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THERMODYNAMIC ASPECTS OF KORNAT ACCIDENT

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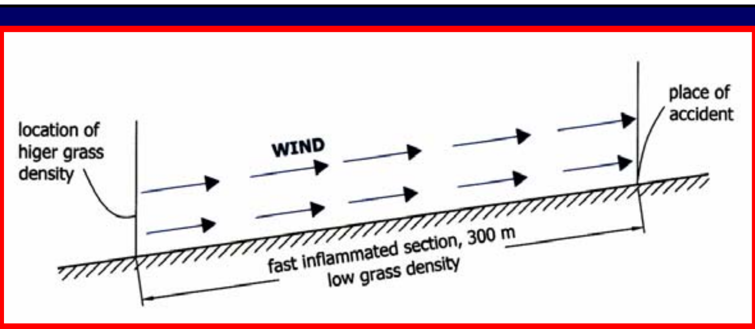


Figure 1. ***Up wind section before inflammation***

This consideration starts immediately before fast inflammation of the section on wind of the place of the accident

We consider the ground strip 300 x 1 m
grass density : 0,6 kg/m^2
grass quantity: 0,6·300·1=**180 kg**
Air/fuel stoichiometric ratio: 7
relative air fuel ratio : λ= 1,5
(the same as air/fuel stoichiometric ratio equal to 8, with λ = 1,31)

Air quantity for grass combustion:
G_a = 180·7·1,5 = **1890 kg**

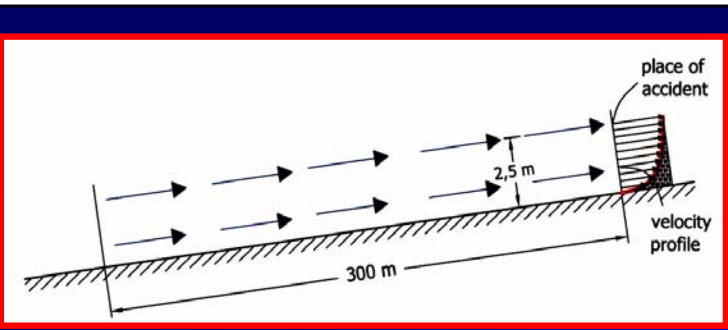


Figure 2. ***Velocity profile of the air flow***
(according to the chapter VII)

Temperature boundary layer thickness at the place of the accident:

$$\delta = 2,5 \text{ m}$$

wind velocity at 2,5 m above ground

$$w_{TM} = 8,0 \text{ m/s}$$

Coefficient of flow reduction due to ground friction, φ, and air density for cold flow $\varphi \approx 0,86$, ρ_a=1,2 kg/m^3.

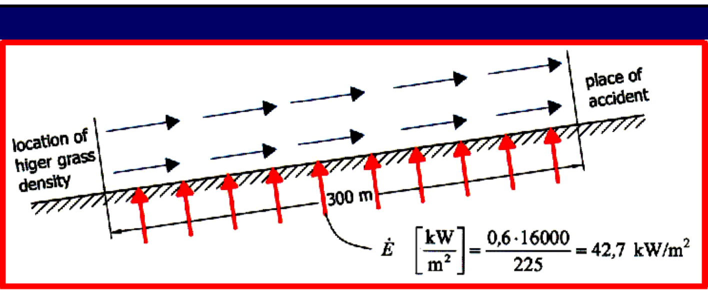


Figure 3. ***Fast inflammation along on wind section***
(according to the chapter VI)

after inflammation air mass flow rate $\dot{m}_a$ is additionaly reduced as follows

$$\dot{m}_a = 2,5 \cdot 1,0 \cdot 8 \cdot 1,2 \cdot \frac{300}{600} \cdot 0,86 \cdot 0,6 = 8,4 \text{ kg/s}$$

So the air flow is $\dot{m}_a = 8,4$ **kg/s**

Time for combustion of the grass in fast inflammed section is

$$\Delta\tau = \frac{1890}{8,4} = 225 \text{ s}$$

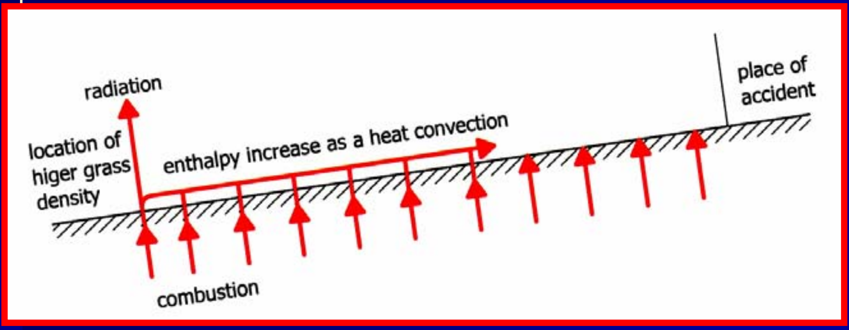


Figure 4. ***Begining of the ‘’Fast Heat Shock ‘’phenomenon (FHS)***

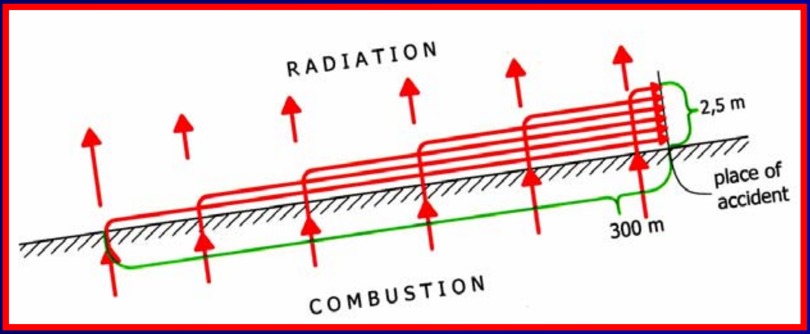


Figure 5. ***Fully developed FHS***

- geometric concentration factor : **300:2,5**

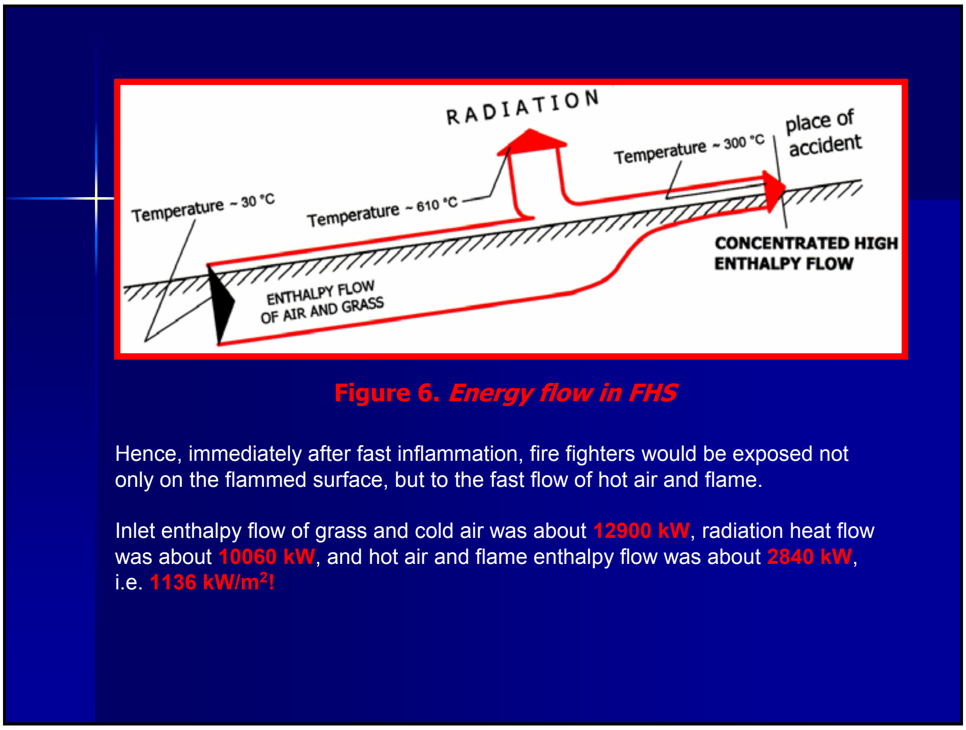


Figure 6. *Energy flow in FHS*

Hence, immediately after fast inflammation, fire fighters would be exposed not only on the flammed surface, but to the fast flow of hot air and flame.

Inlet enthalpy flow of grass and cold air was about **12900 kW**, radiation heat flow was about **10060 kW**, and hot air and flame enthalpy flow was about **2840 kW**, i.e. **1136 kW/m^2!**

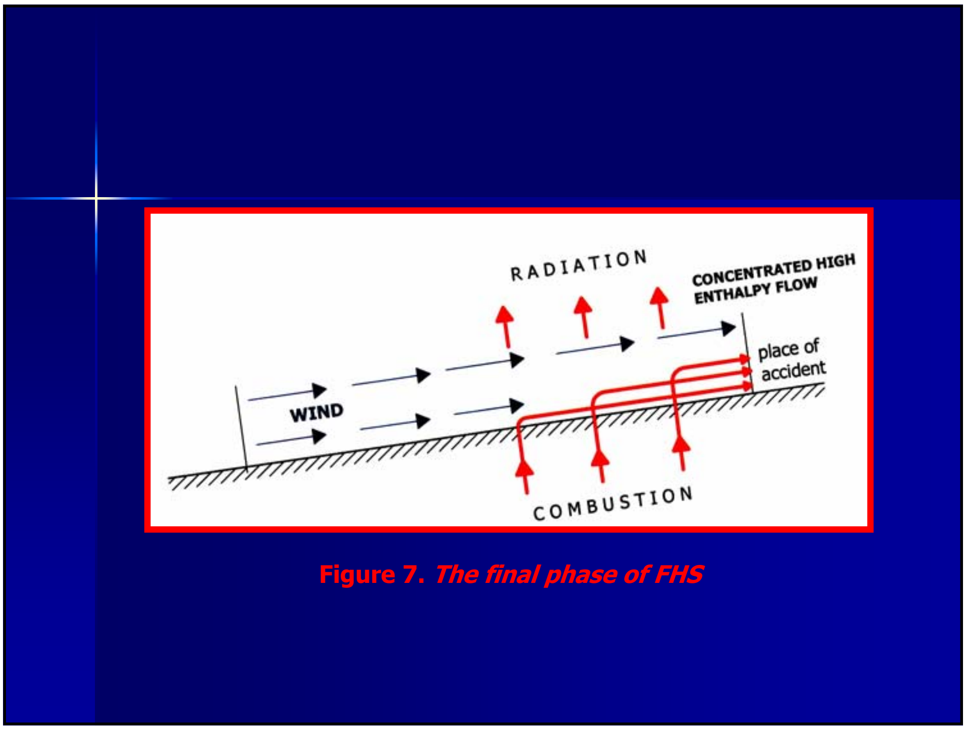


Figure 7. *The final phase of FHS*

FAST HEAT SHOCK - "FHS" MODEL ANALYSIS

Input parametres for FHS:

L(m)– burnt section length,
δ(m)–thickness of temperature boundary layer at the end of the section, estimated δ= 2,5 m,
φ – air flow reduction coefficient due to ground friction,
w_{wind}(m/s) – air flow velocity at the top of the temperature boundary layer,
g_g (kg/m^2) – average fuel load (vegetation cover),
g_{Zmin}(kg$_{air}$/kg$_{fuel}$) – minimal estimated quantity of air for combustion of 1,0 kg of fuel. Here estimated g_{Zmin}= 8,0 (kg$_{air}$/kg$_{fuel}$) with $1,2< \lambda<1,7$ (this is the same as g_{Zmin}= 7,0 (kg$_{air}$/kg$_{fuel}$), with $1,37< \lambda<1,94$)
λ–relative air fuel ratio,
T_f (K) – mean surface temperature of the volume embodied by flame, in short: "mean flame temperature" ,
t_a (°C) – environment temperature, estimated t_a=27 °C,
H_d(MJ/kg) – lower heat content of fuel, including the 30 % of moisture in fuel, calculated H_d=16000 (MJ/kg),
c_p(kJ/kgK) – mean specific heat capacity of combustion products and air mixture, estimated c_p=1,15 (kJ/kgK).

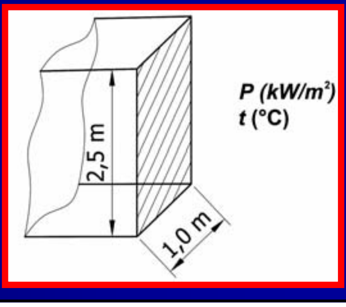
Calculated parameters for FHS:

m_{air} (kg/s)– mass flow rate of air,
m_{fuel} (kg/s)– mass flow rate of burned fuel,
G_f(kg$_{fuel}$) – quantity of fuel on section length and width 1,0 m,
G_a(kg$_{air}$) – quantity of air for combustion of fuel,
Q_f (kW) – heat flow produced from combustion of fuel,
Q_r(kW) – radiation heat flow,

Calculated parameters for FHS at the place of the accident:

t (°C) – average temperature of air flow at the place of the accident,
$\Delta\tau$ (s) – duration time of FHS (i.e., for burning of complete section length L)
P (kW/m^2) –specific power of FHS at the place of the accident per square meter of vertical cross section.

Figure 8. *Vertical cross section at the place of the accident*



RESULTS OF PARAMETER ANALYSIS FOR FHS

INPUT PARAMETERS OF "FAST HEAT SHOCK"											PLACE OF THE ACCIDENT		
L (m)	φ	w_{wind} (m/s)	g_g (kg/m^2)	λ	T_f (K)	m_{air}(kg/s)	m_{fuel}(kg/s)	G_a(kg)	G_f(kg)	Q_f(kW)	Q_r(kW)	t (°C)	$\Delta\tau$ (s)	P (kW/m^2)
250	0,5	10,0	0,6	1,5	880	8,3	0,688	1800	150	11009	8496	271	218	1005
300	-II-	-II-	-II-	-II-	-II-	9,3	0,772	2160	180	12346	10195	213	233	860
350	-II-	-II-	-II-	-II-	-II-	10,3	0,854	2520	210	13667	11895	166	246	709
300	-II-	-II-	**0,4**	-II-	-II-	9,3	0,772	1440	120	12346	10195	213	156	860
-II-	-II-	-II-	**0,8**	-II-	-II-	9,3	0,772	2880	240	12346	10195	213	311	860
-II-	-II-	-II-	0,6	**1,2**	-II-	7,8	0,81	1728	180	12953	10195	306	222	1103
-II-	-II-	-II-	-II-	**1,7**	-II-	10,2	0,749	2448	180	11978	10195	169	240	713
-II-	-II-	-II-	-II-	1,5	**980**	12,5	1,039	2160	180	16620	15681	87	173	376
-II-	-II-	-II-	-II-	-II-	**780**	7,0	0,581	2160	180	9302	6293	373	310	1204
-II-	**0,8**	-II-	-II-	-II-	880	11,2	0,936	2160	180	14977	10195	369	192	1912
350	0,5	-II-	-II-	**1,2**	-II-	8,6	0,898	2016	210	14368	11895	253	234	989
300	0,5	**8,0**	0,6	1,5	-II-	8,6	0,716	2160	180	11456	10195	145	251	504
-II-	-II-	**6,0**	-II-	-II-	-II-	7,9	0,662	2160	180	10588	10195	67	272	157
200	-II-	10,0	0,4	1,5	880	7,3	0,605	960	80	9677	6797	346	132	1152

Variable parametres of FHS are:

L – section lenght
g_g – average fuel load
λ, – air fuel ratio
T_f, – mean flame temperature
φ – air flow reduction coefficient
w_{wind} – air flow velocity

Conclusions based on the performed parameter analysis for the FHS:

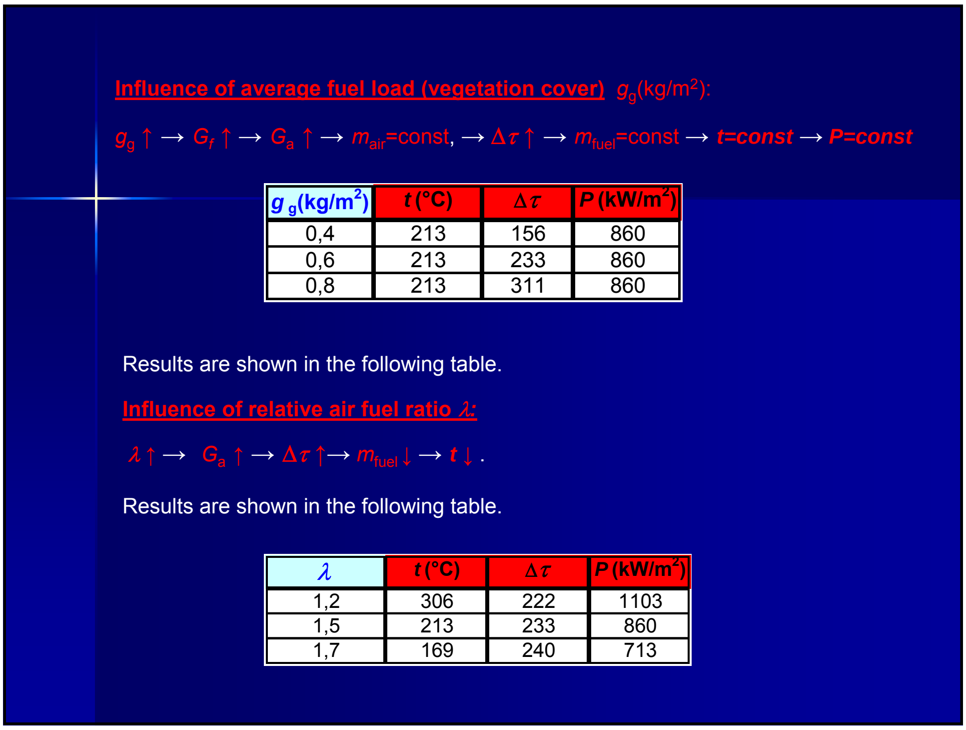
Note: *In the following analysis of each characteristic influence parameter, all other input parameters of FHS retain constant!*

Influence of burnt section length L (m):

$L\uparrow \rightarrow G_a\uparrow \rightarrow \Delta\tau\uparrow \rightarrow Q_r\uparrow \rightarrow t\downarrow$.

Results are shown in the following table.

L	t (°C)	$\Delta\tau$	P (kW/m^2)
250	271	218	1005
300	213	233	860
350	166	246	709



Influence of average fuel load (vegetation cover) g_g(kg/m^2):

$g_g \uparrow \rightarrow G_f \uparrow \rightarrow G_a \uparrow \rightarrow m_{air}$=const, $\rightarrow \Delta\tau \uparrow \rightarrow m_{fuel}$=const $\rightarrow$ ***t=const*** $\rightarrow$ ***P=const***

g_g(kg/m^2)	t (°C)	$\Delta\tau$	P (kW/m^2)
0,4	213	156	860
0,6	213	233	860
0,8	213	311	860

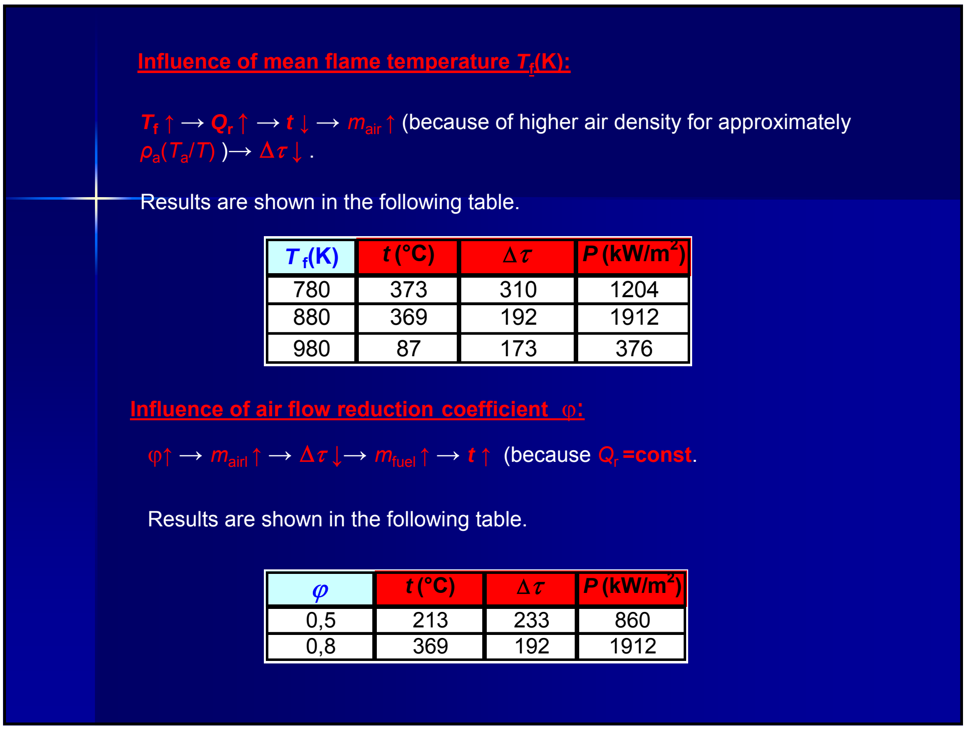
Results are shown in the following table.

Influence of relative air fuel ratio λ:

$\lambda \uparrow \rightarrow G_a \uparrow \rightarrow \Delta\tau \uparrow \rightarrow m_{fuel} \downarrow \rightarrow t \downarrow$.

Results are shown in the following table.

λ	t (°C)	$\Delta\tau$	P (kW/m^2)
1,2	306	222	1103
1,5	213	233	860
1,7	169	240	713



Influence of mean flame temperature T_f(K):

$T_f \uparrow \rightarrow Q_r \uparrow \rightarrow t \downarrow \rightarrow m_{air} \uparrow$ (because of higher air density for approximately $\rho_a(T_a/T)$)$\rightarrow \Delta\tau \downarrow$.

Results are shown in the following table.

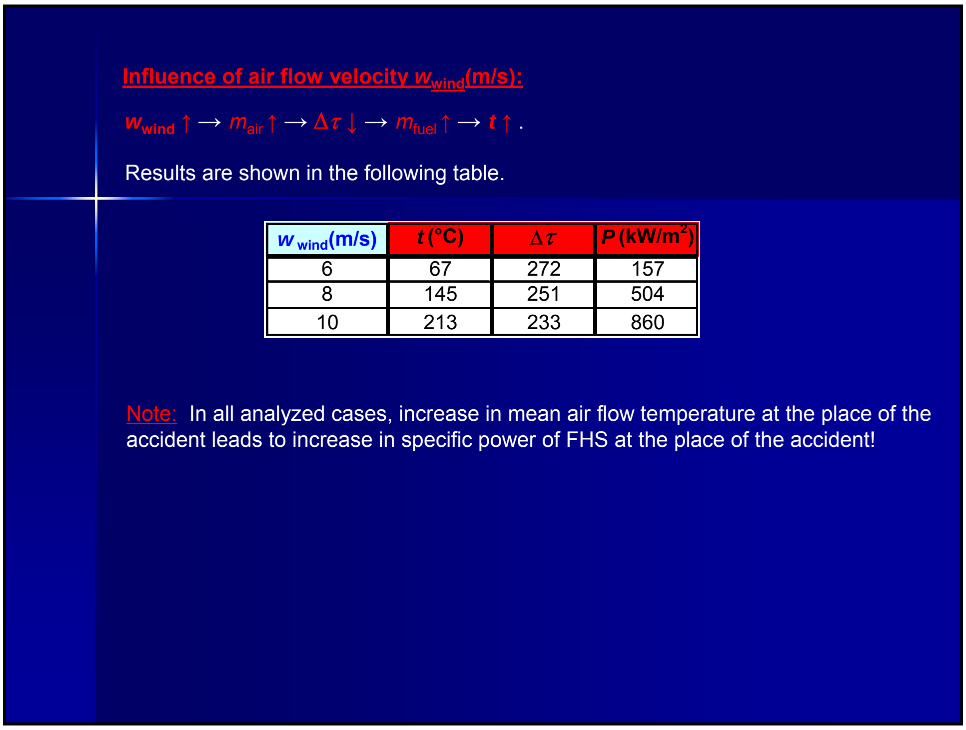
T_f(K)	t (°C)	$\Delta\tau$	P (kW/m^2)
780	373	310	1204
880	369	192	1912
980	87	173	376

Influence of air flow reduction coefficient φ:

$\varphi \uparrow \rightarrow m_{airl} \uparrow \rightarrow \Delta\tau \downarrow \rightarrow m_{fuel} \uparrow \rightarrow t \uparrow$ (because Q_r **=const**.

Results are shown in the following table.

φ	t (°C)	$\Delta\tau$	P (kW/m^2)
0,5	213	233	860
0,8	369	192	1912



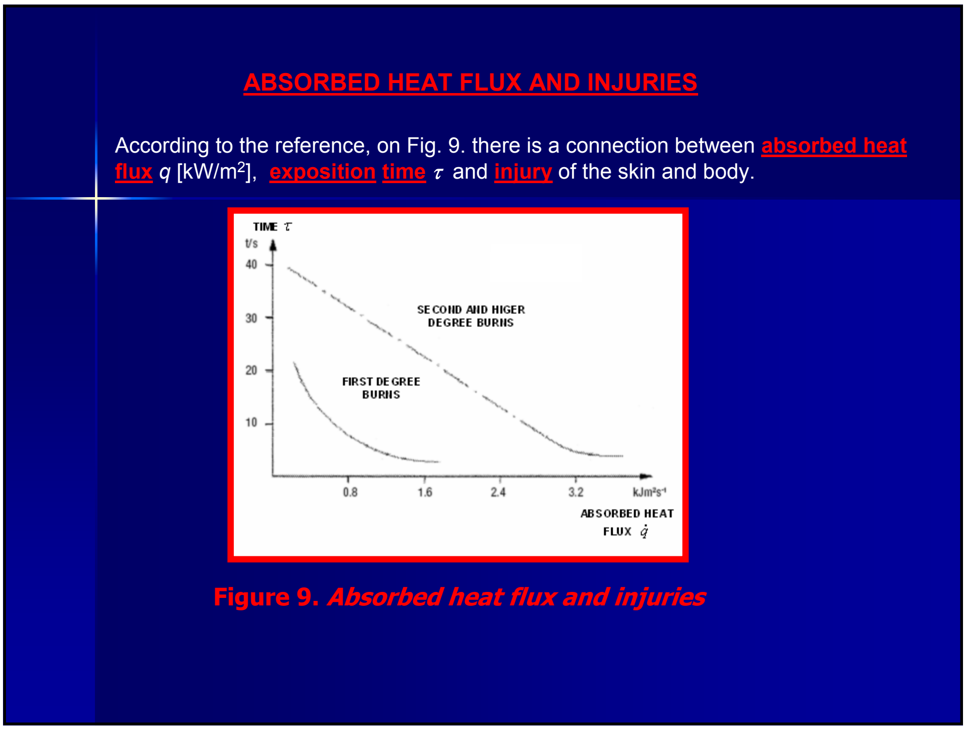
Influence of air flow velocity w_{wind}(m/s):

$w_{wind}\uparrow \rightarrow m_{air}\uparrow \rightarrow \Delta\tau\downarrow \rightarrow m_{fuel}\uparrow \rightarrow t\uparrow$.

Results are shown in the following table.

w_{wind}(m/s)	t (°C)	$\Delta\tau$	P (kW/m^2)
6	67	272	157
8	145	251	504
10	213	233	860

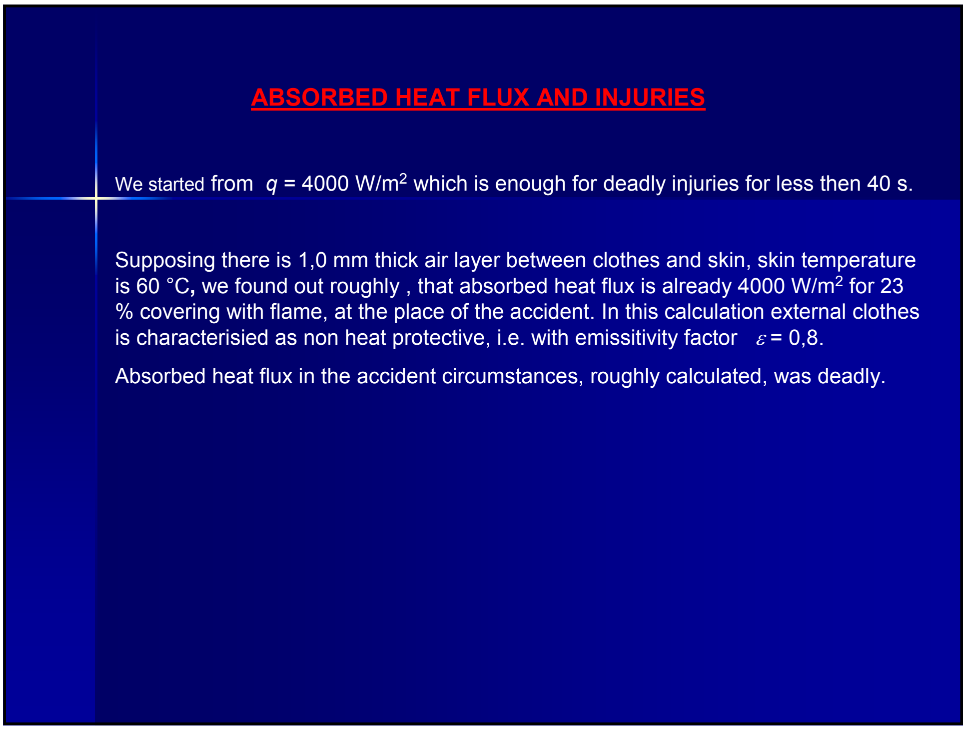
Note: In all analyzed cases, increase in mean air flow temperature at the place of the accident leads to increase in specific power of FHS at the place of the accident!



ABSORBED HEAT FLUX AND INJURIES

According to the reference, on Fig. 9. there is a connection between **absorbed heat flux** q [kW/m^2], **exposition time** τ and **injury** of the skin and body.

Figure 9. *Absorbed heat flux and injuries*



ABSORBED HEAT FLUX AND INJURIES

We started from q = 4000 W/m^2 which is enough for deadly injuries for less then 40 s.

Supposing there is 1,0 mm thick air layer between clothes and skin, skin temperature is 60 °C, we found out roughly , that absorbed heat flux is already 4000 W/m^2 for 23 % covering with flame, at the place of the accident. In this calculation external clothes is characterisied as non heat protective, i.e. with emissitivity factor ε = 0,8.

Absorbed heat flux in the accident circumstances, roughly calculated, was deadly.