20th International Water Mist Conference (IWMC)

Experimental Study on Gases Produced from Polymers Burning with Water Mist

- Influence of droplet size of spray -

N. Thinnakornsutibutr, M. Mizuno

Tokyo University of Science

Graduate School of Science and Technology

27th – 28th October 2021

Warsaw, Poland

Outline

I. Introduction

- Background
- Purpose of this study

II. Test methods

- Water mist characteristics
- Test apparatus set-up

III. Results and Discussion

- Extinguishment of natural polymer
- Extinguishment of thermoplastic polymer
- Toxic gases production

IV. Summary

Background

- **Water mist fire suppression system (WMFSS)** is an alternative instead of bubble, inert gas and halon extinguishing system

- In Japan, water spray fire extinguishing system has been a subjected of many applications such as
  - **Road tunnels**
  - **Parking lots**

Background

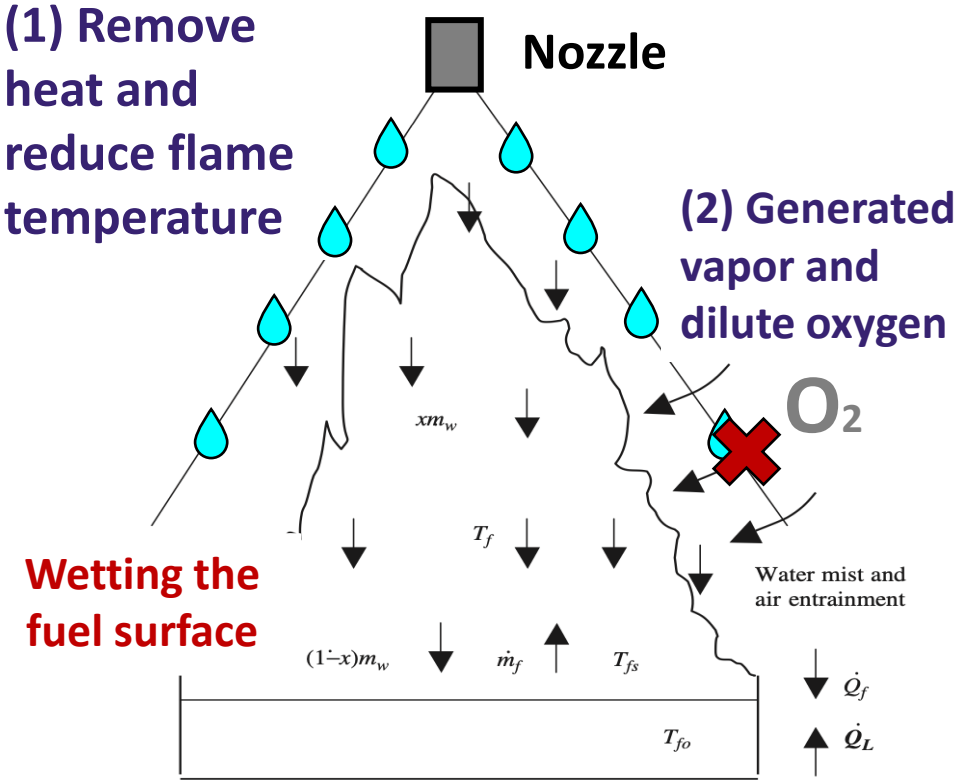


Fig. 2 *Water mist suppression mechanism*

- According to NFPA, water mist defines as 99% of the discharged water droplets are **smaller than 1000 µm**
- Mechanism: (1) **cooling effect** and (2) **oxygen diluted** by evaporation of water mist

Background

➢Advantages

- Fire extinguishment with **less facility damage**
- Rapid suffocation when water mists vaporized
- **Environmental friendly** because of water used as an extinguishing agent
- Less amount of water for fire suppression

➢Problems

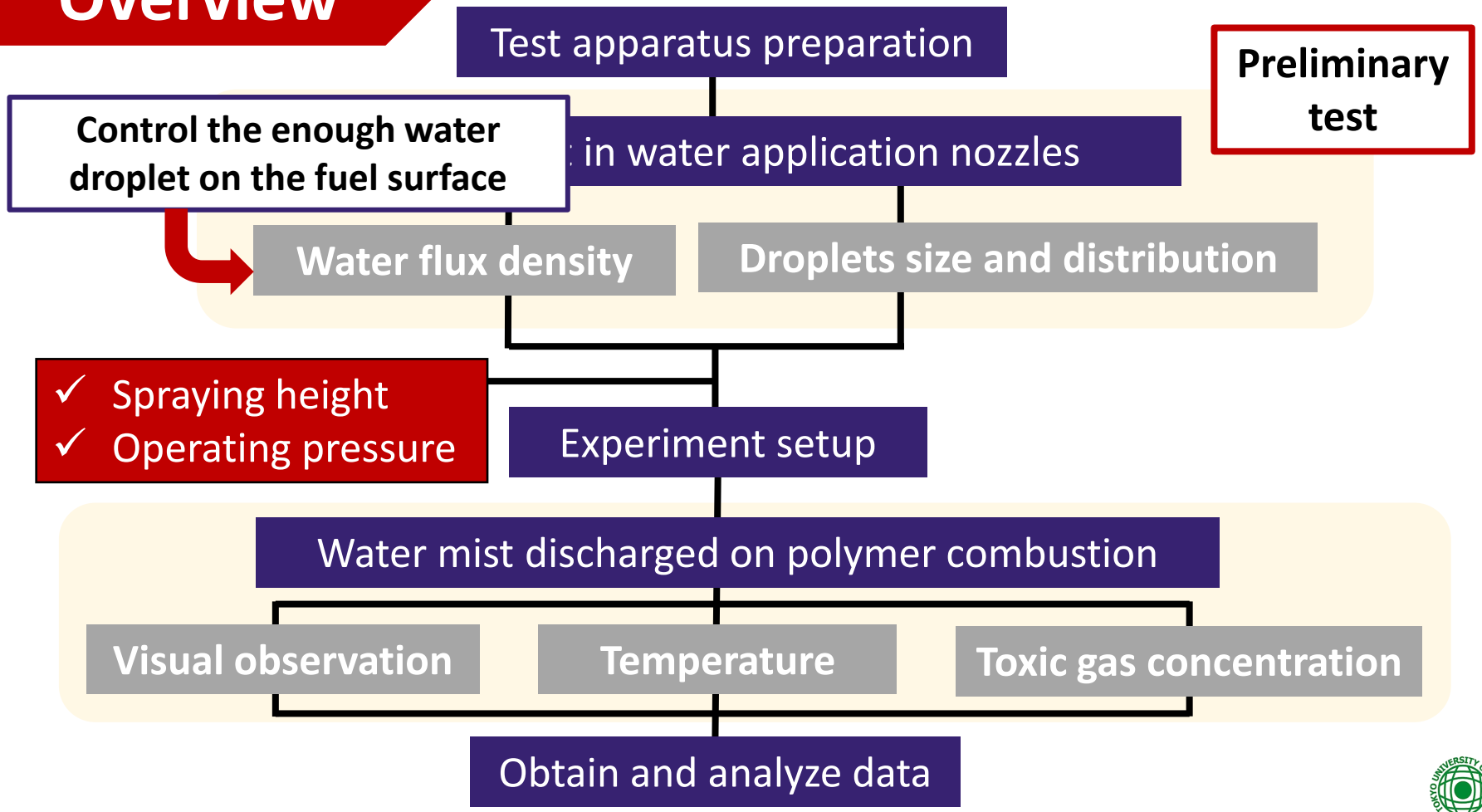
- **The possibility of toxic and irritant gases** will be produced during water mist discharge

Purpose of this study

To study on the combustion produced gases from burning polymers with water mist discharge for fire extinguishment

- There were three types of polymeric materials to be analyzed: **wood cribs**, **polyethylene** and **polypropylene**.
- The **two types of water spray nozzles**, which can simulate water mist droplets, were adapted to analyze toxic gases by spraying different size distribution of water droplet.

Overview


Test apparatus preparation
Preliminary test
Control the enough water droplet on the fuel surface
in water application nozzles
Water flux density
Droplets size and distribution
✓ Spraying height
✓ Operating pressure
Experiment setup
Water mist discharged on polymer combustion
Visual observation
Temperature
Toxic gas concentration
Obtain and analyze data

Water mist characteristics

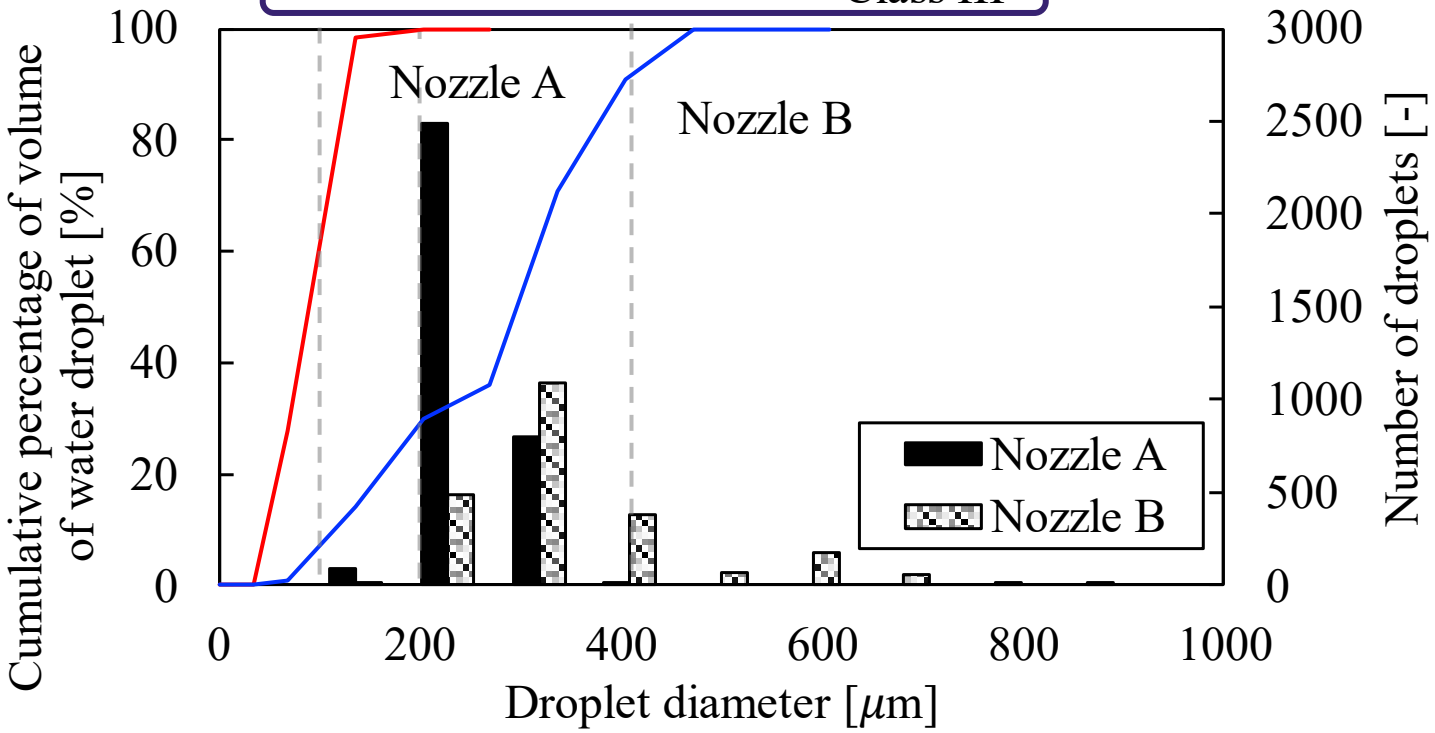
Ikeuchi company

- **Nozzle A "7KB" characteristics**
  - Operating pressure : 1.0 MPa
  - Spraying height : 20.0 cm
  - Water flux density : 1.625 L/m^{2}min
  - Mean droplet diameter : **106.2 µm**

- **Nozzle B "J" characteristics**
  - Operating pressure : 1.0 MPa
  - Spraying height : 25.0 cm
  - Water flux density : 1.619 L/m^{2}min
  - Mean droplet diameter : **262.7 µm**

Water mist characteristics

According to **NFPA 750**…



Test apparatus setup

- **Test chamber**
  - 0.7 x 0.7 x 0.9 m^3
  - Stainless-steel
- **Openings**
  - Top
  - Bottom
- **Low pressure** water mist system

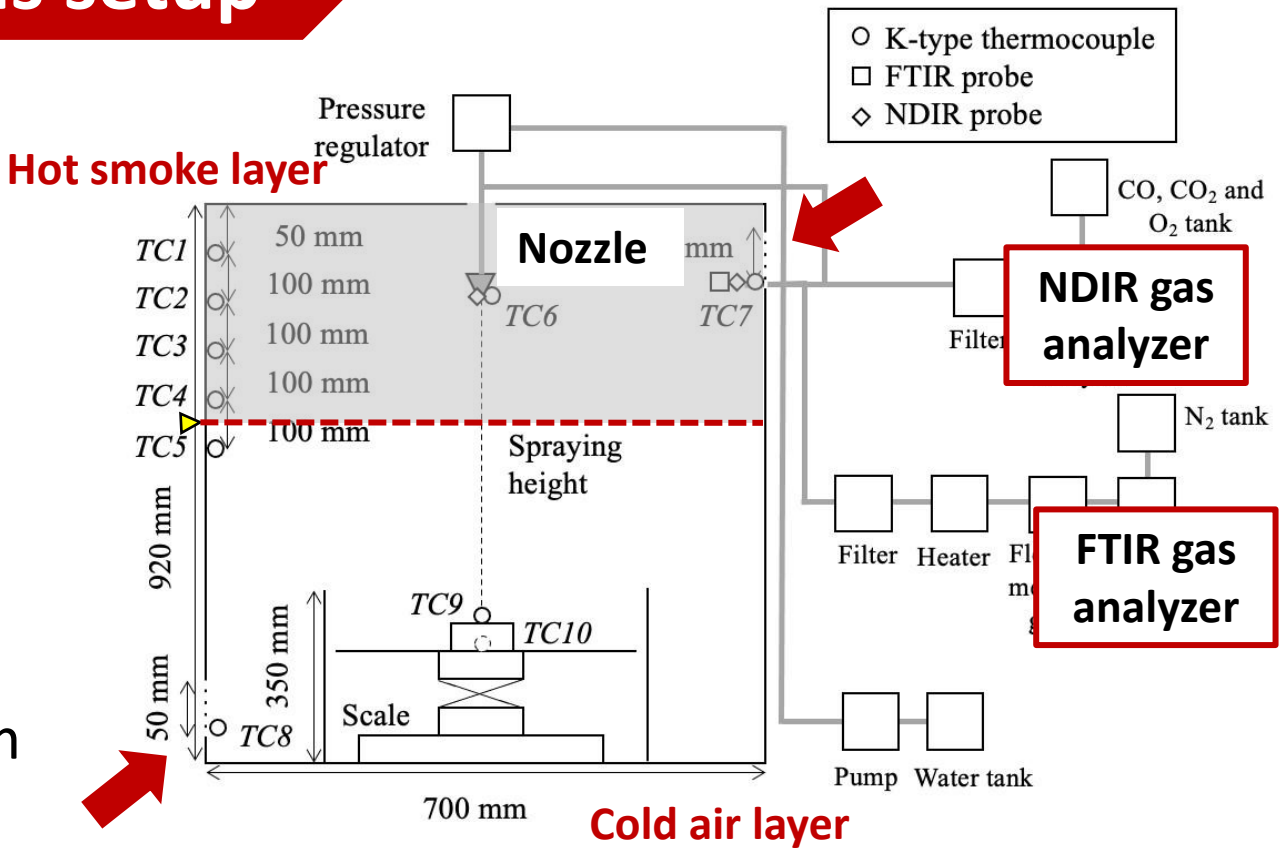


Fig. 3 *Schematic diagram of test apparatus setup*

Test sample

Test methods

The test sample was ignited on flammable gel. Water mist was discharged at a certain time when the combustion of polymers was sustained at approximately 2.0-8.0 kW.

Polymer types	Test sample
Natural	**Timbers**
Synthetic	Polyethylene (**PE**)
	Polypropylene (**PP**)

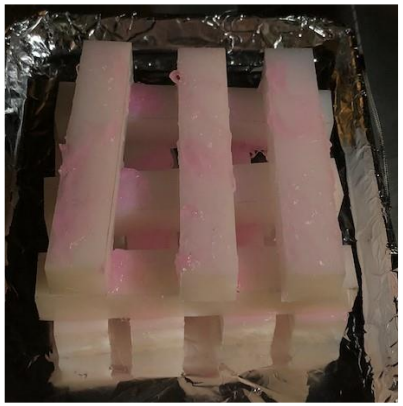


Fig. 4 Test sample configuration

Extinguishment of natural polymer

Nozzle A
- Wood cribs
- Extinguished


60 s


102 s


240 s


293 s

Nozzle B
- Wood cribs
- Extinguished


60 s


93 s


100 s

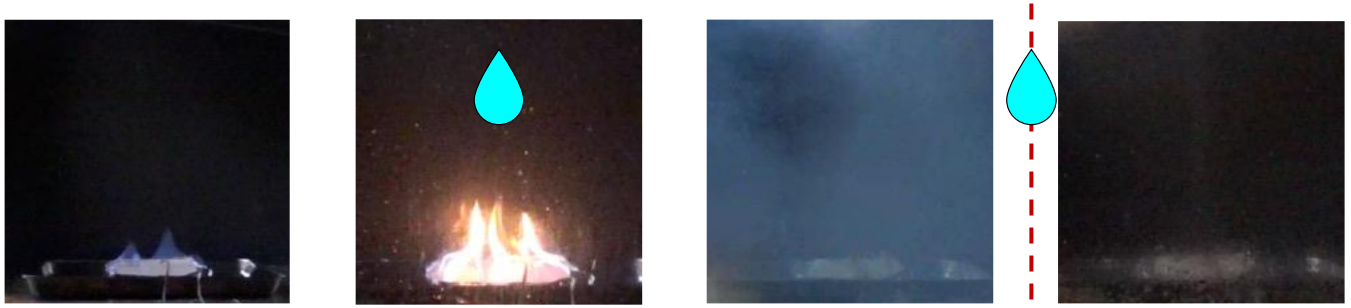

111 s

Water mist activation

Completely extinguished

Extinguishment of thermoplastic polymer

Nozzle A
- PP
- Extinguished



60 s | 300 s | 326 s | 358 s

Nozzle B
- PP
- Extinguished

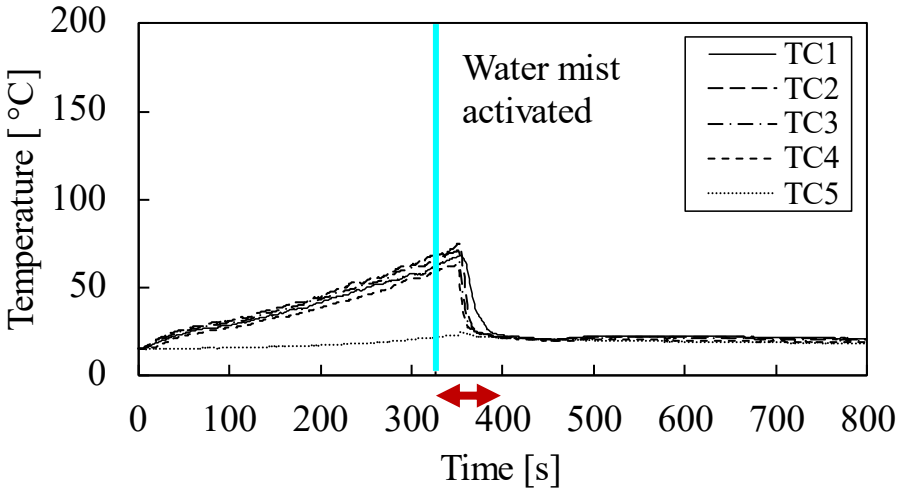
60 s | 297 s | 300 s | 303 s

Water spray activation Completely extinguished

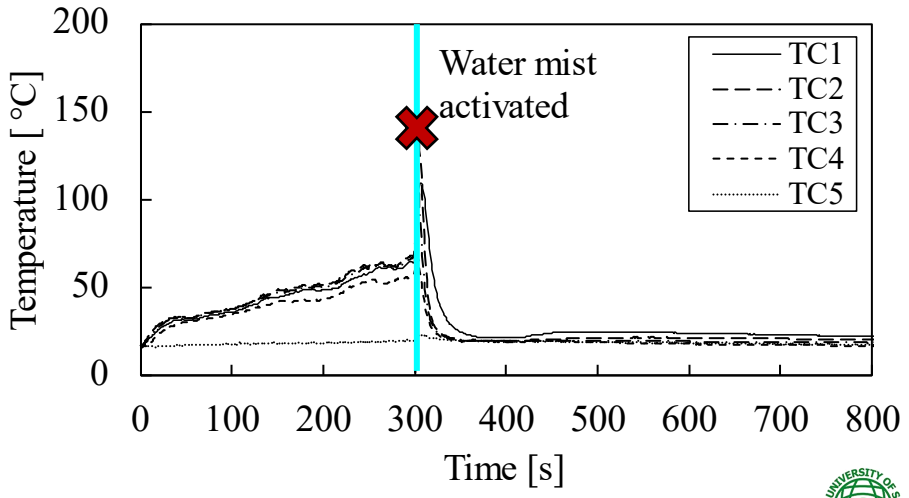
Temperature

- Test sample: **PP burning** with water mist activation
- **Nozzle A: 20 cm** and **Nozzle B: 25 cm** below the ceiling
- Measured by **thermocouple** (5 positions)

Nozzle A

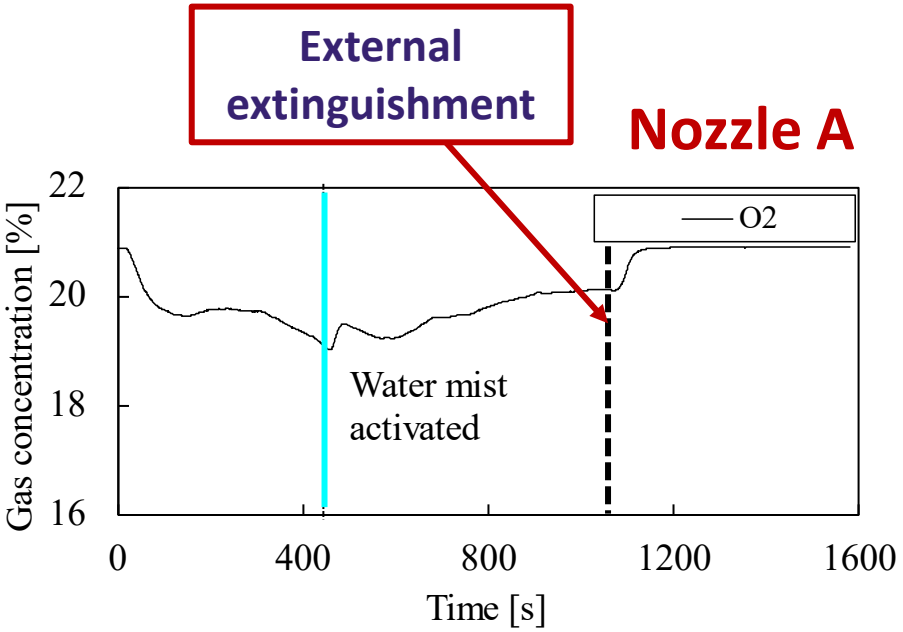


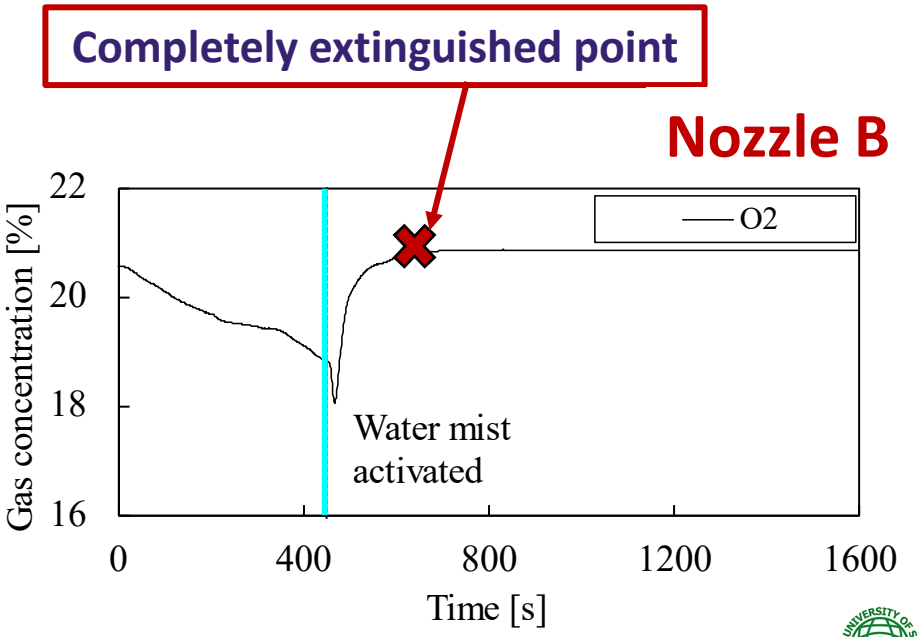
Nozzle B



Oxygen concentrations

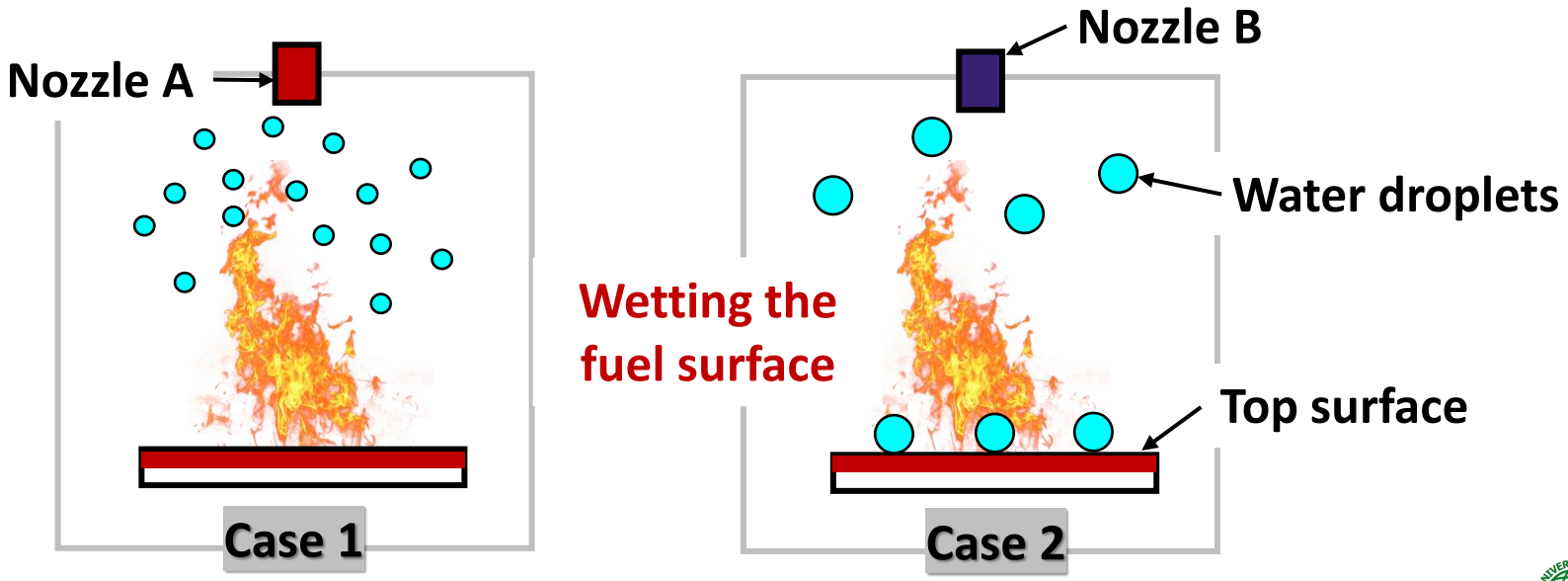
- Test sample: **PE burning** with water mist activation
- **Nozzle A: 20 cm** and **Nozzle B: 25 cm** below the ceiling
- Measured by **magnetic oxygen analyzer**





Discussions

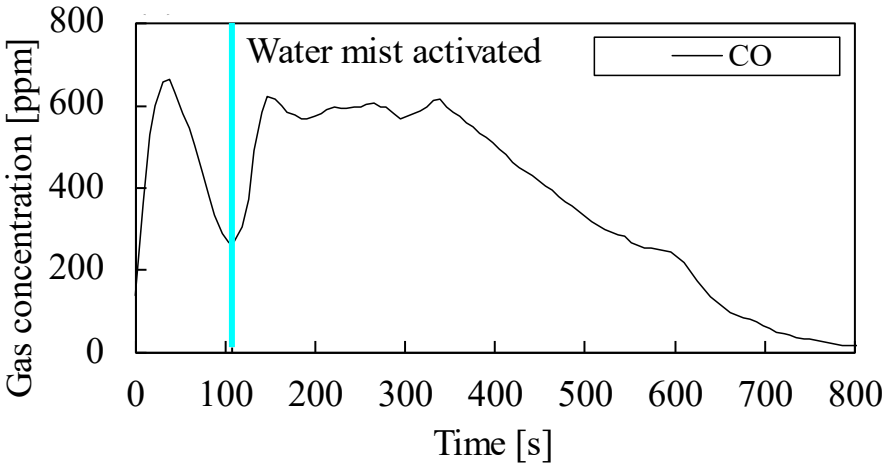
- The flame of burning polymers could be **controlled** or/and **extinguished** depending upon the size of water mist droplets.



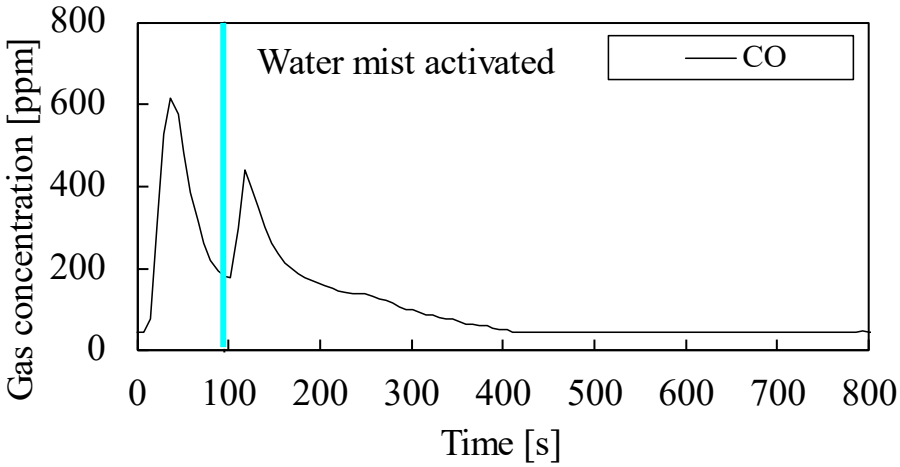
Toxic gas concentrations

- Test sample: **wood cribs burning** with water mist activation
- **Nozzle A: 20 cm** and **Nozzle B: 25 cm** below the ceiling
- Measured by **NDIR gas analyzer**

Nozzle A



Nozzle B

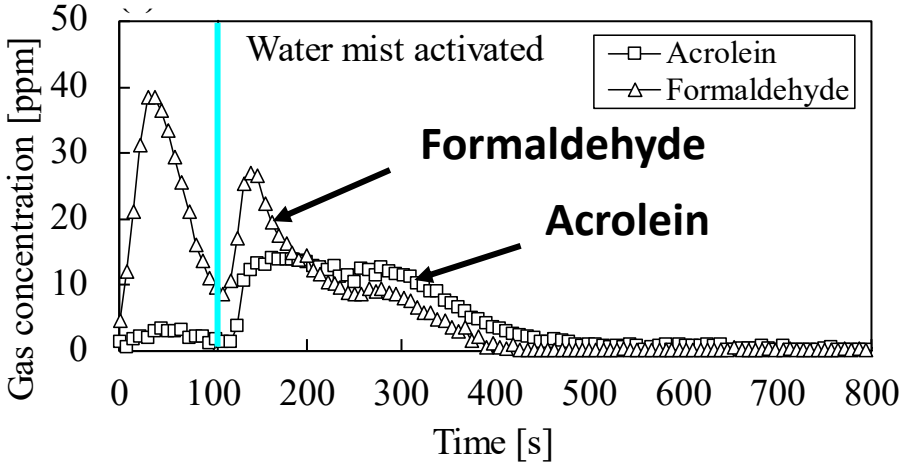


CO: highly toxicity asphyxiant gas

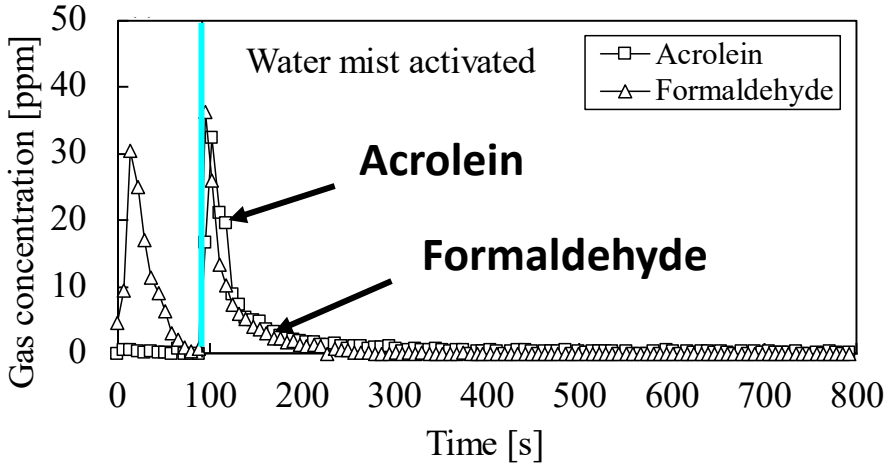
Toxic gas concentrations

- Test sample: **wood cribs burning** with water mist activation
- **Nozzle A: 20 cm** and **Nozzle B: 25 cm** below the ceiling
- Measured by **FTIR gas analyzer**

Nozzle A



Nozzle B



Acrolein: strong irritant for skin and respiratory

Formaldehyde: eye and nasal irritation

Discussions

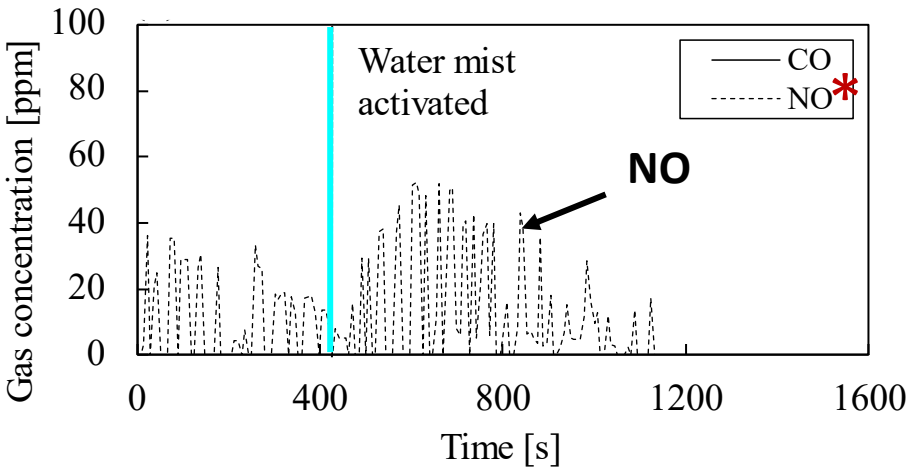
- The asphyxiant gas concentrations especially **CO concentration** was related to water droplet size discharged on natural polymers burning due to water-gas reaction.

- The relatively high concentration of CO accumulated inside the chamber for a long time with the **small size of water mist droplets** on the combustion of polymers.

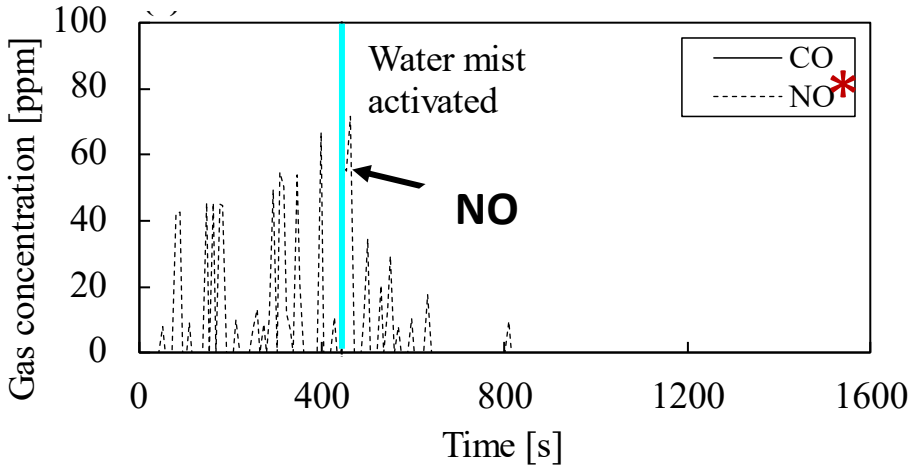
Toxic gas concentrations

- Test sample: **PE burning** with water mist activation
- **Nozzle A: 20 cm** and **Nozzle B: 25 cm** below the ceiling
- Measured by **NDIR and FTIR gas analyzers**

Nozzle A



Nozzle B



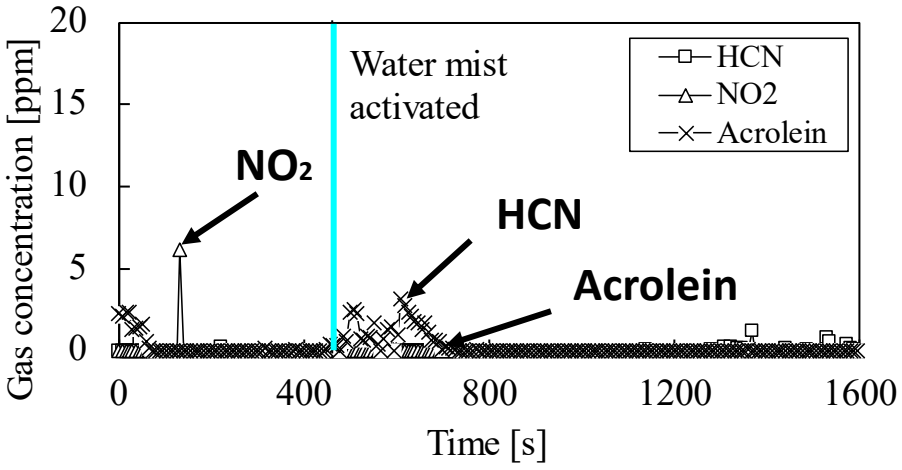
NO: combined with water and forms nitric acid

***Ingestion/inhalation are not considered toxic, depending on the dose**

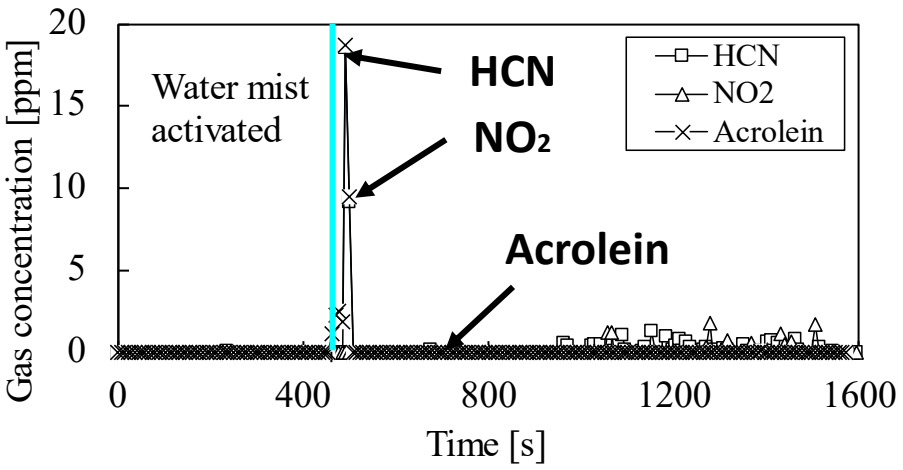
Toxic gas concentrations

- Test sample: **PE burning** with water mist activation
- **Nozzle A: 20 cm** and **Nozzle B: 25 cm** below the ceiling
- Measured by **FTIR gas analyzers**

Nozzle A



Nozzle B



HCN: loss of consciousness, respiratory restraining

NO_2: cause the upper airway and mucous membrane irritation

Discussions

- The water mist instantly **increased the concentrations of HCN and acrolein** produced from the combustion of thermoplastic polymers.

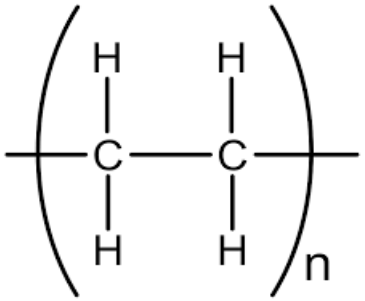


Fig. 16 *PE chemical structure*

- It can be deduced that **forming NO** affected to the production of HCN due to the thermal NO_x reaction that occurred in PE burning could produce HCN as an intermediate product.

Conclusions

- The influence of water droplet size is related to **time to extinguish** and **flame characteristics**. Also, water mist plays a dominant role to control the flame size instead of fire extinguishing.
- Toxic gas concentrations, especially **CO**, are associated with the water mist in mean droplet diameter ~ 106.2 µm discharged on natural polymer due to the water gas reaction.
- **HCN** and **acrolein** are generated with the size of water mist on synthetic thermoplastic polymers, droplet diameter ~262.7 µm.

Future work

- The velocity and flow rate of water mist droplets depended on the operating pressure will be studied in the future.

Acknowledgement

Nicharee Thinnakornsutibutr

Masayuki Mizuno

Department of Global Fire Science and Technology

Graduate School of Science and Technology

Tokyo University of Science

Chiba, Japan

Thank you for your kind attention!