3. Matches on fire

Team Croatia

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Problem statement

When the outermost match in a regular array of matches is lit, the following matches **ignite** one by one. Investigate the parameters that determine the **speed** for such a **fire wave**.

Dependent variable:
- Time for propagation

Independent variables:
- The angle
- The distance between matches
- Number of rows of matches

How to light a match?

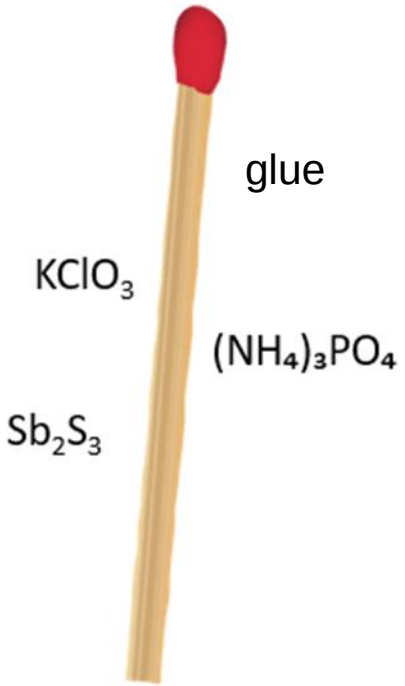


Figure 1. Match composition (https://pixabay.com/vectors/match-matches-fire-matchbox-1717377/)

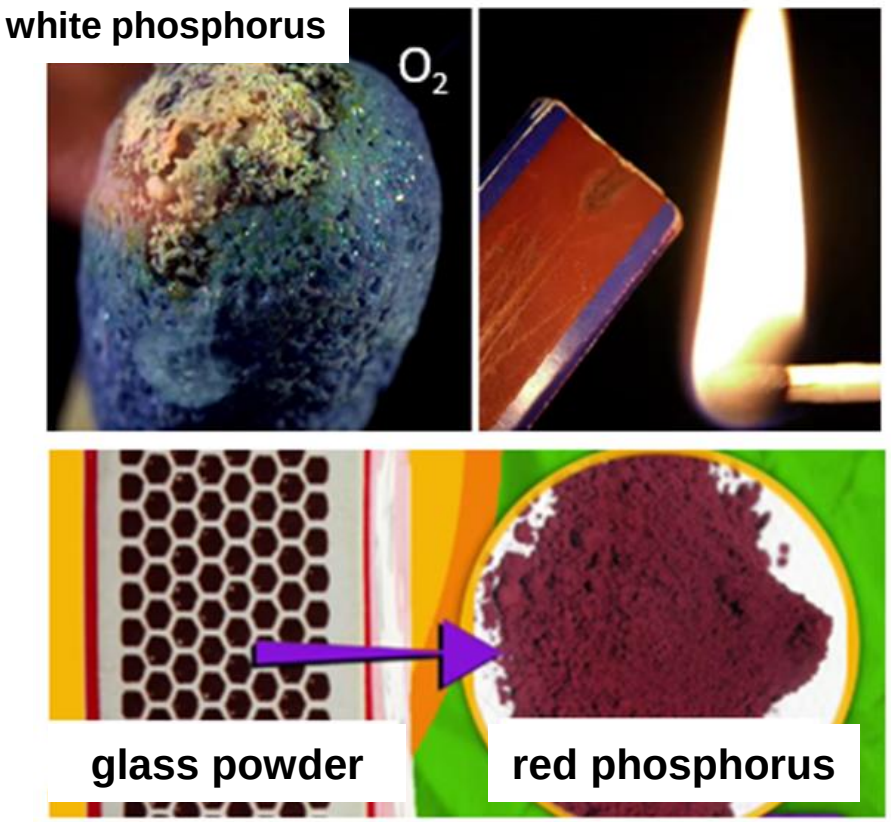


Figure 2. Tarile composition and match ignition (https://youtu.be/y2ErAPODA6U, (https://youtu.be/y2ErAPODA6U)

The rate of ignition of matches and the rate of combustion of a series of matches are affected by:

- ✓ the slope of the substrate
- ✓ oxygen supply
- ✓ humidity in the environment
- ✓ temperature
- ✓ type and shape of substrate
- ✓ fuel substance, etc.

✓ Const.
✓ Changing

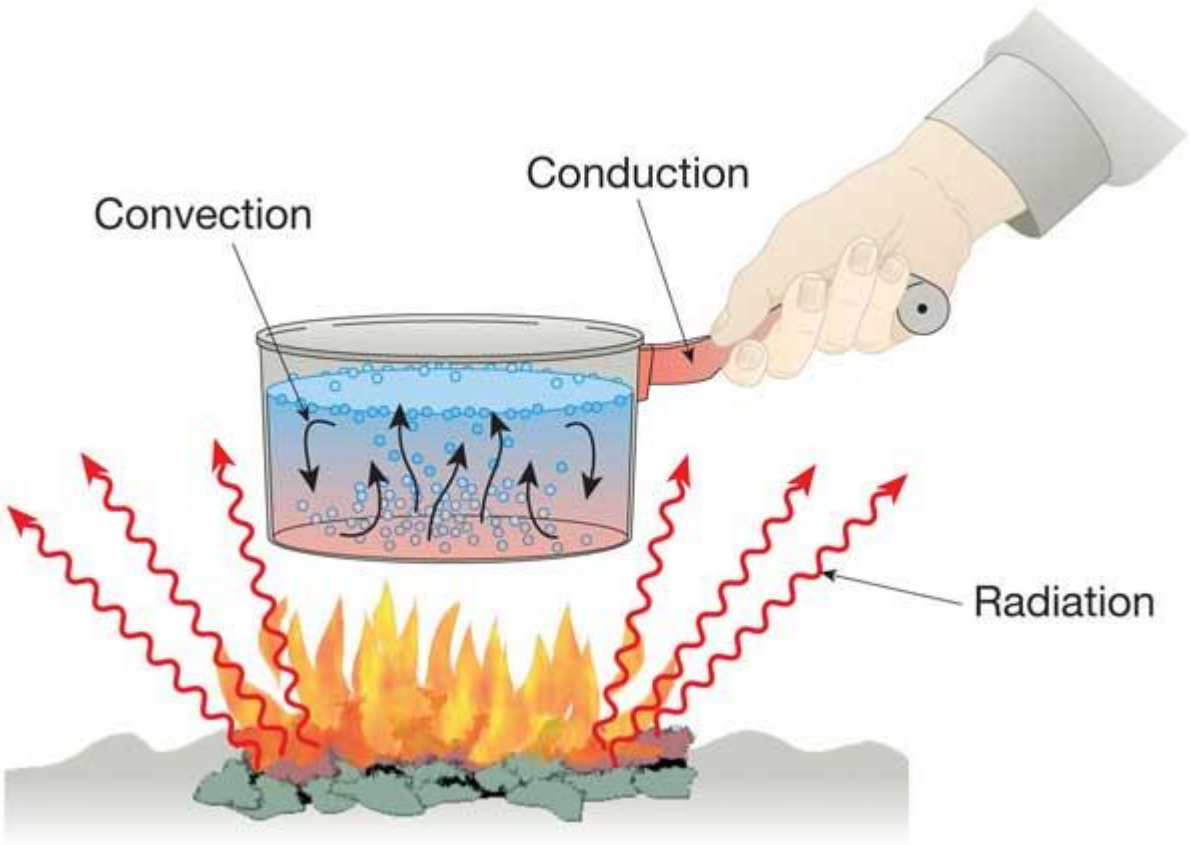


Figure 3. Methods of heat transfer
(https://www.stemlittleexplorers.com/hr/pokus-toplinske-kondukcije/)

Speed and time fire wave propagation

$$\bar{v}_{uk} = \frac{s_{uk}}{t_{uk}} \qquad t = (\bar{t} \pm \Delta t_{max})\ \mathrm{s}$$

- the propagation of the fire wave is not uniform
- determination of mean velocity
- [6] - the time required for the propagation of the fire wave is expressed and for matches without heads

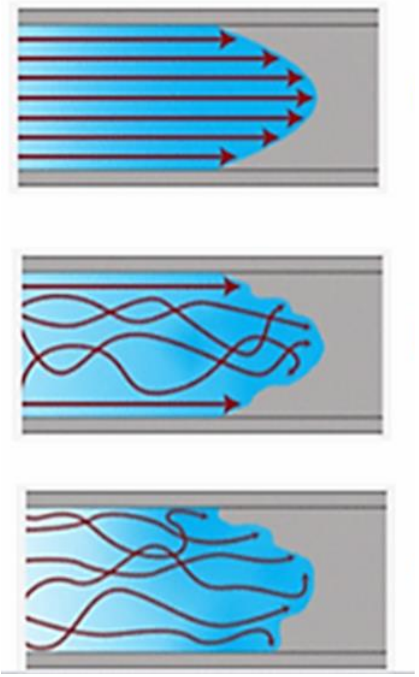


Figure 4. Types of fluid flow
(https://www.fkit.unizg.hr/_download/repository/III._predavanje_PKG_2.pdf)

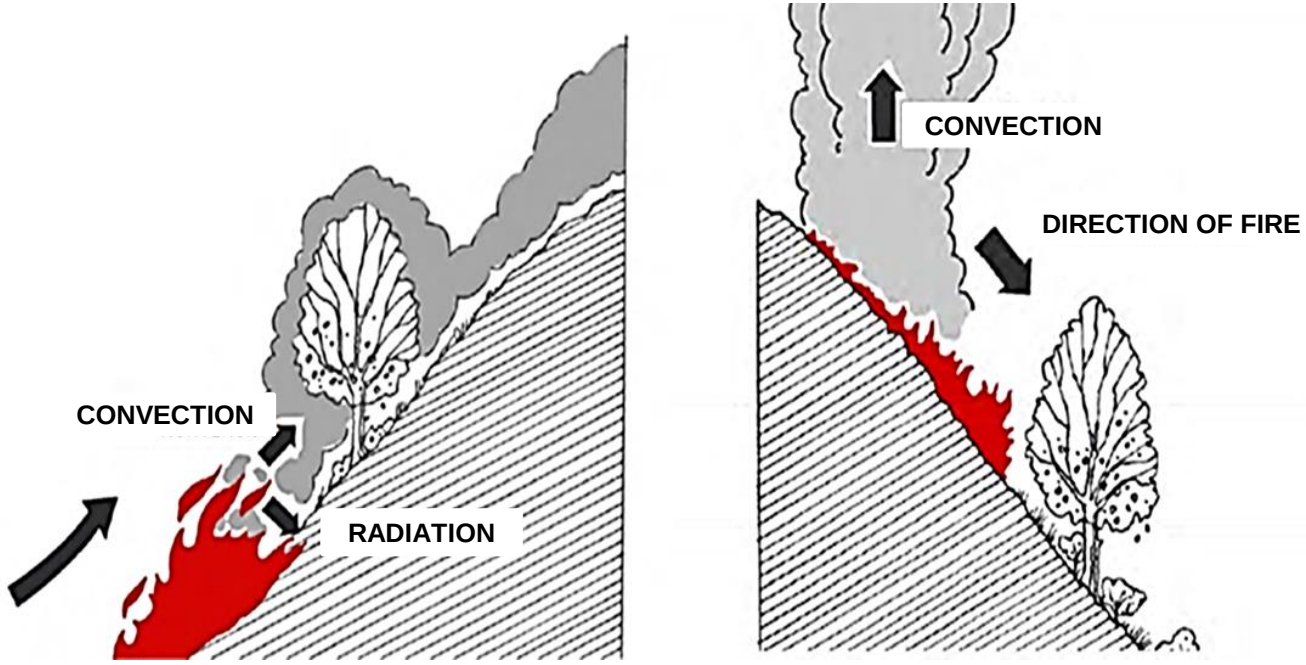
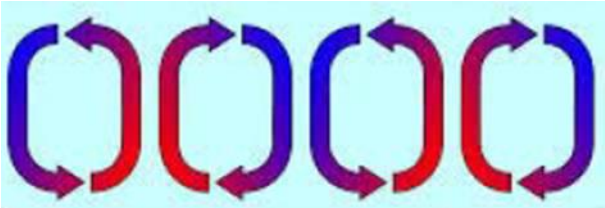


Figure 5. Fire behavior when fire spreads on slopes
(EuroFire, Obuka: Primijeniti tehnike i taktike kontrole požara vegetacije, EuroFire©İyil 2008.)

- the warmer fluid of lower density flows upwards
- the colder the fluid of higher density flows downward



= CIRCULATION

Measurement methods and experimental setup

- matches - 9.5 cm long and 3 mm wide
- metal tripod
- metal plates
- plasticine
- pliers
- adhesive crepe tape
- aluminum foil
- ruler, protractor
- paper boats
- *Canon* camera
- camera stand
- analytical balance

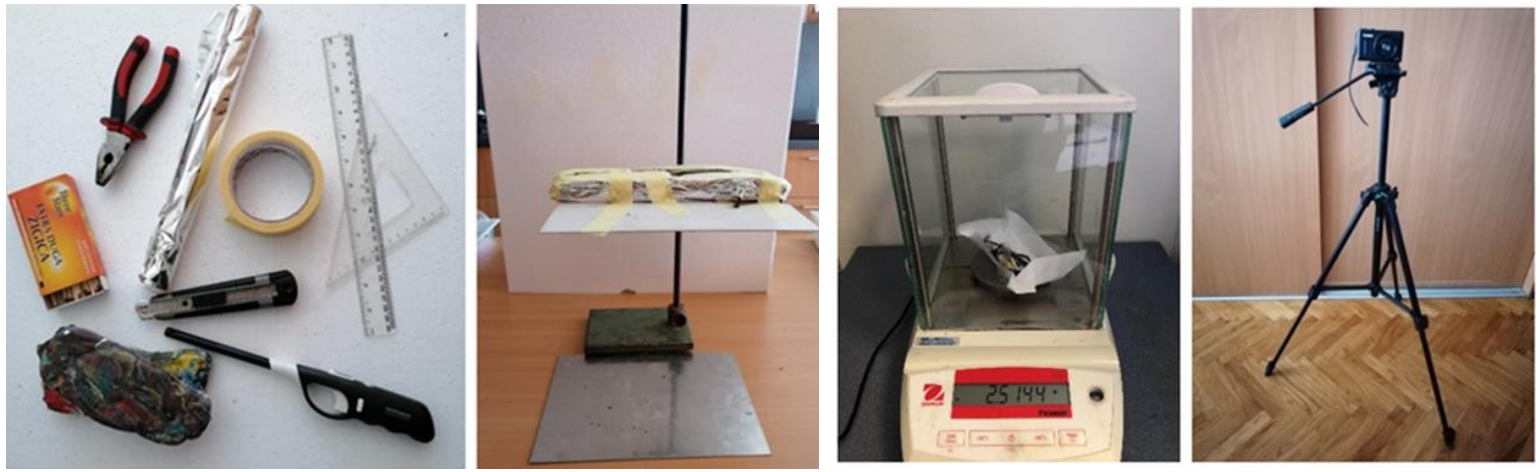
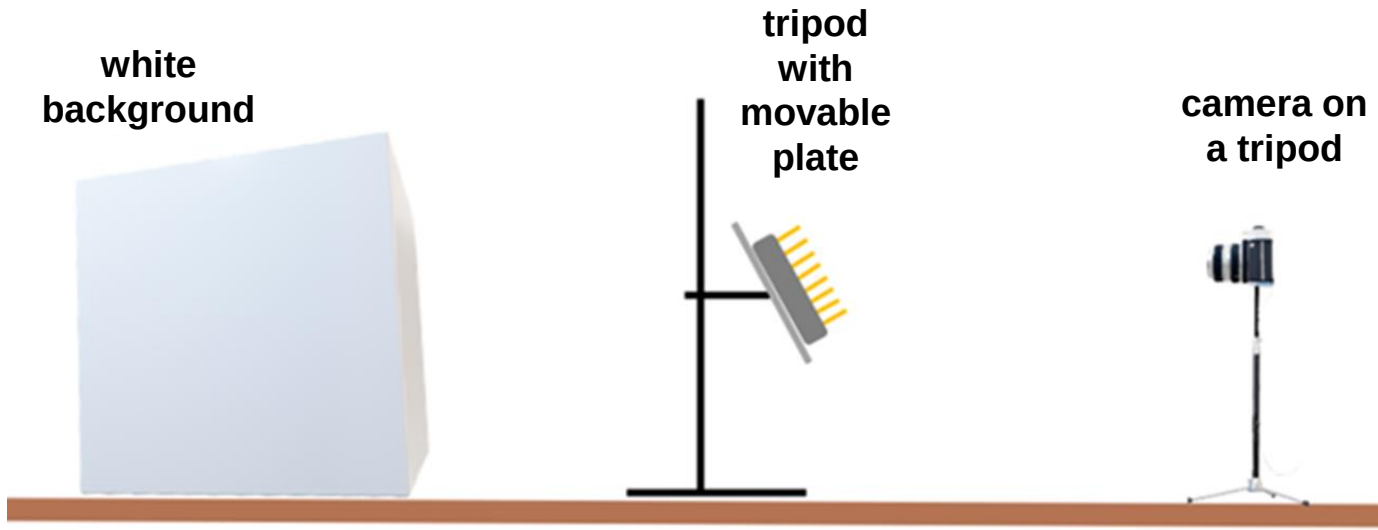


Figure 6. Accessories used to perform the experiment

EXPERIMENTAL SETUP:



Measurement data processing : *Tracker* i *Excel.*

Parameters:

t_1, t_2 = the **ignition** time of a series of matches

t_3, t_4 = the time of **complete combustion** of a series of matches

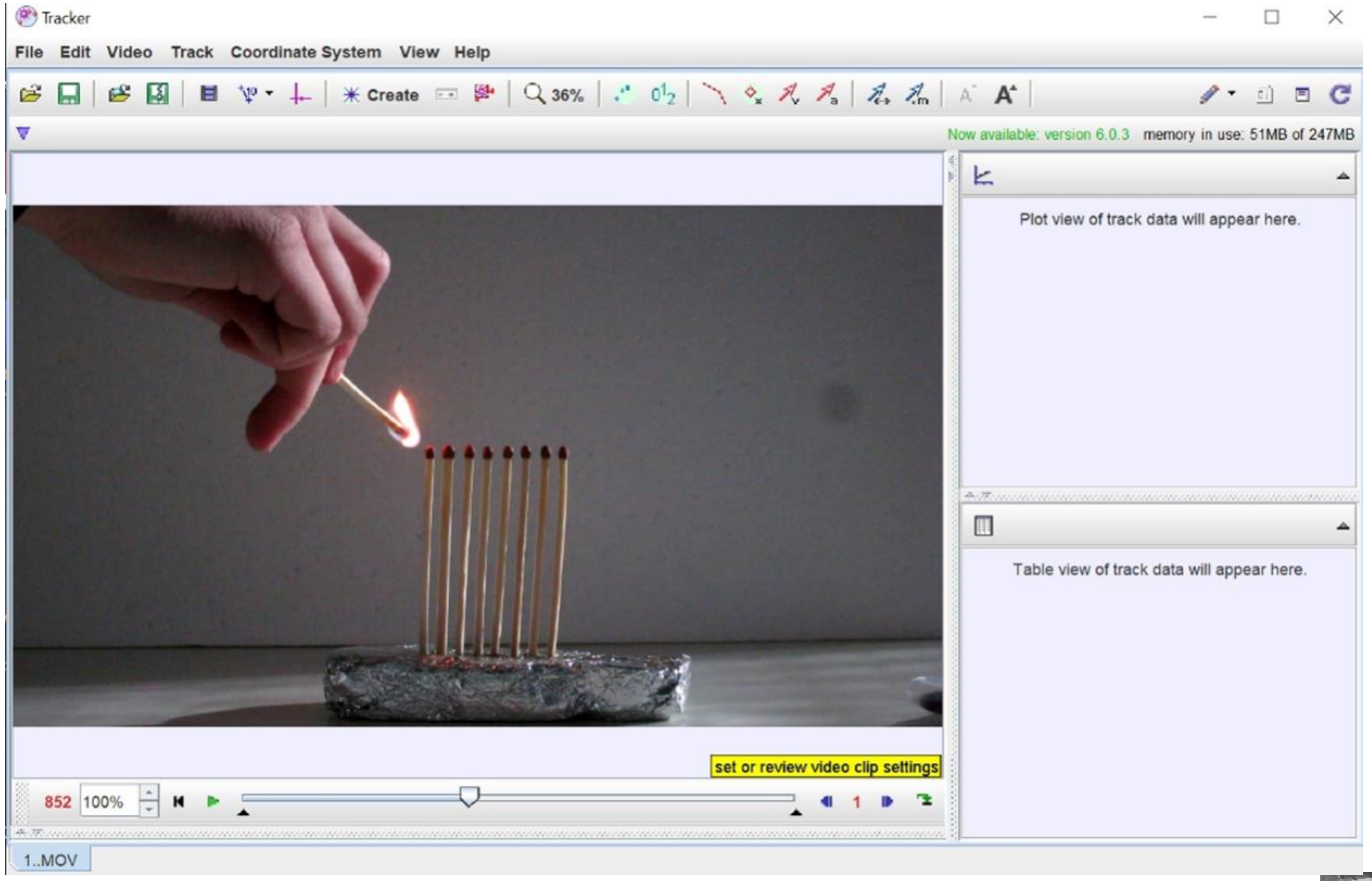
$\overline{v}$ = medium ignition velocity

d = the distance between the matches

α = the angle of inclination of the substrate

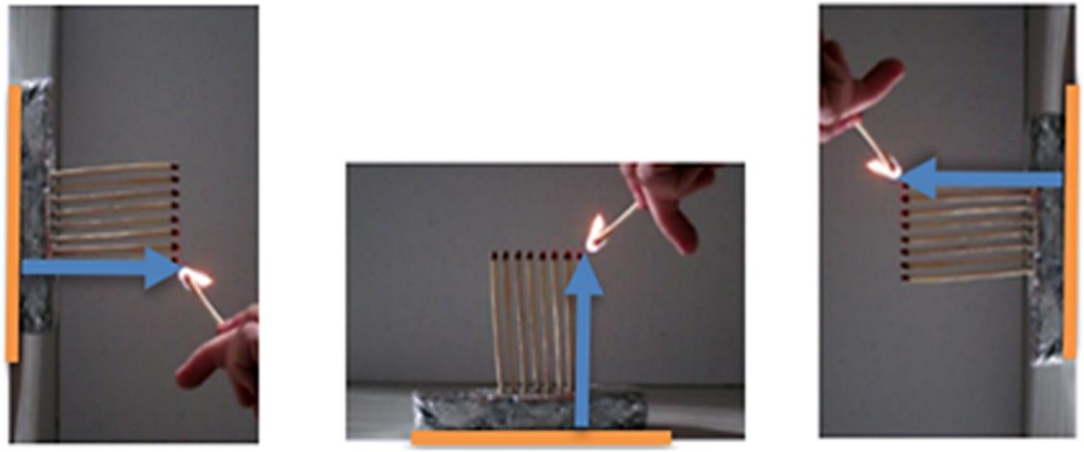
N = number of matches

✓ **Tracker:**



- approx. 50 videos
- moving frame by frame
- difficulties - the moment of ignition is very bright
- geometric characteristics of the flame

- **The time of propagation of the fire wave depending on the angle of inclination of the substrate on which the matches are**



α = 90°
first lower

α = 0°

α = -90°
first upper

- measurement for 30°, 45 ° and 60° angles

- **Time of propagation of the fire wave depending on the distance between the matches**

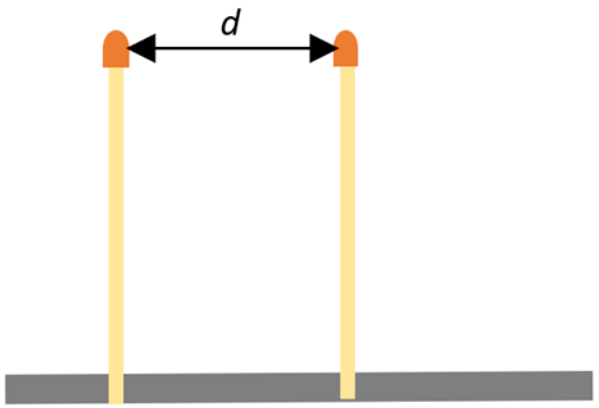


Figure 7. Method of measuring the distance between matches

- for distances d = 0 mm - 8 mm
- constant parameters: N = 8, $\alpha = \pm 90°$

- three measurements for each video
- error account performed

- Propagation of the fire wave in **several rows of matches**

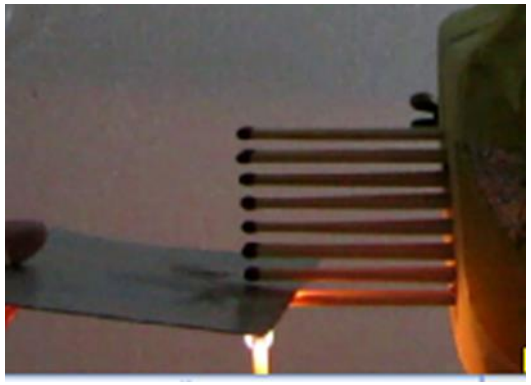


Figure 8. Setup for burning matches in several rows

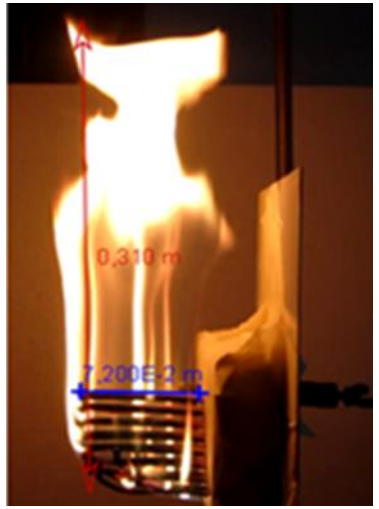


Figure 9. Determining the height of the fire wave

- **Determining the height of a fire wave in several rows of matches**
  - after the first 30s
  - for matches in 1st, 2nd and 3rd rows
  - 8, 16, 24 matches

- Head fire propagation for **headless matches** – ignition time

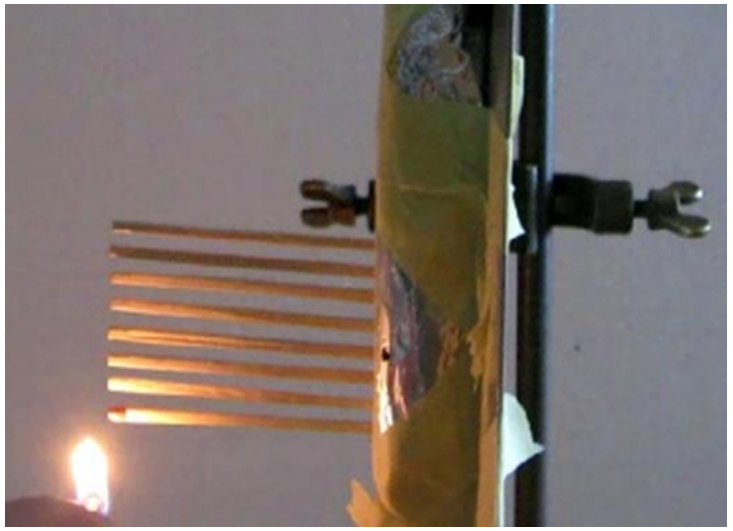


Figure 10. Match setting without head

CONDITIONS: N = 8, d = 3 mm, α = 90 °

Hypotheses

H1

- the **propagation time** of the fire wave will be **smaller** the **greater** the **angle** of inclination of the match surface - the largest for the vertical position (α = 90 ° - the **first** match is lit from the **bottom**)

H2

- the **greater** the **distance** between the matches the **ignition** time and the **burning** time in the series will be **less**; average ignition rates decrease with increasing spacing

H3

- matches arranged in several rows - **burning** time per match **decreases**
- more rows of matches - the **height** of the fire wave is **higher**, and the flow is more **turbulent**

H4

- **faster propagation** of the fire wave when all matches **have a flammable head** compared to a series in which only the first match has a flammable head

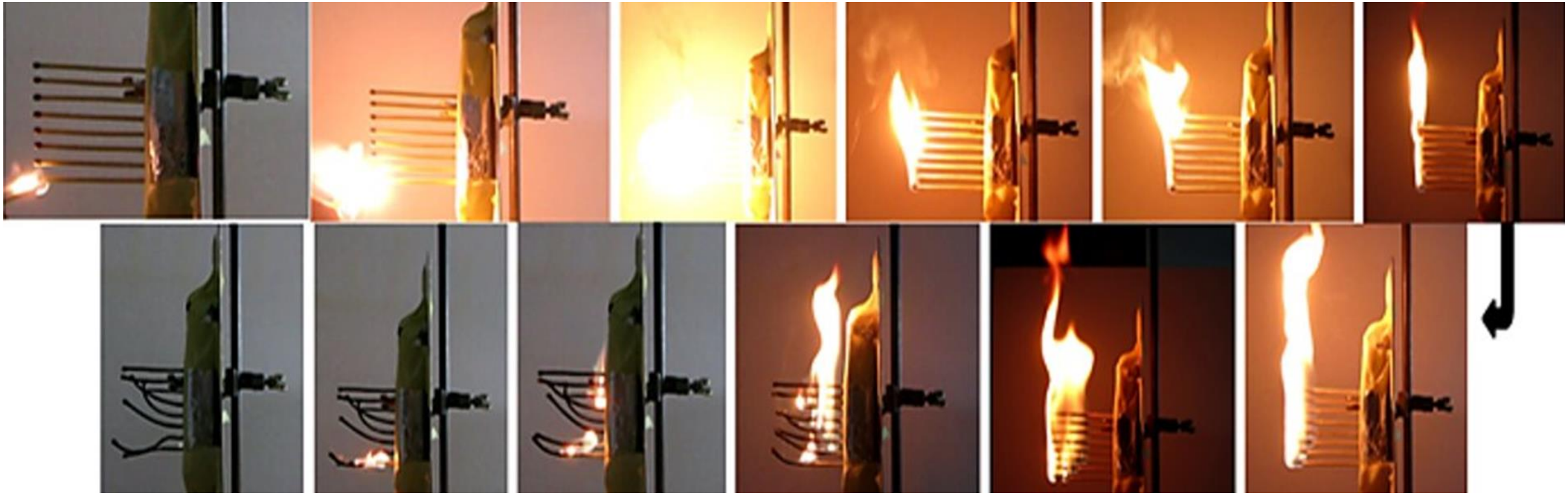
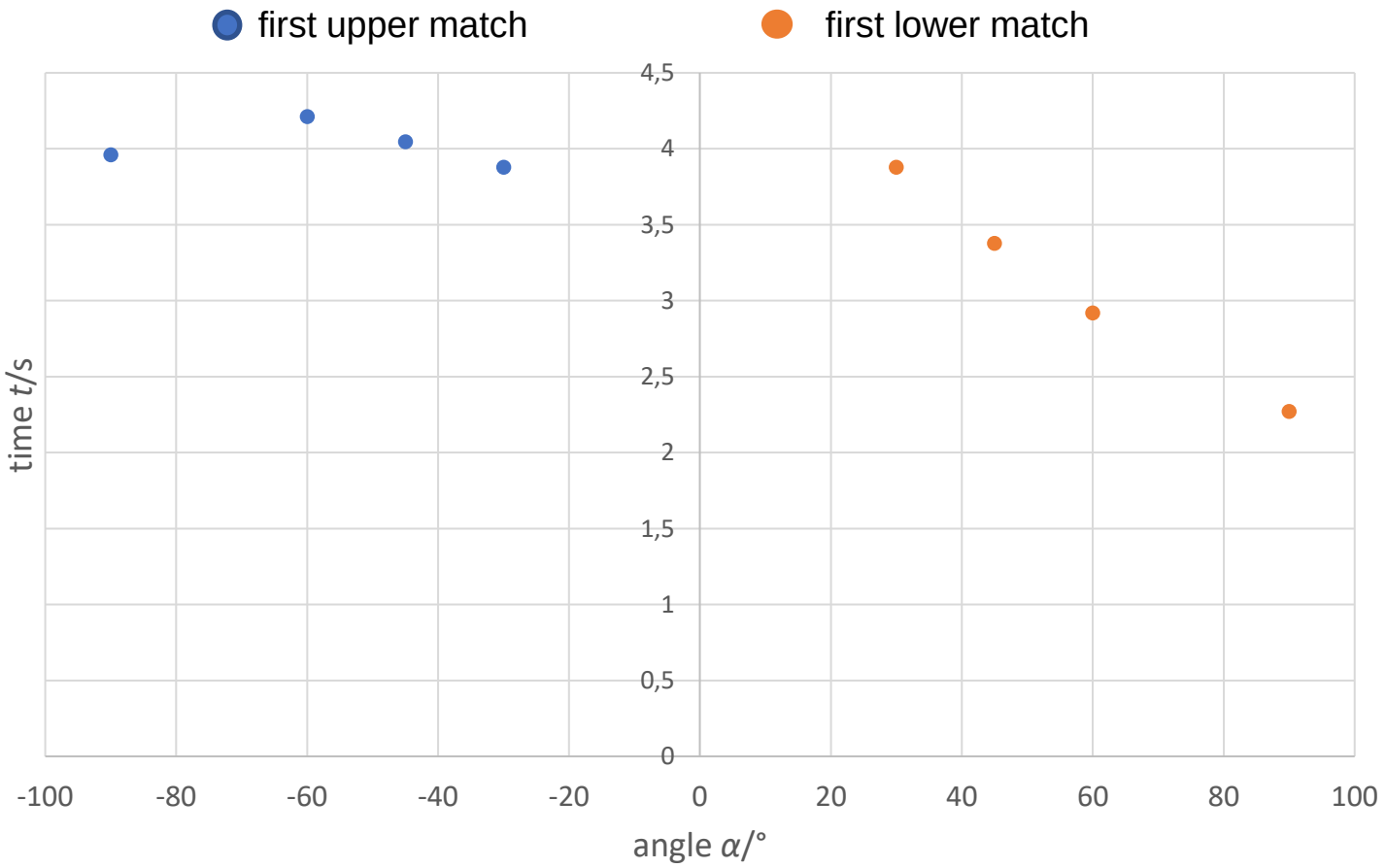
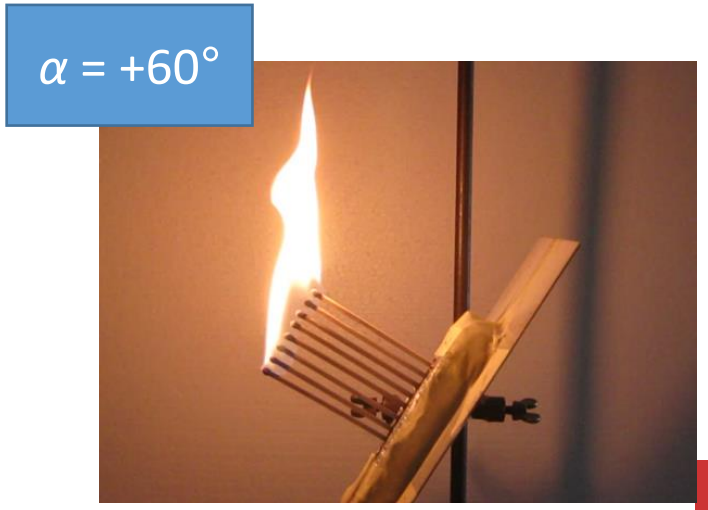


Figure 11. Match burning process, d = 6 mm, N = 8, α = 90 ° (vertical, first match down)

H1: The **propagation time** of the fire wave will be **smaller** the **greater** the **angle** of inclination of the match surface - the largest for the vertical position (α = 90 ° - the **first** match is lit from the **bottom**).



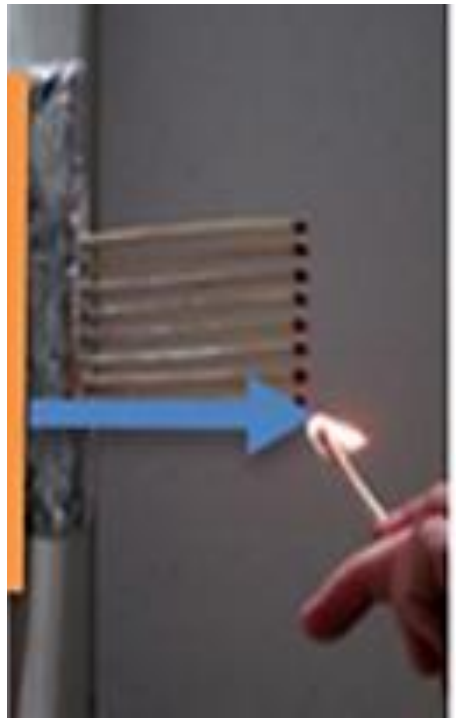
Graph 1. Comparison of the ignition timing of a series of matches in the vertical position with the ignition of the first lower or first upper match (N = 8, d = 3 mm) depending on the angle of inclination



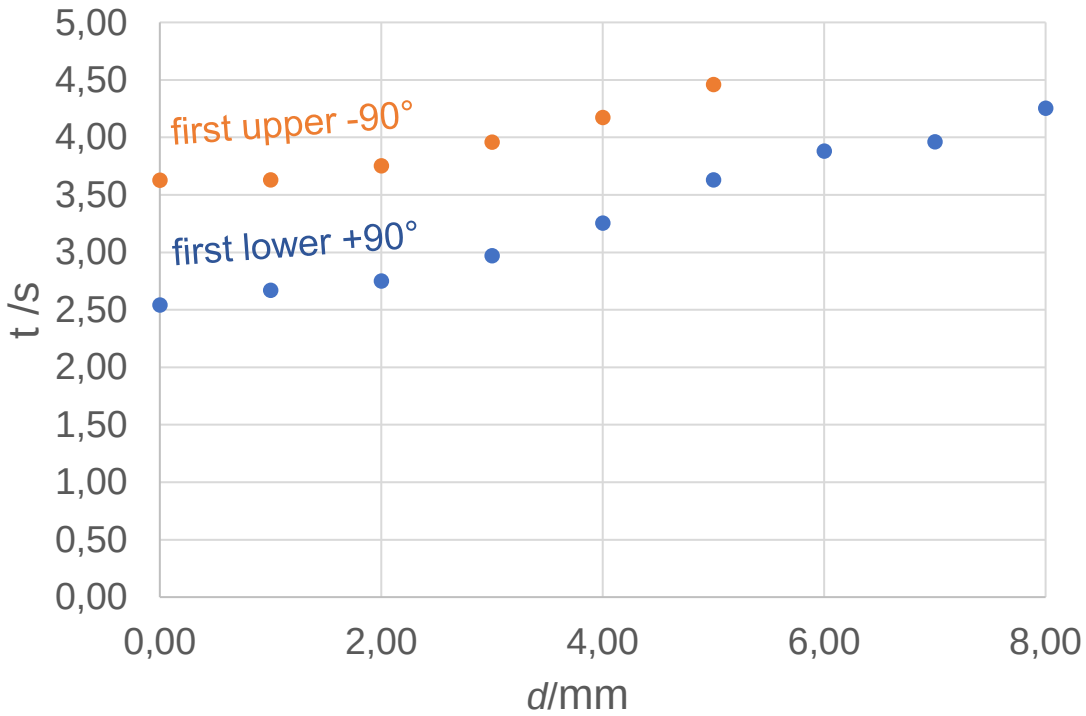
H1: The **propagation time** of the fire wave will be **smaller** the **greater** the **angle** of inclination of the match surface - the largest for the vertical position (α = 90 ° - the **first** match is lit from the **bottom**).

Table 1. Results of measuring the ignition time of all matches in a row in vertical and horizontal position for *d* = 3mm, *N* = 8

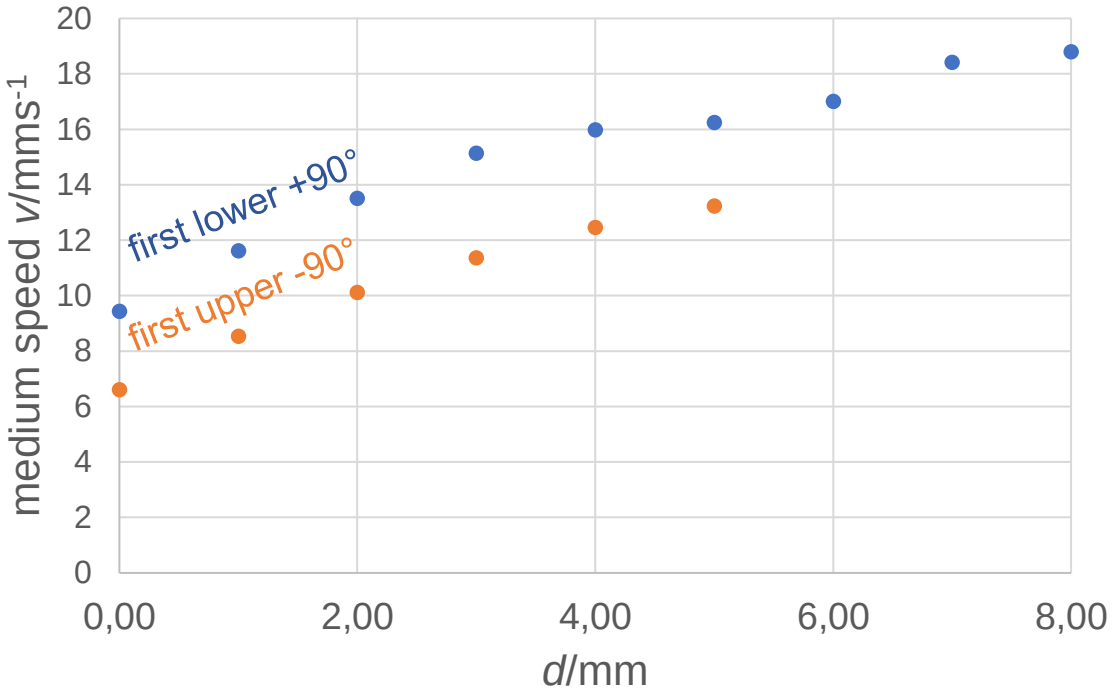
Match plate position	α / °	$t = (\overline{t} \pm \Delta t_{max})$/s
horizontal	0	4,157 ± 0,006
vertical – first upper	- 90	3,959 ± 0,003
vertical – first lower	+ 90	2,971 ± 0,008



H2: The **greater** the **distance** between the matches the **ignition** time and the **burning** time in the series will be **less**; average ignition rates decrease with increasing spacing.



Graph 2. Comparison of ignition times in series depending on the distance between matches (N = 8, α = ± 90 °)



Graph 3. Comparison of mean ignition rate in series depending on the distance between matches (N = 8, α = ±90 °)

- the fire wave no longer propagates in a vertical sequence
  - ➢ to light the upper match at a distance of 7 mm
  - ➢ to light the lower match at a distance of 8 cm

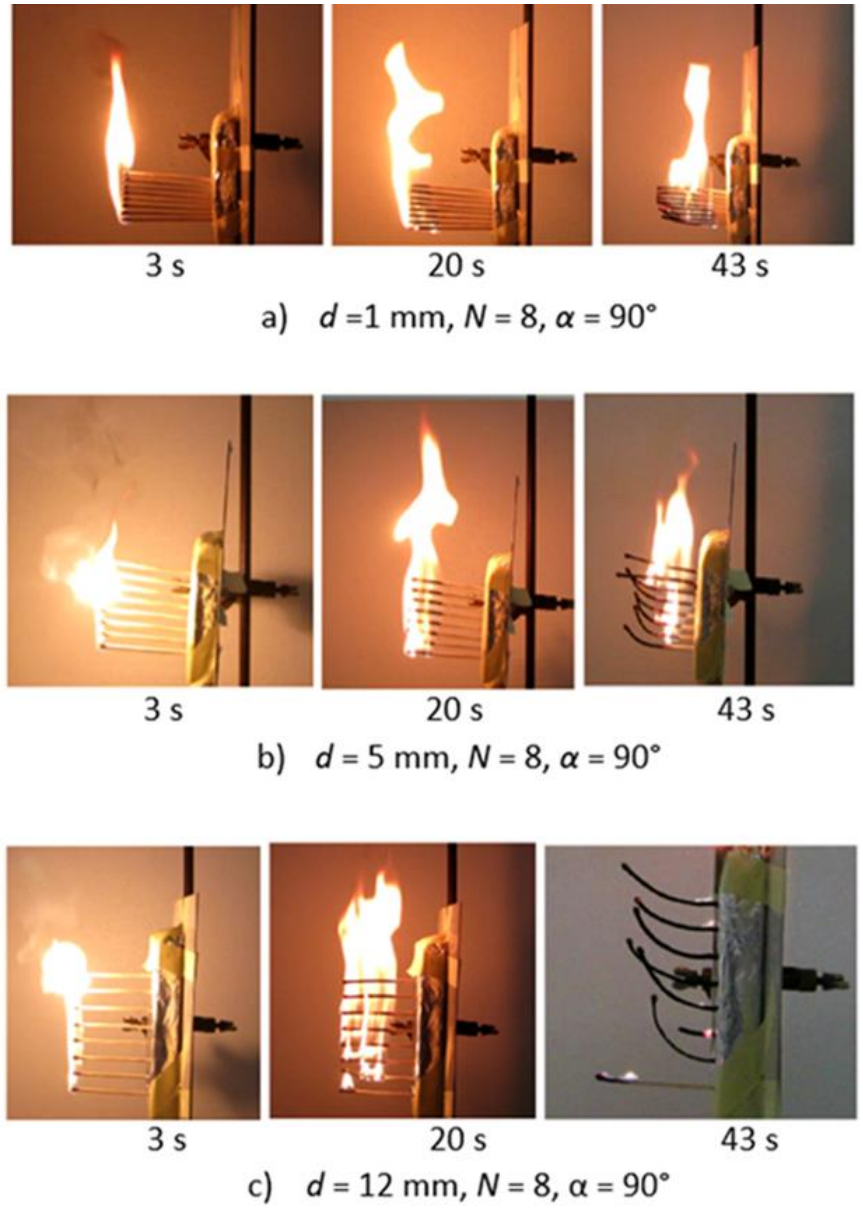
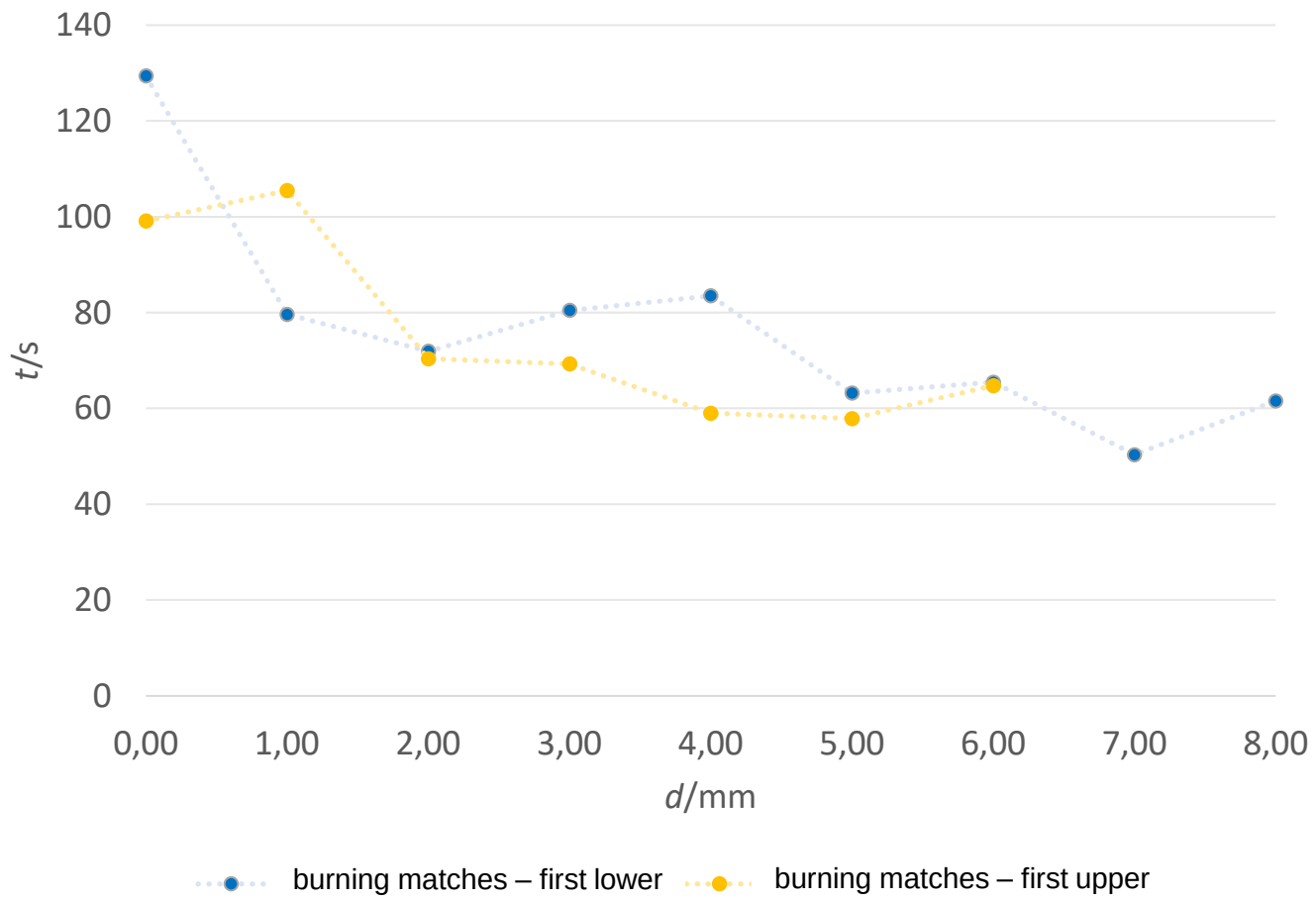


Figure 12. Comparison of burning matches in the same time interval for different distances *d*

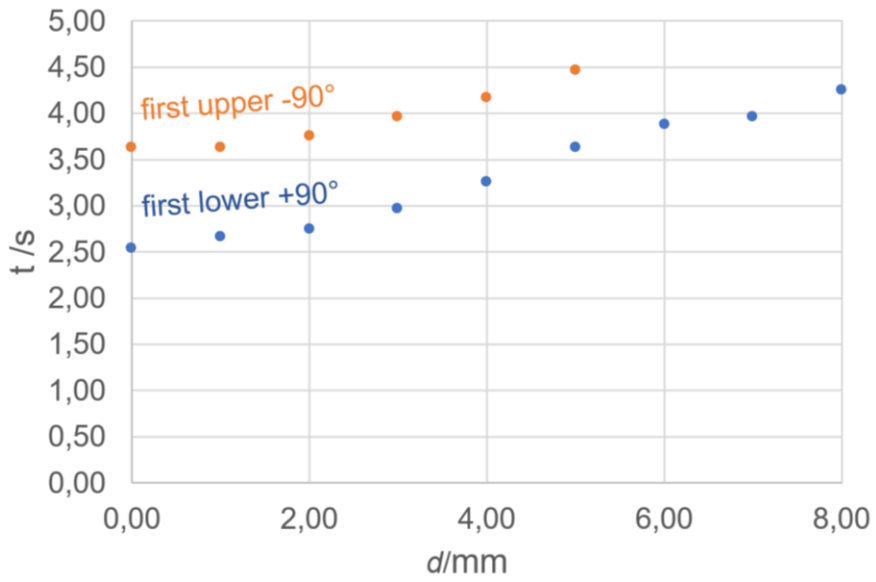
H2: The **greater** the **distance** between the matches the **ignition** time and the **burning** time in the series will be **less**; average ignition rates decrease with increasing spacing.



Graph 4. Comparison of combustion of all matches in a row depending on the distance between matches (N = 8, α = ±90 °)

- poor heat convection and weaker oxygen supply

Compare with:



- ignite faster due to heading

H3: Matches arranged in several rows - **burning** time per match **decreases,** more rows of matches - the **height** of the fire wave is **higher**, and the flow is more **turbulent.**

Table 2. Comparison of match burning(combustion) time in several rows, *N* = 8, *α* = 90 °, distance *d* = 3 mm between matches in a row and between rows

number of rows of matches	total number of matches	$(\bar{t} \pm \Delta t_{max})/s$	burning time *t* of all matches/*s*	average burning time of 1 match /*s*
1	8	2,669 ± 0,002	71,863	8,983
2	16	2,127 ± 0,001	76,952	4,8095
3	24	3,337 ± 0,001	70,571	2,940

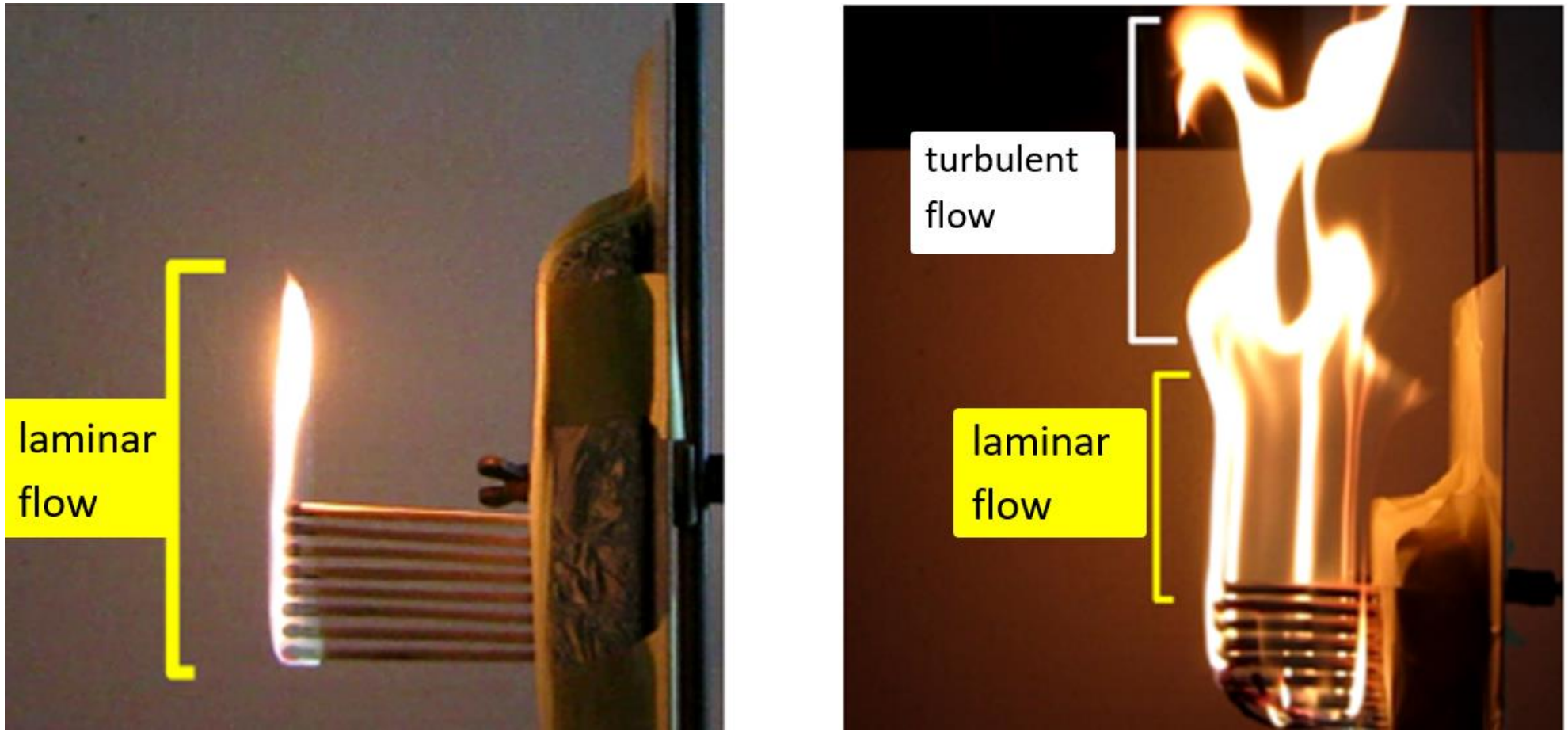
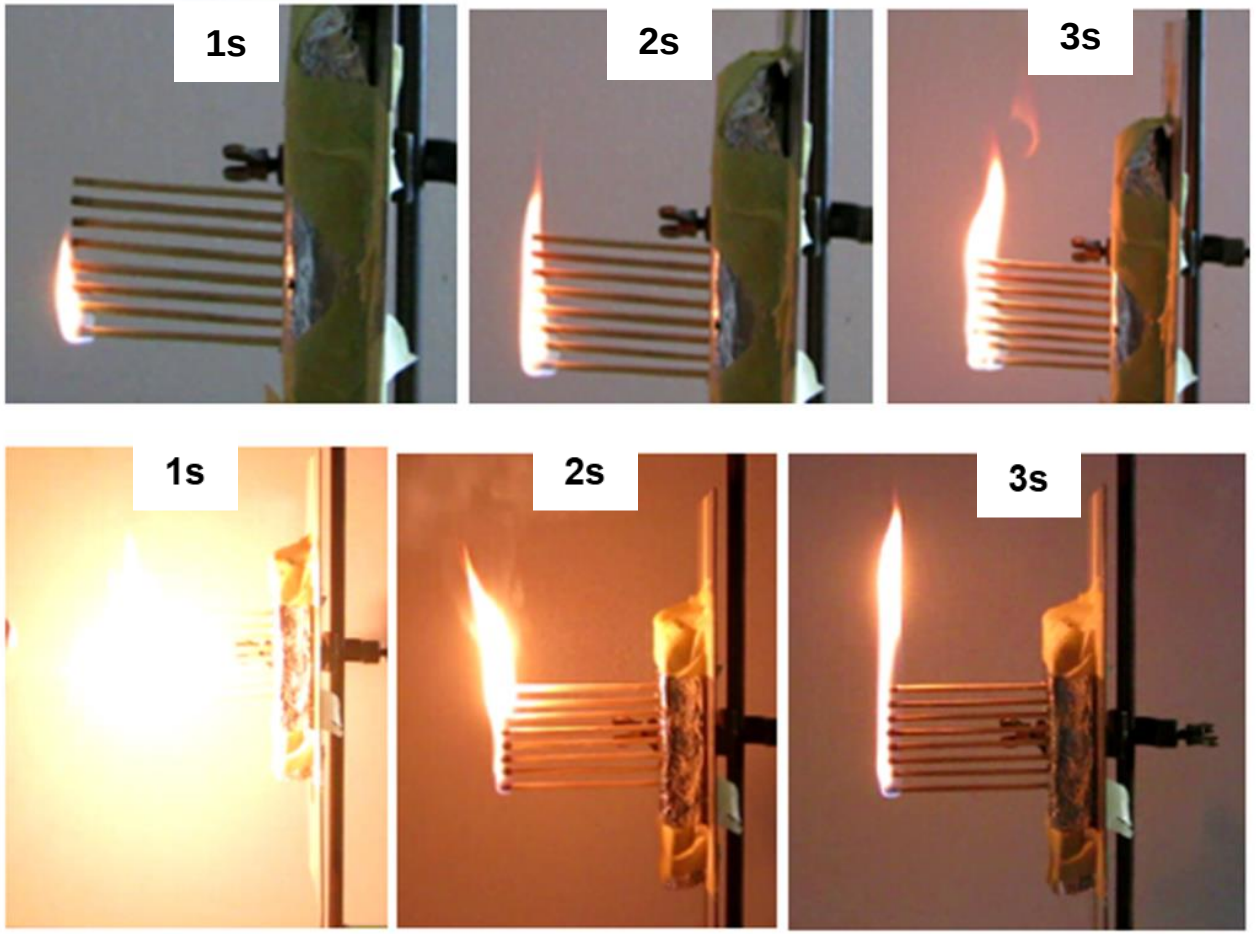


Figure 14. Types of flow in flames (N = 8, α = 90 °, d = 1 mm and N = 8, α = 90 °, d = 3 mm)

H3: Matches arranged in several rows - **burning** time per match **decreases,** more rows of matches - the **height** of the fire wave is **higher**, and the flow is more **turbulent.**

H4: Faster propagation of the fire wave when all matches **have a flammable head** compared to a series in which only the first match has a flammable head.

- comparison of images in the same time interval from the beginning of ignition;



matches without flammable heads (except the first lower)

- greater ignition time
- less combustion time

matches with flammable heads

Figure 15. Propagation of the fire wave when there matches without heads and when they have flammable heads (N = 8, d = 3 mm, α = 90 °)

Conclusions

H1: the ignition time of all matches is the **shortest** for the vertical position substrates - the **lower** one burns first

H3: more rows of matches - **faster** process, flame **higher** and **turbulent**

H2: **ignition** process faster for **smaller** distances, the process of **burning** all matches faster for **longer** distances

H4: matches without a head - the **longer** the **ignition** time, the **shorter** they **burn**

Literature

[1] EuroFire, Obuka: Primijeniti tehnike i taktike kontrole požara vegetacije, EuroFire©İyil 2008.

[2] Procesi prijenosa i separacija , Sveučilište u Zagrebu, Fakultet kemijskog inženjerstva i tehnologija, 5.3.2020. , Zagreb, https://www.fkit.unizg.hr/_download/repository/III._predavanje_PKG_2.pdf

[3] How do matches work?, Reactions, 2016., https://youtu.be/y2ErAPODA6U

[4] White Gormandy Mary, Examples of Convection, Yourdictionary, https://examples.yourdictionary.com/examples-of-convection.html

[5] Ao Irene, Hanania Jordan, Heffernan Braden, Jenden James, Lloyd Ellen, Strange Maddy, Toor Jasdeep, Wiebe Dayna, Donev Jason, Energy education, Convection, 2021. , https://energyeducation.ca/encyclopedia/Convection

[6] Gollner, Nakamura, Rangwala, Burning Behavior of Vertical Matchstick Arrays, Combustion Science and Technology, 2012.

[7] Gollner, Michael J., Studies on upward flame spread, 2012., https://escholarship.org/uc/item/4f41b6xr

Thank you!

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