FLAME HEIGHT

i. **Modelo Heskestad**

ii. **Modelo Delichatsios**

FLAME HEIGHT

Lembrando...

Método via HHR (heat release rate) por unidade de área da base

$$Q = q_f'' \; A$$

Tabela A4

Área da base da poça

A4

Liquid	Mass Burning Rate, $\dot{m}''$ kg/m²/s	Heat of Combustion kJ/kg	HRR Per Unit Area, $\dot{q}_f''$ kW/m²
Acetic Acid	0.033	13,100	400
Acetone	0.041	25,800	1,100
Acrylonitrile	0.052	31,900	1,700
Amyl Acetate	0.102	32,400	3,300
Amyl Alcohol	0.069	34,500	2,400
Benzene	0.048	44,700	2,100

Flame Height

Hipótese: chama cilíndrica ou cônica com base de diâmetro D.

i. Modelo Heskestad

Boa opção para incêndios em poça

$$L_f = 0.23\, Q^{2/5} - 1.02\, D$$

Where: L_f = Flame height, m
Q = Heat release rate, kW
D = Fire diameter, m

Hipótese:

7 < [(Q^(2/5)) / D] < 700 (kW^(2/5) / m)

Referência: pag 342, Robert G. Zalosh, “Industrial Fire Protection”

Flame Height

i. Modelo Heskestad

$$L_f = 0.23\, Q^{2/5} - 1.02\, D$$

↑ D **2º Termo aumenta em módulo**

$Q = q_f'' A$ ↑

↑ Área da base

↑ D

1º Termo aumenta

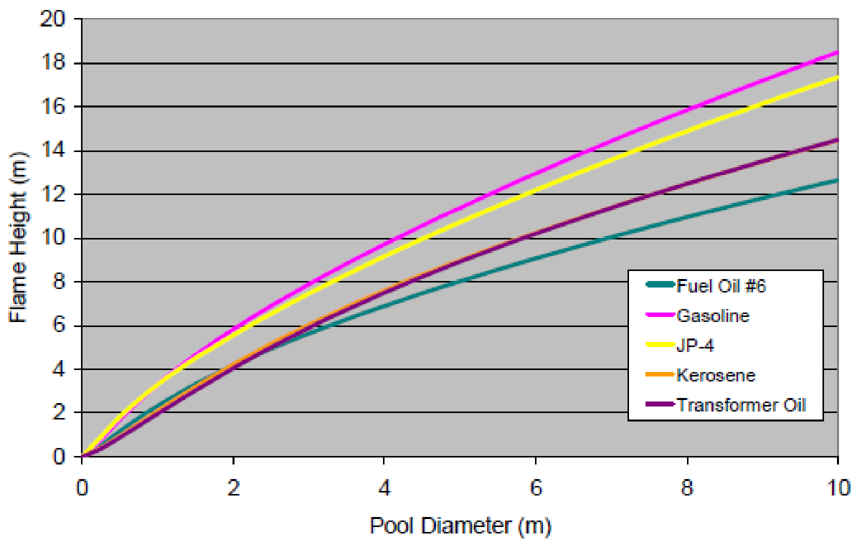

Figure 3.4.2-4: Pool Fire Flame Heights

Flame Height

i. Modelo Heskestad

Aplicação direta para altura de chama em piscina

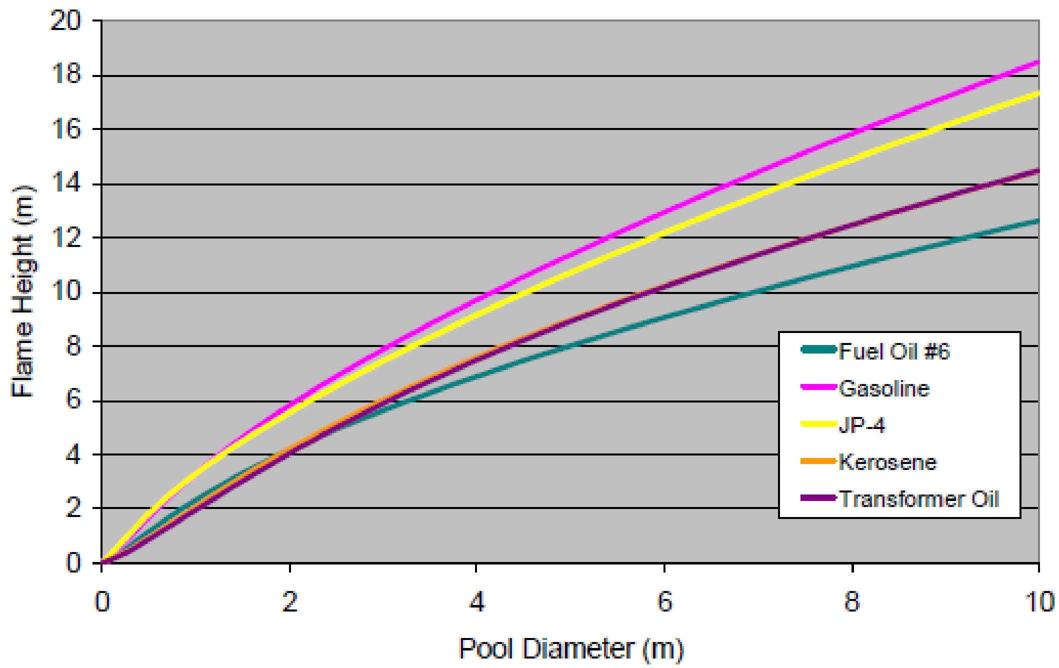

Figure 3.4.2-4: Pool Fire Flame Heights

http://www.wpi.edu/Pubs/ETD/Available/etd-0501102-221341/unrestricted/leblanc.pdf

Flame Height

Exemplo:

Example 3-1 You are conducting a pre-fire inspection in an industrial plant. One of their processes involves an open container of transformer oil. The container is 1 foot (0.3048 m) deep and 3 feet (0.914 m) in diameter. Directly overhead is a cable tray 8.5 feet (2.6 m) above the top of the oil container. The ceiling is 10 feet (3.05 m) high. Using methods you learned in Module II, you calculated the heat release rate as 614 kW if the transformer oil caught fire. Your question is, will the flames reach the bottom of the cable tray?

Using **Equation 3-1**:

$$L_f = 0.23Q^{2/5} - 1.02D = (0.23)(614)^{2/5} - (1.02)(0.914) = 2.07\ m$$

Since the flames are 2.07 m high and the cable tray height is 2.6 m, the flames won't quite reach the cable tray.

Flame Height

Exemplo:

```
>> Q=614

Q =

   614

>> D=0.914

D =

    0.9140

>> Lf =  (0.23*Q^(2/5)) - ( 1.02 *  D)

Lf =

    2.0668
```

Flame Height

i. Modelo Heskestad

$$L_f = 0.235\, Q^{2/5} - 1.02\, D$$

Usando com três casas decimais.

Fire size

614 kW

Fire diameter

0.914 m

Radiative fraction

0.5 -

Calculate plume characteristics

Embora o site peça a fração radiada, ela não influencia nesta estimativa.

Heskestad Flame Height:

For a 614 kW fire with a diameter of 0.914 m:

The flame height is **2.13 m (6.99 ft)**

http://www.koverholt.com/flame-height-and-plume-centerline-temperature-calculator/

Flame Height

Lf considerando 0,235 na equação:

```
>> Lf =  (0.235*Q^(2/5)) - ( 1.02 *  D)

Lf =

    2.1320
```

Material complementar sobre Modelo Heskestad e outros modelos de cálculo de altura.

4 Fire Plumes and Flame Heights

When a mass of hot gases is surrounded by colder gases, the hotter and less dense mass will rise upward due to the density difference, or rather, due to buoyancy. This is what happens above a burning fuel source, and the buoyant flow, including any flames, is referred to as a *fire plume*. As the hot gases rise, cold air will be entrained into the plume, causing a layer of hot gases to be formed. Many applications in fire safety engineering have to do with estimating the properties of the hot layer and the rate of its descent. This depends directly on how much mass and energy is transported by the plume to the upper layer. This chapter will explain some of the most fundamental properties of fire plumes and provide analytical expressions for their properties. Further, the size and geometry of the flames due to a burning object are of great interest to the fire safety engineer. An estimation of the flame height can facilitate calculations on heat transfer to distant objects, secondary fuel and fire detection, and suppression equipment. This chapter discusses flame heights in general and gives expressions for calculation of the flame heights for certain given scenarios.

CONTENTS

4.1 Terminology
4.2 Introduction
4.2.1 Flame Characteristics
4.2.2 Turbulent Fire Plume Characteristics
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4.3.1 Assumptions
4.3.2 Initial Considerations
4.3.3 The Continuity Equation for Mass
4.3.4 The Momentum and Buoyancy Equation
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4.4.1 The Zukoski Plume
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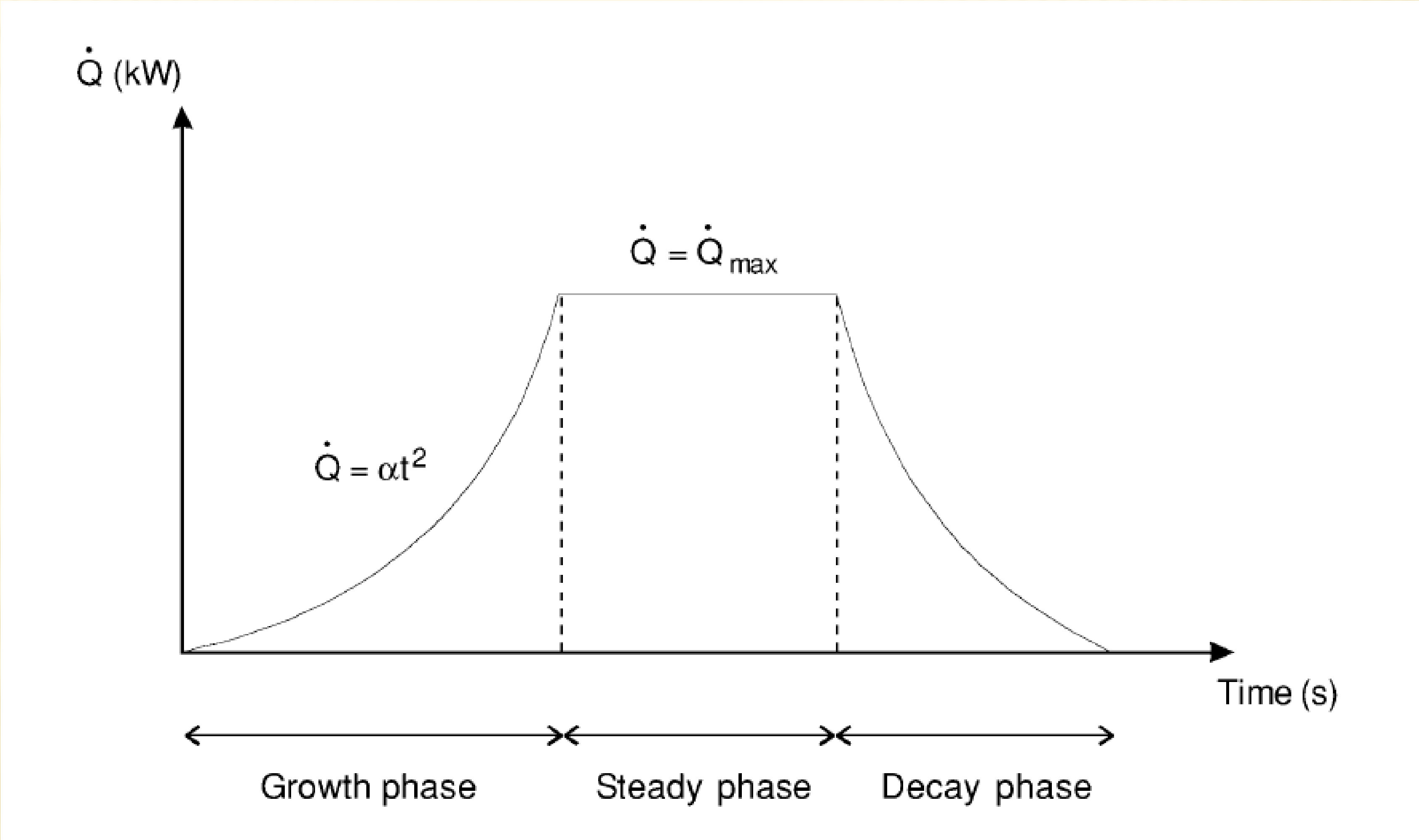
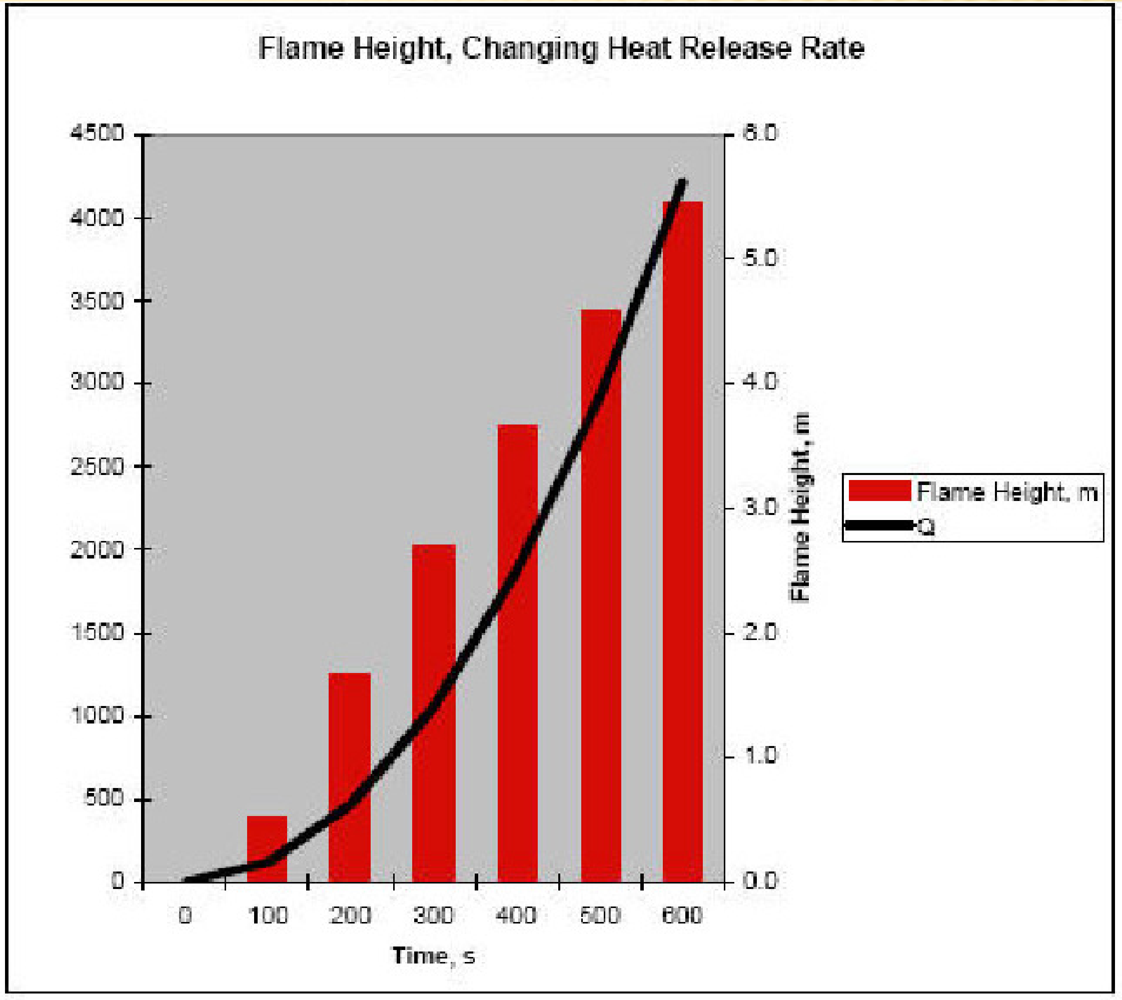
Flame Height

Se Q (heat release rate) for função do tempo, a altura da chama também será.



Flame Height

Burning time Seconds	Heat Release Rate, kW
0	0
100	117
200	469
300	1055
400	1875
500	2930
500	4219



Heat Release Rate como Função do Tempo

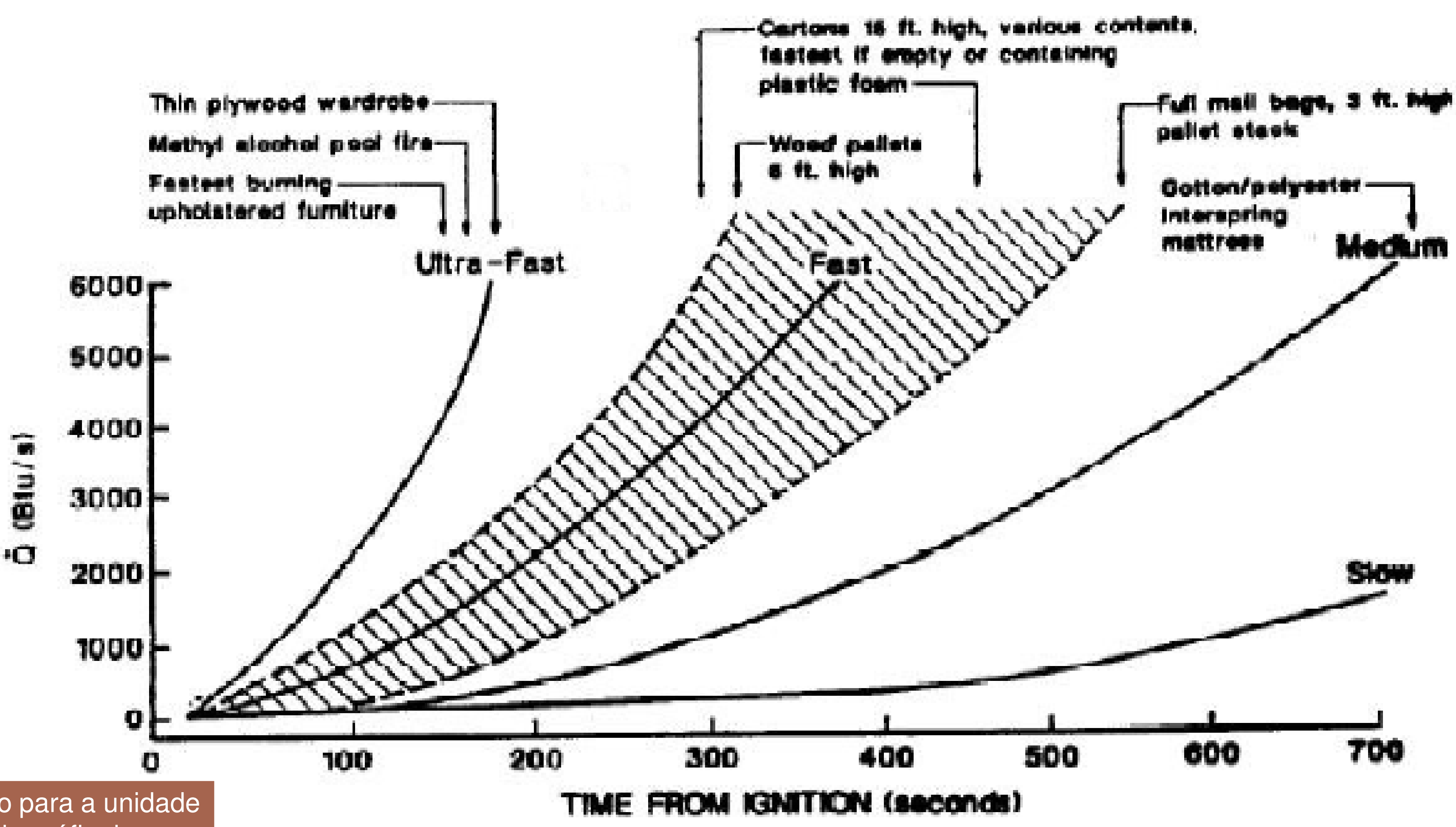
Q (heat release rate) como função do tempo:

A fire's heat release rate increases to a peak and then tapers off as the fire dies down.

It is essential to remember that many of the examples deal with a heat release rate at a particular time (a particular heat release), i.e., the fire was frozen in time. But as the heat release rate changes so do other fire effects.

Heat Release Rate
como Função do Tempo

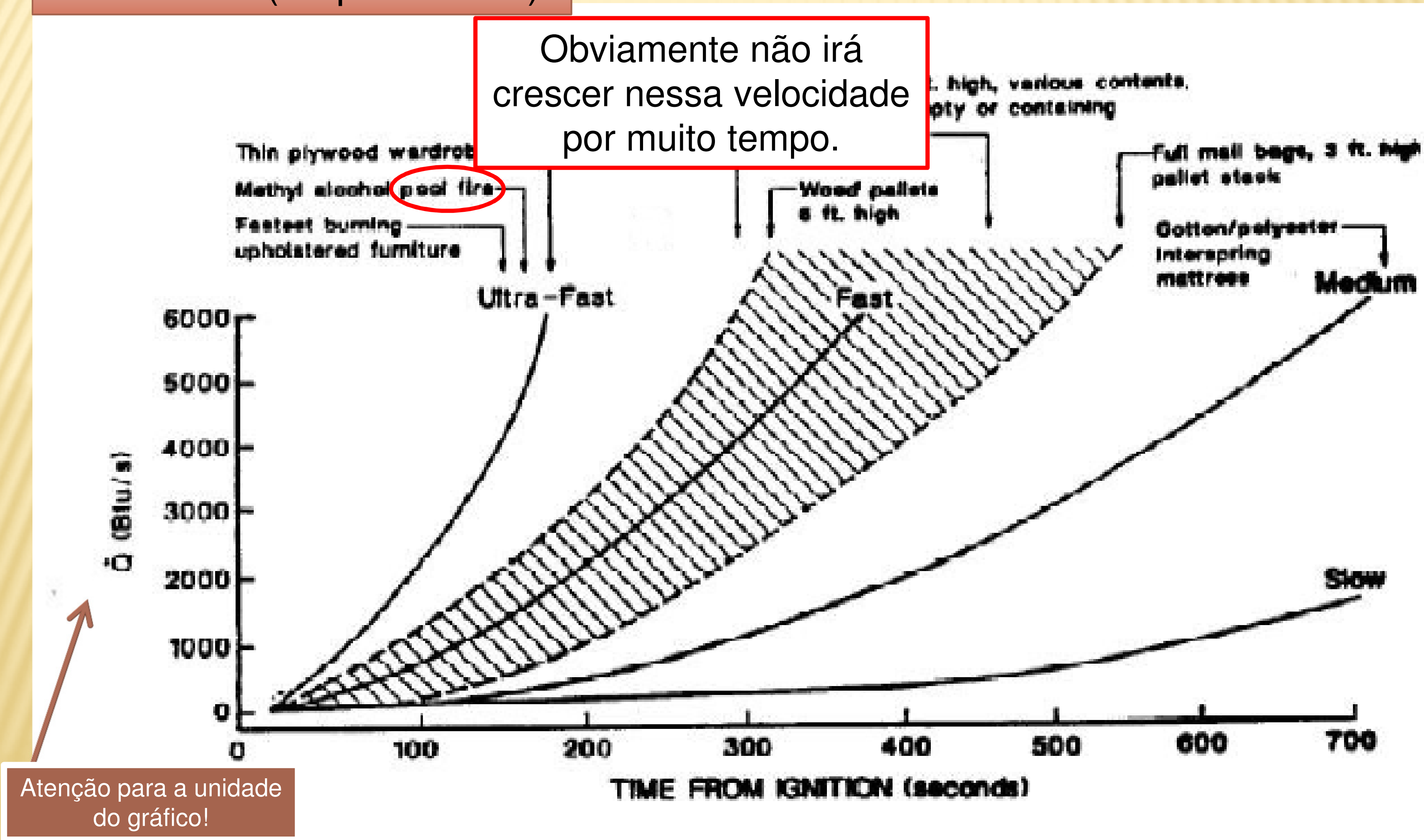
Fase inicial ("exponencial"):



Atenção para a unidade do gráfico!

Heat Release Rate como Função do Tempo

Fase inicial ("exponencial"):



Heat Release Rate como Função do Tempo

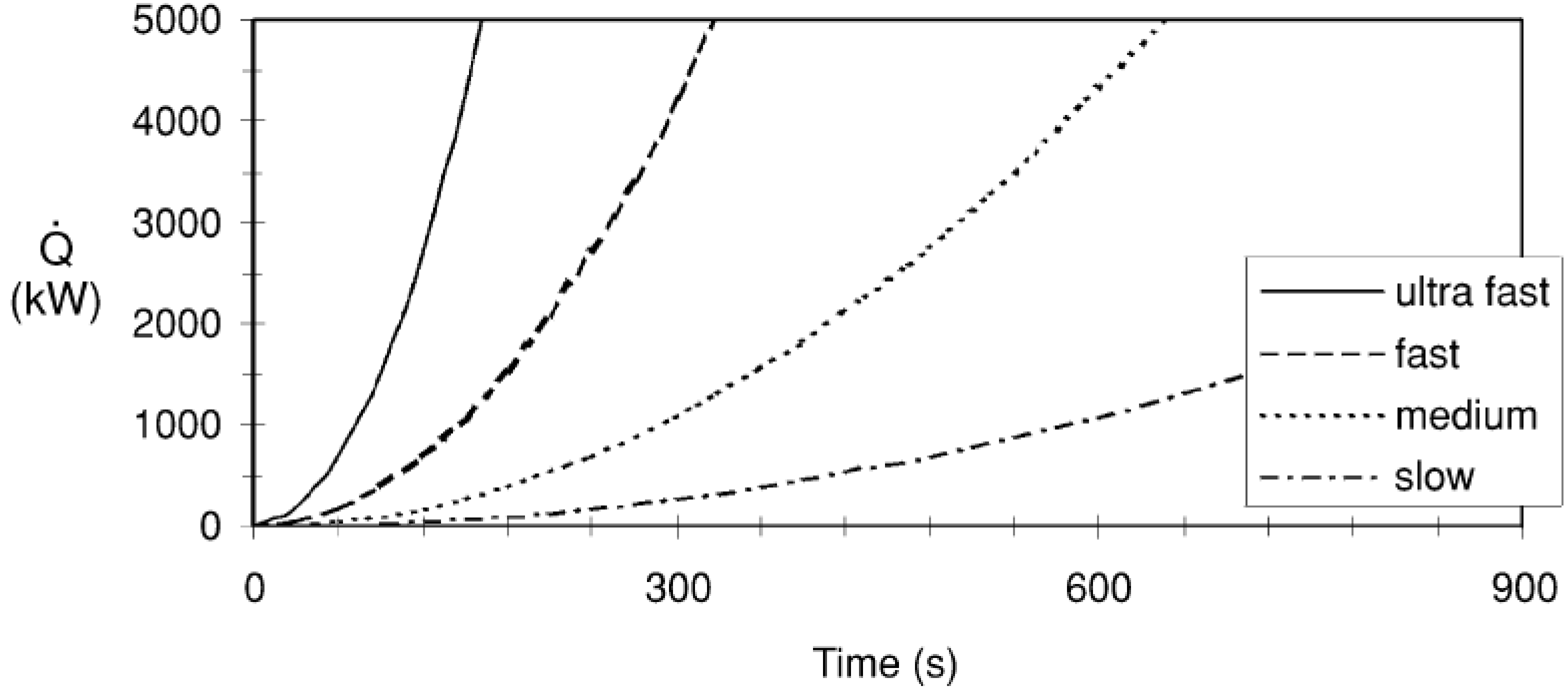


FIGURE 3.14 Energy release rates for different growth rates.

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Heat Release Rate como Função do Tempo

$$Q = \alpha t^2$$

Where: Q = Heat release rate, kW
α = Fire intensity coefficient, kW/s^2
t = Time, s

Valores típicos de alfa para cada um dos "incêndios padrões":

, Table 1 Typical Values of Alpha

Fire Growth	α, kW/s²
Slow	0.00293
Moderate	0.01172
Fast	0.0469
Ultra-fast	0.1876

TABLE 3.5
Values of α for Different Growth Rates According to NFPA 204M

Growth Rate	α (kW/s²)	Time (s) to reach 1055 kW
ultra fast	0.19	75
fast	0.047	150
medium	0.012	300
slow	0.003	600

Source: NFPA, *Guide for Smoke and Heat Venting*, NFPA 204M, National Fire Protection Association, Quincy, MA, 1985.

t0: starting time

TABLE 3.4
Fire Growth Rates for Various Commodities

Test No.	Description	α (kW/s²)	t_0 (s)
15	Metal wardrobe 41.4 kg (total)	0.4220	10
18	Chair F33 (trial loveseat) 39.2 kg	0.0066	140
19	Chair F21, 28.15 kg (initial stage of fire growth)	0.0344	110
19	Chair F21, 28.15 kg (later stage of fire growth)	0.04220	190
21	Metal wardrobe 40.8 kg (total) (average growth)	0.0169	10
21	Metal wardrobe 40.8 kg (total) (later growth)	0.0733	60
21	Metal wardrobe 40.8 kg (total) (initial growth)	0.1055	30
22	Chair F24, 28.3 kg	0.0086	400
23	Chair F23, 31.2 kg	0.0066	100
24	Chair F22, 31.9 kg	0.0003	150
25	Chair F26, 19.2 kg	0.0264	90
26	Chair F27, 29.0 kg	0.0264	360
27	Chair F29, 14.0 kg	0.1055	70
28	Chair F28, 29.2 kg	0.0058	90
29	Chair F25, 27.8 kg (later stage of fire growth)	0.2931	175
29	Chair F25, 27.8 kg (initial stage of fire growth)	0.1055	100
30	Chair F30, 25.2 kg	0.2931	70
31	Chair F31, (loveseat) 39.6 kg	0.2931	145
37	Chair F31, (loveseat) 40.4 kg	0.1648	100
38	Chair F32, (sofa) 51.5 kg	0.1055	50
39	1/2 inch plywood wardrobe w/ fabrics 68.8 kg	0.8612	20
40	1/2 inch plywood wardrobe w/ fabrics 68.32 kg	0.8612	40
41	1/8 inch plywood wardrobe w/ fabrics 36.0 kg	0.6594	40
42	1/8 inch plywood wardrobe w/ fire-ret. (int. fin. initial)	0.2153	50
42	1/8 inch plywood wardrobe w/ fire-ret. (int. fin. later)	1.1722	100

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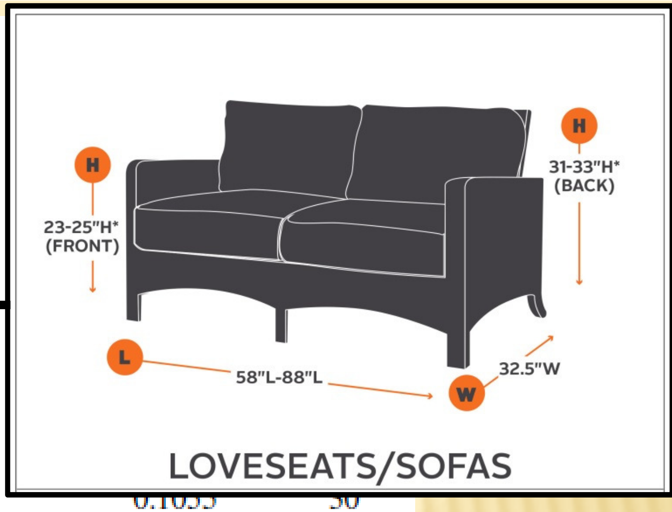
TABLE 3.4
Fire Growth Rates for Various Commodities

Test No.	Description		
15	Metal wardrobe 41.4 kg (total)		
18	Chair F33 (trial loveseat) 39.2 kg		
19	Chair F21, 28.15 kg (initial stage of fire growth)		
19	Chair F21, 28.15 kg (later stage of fire growth)		
21	Metal wardrobe 40.8 kg (total) (average growth)		
21	Metal wardrobe 40.8 kg (total) (later growth)		
21	Metal wardrobe 40.8 kg (total) (initial growth)		
	Chair F24, 28.3 kg	0.0086	400
	Chair F23, 31.2 kg	0.0066	100
	Chair F22, 31.9 kg	0.0003	150
	Chair F26, 19.2 kg	0.0264	90
	Chair F27, 29.0 kg		
	Chair F29, 14.0 kg		
	Chair F28, 29.2 kg		
	air F25, 27.8 kg (later stage of fire growth)		
	air F25, 27.8 kg (initial stage of fire growth)		
	Chair F30, 25.2 kg		
	Chair F31, (loveseat) 39.6 kg		
	Chair F31, (loveseat) 40.4 kg		
	Chair F32, (sofa) 51.5 kg		
	2 inch plywood wardrobe w/ fabrics 68.8 kg		
40	1/2 inch plywood wardrobe w/ fabrics 68.32 kg		
41	1/8 inch plywood wardrobe w/ fabrics 36.0 kg		
42	1/8 inch plywood wardrobe w/ fire-ret. (int. fin. initial)		
42	1/8 inch plywood wardrobe w/ fire-ret. (int. fin. later)		



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dynamics/1300_P

42	1/8 inch plywood wardrobe w/ fire-ret. (int. fin. later)	1.1722	100
43	Repeat of 1/2 inch plywood wardrobe 67.62 kg	1.1722	50
44	1/8 inch plywood wardrobe w/ fire ret., latex paint 37.26 kg	0.1302	30
45	Chair F21, 28.34 kg (large hood)	0.1055	120
46	Chair F21, 28.34 kg	0.5210	130
47	Chair, adjustable back metal frame, foam cushion, 20.8 kg	0.0365	30
48	Easychair CO7 11.52 kg	0.0344	90
49	Easychair 15.68 kg (F-34)	0.0264	50
50	Chair metal frame minimum cushion, 16.52 kg	0.0264	120
51	Chair molded fiberglass no cushion, 5.28 kg	0.0733	20
52	Molded plastic patient chair, 11.26 kg	0.0140	2090
53	Chair metal frame w/padded seat and back 15.5 kg	0.0086	50
54	Loveseat metal frame w/foam cushions 27.26 kg	0.0042	210
55	Group chair metal frame w/foam cushion, 6.08 kg	Never exceeded 50 kW	
56	Chair wood frame w/latex foam cushions, 11.2 kg	0.0042	50
57	Loveseat wood frame w/foam cushions, 54.60 kg	0.0086	500
61	Wardrobe 3/4 inch particle board, 120.33 kg	0.0469	0
62	Bookcase plywood w/aluminum frame, 30.39 kg	0.2497	40
64	Easychair molded flexible urethane frame, 15.98 kg	0.0011	750
66	Easychair, 23.02 kg	0.1876	3700
67	Mattress and boxspring, 62.36 kg (initial fire growth)	0.0086	400
67	Mattress and boxspring, 62.36 kg (initial fire growth)	0.0009	90

Source: Adapted from Schifility, R.P., et al., in *SFPE Handbook of Fire Protection Engineering*, 2nd ed., National Fire Protection Association, Quincy, MA, 1995.

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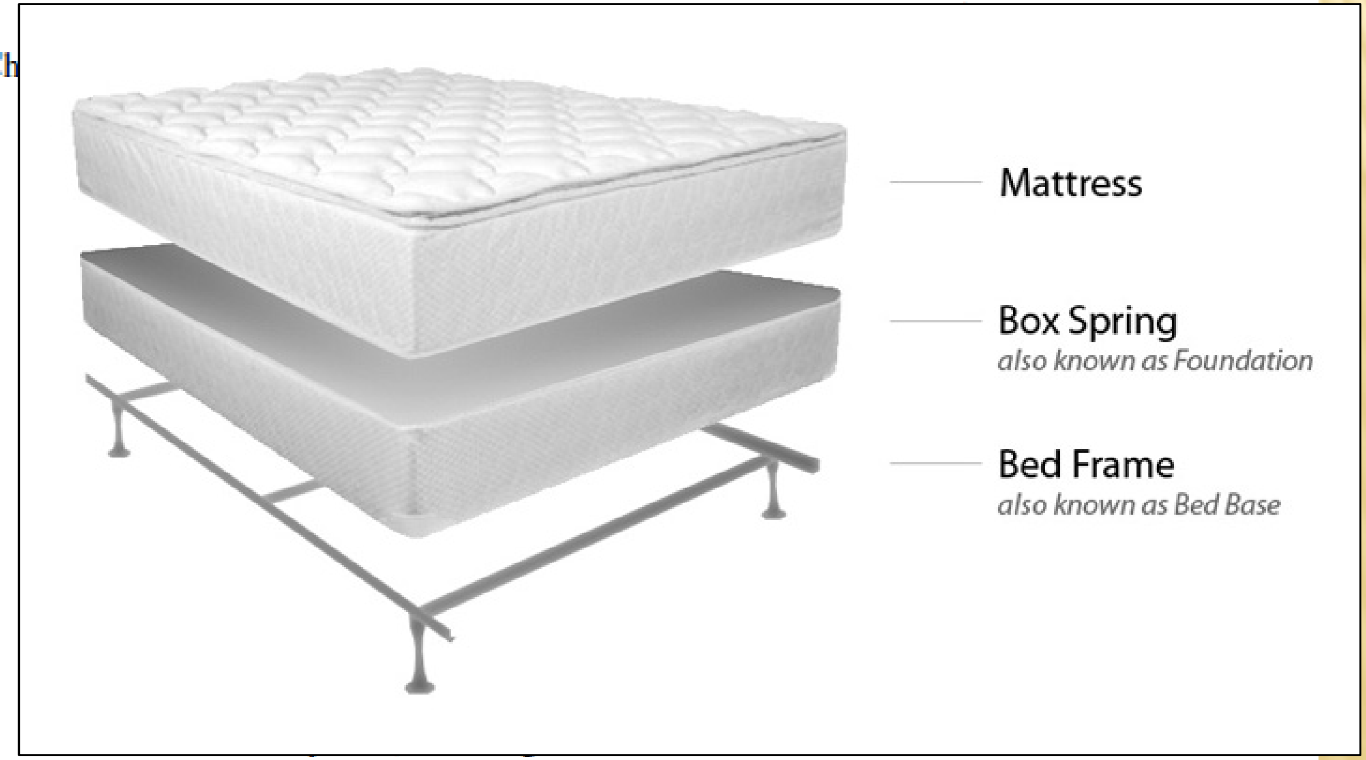
42	1/8 inch plywood wardrobe w/ fire-ret. (int. fin. later)	1.1722	100
43	Repeat of 1/2 inch plywood wardrobe 67.62 kg	1.1722	50
44	1/8 inch plywood wardrobe w/ fire ret., latex paint 37.26 kg	0.1302	30
45	Chair F21, 28.34 kg (large hood)	0.1055	120
46			
47	Ch		
48			
49			
50			
51			
52			
53			
54			
55			
56			
57			
61			
62			
64			
66			
67	Mattress and boxspring, 62.36 kg (initial fire growth)	0.0086	400
67	Mattress and boxspring, 62.36 kg (initial fire growth)	0.0009	90



Source: Adapted from Schifility, R.P., et al., in *SFPE Handbook of Fire Protection Engineering*, 2nd ed., National Fire Protection Association, Quincy, MA, 1995.

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Curva experimental para definição dos alfas

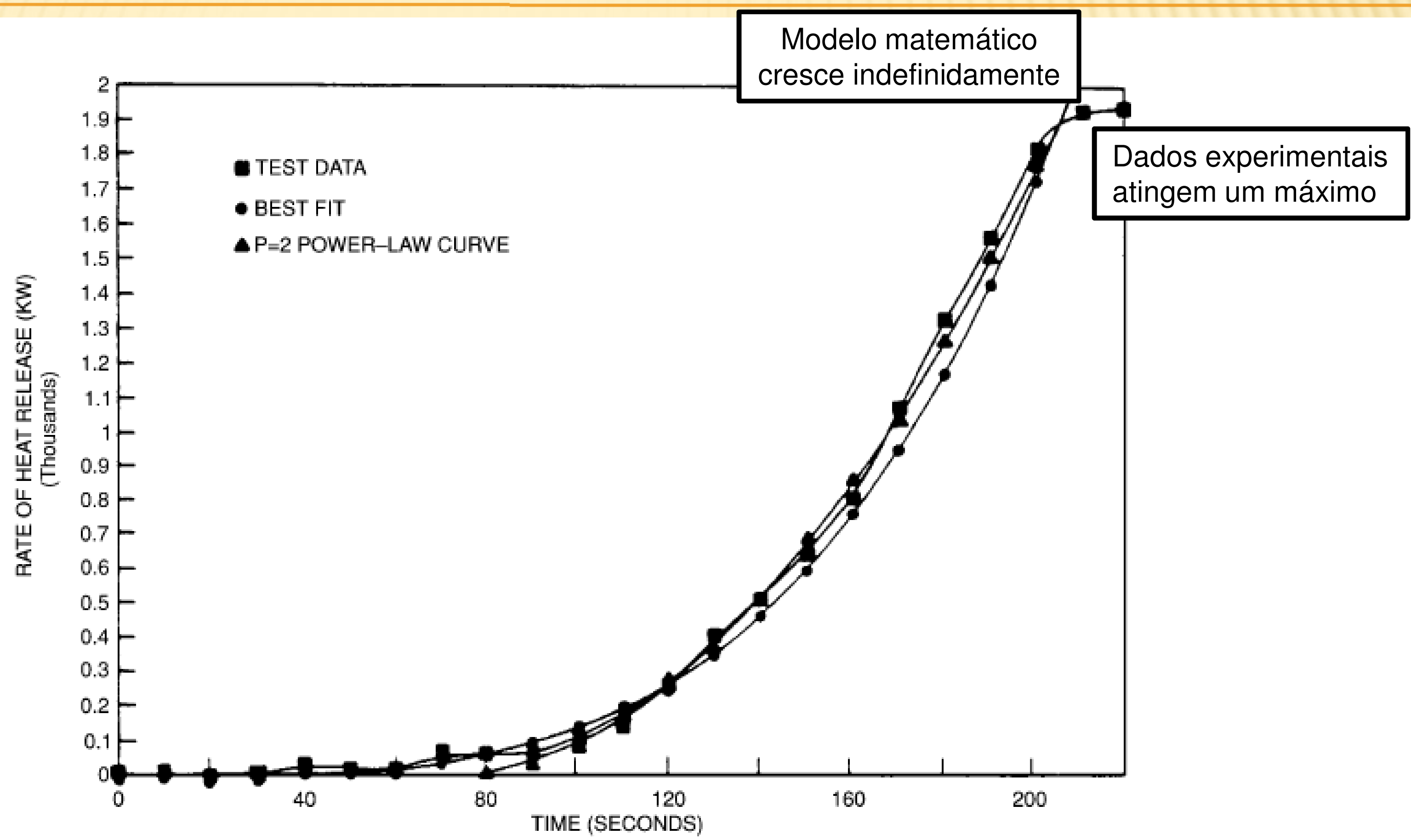

FIGURE 3.13 An example of one of the tests reported in Table 3.4. (From Schifility et al.[8] With permission.)

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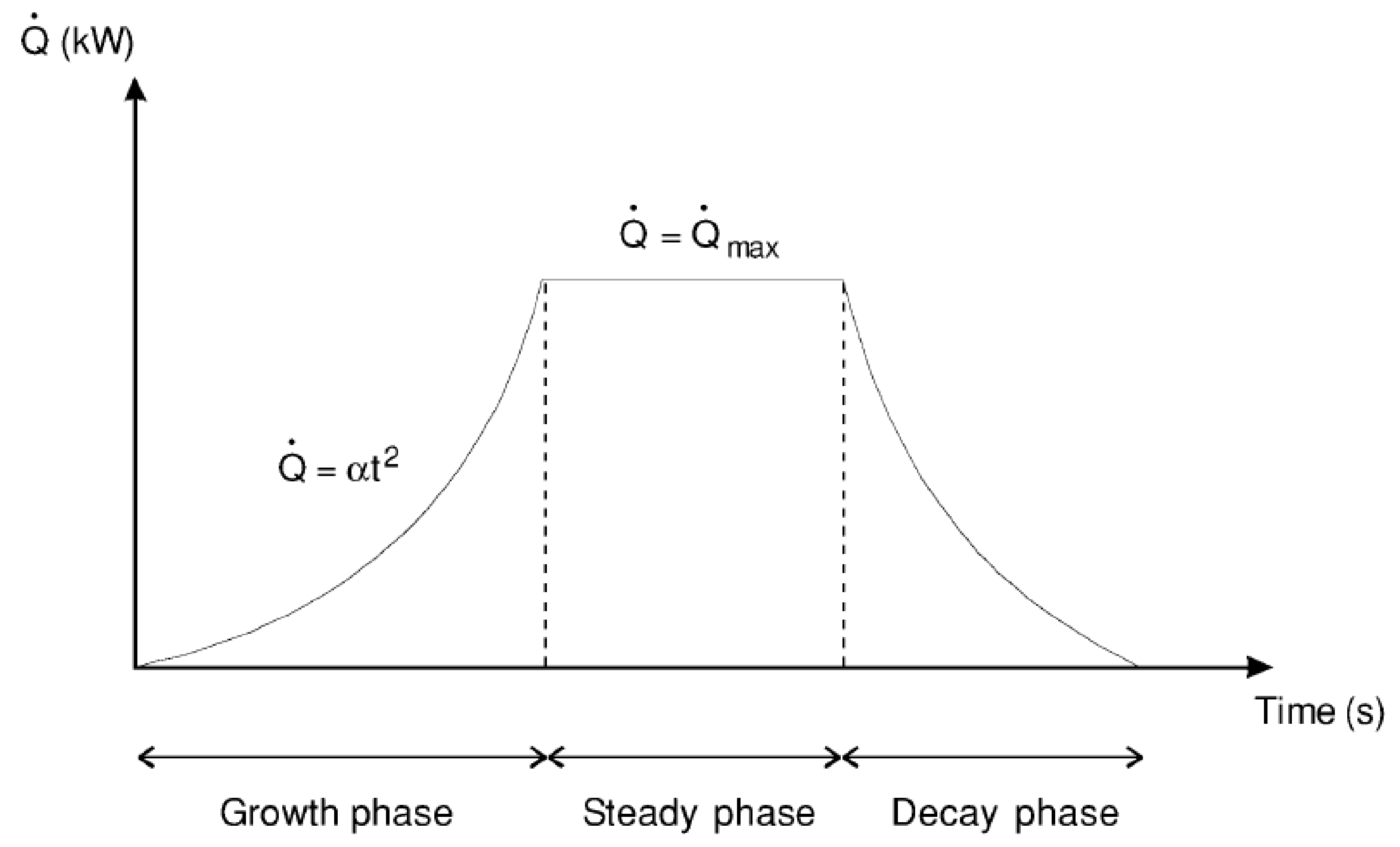

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Heat Release Rate
como Função do Tempo

Exemplo:

Example 3-5 A sofa fire (which you deem to be a moderate fire) was burning for 90 seconds. Using the t^2 equation, Equation 3-7, what is the heat release rate at that time?

Solution:

$$Q = \alpha t^2 = (0.01172)(90)^2 = 95\ kW$$

Flame Height

ii. Modelo Delichatsios

Hipótese:
Chama Retangular

$$H_f = 0.050\ Q_w^{\ 2/3}$$

Heat release rate (kW)

Heat release rate per unit wall width (kW/m)

Width: largura

Use APENAS os valores relativos a "**WIDTH**" da tabela A3 (próximo slide). Lembre-se de multiplicar pela largura do objeto.

Referência: pag 342, Robert G. Zalosh, "Industrial Fire Protection"

A3

Table A.3. Theoretical unit heat release rates for fuels burning in the open

Commodity	Heat release rate (Btu/sec)
Flammable Liquid Pool	290/ft^2 of surface
Flammable Liquid Spray	2000/gpm of flow
Wood Pallets (Single Stack)	1000/ft of height
Wood or PMMA (Vertical)	
2 ft Height Burning	30/ft of width
4 ft Height Burning	70/ft of width
8 ft Height Burning	180/ft of width
12 ft Height Burning	300/ft of width
Wood of PMMA	
Top of Horizontal Surface	65/ft^2 of surface
Solid Polystyrene (Vertical)	
2 ft Height Burning	65/ft of width
4 ft Height Burning	150/ft of width
8 ft Height Burning	400/ft of width
12 ft Height Burning	680/ft of width
Solid Polystyrene (Horizontal)	120/ft^2 of surface
Solid Polystyrene (Vertical)	
2 ft Height Burning	45/ft of width
4 ft Height Burning	100/ft of width
8 ft Height Burning	280/ft of width
12 ft Height Burning	470/ft of width
Solid Polypropylene (Horizontal)	70/ft^2 of surface

Modelo Delichatsios

Flame Height

i. Modelo Heskestad

Melher para pool fire

ii. Modelo Delichatsios

Melhor para incêndio em placa sólida vertical

Flame Height

Altura da Chama em parede ou quina

"Walls and corners reduce the entrained air into the flame or plume. This lengthens flames and increases the plume temperature over that of fire in the open. Thus a wall fires, and especially corner fires, are more hazardous than a fire in the center of the room. The flame in these fires will roll on to the ceiling quicker than a fire in the center of the room."

The equations for corner and wall fires flame length are:

Corner: $L = 0.075\ Q^{(3/5)}$

Wall: $L = 0.034\ Q^{(2/3)}$

Flame Height

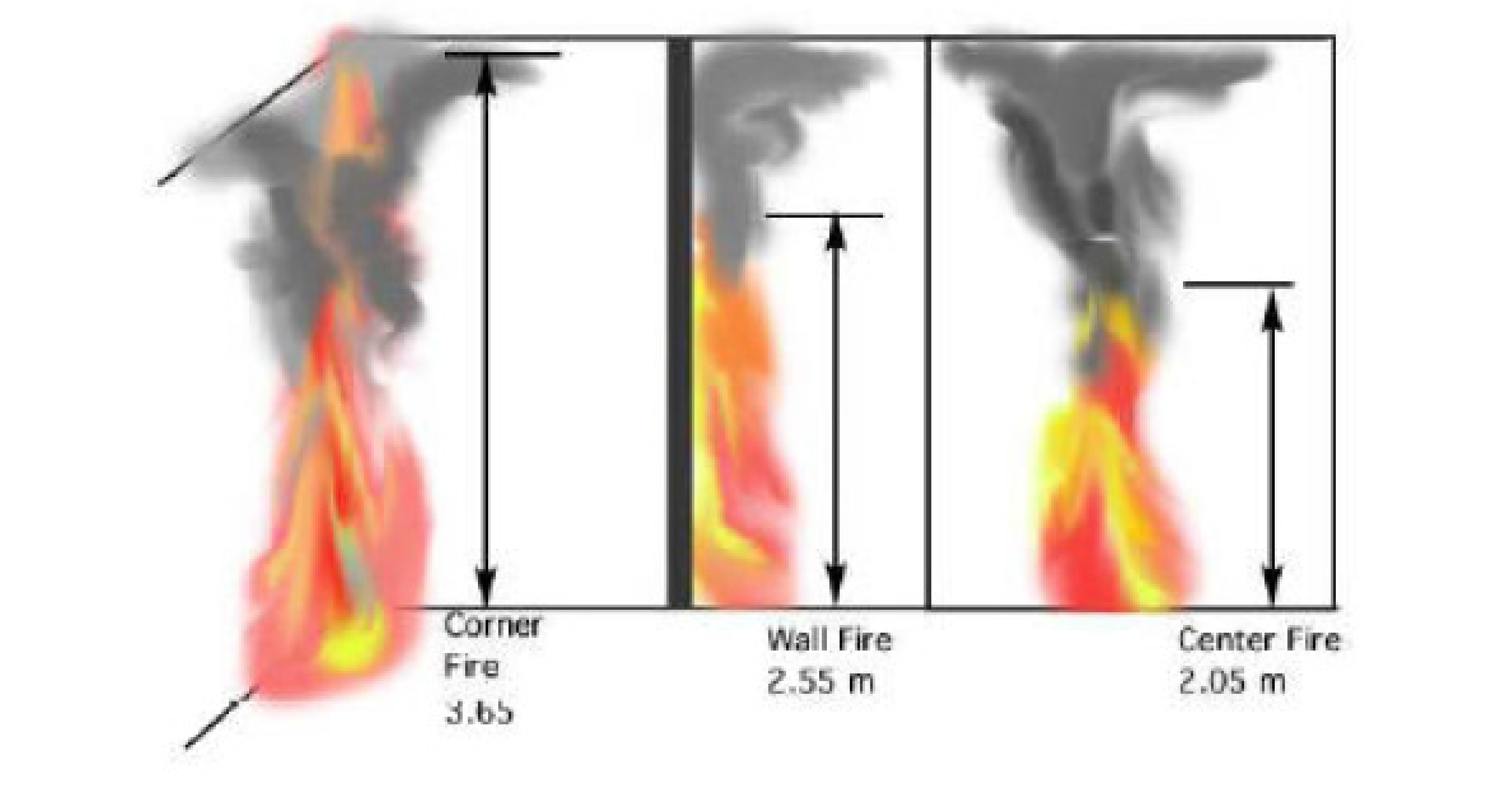
Exemplo:

Solution:

Modelo Heskestad

Corner fire $Q = 650$ kW	Wall fire, $Q = 650$ kW	Center fire, $Q = 650$ kW D = 1 m
$L = 0.075\dot{Q}^{3/5}$ $L = (0.075)(650)^{3/5}$ $L = 3.65\ m$	$L = 0.034\dot{Q}^{2/3}$ $L = (0.034)(650)^{2/3}$ $L = 2.55\ m$	$L = 0.23\dot{Q}^{2/5} - 1.02D$ $L = (0.23)(650)^{2/5} - (1.02)(1)$ $L = 2.05\ m$

Exemplo:



Agências americanas aplicam os modelos Wall e Corner nessa estimativa:

82	**ESTIMATING WALL FIRE FLAME HEIGHT**		
83		Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.*	
84			
85		$H_{f(wall)} = 0.034\ Q'^{2/3}$	
86		Where	$H_{f(wall)}$ = wall fire flame height (m)
87			Q' = rate of heat release per unit length of the fire (kW/m)
88		$H_{f(wall)} = 0.034\ Q'^{2/3}$	
89		**$H_{f(wall)}$ = 3,04 m 9,96 ft**	**Answer**

67	**ESTIMATING CORNER FIRE FLAME HEIGHT**		
68		Reference: *Hesemi and Tokunaga, "Modeling of Turbulent Diffusion Flames and Fire Plumes for the Analysis of Fire Growth,"*	
69		*Growth," Proceeding of the 21st National Heat Transfer Conference, American Society of Mechanical Engineers (ASME), 1983.*	
70		$H_{f(corner)} = 0.075\ Q^{3/5}$	
71		Where	Q = heat release rate of the fire (kW)
72		$H_{f(corner)} = 0.075\ Q^{3/5}$	
73		**$H_{f(corner)}$ = 6,43 m 21,10 ft**	**Answer**

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCYQFjAA&url=http%3A%2F%2Fwww.nrc.gov%2Freading-rm%2Fdoc-collections%2Fnuregs%2Fstaff%2Fsr1805%2F04_Flame_Height_Calculations.xls&ei=G4GWUY-ZKtan4AOUpoGQBQ&usg=AFQjCNHI2nuCLScz2MdXWzl_W7RZ_QJRTA&sig2=wTMhiy7T5vg2qV5dbiuwSQ&bvm=bv.46751780,d.dmg