# Simulation of Engine Room Fire and Water Mist

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# Fire on MS Nordlys


15th September 2011 a fire started in the engine room of the cruise ship, outside Ålesund, at the west coast of Norway.

# More about the accident.

- Fuel leak from a hose to the fuel pump caught fire, when it came in contact with a hot surface [1].
- No automatic extinguishing was activated.
- Carbon dioxide based system was present, but never activated.
- Two people was killed in the accident.
- The Norwegian Maritime Directorate wish to find out if water mist could have change the tragic outcome of the fire.

# Picture of the rebuilt engine room at MS Nordlys

# Use of Data Modeling

- We will try to set up and simulate the fire of MS Nordlys in a data model.
- We do not have data from the fire.
- In order to calibrate the data model, we used United State Coast Guard (USCG) tests from 1999.

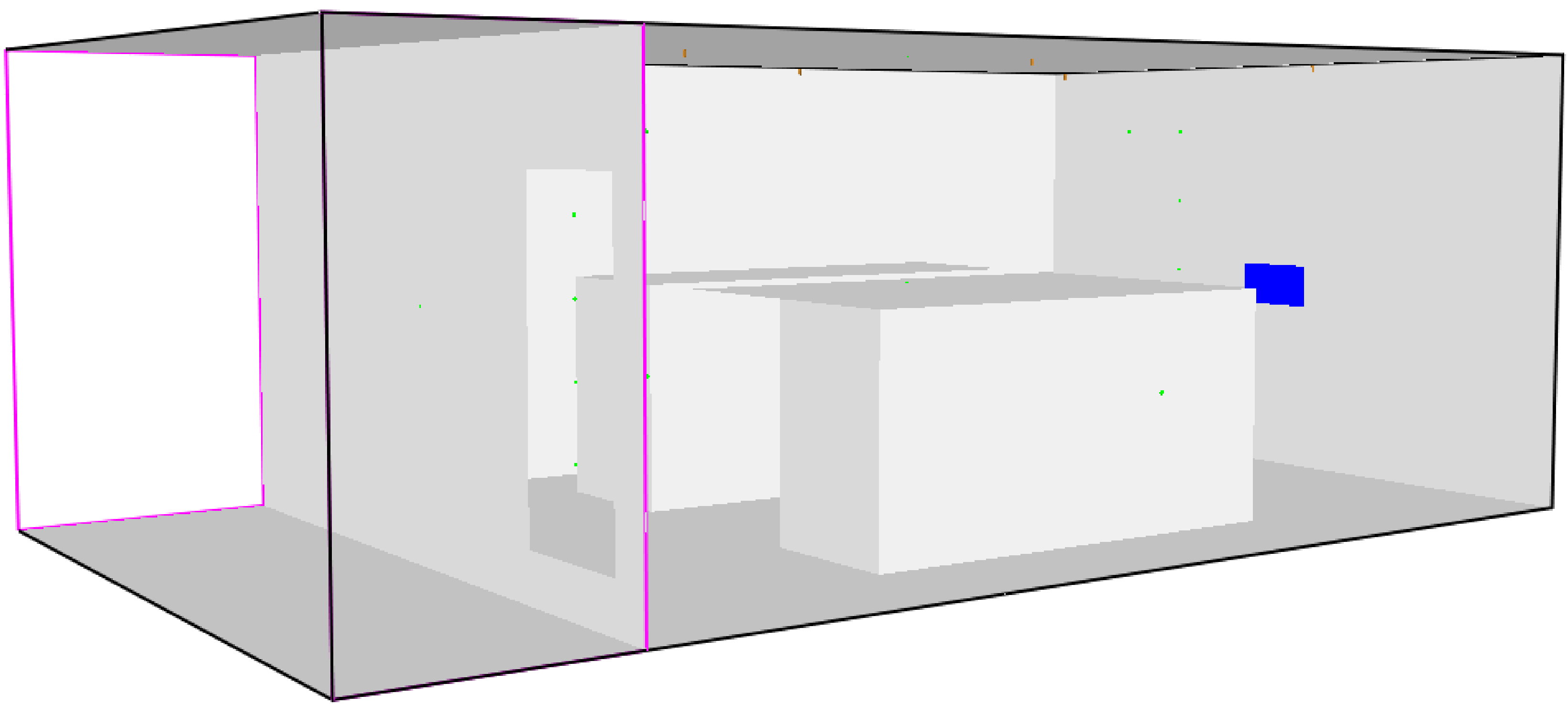
# Case Study - USCG.

- Full-scale testing on engine room of ships in the late 90’s.
- Report "Full-scale testing of water mist re-suppression system for small machinery spaces and spaces with combustible boundaries“ [3].

# FDS-Fire Dynamic Simulator

- CFD - *Computing Fluid Dynamics* program, developed by NIST [2].
- Widely used in fire simulation world wide.
- Conservation of mass, momentum and energy are solved by partial differential equation
- Difficult to predict extinguishing with water mist.
- Simulation is time consuming.

# Simulation Setup



# Ventilation scenarios

- **Closed**: Neither the door or the fan is ventilating
- **Natural**: The door is ventilating, not the fan.
- **Forced**: Both the door and the fan is ventilating.

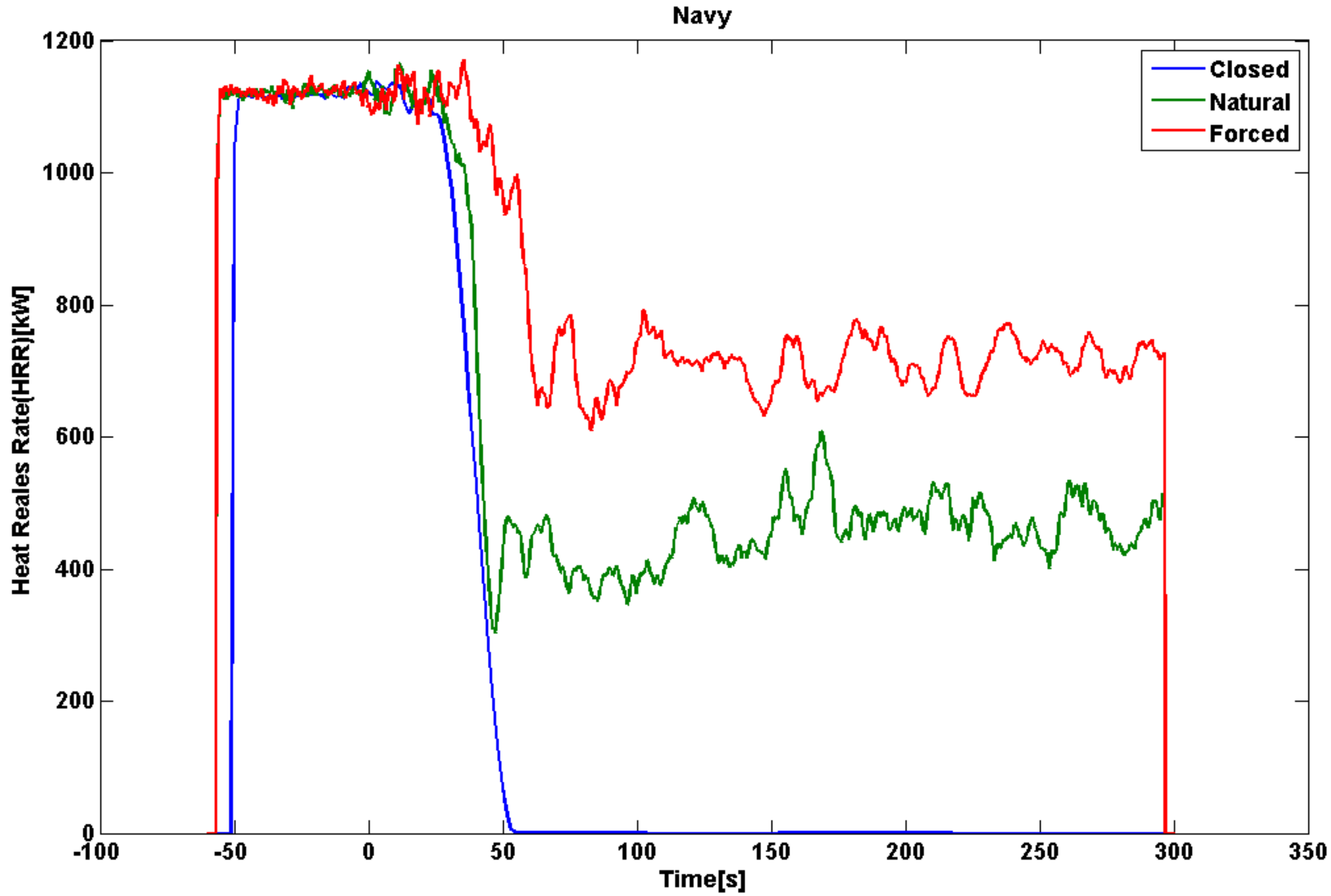
# Result from USCG - Tests

**System Capabilities Test Results**

| System | | Navy | Grinnell | Fogtec | Chemetron | Fike |
|---|---|---|---|---|---|---|
| Number of Nozzles | | 6 | 6 | 6 | 15 | 6 |
| Operating Pressure (bar) | | 70 | 13 | 100 | 12 | 21 |
| Flow Rate (Lpm) | | 68 | 75 | 22 | 70 | 48 |
| Fire Scenario | Ventilation | Extinguishment Times (sec) | | | | |
| 1.0 MW Spray | Closed | 15 | 26 | 21 | 27 | 21 |
| 1.0 MW Spray | Natural | 15 | 40 | 32 | 43 | 35 |
| 1.0 MW Spray | Forced | 17 | 55 | 76 | 357 | 133 |

In our simulation we used Navy-nozzles, an 1.0 MW fire and all three ventilation scenarios.

# The first simulation



# Problem

- FDS did not predict extinguishing of scenario natural and forced.
- Smoke view showed that the flame moved from the heptane outlet area to the ventilation area.
- This effect was not described in USCG test. Is it possible to overcome this?

# Parameter Study in FDS

- Particle per Second - pps
- Auto Ignition Temperature – AIT
- Critical Flame Temperature – CFT

# Particle Per Second - pps

- What is pps?
  - This is how many droplets FDS use in its calculation.
- Lagrangian particle, is a method to calculate the particle movement.
- Why more particles?
- Simulation done by changing the “closed-ventilation scenario”

# Auto Ignition Temperature – AIT

- What is AIT?

  The temperature where the mixture of air and combustible gas will ignite due to heating.

- Preset by FDS to 0 degree, then it is not necessary to set an ignition source.

- How to calculate [4]

$$\Delta T_{crit} = T_0 - T_{a.cr} \approx \frac{RT_{a,cr}^2}{E_A}$$

$$\Delta T_{crit} = \text{Critical temperature rise[K]}$$

$$T_0 = \text{Start temperature[K]}$$

$$T_{a.cr} = \text{Auto ingnition temperature[K]}$$

$$R = \text{Gas constant[J/K} \cdot \text{mol]}$$

$$E_A = \text{Activation energy[J/mole]}$$

- This is one method, but is not the best.

# Critical Flame Temperature – CFT

- What is CFT?
  - Critical Flame Temperature is the highest temperature where the heat loss is larger than the heat production.
  - This is the same as adiabatic flame temperature at the lower flammability limit.
  - In FDS it is used as extinction criteria, Preset value is about 1300 degree.
  - The simulations in this work is done by setting the AIT to 500 degree.

How to calculate[4]:

$$T_F = T_0 + \frac{\Delta H_{c,air}}{c_p}$$

$T_F$ = Adiabatic flam temperature [K]

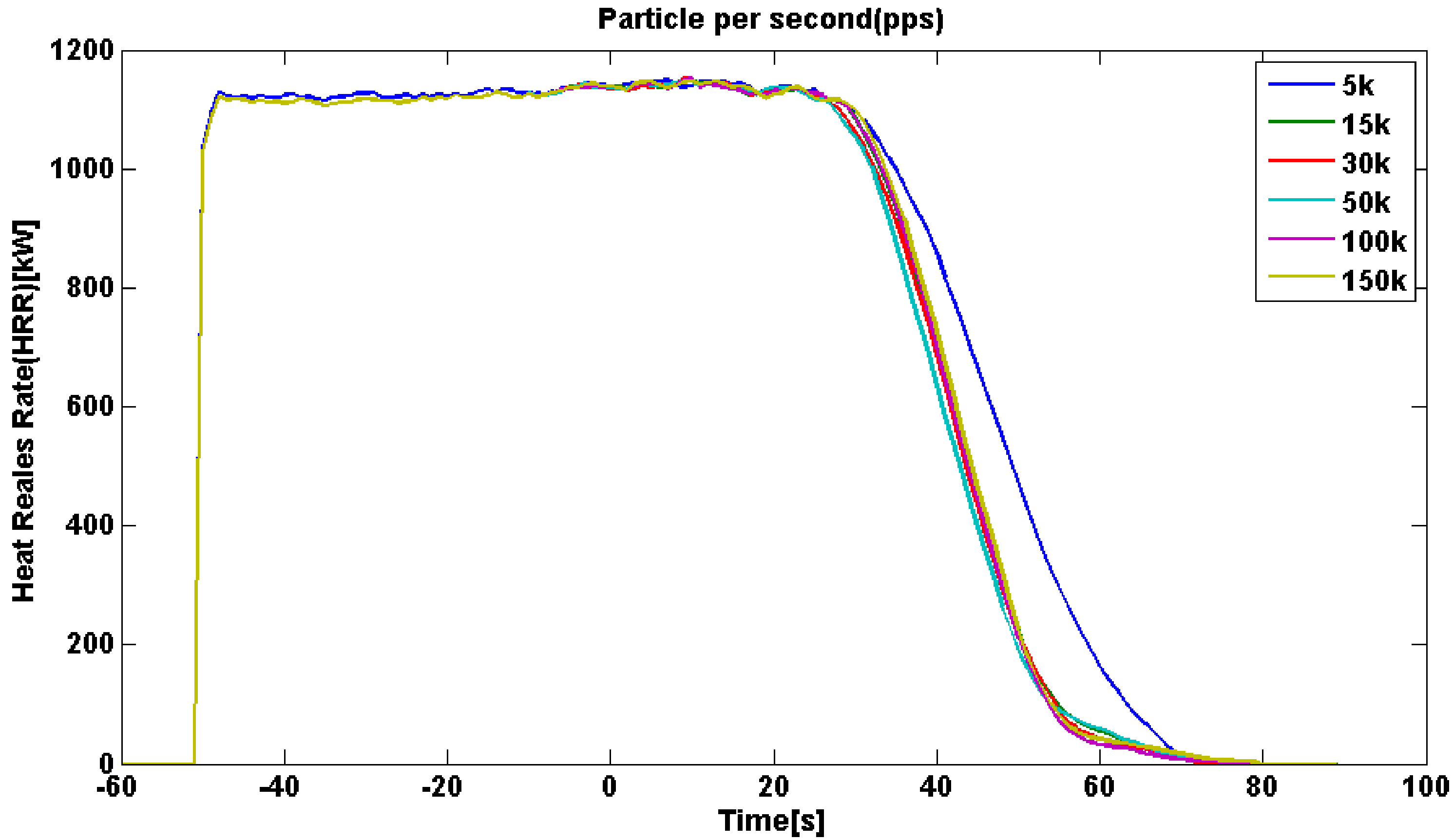
$T_0$ = Ambient temperature [K]

$\Delta H_{c,air}$ = Heat of combustion for species and air [kJ/mol]

$c_p$ = Thermal heat capacity at constant pressure [kJ/(mol·K)]

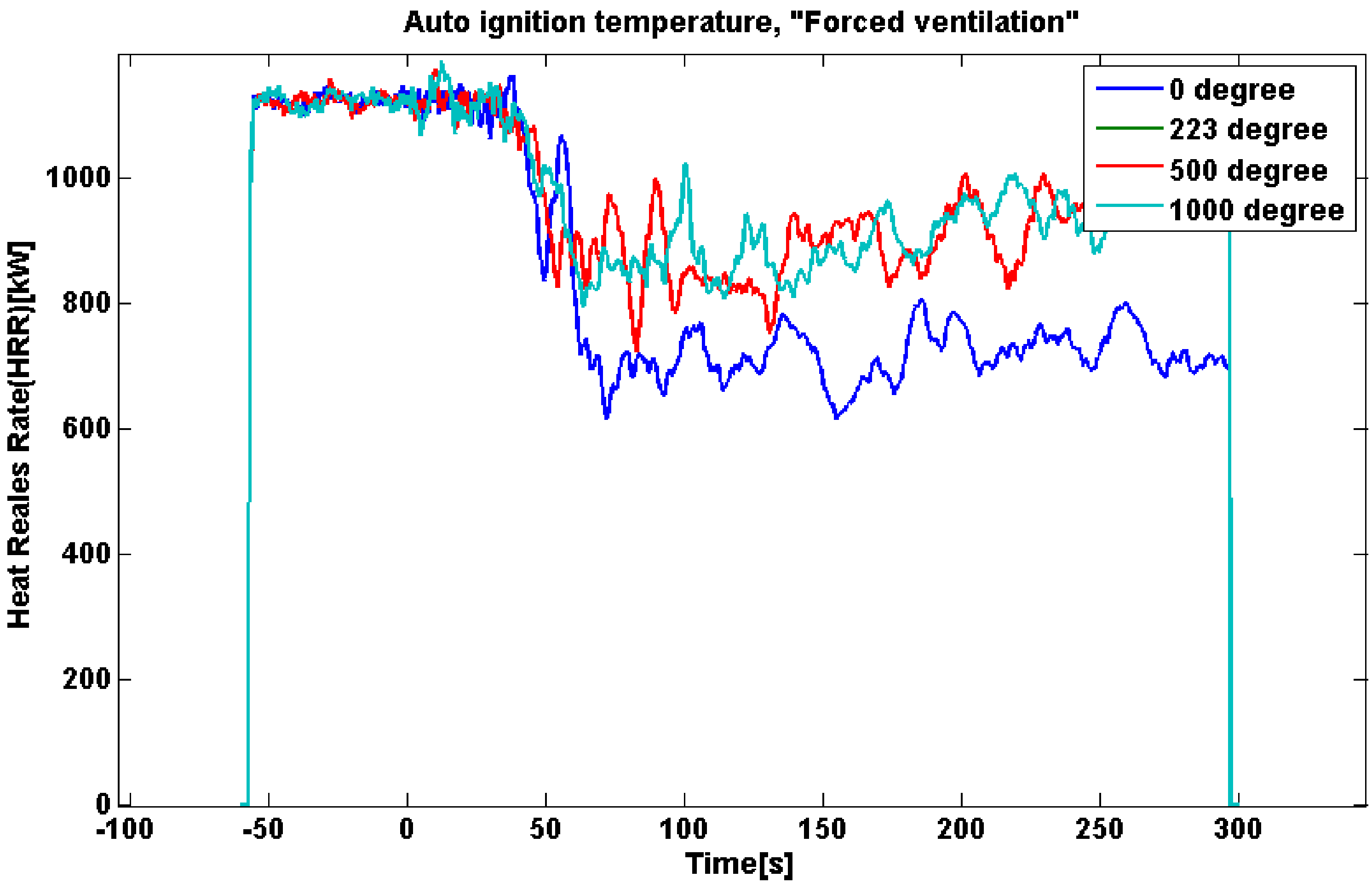
This gives the value of about 1600K for n-Heptane

# Result pps

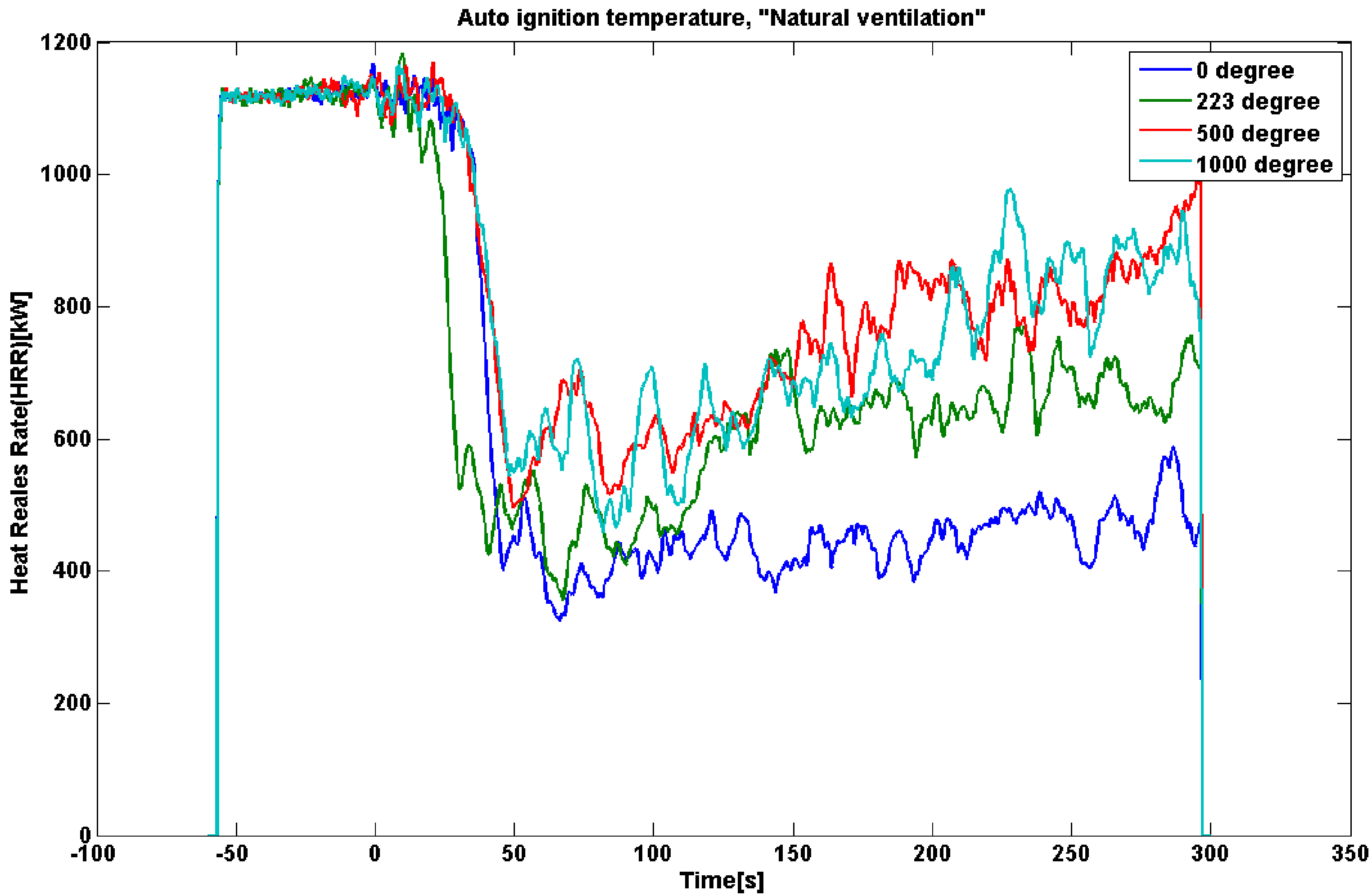


Particle per second(pps)
Heat Reales Rate(HRR)[kW]
Time[s]
1200
1000
800
600
400
200
0
-60
-40
-20
0
20
40
60
80
100
5k
15k
30k
50k
100k
150k

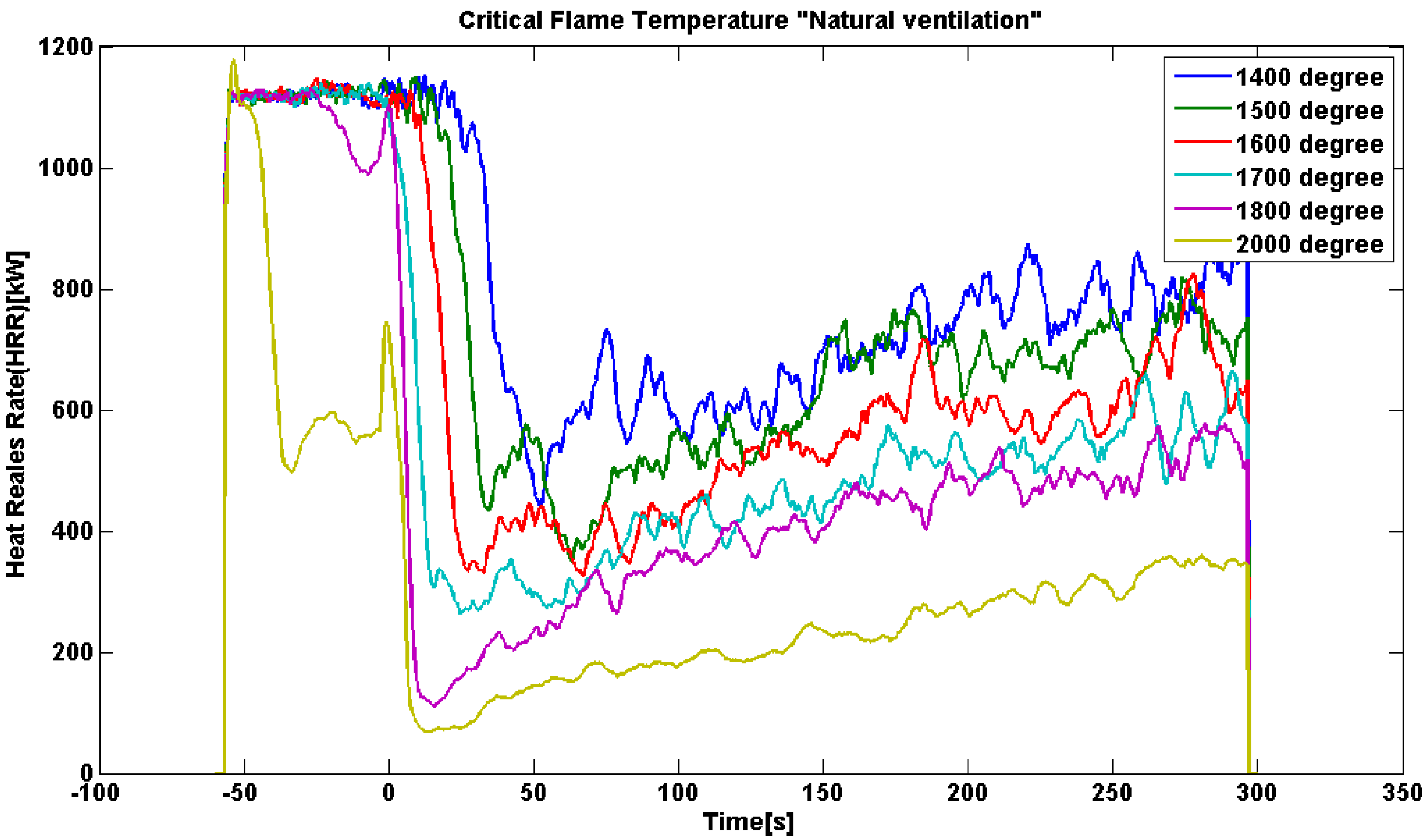
# Result AIT



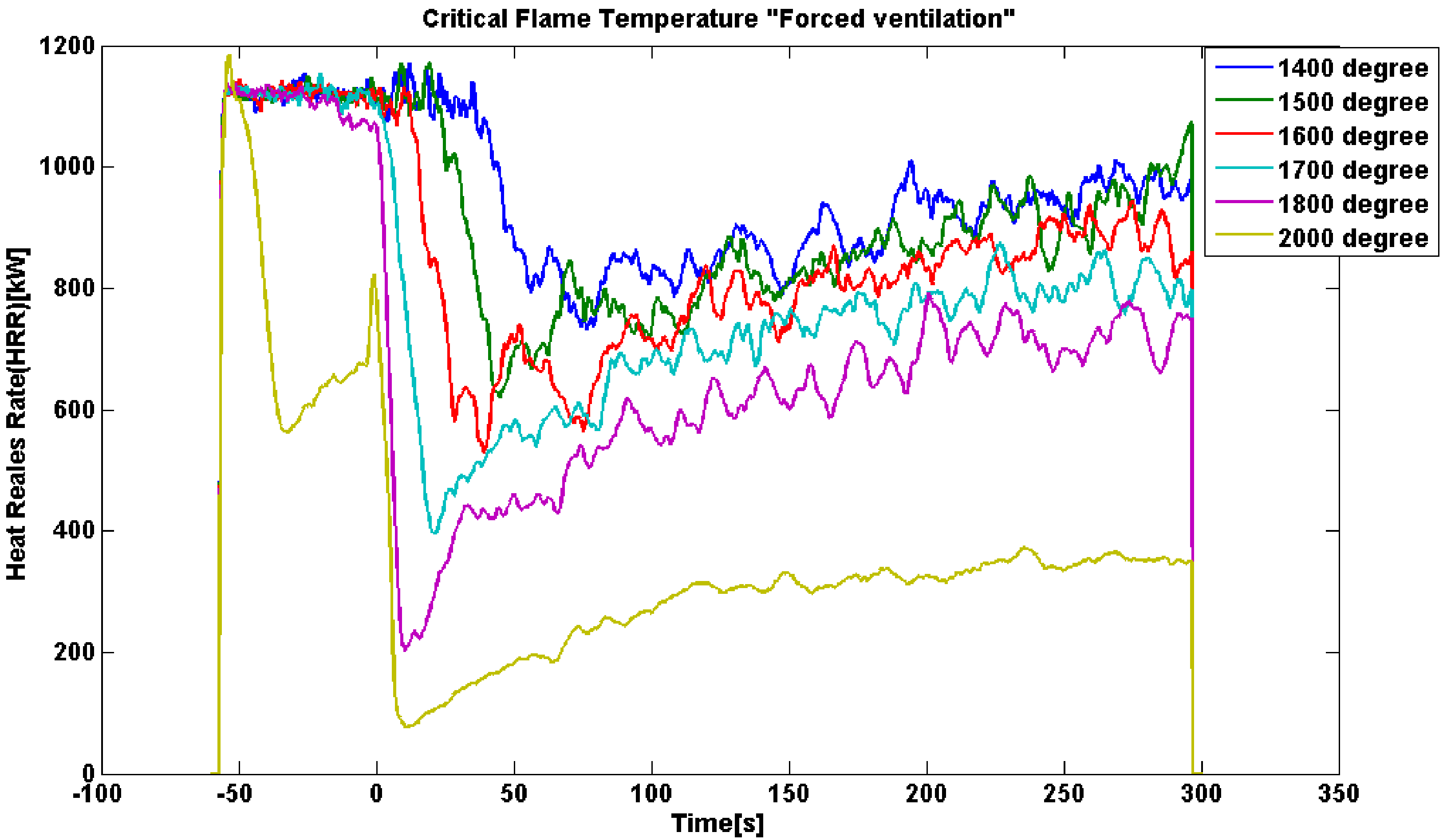
Auto ignition temperature, "Forced ventilation"
0 degree
223 degree
500 degree
1000 degree
Heat Reales Rate(HRR)[kW]
0
200
400
600
800
1000
-100
-50
0
50
100
150
200
250
300
Time[s]


Auto ignition temperature, "Natural ventilation"
Heat Reales Rate(HRR)[kW]
Time[s]
0 degree
223 degree
500 degree
1000 degree
1200
1000
800
600
400
200
0
-100
-50
0
50
100
150
200
250
300
350

# Result CFT



Critical Flame Temperature "Natural ventilation"
Heat Reales Rate(HRR)[kW]
Time[s]
1400 degree
1500 degree
1600 degree
1700 degree
1800 degree
2000 degree
0
200
400
600
800
1000
1200
-100
-50
0
50
100
150
200
250
300
350


Critical Flame Temperature "Forced ventilation"
1400 degree
1500 degree
1600 degree
1700 degree
1800 degree
2000 degree
Heat Reales Rate(HRR)[kW]
Time[s]
0
200
400
600
800
1000
1200
-100
-50
0
50
100
150
200
250
300
350

# What Does This Tell Us?

- Increasing the number of particles give a better prediction but it is not necessary to use tens of thousand. 15k seems to be enough.
- It was expected that with high AIT the flame movement to the ventilation area would disappear. This did not happen, and the gas mixture reignite even for AIT at 1000 degrees.
- Critical Flame Temperature improved the prediction but the fire still moved from the outlet to the ventilation area.
- This result point in the direction of flame propagation and not re-ignition.

# Future Work

- Simulate the MS Nordlys accident as a closed ventilated scenario.
- It is possible to work with the source of FDS.
- Try to make another case study of a smaller volume.

# References

1. The Accident Investigation Board Norway "*Foreløpig rapport om undersøkelse i forbindelse med brann ombord i hurtigruteskipet Nordlys- LHCV- under innseiling til Ålesund 15. september 2011"* Lillestrøm 2013.
2. K. McGrattan, S. Hostikka, J. Floyd *"Fire Dynamics simulator(Version 6) User's Guide, FDS Version 6.",* Washington 2012.
3. *G. Back, B. Lattimer, C. Beyler, P. DiNenno, R. Hansen, "Full-scale testing of water mist re suppression system for small machinery spaces and spaces with combustible boundaries" 1999 Washington*
4. D. Drysdale, "*Fire Dynamics*", third edition, 2011 Edinburg
5. E.A. Kolstad, B.P. Husted. *"Effect of water mist and ventilation on engine room fire."* Interflam 2013, London 2013.