
<td>Twill weave, 100% FR cotton</td>
<td>39 x 20</td>
<td>266</td>
<td>0.73</td>
<td>6.44</td>
<td>0.074</td>
<td>11.54</td>
</tr>
<tr>
<td>Apron 1</td>
<td>Twill weave, 65% polyester/35% cotton</td>
<td>44 x 22</td>
<td>258</td>
<td>0.74</td>
<td>10.31</td>
<td>0.076</td>
<td>10.39</td>
</tr>
<tr>
<td>Apron 2</td>
<td>Plain weave 100% nylon with polyurethane coating</td>
<td>17 x 17</td>
<td>106</td>
<td>0.18</td>
<td>0.00</td>
<td>0.071</td>
<td>63.24</td>
</tr>
</tbody>
</table>

\(^a\) Measured following CAN/CGSB-4.2, No. 6-M89/ISO 7211/2:1984.
\(^b\) Measured following CAN/CGSB-4.2, No. 5.1-M90: 2004.
\(^c\) Measured following CAN/CGSB-4.2, No. 37-2002.
\(^d\) Measured following CAN/CGSB-4.2, No. 36-M89.
\(^e\) Measured following ISO 11092:1993/Amd 1:2012(E).
seven fabrics were evaluated in the ease of ignition tests to evaluate fabric flammability.

Ease of ignition
Ease of ignition was conducted in accordance with CAN/CGSB-4.2 No. 27.4-2010/ISO 6940:2004 for all seven fabrics. A test flame was applied to the outer surface of a fabric specimen (single layers only) or bottom edge of a fabric specimen (single layers and four layers of fabrics stitched together to simulate a jacket cuff) to estimate the shortest time to cause ignition.

In brief, the flame application time was recorded and the occurrence of ignition was observed. The test was continued until there were at least five instances of ignition and five instances of non-ignition. The recorded times for ignition or non-ignition, which ever was less frequent, were used to calculate the mean ignition time.

Hot surface contact
Evaluation of protective performance against exposure to hot surfaces was conducted following ASTM F1060-08. The hot plate was set at a lower temperature of 200 ± 3°C to reflect the temperatures of equipment in a commercial kitchen, as well as factoring in the melting point of synthetic fibres present in the study. The specimens were placed between the heated surface plate and the sensor, with a copper sensor on top. Fabric layers were placed in an order as would be worn, with the outermost side of the outer fabric placed adjacent to the hot-plate and the side of the fabric to be worn next to the skin facing up. The test was continued until the sensor indicated sufficient heat had transferred to result in a predicted second-degree burn.

Hot water exposure
Thermal protective properties of fabric systems when exposed to distilled water (85°C) was determined using a test apparatus described elsewhere (Jalbani et al., 2012) based on ASTM F 2701-08. In brief, the test apparatus consists of a temperature-controlled heating and pumping container, a water spout and an inclined specimen mounting board, equipped with thermal energy sensors connected to a computer data acquisition system. Fabric specimens were placed on the specimen mount in the order they would be worn with the outermost layer exposed to the hot water.

The water temperature and flow rate were set at 85°C and 100 ml s⁻¹ respectively. Exposure time was 10 s with the data recording period extended a further 50 s to account for effects of stored energy. Sensors were cooled to ~30°C after each test. Data from the sensor located directly under the water stream were reported. Heat flux and absorbed energy were calculated and time to second-degree burn was estimated.

Low-pressure steam exposure
A test apparatus developed by Ackerman et al. (2012) was utilized to assess the performance of fabrics against low-pressure steam. The apparatus was constructed with hot steam jet assembly, sensor, and support. The sensor consisted of a thermocouple attached to the surface of a material block of known thermal properties and heat transfer to the sensor was calculated using the measured surface temperature. A computer data acquisition system was attached to the sensor, recording the temperature over time. The sensor was mounted in a perforated polytetrafluoroethylene support, which allows transmission of vapour. The steam test apparatus and procedures were initially developed to simulate pressurized hot steam in the oil and gas industry so was capable of delivering steam up to 600 kPa and 400°C. However, as the pressure of steam within a kitchen is much lower the pressure and temperature were set at 70 kPa and 108 ± 3°C respectively.

Fabric specimens were placed on the skin-simulant sensor immediately below the steam jet assembly. The face of the fabric was placed 62 mm from the jet outlet with a sample restraint placed on top of the fabric to avoid displacement. Each specimen was placed in an order that it would be worn with the outermost surface of the fabric facing the steam jet.

Data collection lasted 60 s, including 10 s of exposure time and 50 s after exposure to incorporate effects of stored energy. Heat flux sensor data were recorded during this period and total absorbed energy was calculated from the heat flux data. The time to second-degree burn was estimated by using heat flux history in a multi-layer skin model. If no predicted thermal injury occurred during the test, the result was recorded as >60 s (Ackerman et al., 2012).

Statistical analysis
Mean and standard deviation were calculated for absorbed energy and second-degree burn for hot
surface contact, hot liquid contact, and low-pressure steam. A three-way analysis of variance was carried out with fabric (P-J1, P-J2), apron (none, Apron-1, Apron-2), layers (1L, 2L, 4L) as independent variables. The significance was taken at $P < 0.001$. Post-hoc comparisons were made using Tukey’s test on data.

RESULTS

Thermal comfort-related fabric properties
Air permeability and thermal resistance of the polyester/cotton blended jacket fabrics are shown in Figs 1 and 2, respectively. Air permeability decreased as the number of layers increased, regardless of whether an additional layer of the same fabric ($P < 0.001$) or an apron ($P < 0.001$) was added. The impermeable Apron-2 reduced air permeability to effectively zero as no air passed through it or fabric systems that included Apron-2. Air permeability of Apron-1 was $10.31 \text{cm}^3 \text{cm}^{-2} \text{s}^{-1}$ (Table 1) and when tested with single layers of jacket fabrics P-J1 or P-J2, air permeability was slightly higher than for the multiple layers of the same jacket fabrics because of the apron’s higher air permeability.

No differences in thermal resistance between P-J1 and P-J2 fabrics were found (Fig. 2). As the number of layers increased, thermal resistance also increased. Greatest thermal resistance was found for fabrics covered by Apron-2. However, thermal resistance for Apron-2 as a single layer was $0.071 \text{m}^2 \text{K W}^{-1}$, which was no different from jacket fabrics, nor Apron-1 (Table 1).

Ease of ignition
Time to ignition for test fabrics following exposure to a flame is provided in Table 2. As single layers, fabrics ignited more rapidly when the flame was applied to the bottom edge (1 s or less) as compared to when the flame was applied to the fabric surface (2–6 s). Essentially, all fabrics regardless of weight and thickness took <1 s to ignite at the bottom edge. For surface ignition, the lightweight, thinner jacket fabrics ignited more quickly than the heavier-weight, thicker fabrics. The lightweight, impermeable nylon/PU coated Apron-2 fabric ignited quickly at 2 s when exposed to the surface flame, and immediately at bottom edge ignition.

In the comparison of single layer fabrics with four layers of jacket fabrics sewn together (to simulate a jacket cuff), the multiple-layered fabrics took ~1–2 s
longer to ignite, except for P-J1, which took 1 s as both single and multiple layers.

With the exception of FRC, all fabrics sustained combustion, giving an after-flame time of 5 s or more as the flames reached the top and vertical edges of the tested specimens. Therefore, once ignited, all fabrics (except FRC) burned completely. Of the four fabrics cut from the chefs’ jackets, P-J1 and P-J2 (polyester/cotton fabrics) appeared to burn more intensely compared to C-J1 and C-J2 (100% cotton). Onset of ignition for FRC could not be obtained because it quickly self-extinguished.

**Hot surface contact**

The time to predicted second-degree burn following contact with a 200°C surface, for the polyester/cotton jacket fabrics in single and multiple-layered configurations is shown in Fig. 3. As the number of layers increased, the time to predicted burn injury also increased ($P < 0.001$). For example, for P-J1 the mean burn injury time was 1.6, 3.4, and 8.6 s for 1L, 2L, and 4L respectively. With the addition of an apron, burn injury time also increased compared to that of the uncovered jacket fabrics ($P < 0.001$). Again for P-J1, the time to second-degree burn when covered by Apron-1 was 3.8, 6.2, and 11.9 s for 1L, 2L, and 4L respectively; and when covered by Apron-2, it was 2.5, 4.6, and 10.5 s for 1L, 2L, and 4L respectively. The thicker, heavier-weight jacket (P-J2) offered greater protection than the thinner, lighter-weight jacket (P-J1) ($P < 0.001$). The burn time increased by about 30–40% for the P-J2 fabric systems compared with P-J1 (Fig. 3).

**Hot water contact**

Absorbed energy and time to predicted second-degree burn following exposure to 85°C water for P-J1 and P-J2 fabric systems are shown in Fig. 4. The benefit of including an impermeable apron in the fabric system was the most notable in the hot water exposure tests. None of the fabrics covered by Apron-2, regardless of the number of layers, reached the limit for second-degree burn prediction within the 60-s recording period. Absorbed energy was also considerably lower for the fabrics covered by Apron-2, mean values ranging from 29.5 to 56.2 kJ m$^{-2}$ compared with 146.4–406.7 kJ m$^{-2}$ for all other fabric systems. The additional layer of Apron-1 did not offer any greater protection against hot water exposure compared with
uncovered fabrics, as differences were not found to be significant at the 5% level.

Comparing only uncovered and Apron-1 covered fabric systems, there was an effect due to increasing the number of fabric layers in the system for burn injury time ($P < 0.001$). However, for absorbed energy this was only evident as a significant ‘fabric x layer’ interaction ($P < 0.001$). Interestingly, absorbed energy increased for the heavy-weight P-J2 fabric as the number of layers increased, whereas, it tended to decrease for P-J1 as the number of layers increased, particularly for the fabric systems covered

### Table 2. Time to surface and bottom edge ignition of fabrics used in chefs’ uniform

<table>
<thead>
<tr>
<th>Fabric code</th>
<th>Time to surface ignition (s)</th>
<th>Time to bottom edge ignition (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single layer</td>
<td>Single layer</td>
</tr>
<tr>
<td>P-J1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>P-J2</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>C-J1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>C-J2</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>FRC</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Apron 1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Apron 2</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

‘ND’, ‘not detectable’: because the FR cotton fabric extinguished itself very quickly after the ignition flame was removed and did not sustain combustion.

![Figure 3](https://academic.oup.com/annweh/article-abstract/59/8/1058/2196076)

**Figure 3** Skin-burn injury prediction of fabric systems against hot surface contact.
Figure 4  (a) Absorbed energy and (b) skin-burn injury prediction of fabric systems against hot water.
with Apron-1. Therefore, it was apparent that P-J1 and P-J2 fabric systems offered quite different levels of protection against hot water (P < 0.001), with P-J1 exhibiting lower results for absorbed energy and longer times to reach a predicted second-degree burn.

**Low-pressure steam**

Absorbed energy and time to second-degree burn against low-pressure steam for P-J1 and P-J2 fabric systems are shown in Fig. 5. Similar to the protection offered against hot water, the impermeable apron offered significantly greater protection against burns from steam (P < 0.001). Mean times to reach second-degree burn ranged from 7.4 s for the single layer of P-J1 to >60 s for four layers of P-J2. For the uncovered and Apron-1 covered fabric systems, the longest mean time to second-degree burn was for the four layers of P-J1/Apron-1 at 5.5 s. For protection against steam burns, any effect related to the number layers was less clear and greatly depended upon whether the fabric system was covered by an apron or not, as well as depending on the jacket fabric type. For example, of the fabric systems without an apron only a minimal increase in time to second-degree burn was apparent (P-J1 ranged from 0.7 s to 1.8 s for 1L and 2L respectively; and P-J2 from 1.1 s to 2.4 s for 1L to 4L respectively). Whereas, for the fabrics covered by Apron-1, the predicted burn time increased from 1.7 s for 1 layer of P-J1/Apron-1 to 5.5 s for 4 layers of P-J1/Apron-1. For P-J2/Apron-1 system, no differences due to number of layers occurred for second-degree burn time, although the four-layered system did have a lower mean absorbed energy (383 kJ m\(^{-2}\)). Increasing the number of layers in the fabric system protected by the impermeable Apron-2, had an effect of lowering the amount of absorbed energy and increasing time to second-degree burn.

A significant difference between the types of jacket fabrics was apparent (P < 0.001) when covered by Apron-2. The mean values for time to second-degree burn were higher, and subsequently absorbed energy was lower, for the P-J2 fabric when covered by the impermeable Apron-2. However, in the uncovered and covered with Apron-1 configurations, no differences between the two jacket fabrics were observed.

**DISCUSSION**

None of the fabrics obtained from chefs’ clothing (i.e. jacket and apron) were flame retardant. This was evident in the fact that all fabrics ignited rapidly when exposed to a flame from the bottom edge and sustained combustion. In comparison, the FR cotton fabric taken from fabrics used to make coveralls for specific industrial applications (e.g. oil and gas industry employees) did not sustain combustion. As the jackets were either 100% cotton or a blend of polyester/cotton, the short time to ignite and burning behavior was characteristic of cotton fabrics. The observation that the polyester/cotton fabrics seemed to burn more intensely than the 100% cotton fabrics highlights how the burning behavior of polyester can differ when in a cotton blend compared to 100% polyester fibre content. Typically, a fabric composed of 100% polyester would draw back and drip away from the flame, sometimes self extinguishing (Tesoro and Meiser, 1970; Horrocks, 1989). However, in a cotton blend, the cotton contributes to the flammability of the fabric and the cotton can support the polyester preventing polyester from drawing back out of the flame (Horrocks, 1989). In the case of ignited polyester/cotton clothing, molten polyester could also adhere to the skin of the wearer (Horrocks et al., 2004).

The impermeable polyurethane-coated nylon apron (Apron-2) was the quickest to ignite of all fabrics and also continued to burn following ignition. An apron is worn to cover the front of the jacket and top part of the pants, therefore, although close to the torso is not directly against the skin. A flame from a gas cooker will be one of the most common sources of possible ignition, therefore, the apron closely fitting the torso is less likely to be at risk of being ignited compared with a jacket sleeve.

Thickness is a major predictor of insulation (Bajaj and Sengupta, 1992; Epps and Song, 1992). This means that multiple layers of fabrics will increase the thermal insulation and reduce the air permeability of a clothing system so a wearer will be kept warmer (Epps and Song, 1992). An increase in thermal insulation also results in an increase in thermal protection against an extreme heat source where conduction is the major mode of heat transfer (Bajaj and Sengupta, 1992). This relationship between thickness of the clothing ensemble and thermal insulation and protection was evident in the current study. Increasing the number
Figure 5  (a) Absorbed energy and (b) skin-burn injury prediction of fabric systems against low-pressure steam.
of layers of the same fabric, or including an apron fabric on top of a jacket fabric, increased the thermal resistance (Fig. 2). Another factor affecting thermal insulation of the fabric system was air permeability. Since Apron-2 was an air-impermeable fabric and did not allow for the passage of air the insulating layers of fabrics beneath this were protected from convective currents during the test and therefore insulation increased under Apron-2 compared with Apron-1, despite Apron-1 being thicker. However, as the apron only covers a small portion of the body, Apron-2 will have little influence on the overall thermal comfort of the wearer.

The thermal protection against hot surface contact was clearly associated with fabric system thickness, regardless of the air permeability of the top layer. In Fig. 6, thickness of the fabric layers and time to second-degree burn upon exposure to a hot surface shows an almost linear relationship between increasing thickness and increasing time to predicted burn injury. Therefore, increasing the number of fabric layers (or thickness) of key areas within the chef’s jacket such as in the sleeves will enhance the level of protection to the forearm and wrists against burns from hot surfaces.

The ability of a fabric system to resist penetration by liquids is important for thermal protection against hot liquids (Jalbani et al., 2012; Lu et al., 2013). In firefighters turn-out gear, a moisture barrier between the outer shell and thermal liner is necessary to keep the insulation dry from external water sources to reduce potential scalds or steam burns (Mell and Lawson, 2000). In research related to clothing protection for Canadian oil and gas workers, semi-permeable or impermeable fabric systems were the only type offering any protection against hot water (Jalbani et al., 2012). Therefore, it is not surprising that water-impermeable Apron-2 offered the greatest protection against hot water among all other fabric systems. Hot liquids were prevented from completely penetrating the system, so any thermal energy transfer occurred via conduction through dry fabric rather than hot water directly contacting the sensor. Even one layer of P-J1 or P-J2 jacket fabric beneath Apron-2 provided
sufficient thermal insulation to prevent a burn injury being detected within the 60-s test period.

When comparing fabric systems (uncovered or with Apron-1), the relationship between number of layers, which directly corresponded to thickness, differed considerably between the plain weave light-weight P-J1 and the twill weave heavier-weight P-J2 fabrics. Unlike for hot surface contact, increasing the thickness of the fabric system through increasing layers did not always result in increased protection against hot water or steam. **Fig. 7** shows the relationship between fabric system thickness against absorbed energy for hot water. For the heavier-weight P-J2 fabric absorbed energy progressively increased as thickness increased. For the lighter-weight P-J1 fabric systems, when there were only one or two layers of fabric (i.e. 1L, 2L and 1L + Apron-1), no difference in absorbed energy was found. However, for three or more layers absorbed energy following exposure to hot water decreased as the fabric system thickness increased.

It was observed during the hot water exposure tests that P-J2 became quickly saturated by the water, whereas P-J1 did not. This may be due to differences in fabric structure (plain versus twill) or the possibility that P-J1 had a water/stain repellent finish. In terms of fabric structure, twill weave fabrics can transport liquid water through capillary action more readily than plain weave (Babu et al., 2012). For a single layer, there was only a small difference (not statistically significant) between the two jacket fabrics in absorbed energy or time to second-degree burn. However, once the fabrics became layered, the difference between P-J1 and P-J2 fabric systems in the level of protection widened. One explanation is due to differences in fabric mass. More thermal energy was stored within the heavier-weight P-J2 fabric system. However, the differences in the fabrics’ ability to be wetted and wick liquid is more likely to explain why increasing the number of layers resulted in a decrease in absorbed energy for P-J1 and an increase for P-J2. As fabric weight and thickness were not matched in this study, it is not possible to state with certainty that the increase in protection afforded by the layered P-J1 was due to fabric structure or a water/stain repellent finish. Many chefs’ jackets

![Figure 7](https://example.com/figure7.png)  
**Figure 7** Relationship between thickness of the fabric systems and absorbed energy against hot water (Apron-2 excluded).
on the market tend to be twill weave. Plain weave jackets, although present, are less prevalent. Adding stain repellent finishes may be done to improve durability and aesthetics. The findings in this study suggest more research into examining the effect of fabric structure and finishing on protective performance against hot liquid splashes should be conducted.

A fabric system’s resistance to water vapour diffusion and thermal insulation are both important for protection from steam (Ackerman et al., 2012). Similarly to hot water tests, Apron-2 in the system increased the thermal protection against low-pressure steam, as time to second-degree burn increased and absorbed energy decreased when covered by Apron-2. Therefore, Apron-2 although impermeable to liquid water, was not completely impermeable to water vapour as shown by the water vapour resistance value of 63.24 m² Pa/W. This accounted for the penetration of steam through Apron-2 and subsequently through the layers of fabric underneath.

The fabric systems (uncovered or covered by Apron-1) were not impermeable so moisture vapour readily entered. Increasing the number of layers, and thereby the thickness of the fabric system, offered some increased level of protection against low-pressure steam. In Fig. 8, it can be seen that there was a decrease in absorbed energy when the combined thickness of the fabric system reached about 2.5 mm. This suggests that when exposed to low-pressure steam, the outermost fabric layers absorb much of the steam condensate lowering the amount of energy absorbed by the skin-simulant sensor. However, the amount of energy transmitted through the fabric was sufficient to result in quite rapid second-degree burn injury predictions.

CONCLUSION
It is clear that providing solutions for protection against the range of thermal hazards in the kitchen environment is complex. The fabrics examined in this study represent those commonly used in chef uniforms. The fabrics easily ignite and provide little protection against the range of thermal hazards encountered in the kitchen. Additional insulation offered by thicker
fabrics or layers of thinner fabrics can offer protection against dry thermal hazards when conduction is the only method of heat transfer (e.g. direct contact with a hot surface). However, wet thermal hazards such as steam and hot water pose another set of challenges, as increasing insulation by increasing the number of layers can increase the amount of thermal energy stored within the fabric system, potentially contributing to more severe burns. In this case a liquid-impermeable barrier is required to protect the insulation from getting wet. However, increasing fabric layers and incorporating a liquid-impermeable barrier increases thermal resistance of the system, so consideration to wearers thermal comfort while still offering thermal protection must be made when selecting fabrics and designing chef’s clothing. As the arms and hands have the greatest risk of burn injury (Islam et al., 2000; Cann et al., 2008; Halpin et al., 2008), incorporating a liquid-impermeable barrier such as a membrane or laminate at the lower arms, and at least two layers of fabric to increase insulation, is a practical solution to improve protection for the forearms against hot water, steam and hot surface contact. By covering only a small portion of the body with a fabric system, this will have a smaller impact on the overall level of thermal comfort provided by the current styles of chefs’ jackets on the market. Due to the ease with which the fabrics ignite using fabrics with FR properties would also enhance the market. Due to the ease with which the fabrics ignite

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