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B. Andersson, S E Magnusson

Introduction

The goal of the project "Fire behaviour of upholstered fur-
niture - an experimental study" was to study in full scale
a number of combinations of fabric, interliner and filling
material with regard to ignitability, burning intensity,
generation of smoke and production of toxic gases. The
possibility of classifying the product after conducting
tests in reduced scale was also investigated.

The experiments were performed during 1978 and 1979. A comp-
rehensive report has been written in Swedish [1].

Experiments in reduced scale

Materials

The project comprised 53 experiments in reduced scale with
different combinations of fabric, interliner and filling
material. 14 different fabrics with varying fibre content,
e.g. cotton, wool, viscose, acrylic and different mixtures
of these fibres were used. The interliners were of three
designs: fire-retardant treated polyurethane foam, felt
of novaloid fibres and modified neoprene foam. Three filling
materials were tested; one standard polyurethane, one high
resilient polyurethane and one flame-retardant treated stan-
dard polyurethane. Two densities were used, 25 kg/m^3 for
backs and 35 kg/m^3 for seats.

Test configuration and instrumentation

The experiments in reduced scale were performed with a testing
rig designed according to DD 58:1978 [2], the original propo-
sal for a British ignitability standard. The seat and back
cushions were 0.5 m x 0.5 m with a thickness of 0.075 m. The
test configuration is outlined by Fig. 1.

During the experiments, measurements were taken of temperatures,
smoke production and mass burning rates. The locations of the
thermocouples, the photocell, the loadcell and the bi-direc-
tional probe are indicated in Fig. 1. All experiments were
also well photodocumented.

The ignition source was a wooden crib weighing 10 g or 40 g.
The small crib was first applied and if this source failed
to ignite the tested combination, the bigger crib was used.
The crib design was according to NT Fire 007 [3] and the small
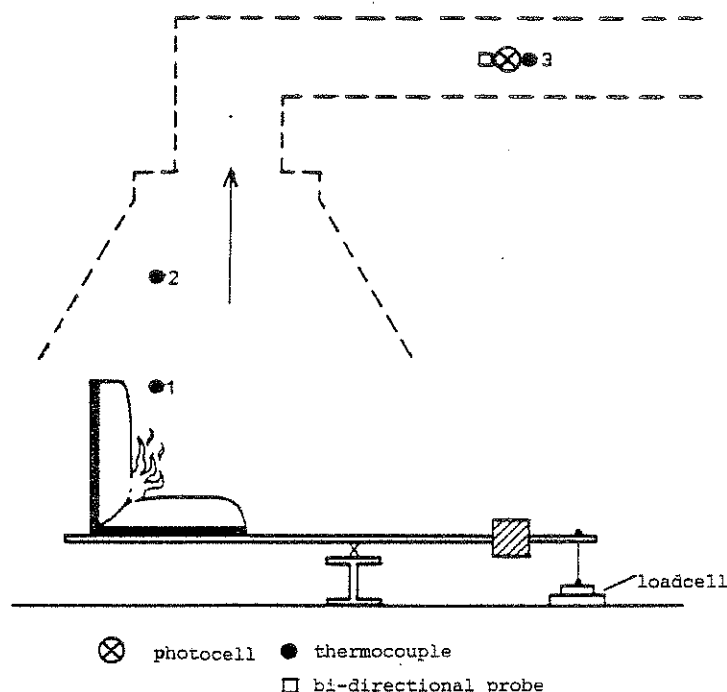crib was one fourth of the big one.

photocell ● thermocouple
□ bi-directional probe

Figure 1   Test configuration for experiments in reduced
          scale

Test results

The experiments indicate that ignitability can be considerably
decreased either by using an interliner between the fabric and
the filling material or by careful choise of the fabric. In
experiments with fabric fibres of acrylic, viscose and cotton,
ignition is achieved with the 10 g crib in combination with
the three filling materials used. This is also valid for fibre
blends with less than 50% wool content. If these covers are
improved with an interliner the 40 g crib is needed to ignite
the combinations. When a fabric with more than 50% wool is
combined with the filling materials, the 40 g crib is necessary
to get ignition. These results are in conformity with the ex-
perience obtained in other investigations [4, 5, 6].

The results from the reduced scale tests also show that the
rate of fire spread across the piece of furniture is strongly
dependent on the fabric (and existing interliner). There is
great need for a testing method which explicitly and in small

scale gives information on this important fire risk characte-
ristic. The total amount of smoke produced during an experi-
ment is given as $D_{tot}(\frac{dB}{m} \cdot m^3)$, Fig. 2, for combinations with
the same fabric but varying filling materials. For a defini-
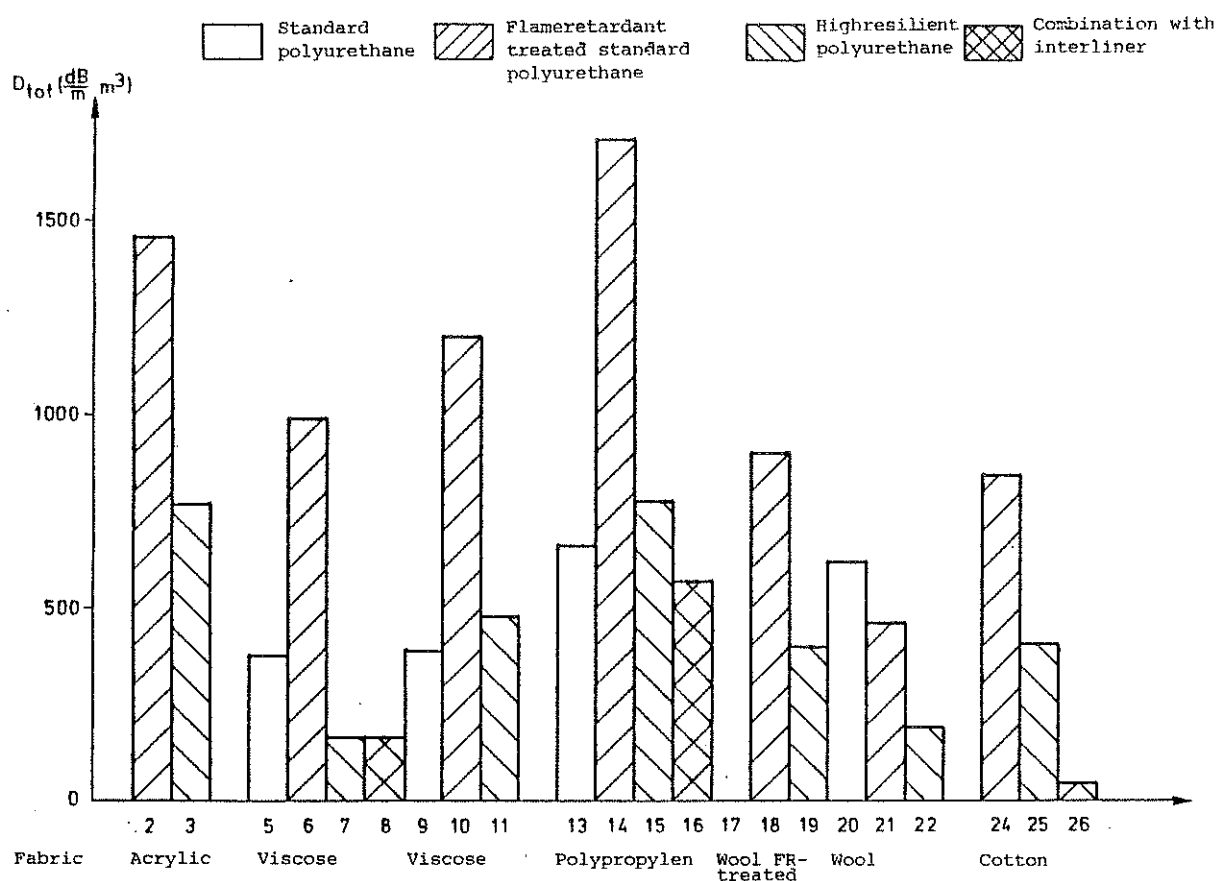tion of the parameter D_{tot}, see Rasbash [7].

Figure 2   The total amount of smoke produced during experi-
ments in reduced scale

From the results it is evident that combinations with flame-
retardant treated standard polyurethane generate more smoke
than other combinations. Combinations with interliners pro-
duce in most cases small amounts of smoke.

Experiments in full scale

Materials

11 full-scale experiments were conducted with combinations of
3 different fabrics, 3 interliners and 3 filling materials.
The combinations are described in Table 1.

Test No.	Fabric	Interliner	Filling material
1	Acrylic	-	Standard polyurethane
2	Acrylic	-	Standard polyurethane
3	Acrylic	-	Flame-retardant treated standard polyurethane
4	Wool	-	Standard polyurethane
5	Acrylic	_	Standard polyurethane
6	Wool 61%, viscose 39%	-	Standard polyurethane
7	Wool 61%, viscose 39%	-	High-resilient polyurethane
8	Wool 61%, viscose 39%	-	Flame-retardant treated standard polyurethane
9	Wool 61%, viscose 39%	Fire-retardant treated polyurethane	Standard polyurethane
10	Wool 61%, viscose 39%	Modified neoprene foam	Standard polyurethane
11	Wool 61%, viscose 39%	Felt of novaloid fibres	Standard polyurethane

Table 1 Combinations tested in the full-scale experiments

Test configuration and instrumentation

The full-scale tests were conducted in a room of 15 cm thick
lightweight concrete with the internal dimensions 2.4 m x 3.6 m
and a height of 2.4 m. A doorway 0.8 m x 2.0 m was situated on
one of the short sides of the room. The room was designed and
instrumented according to ASTM recommendations [8].

Temperatures were measured on 35 locations in the test room;
just under the ceiling and along one vertical profile in the
middle of the room and one in the doorway.

Heat flux measurements were taken in several locations. The
tested piece of furniture was placed on a weighing platform
to facilitate a determination of the mass burning rate. The
gas flows out of and in to the room were measeured with 7-14
bi-directional probes. The optical density of the combustion
products was measured with a vertical light path in the door-
way.

To get reproducible fire scenarios and clearly defined and
measurable reactions to variations in the main parameter,
i.e. material selection, the test furniture was a full-scale
mock-up model of a sofa for three persons, designed with loose
cushions on a steel frame.

A liquid fuel burner with a heat output of 20-30 kW was used
as ignition source.

Test results

The test results show that the rate of fire spread is strongly
dependent on the surface material. The presence of an inter-
liner highly influences the rate of fire spread across the
piece of furniture, as was also evident in the experiments in
reduced scale. One conclusion is that the rate of fire spread
is just as important for the development of a fire as the mass

burning rate, and that choice of fabric determines not only ignitability but also to a large extent the total fire growth process.
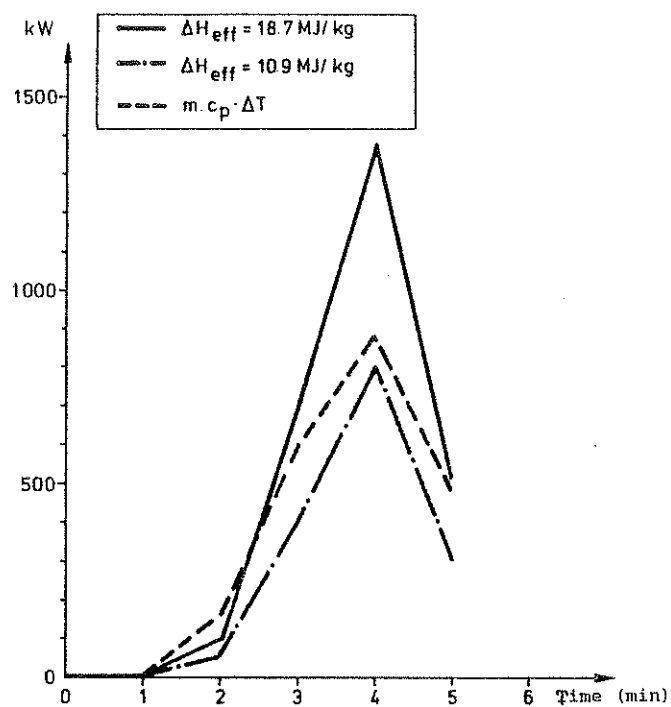
Rate of heat release

The rate of heat release is an important parameter for the development and spread of a fire. With the instrumentation used in the reported experiments, two ways of calculating the rate of heat release are possible:

1) integration of the product of gas flow rate and gas temperature in the gas stream out of the room

2) the product of mass burning rate and an effective heat of combustion (ΔH_{eff}) for the combustion products.

To illustrate results, Fig. 3 presents time curves of the rate of heat release for the experiments 5 and 8. Both methods mentioned above have been used to calculate the rate of heat release. Two different values, indicative of possible upper and lower bounds, of the effective heat of combustion were applied. The theoretical heat of combustion for polyurethane is approximately 28.7 MJ/kg [9]. For combustion in a fully ventilated room about 65% of the heat is released and this gives a ΔH_{eff} of 18.7 MJ/kg. Values for the effective heat of combustion as low as 10.9 MJ/kg have been reported [10].

The curves for rate of heat release in Fig. 3 show that the maximum effect released is 1400 kW during experiment 5 and 580 kW during experiment 8. The time after ignition for these heat release rates were 4 and 22 minutes, respectively. The figures indicate the improvements of the fire growth and heat release characteristics of upholstered furniture that can be achieved within present technological knowledge.
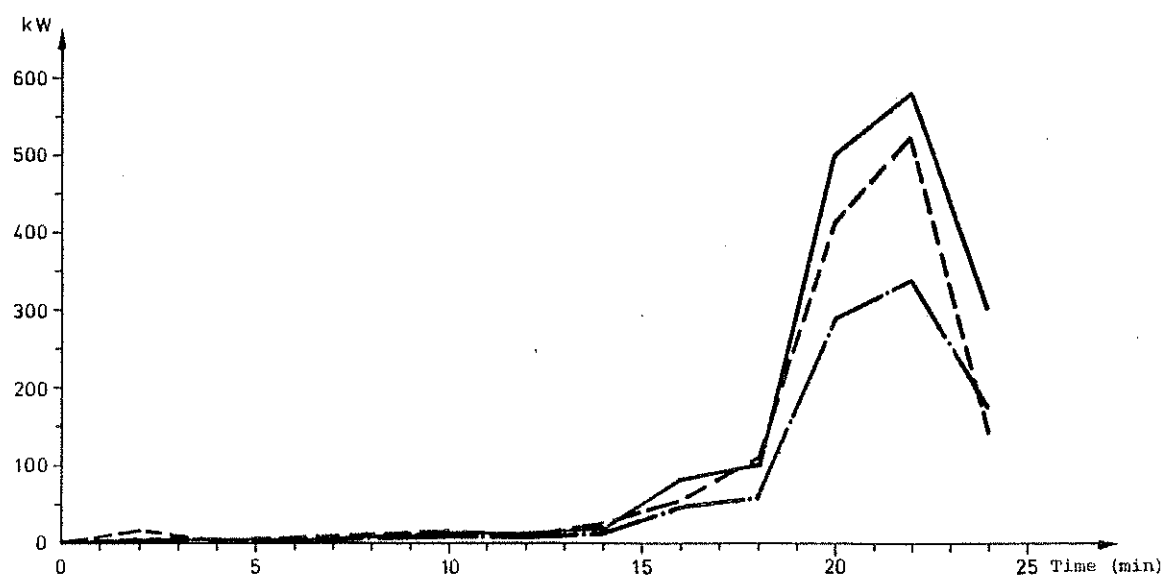
a)

b)

Figure 3   Time curves of the rate of heat release for experiments a) 5 and b) 8

It should be noted that in method 2 no correction is made for losses caused by conduction into surrounding surfaces nor for losses caused by radiation through the doorway.

Production of smoke

Smoke potential, or mass optical density, was measured in the two types of tests as well as the total smoke production. The main conclusion was that the mass optical density parameter is varying strongly during the fire process and is, thus, no meaningful parameter characterizing the material of a product with respect to smoke hazard. On the other hand, the results indicate a positive correlation with regard to total smoke production between the two test methods. It must be emphasized that the number of tests with the same material combination is too small to allow any firm conclusions.

As an example of the results, Fig. 4 gives, for five different material combinations, the total, accumulated smoke production D_{tot} as a function of time. In accordance with the terminology used in [7], D_{tot} is expressed as $(dB/m) \cdot m^3$, where the first factor expresses light attenuation as decibel per meter of light path through the outflowing smoke, and the second one expresses the total flow of combustion products (smoke). Fig. 4 clearly illustrates the influence of material selection on the rate of smoke production.

Risk analysis

Risk for human injury in case of an unwanted fire depends on the combination of exposure time and -level for a number of hazard components: heat, smoke or toxic gas concentration, heat fluxes. In order to summarize the test results, Table 2 gives the time available for escape or evacuation out of the room of fire origin; that is the minimum time for a specified hazard component to reach untenable conditions inside or in the opening of the test compartment.
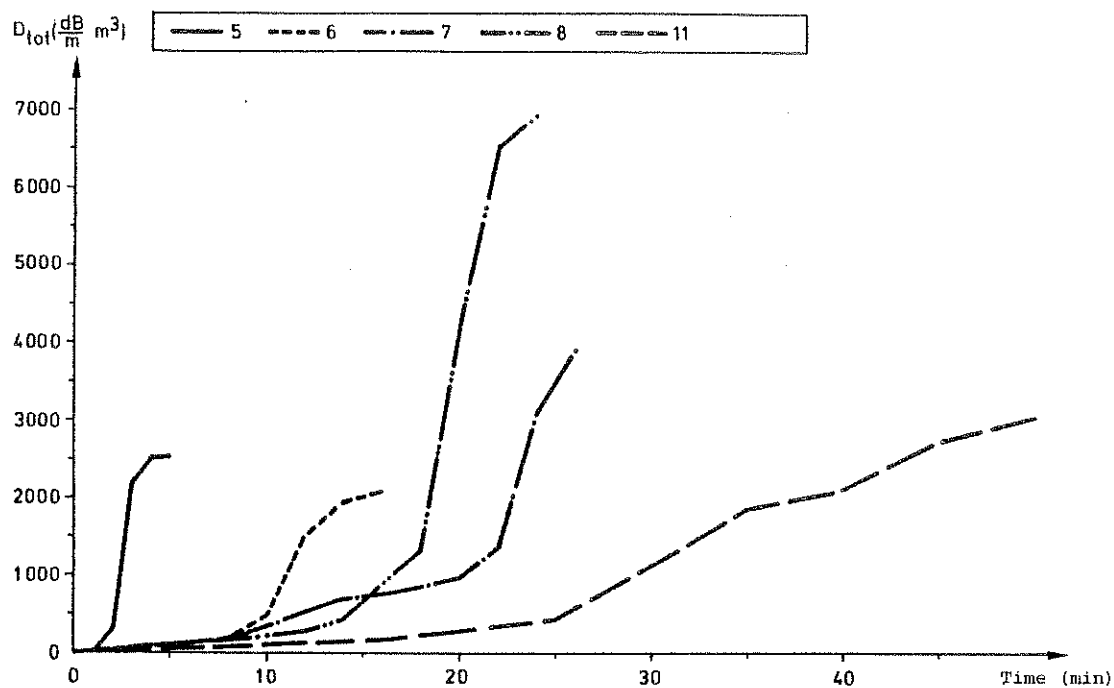
Figure 4   The rate of smoke production for the experiments
            5, 6, 7, 8, and 11

The headings of the table should be self-explanatory; blood
concentration of COHb is computed by the equation given in
[11].

$$\Delta COHb = 5.98 \cdot \Delta t \cdot [CO]^{1.036}$$

The heat flux level 2.5 kW/m^2 is indicative of burn injury
of unprotected human skin and the level 20 kW/m^2 to the
flash-over phenomena.

Test No.	Time to 150°C 1 m above floor level	Time to 2.5 kW/m² towards the floor	Time to 20 kW/m² towards the floor	Time to 15% O_2	Time to 10% CO_2	Time to 8000 ppm CO	Time to COHb≥50%
1	3 min 30 s	3 min	3 min 40 s	2 min 30 s	-	n.a.1)	n.a.
2	2 min 30 s	2 min	2 min 45 s	2 min 30 s	n.a.	n.a.	n.a.
3	3 min 20 s	3 min	3 min 30 s	1 min 30 s	n.a.	n.a.	n.a.
4	8 min 50 s	7 min	10 min	5 min 30 s	n.a.	n.a.	n.a.
5	2 min 50 s	2 min 10 s	2 min 50 s	2 min 30 s	n.a.	n.a.	n.a.
6	11 min 55 s	10 min	15 min	n.a.	-	n.a.	n.a.
7	22 min 30 s	22 min	25 min	n.a.	2 min 30 s	n.a.	n.a.
8	19 min 35 s	18 min 30 s	22 min	n.a.	3 min 30 s	n.a.	n.a.
9	n.a.	n.a.	n.a.	n.a.	8 min	n.a.	n.a.
10	n.a.	1 h 15 min	n.a.	n.a.	5 min	n.a.	45 min
11	n.a.	30 min	n.a.	n.a.	4 min	n.a.	n.a.

1) not achieved

Table 2   Maximum values and times for critical values of different risk factors

Present and future work

The test series reported in this paper was a pilot one. Although the instrumentation used in the test was of an extensive character, it became clear that a reliable assessment of rate of heat release, smoke and toxic gas generation demanded measurement techniques, which, in some aspects, should be changed. It also became apparent that a successful mathematical simulation of the fire growth process required input data that was lacking. Especially, there is a need for flame spread data obtained in small-scale laboratory testing.

A second test series has been carried out during March 1982, comprising both mattresses and upholstered furniture. Tests will be carried out both in the room and in open, free-burning configuration. In both cases, rate of heat release will be measured by oxygen consumption. A correlation will be sought between natural room fire data (full-scale and reduced, one-third scale), laboratory test data (flame spread, rate of heat release and smoke generation) and mathematical simulation results from the Harvard Computer Fire Code [12, 13].

Conclusion

The first and largely experimental part of a research program on flammability characteristics of upholstered furniture has been completed with full-scale tests in an extensively instrumented burn-out room as main element. The results indicate that fire response parameters vary within a large range with choice of filling, interlining and fabric material. Selection of performance criteria may cause difficulties, as parameters like heat release and smoke potential fluctuate strongly during the fire process.

A second part of the program will be directed towards measurement of heat release by oxygen consumption methods, more detailed smoke and gas analysis measurements and use of mathematical simulation procedures.

Acknowledgement

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