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Numerical Investigation of ABS Formation and Deposition in Rotary Air Preheaters

Assoc. Prof. Dr. Zühtü Onur PEHLIVANLI
Kırıkkale University, Faculty of Engineering and Natural Sciences,
Mechanical Engineering Department,
Kırıkkale, Türkiye

PhD Candidate Ing. Baran TASGIN
VSB – Technical University of Ostrava, Centre for Energy
and Environmental Technologies, Energy Research Centre,
Ostrava, Czech Republic

Ing. Berke ERIS
Kırıkkale University, Faculty of Engineering and Natural Sciences,
Mechanical Engineering Department,
Kırıkkale, Türkiye

Research Topic

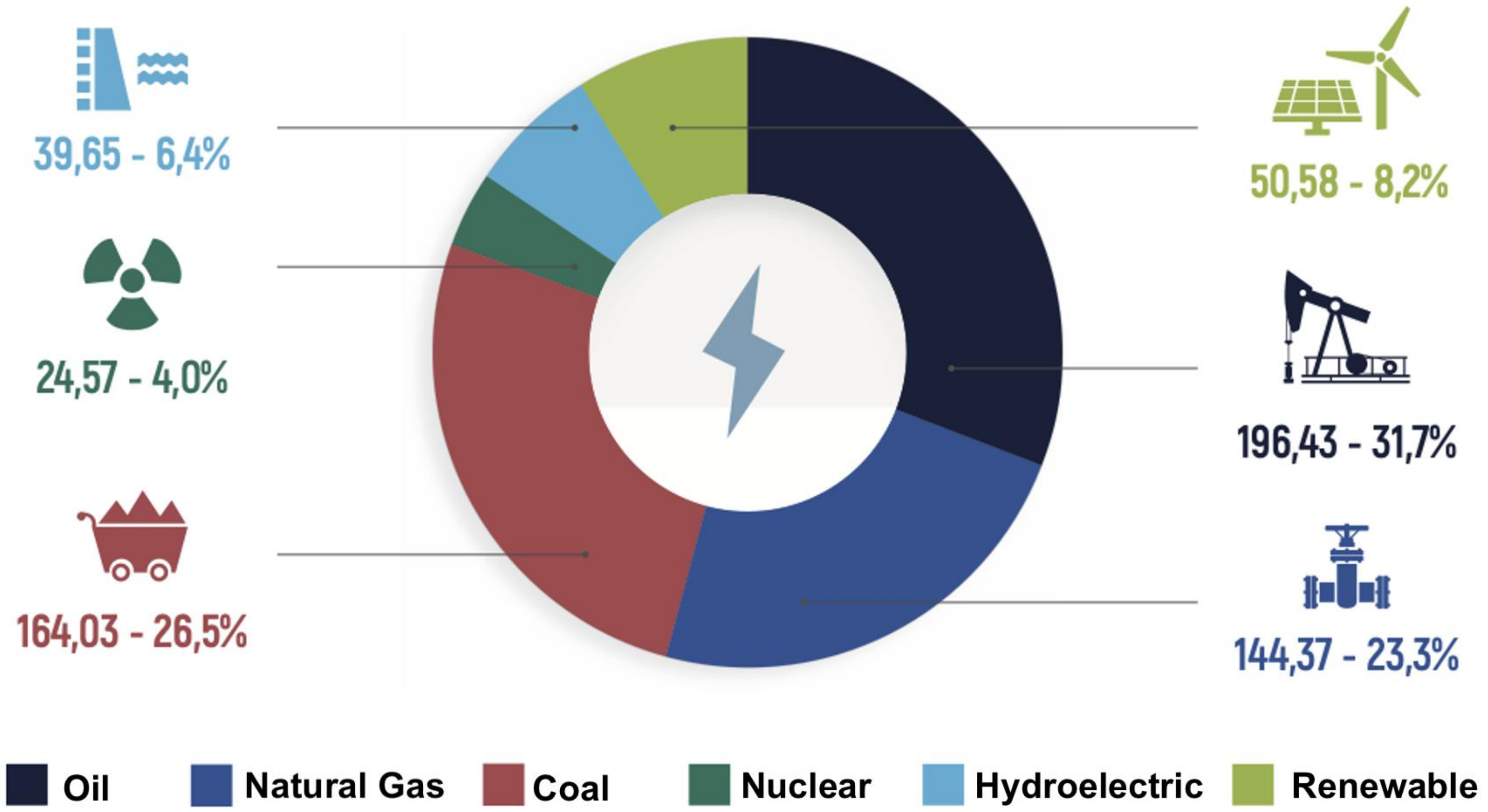


Fig. Distribution of Global Primary Energy Supply by Source in 2023 (Energy Institute 2024)

Research Topic

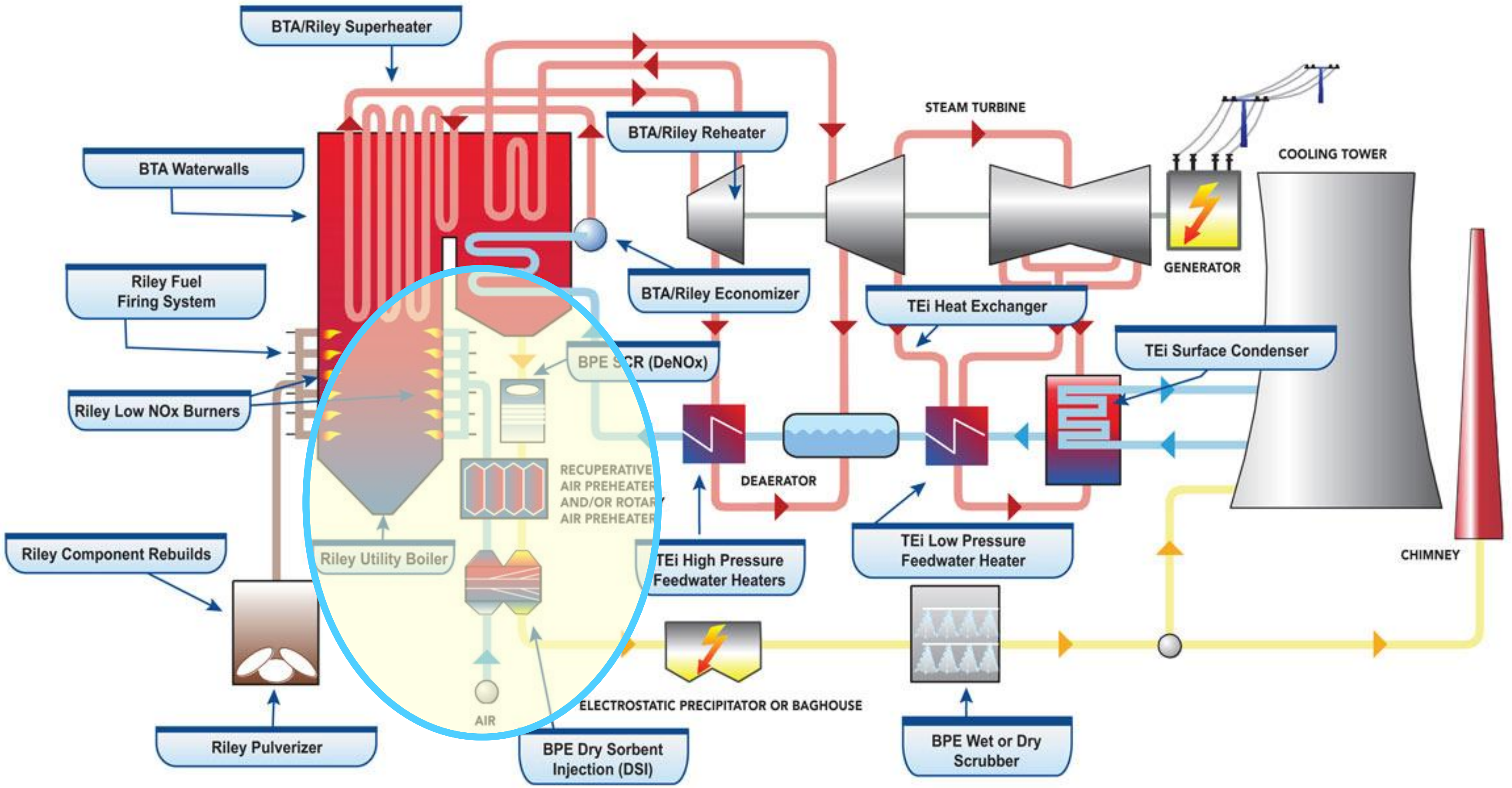


Fig. Thermal power plant operation diagram and air preheater section

Air Preheaters - Properties

Design Types: There are two models: regenerative (Ljungström/rotary) and recuperative (plate-type)

Heat Recovery: Transfers waste heat from the flue gas to the combustion air, increasing the starting air temperature and reducing stack losses

Critical Role: Determines boiler efficiency and fuel consumption

Performance Determinants: Overall heat transfer coefficient, pressure drop, surface cleanliness

Air Preheaters - Problems

- **Fouling:** Ammonium bisulfate (ABS) and ash accumulation narrow the duct cross-section, increasing pressure loss and disrupting flow distribution

- **Corrosion:** Acidic condensate and sulfate species cause corrosion, especially at the cold end

Air Preheaters - Problems

- **Heat transfer loss:** The fouling layer creates additional thermal resistance, lowering the effective U-value and reducing heat recovery

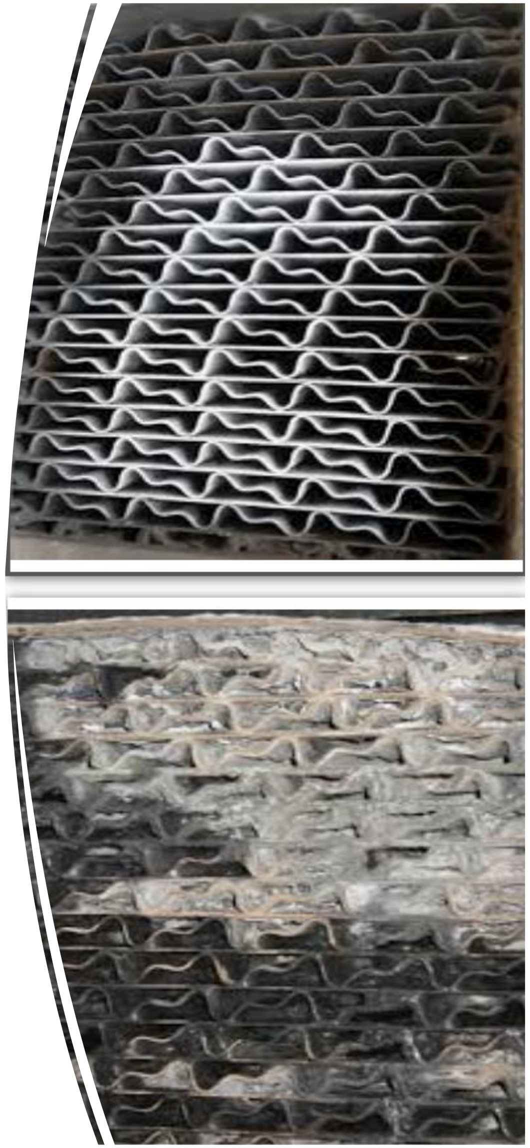
- **Efficiency and cost impact:** Fan power requirements and cleaning frequency increase, increasing unplanned downtime and maintenance costs.

Literature Studies

ABS formation is identified as the primary cause of fouling and corrosion in air preheaters.

ABS, formed as a result of the SO_3–NH_3–H_2O reactions, binds to ash, leading to clogging and loss of efficiency.

Experimental data indicate that the temperature window and the SO_3/NH_3 ratio are critical determinants.



Literature Studies

In studies where ABS formation and deposition behaviors were investigated in the laboratory environment, it was reported that the accumulation of ABS increased at high temperature.

Research highlights the combined effect of sulfuric acid (H_2SO_4) condensation and ABS, particularly at cold regions.

Purpose of the Study

The studies in the literature are mostly experimental and there are no studies on numerical modeling of ABS.

Studies on geometry effects on ABS formation and deposition are very limited.

ABS-ash interaction has been demonstrated, but effective control strategies are still inadequate and an important topic of study.

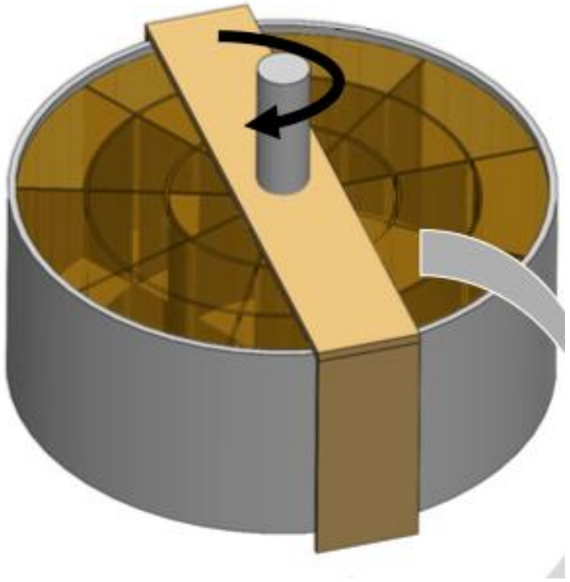
In order to fill these gaps in the literature, CFD-based approaches were used to investigate the behavior of ABS formation in air preheaters.

Numerical Simulation Model

- In this study, the behavior of ABS fouling in a rotary air preheater used in a coal-fired power plant was numerically analyzed.

- CFD-based modeling was performed using ANSYS Fluent for the numerical analysis.

- The industrial-scale system was represented through a single flow channel.

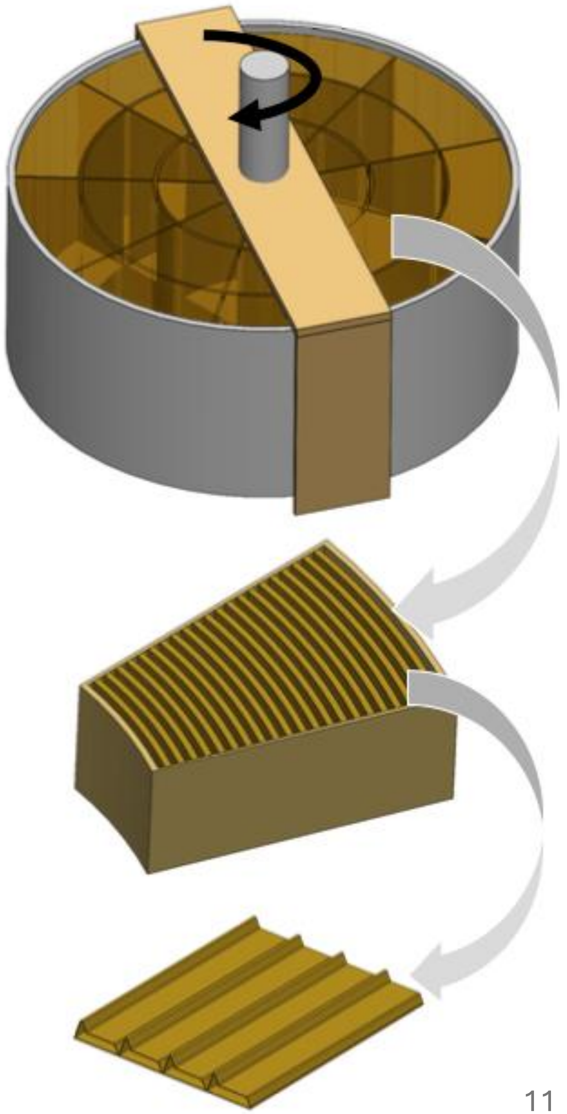


Numerical Simulation Model

- The effects of fouling were compared by selecting two different heat transfer surface geometries.

- The flue gas was treated as a gas-solid two-phase turbulent flow due to ash particles.

- Flooding formation was analyzed using a transient two-phase flow model.



Governing Equations

- Species Transport ($NH_3 + SO_3 + H_2O \rightarrow (NH_4)HSO_4$)
- Turbulence Modeling (k–ε Model)
- Continuity
- Momentum Conservation (Navier–Stokes)
- Energy Conservation

Geometric Modeling

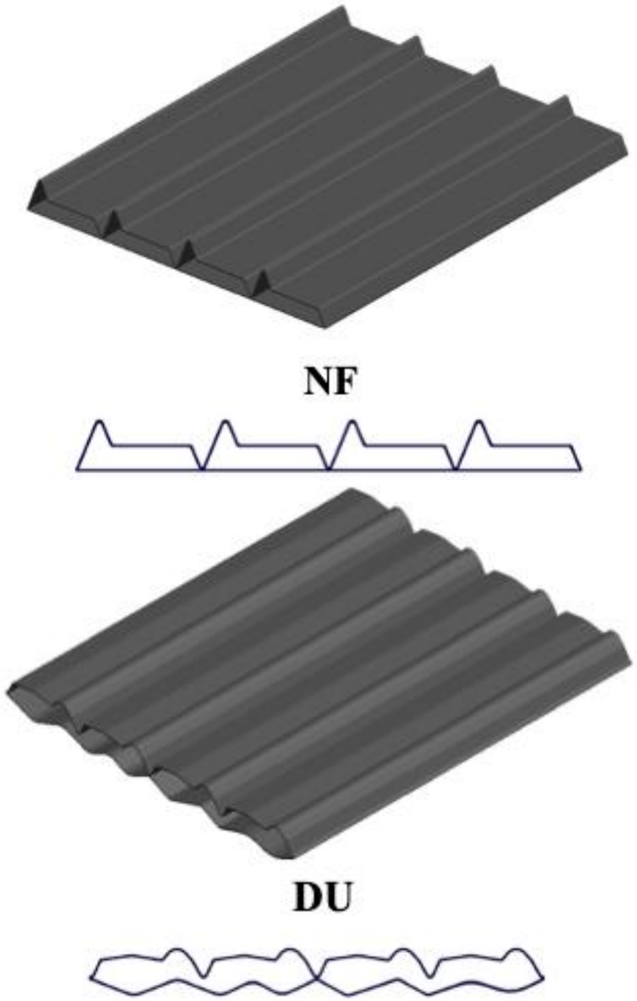


Fig. Solid models and cross-sectional views of the analyzed heat transfer elements

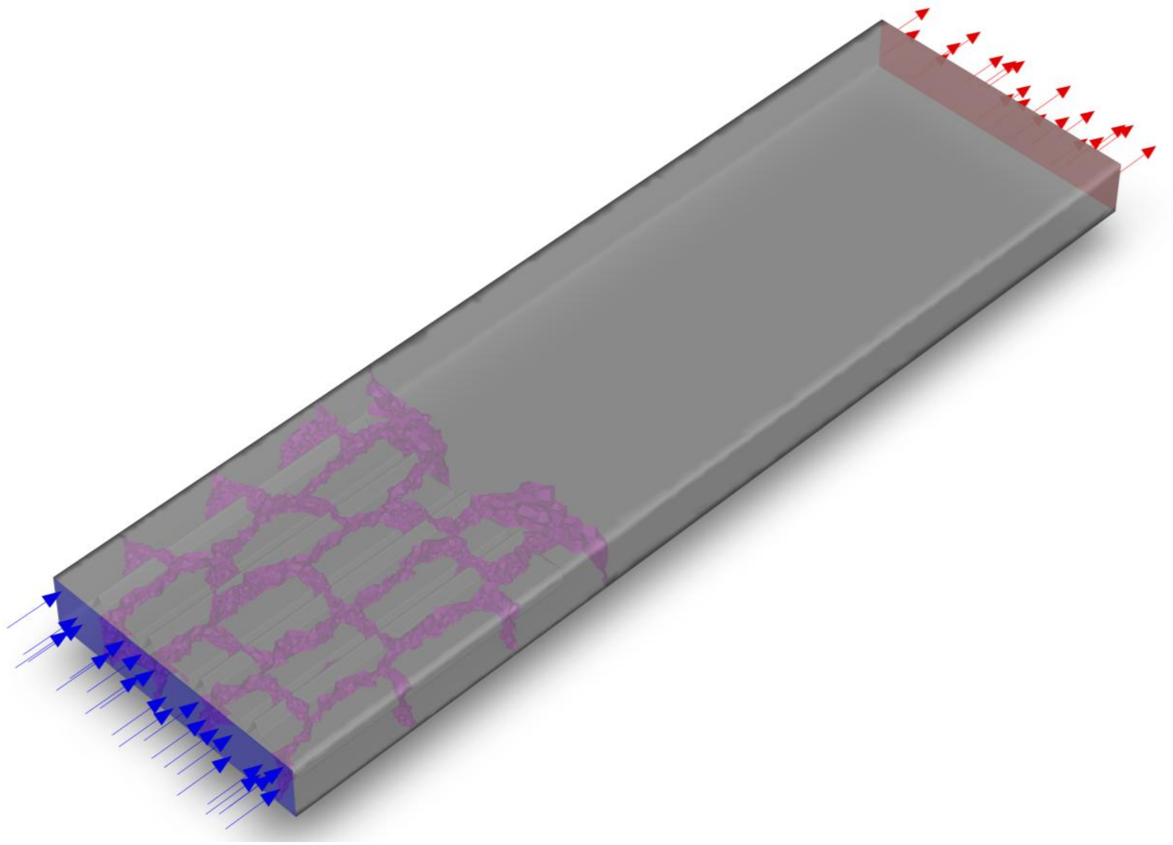


Fig. Heat transfer elements and flow volume

Boundary Conditions

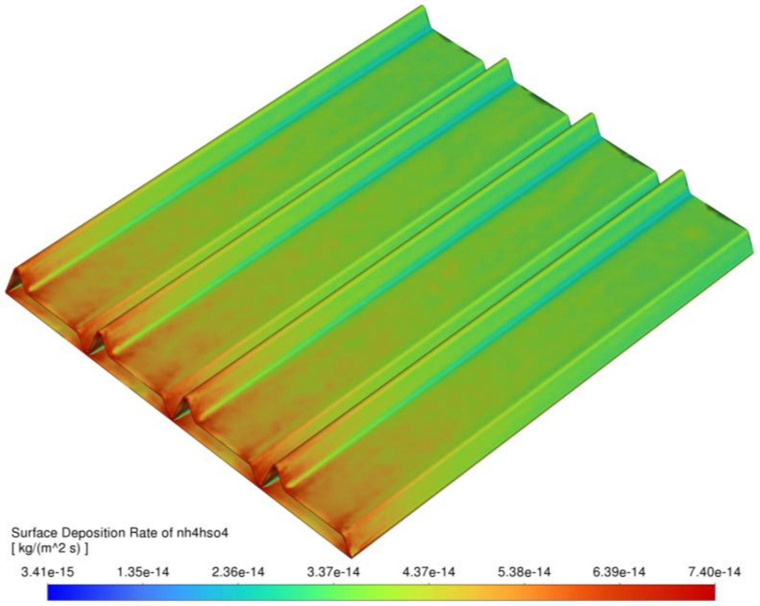
The primary mechanism of ammonium bisulfate (ABS) formation was described by the following gas phase reaction

$$NH_3 + SO_3 + H_2O \rightarrow (NH_4)HSO_4 \text{ (ABS)}$$

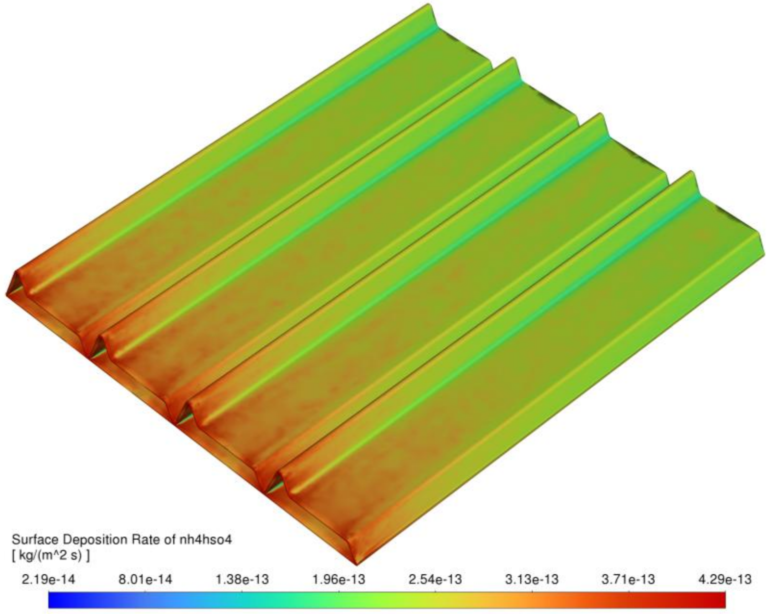
Table 1. Content and mass fractions of the inlet gas (Menasha et al., 2011)

Element	N2	CO2	H2O	O2	SO3	NH3
Mole fraction	0.715153	0.202235	0.0490572	0.0326759	0.000872288	0.000005797

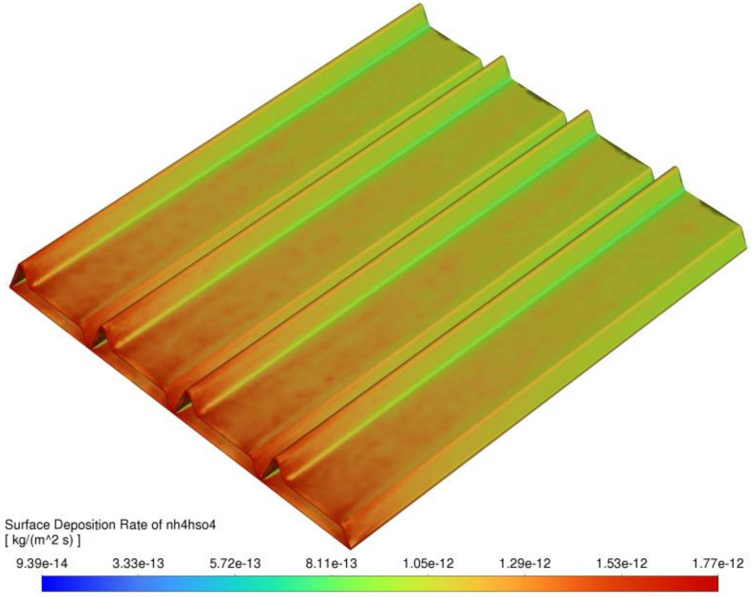
ABS formation and deposition in FN profile



a) flue gas inlet temperature 460 K



b) flue gas inlet temperature 510 K

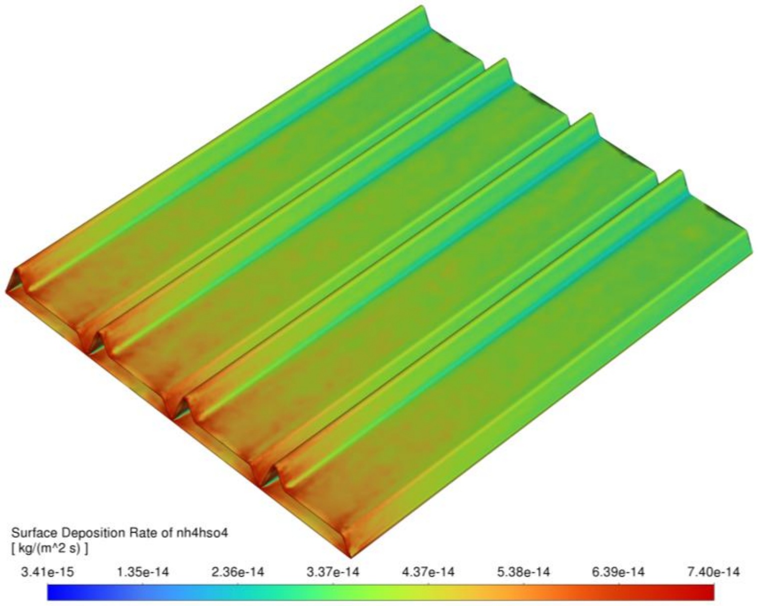


c) flue gas inlet temperature 560 K

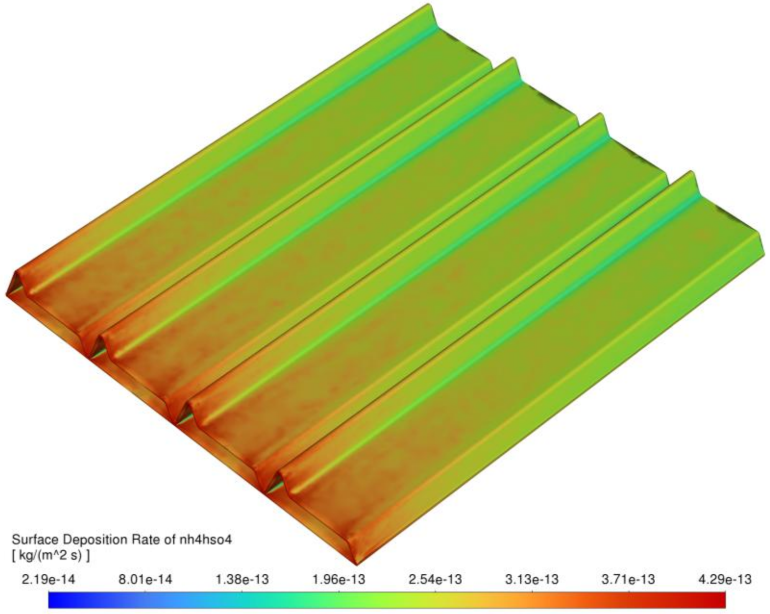
Depending on the temperature, the distribution of ammonium bisulfate on the surfaces of the FN heat transfer profile can be observed.

Results

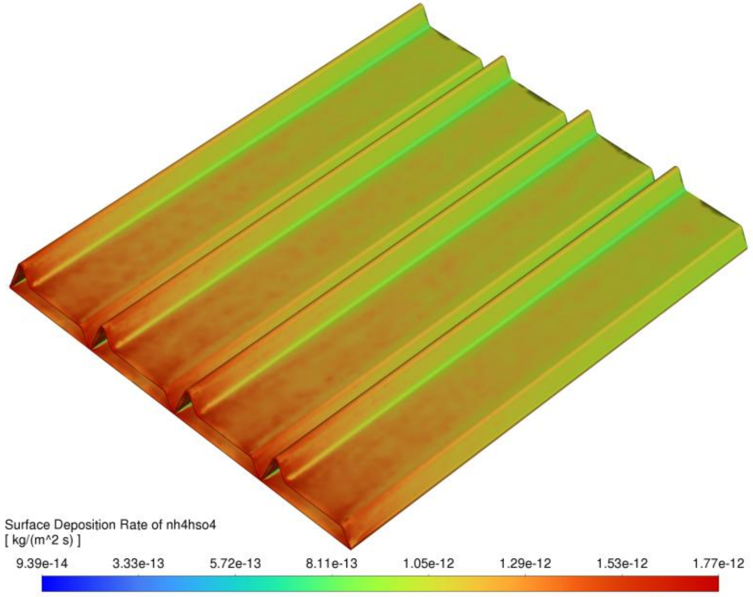
ABS formation and deposition in FN profile



a) flue gas inlet temperature 460 K



b) flue gas inlet temperature 510 K

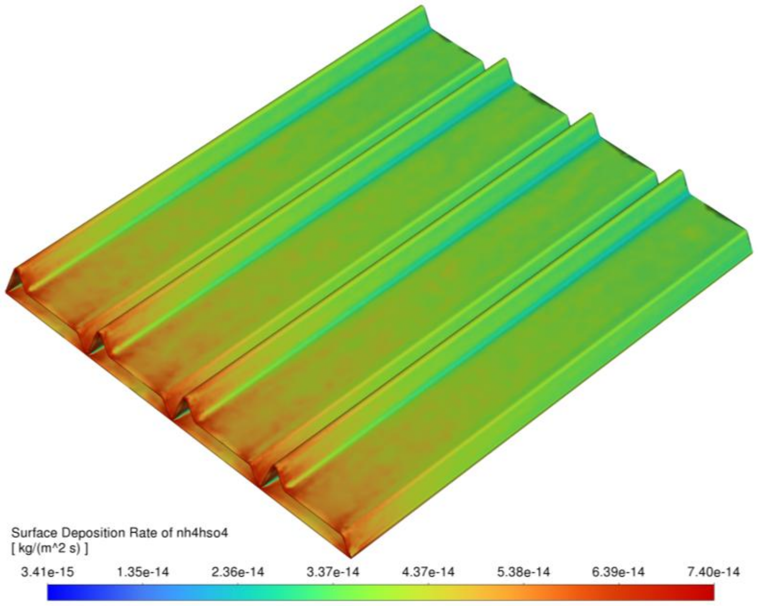


c) flue gas inlet temperature 560 K

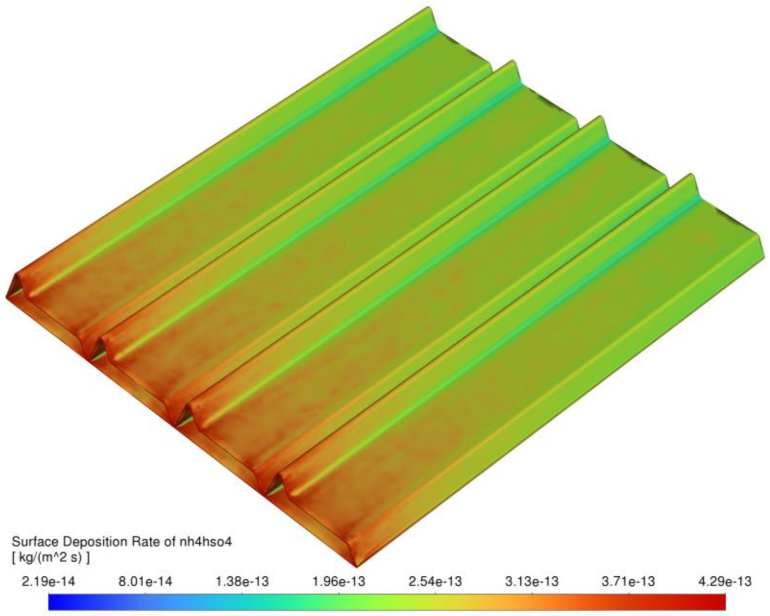
With increasing temperature, the spread on the surfaces also increases. The highest formation rate is observed at 560 K in terms of surface area.

ABS formation and deposition in FN profile

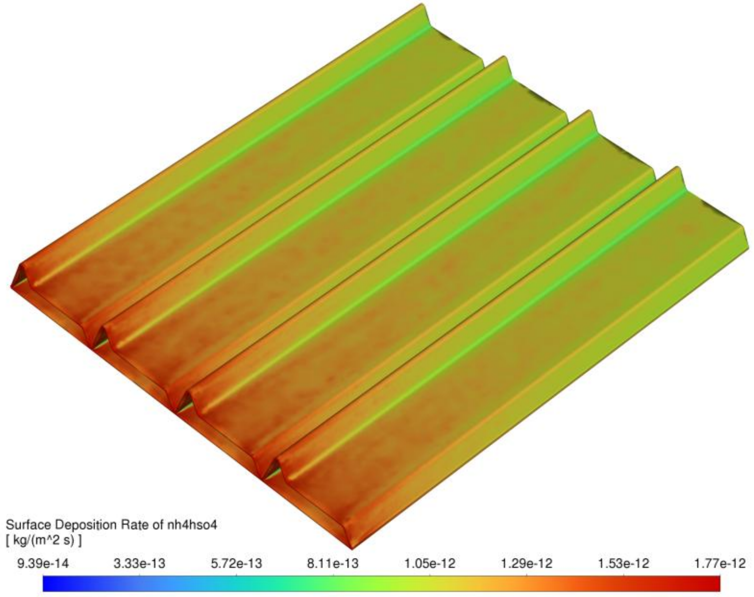
Results



a) flue gas inlet temperature 460 K



b) flue gas inlet temperature 510 K

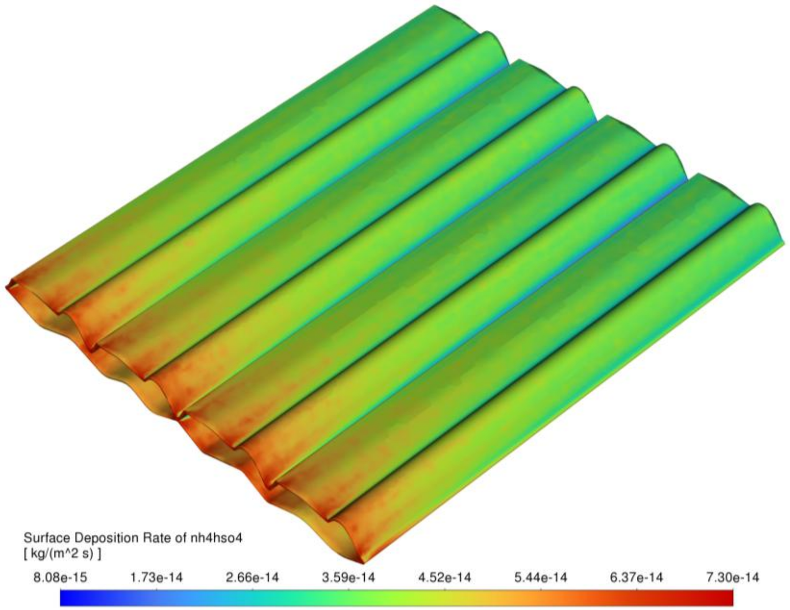


c) flue gas inlet temperature 560 K

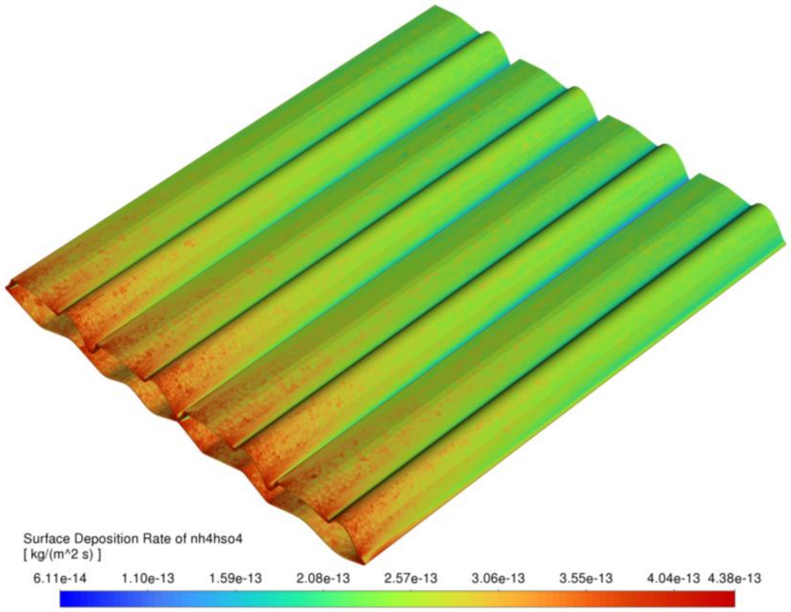
This situation has been evaluated as resulting from the acceleration of the reaction process and the increase in binding with increasing temperature.

ABS formation and deposition in DU profile

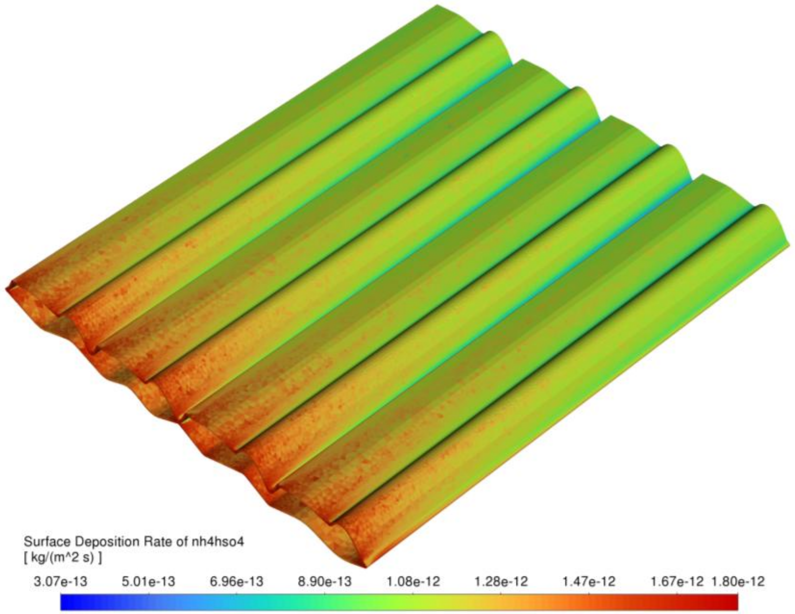
Results



a) flue gas inlet temperature 460 K



b) flue gas inlet temperature 510 K

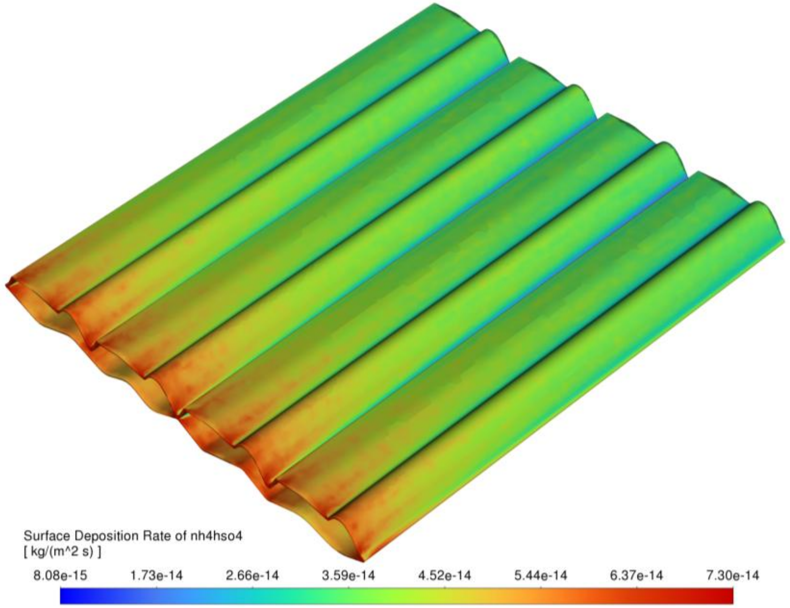


c) flue gas inlet temperature 560 K

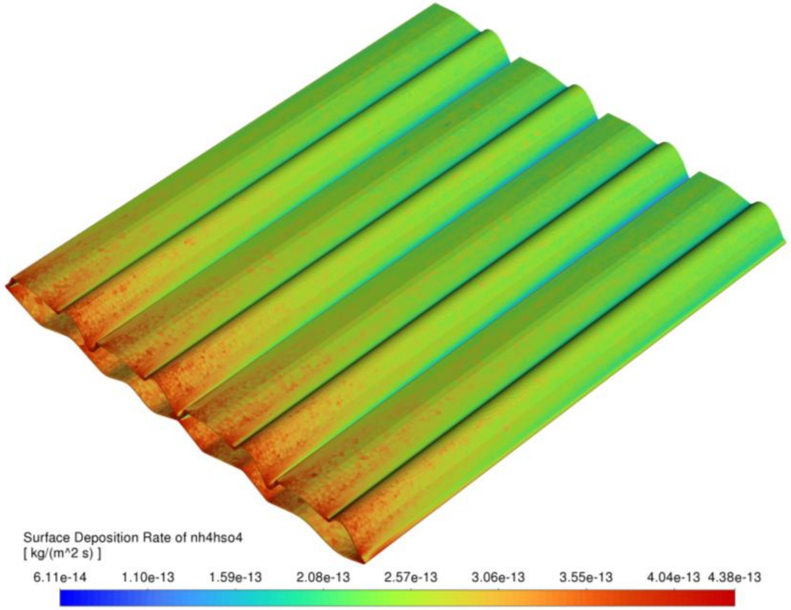
In the DU profile, it was observed that ABS compounding increased with the increase in temperature.

ABS formation and deposition in DU profile

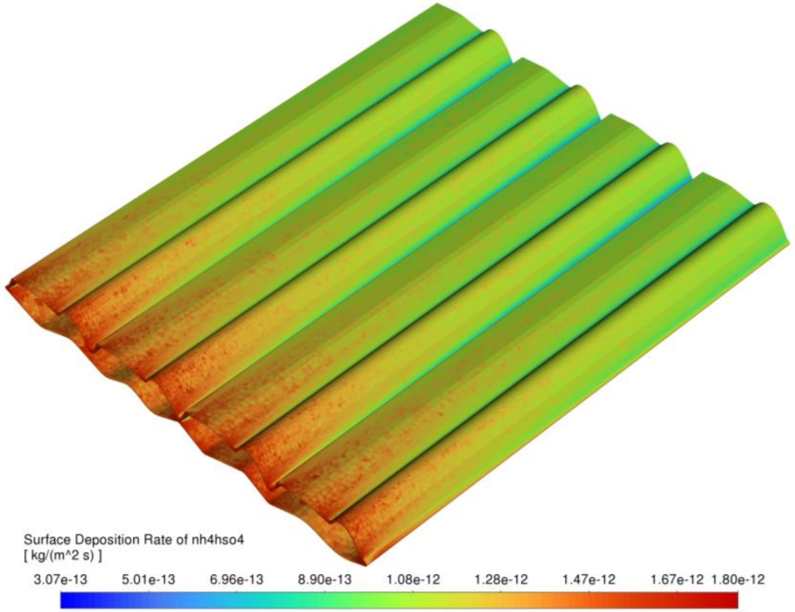
Results



a) flue gas inlet temperature 460 K



b) flue gas inlet temperature 510 K

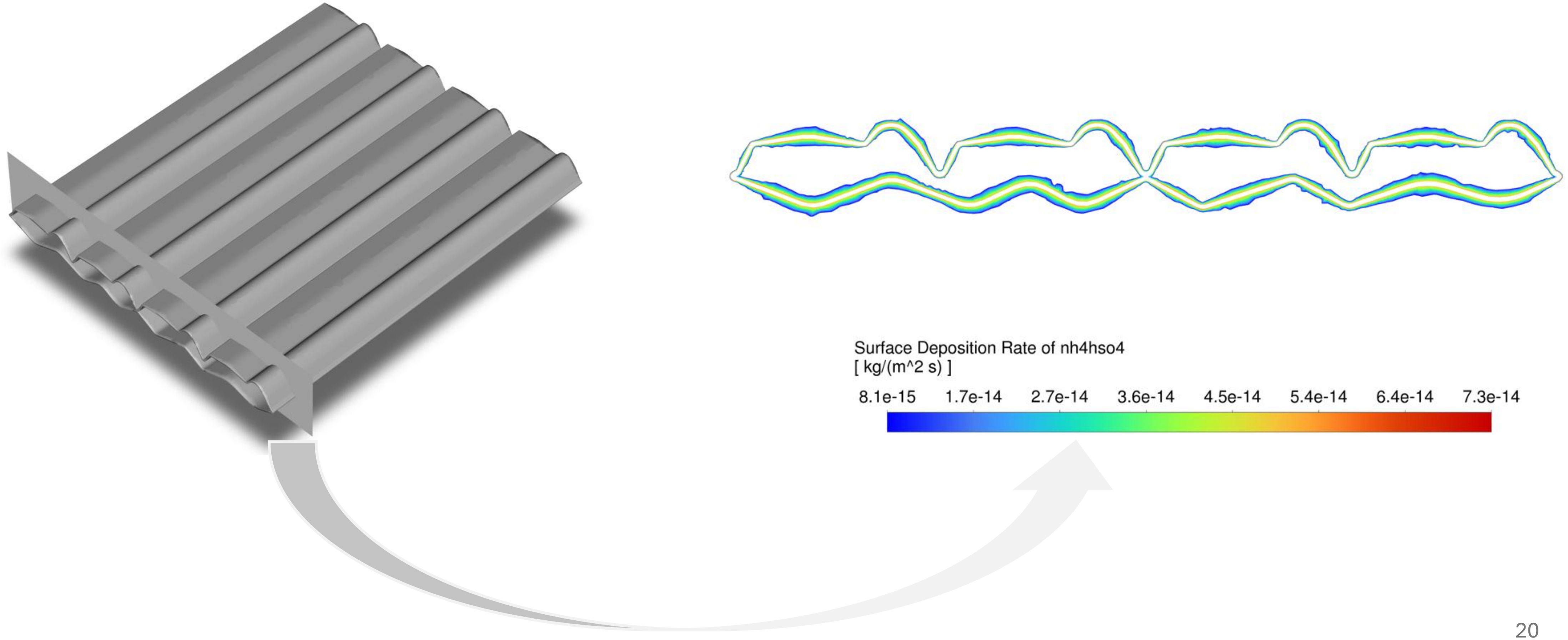


c) flue gas inlet temperature 560 K

However, it was observed that ABS formation and deposition were more concentrated on the surfaces close to the entrance. This shows that geometry is effective on ABS deposition.

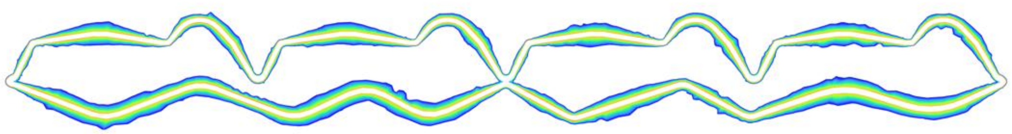
Results

ABS formation and deposition in DU profile of section plane

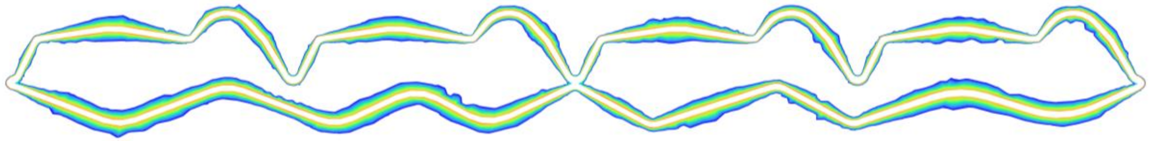


Results

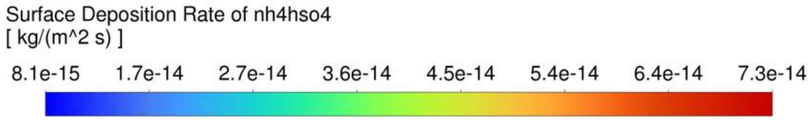
ABS formation and deposition in DU profile of section plane

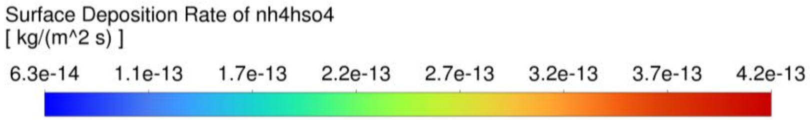


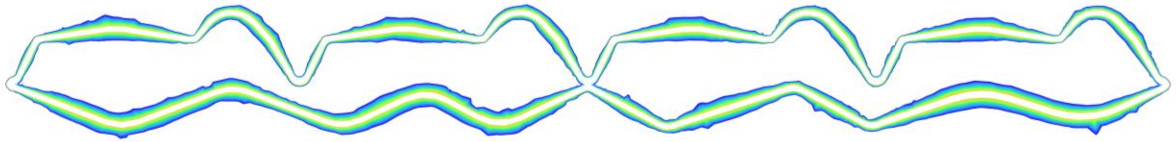
a) 460 K



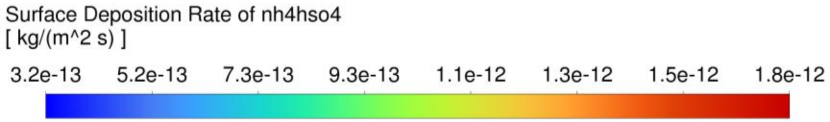
b) 510 K







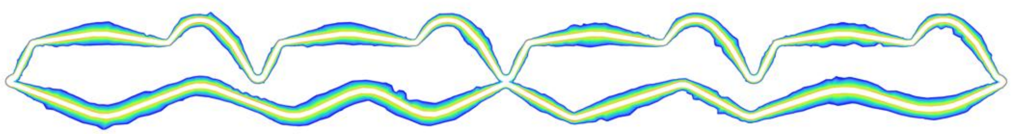
c) 560 K

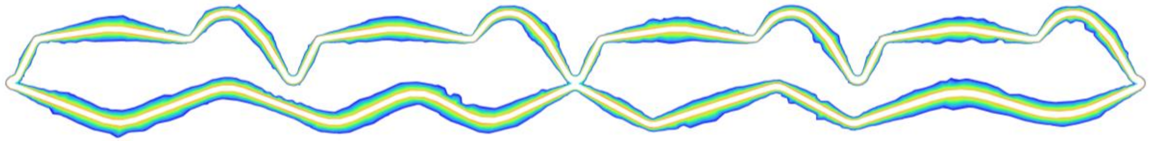


The figure shows the results of high ABS deposition rates for the DU profile heat transfer element at different temperatures. The regional distributions were found to be similar at the studied temperatures.

Results

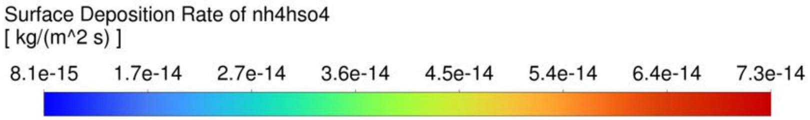
ABS formation and deposition in DU profile of section plane

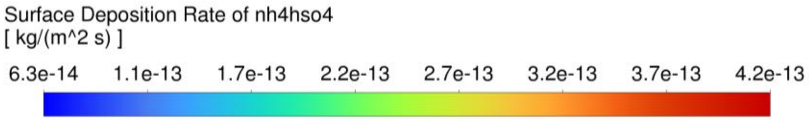


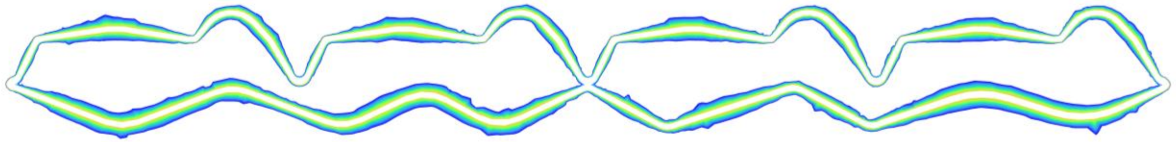


a) 460 K

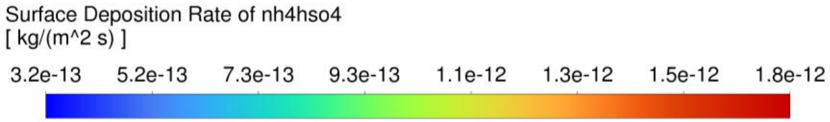
b) 510 K







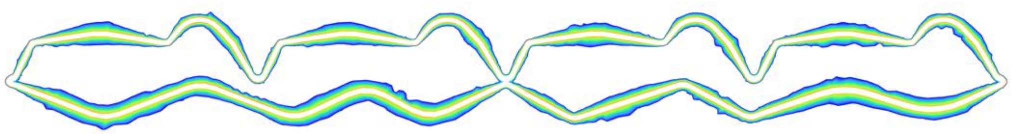
c) 560 K



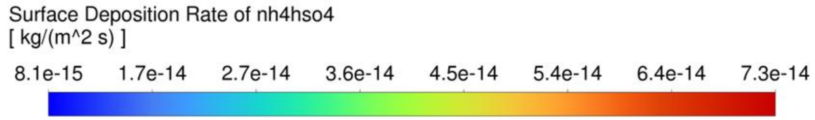
However, as the hot gas temperature increases, the rate of ABS formation increases rapidly. The deposition rate, which is $7.3x10^{-14}$ at 460 K, can reach up to $1.8x10^{-12}$ at 560 K.

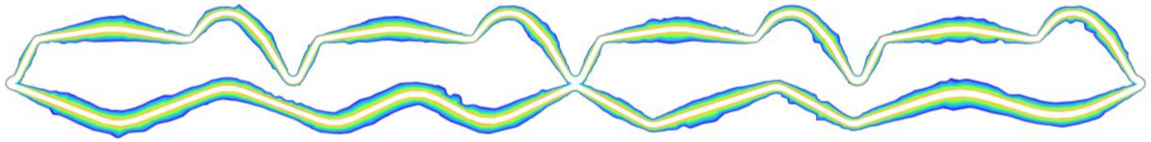
Results

ABS formation and deposition in DU profile of section plane

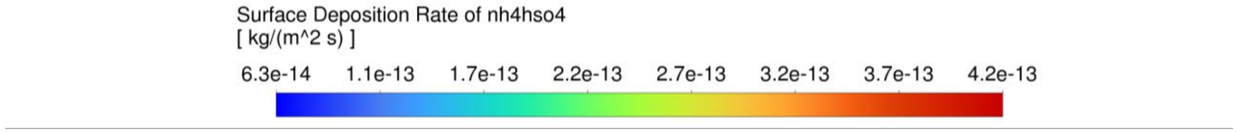


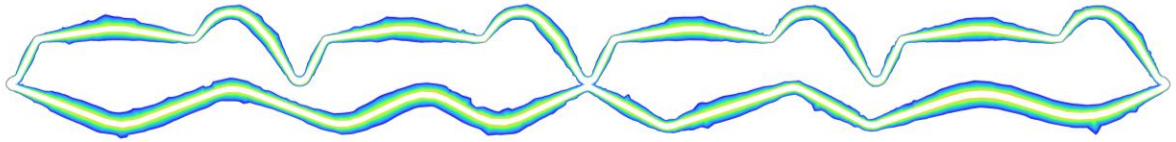
a) 460 K





b) 510 K



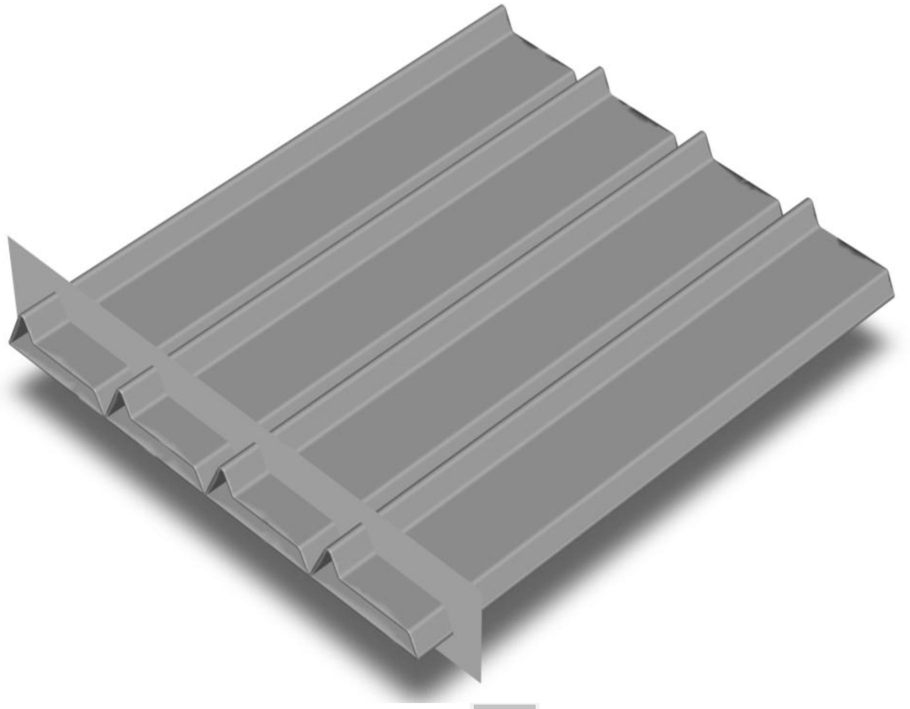


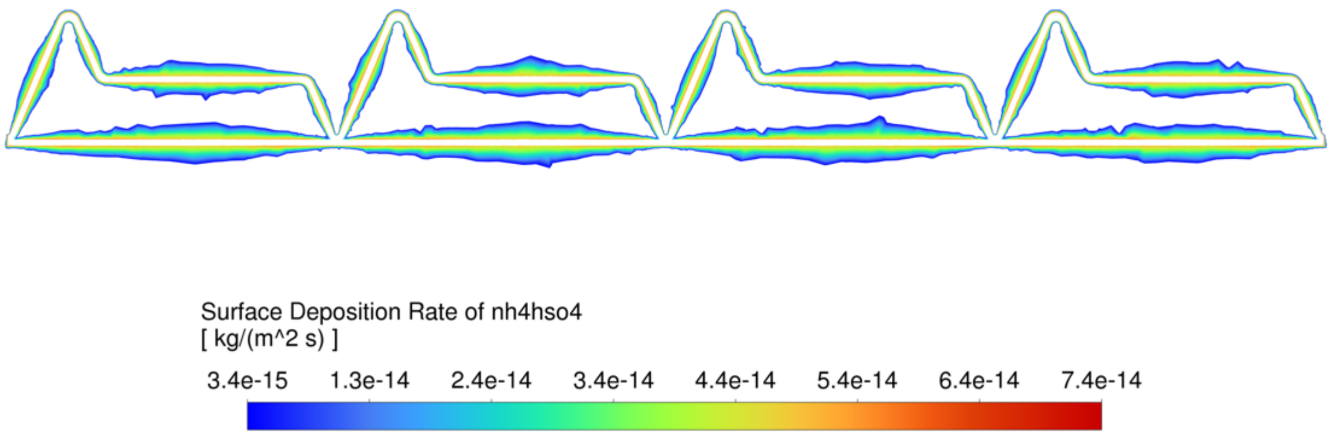
c) 560 K

This finding is consistent with the conclusion in the literature that increasing temperature increases ABS formation.

Results

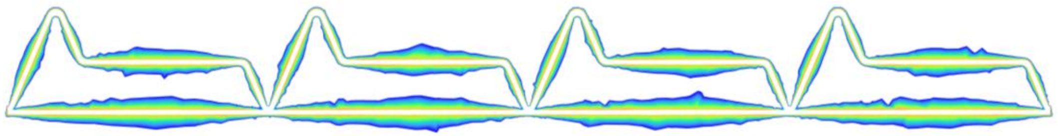
ABS formation and deposition in FN profile of section plane



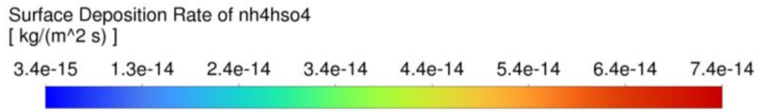


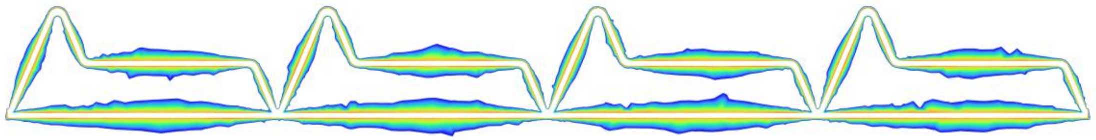
Results

ABS formation and deposition in FN profile of section plane

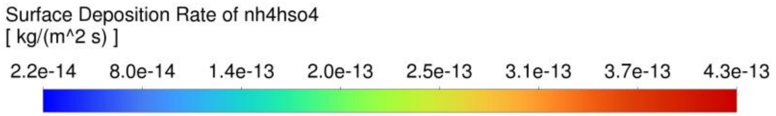


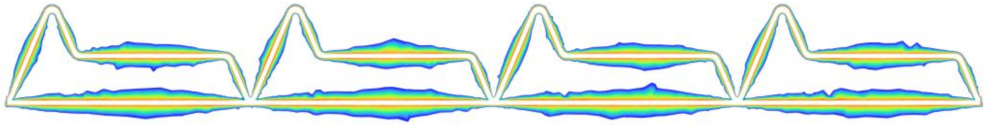
a) 460 K



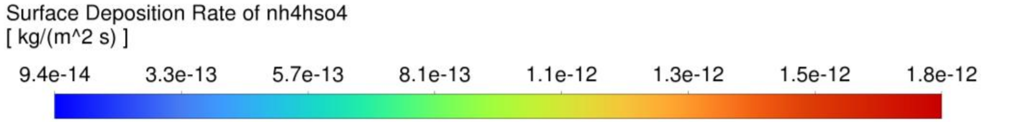


b) 510 K





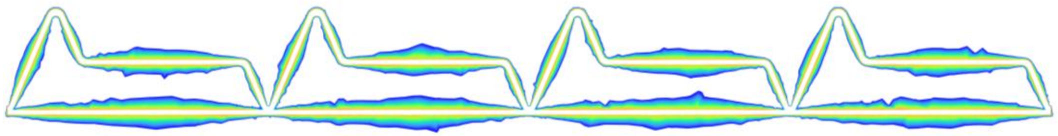
c) 560 K



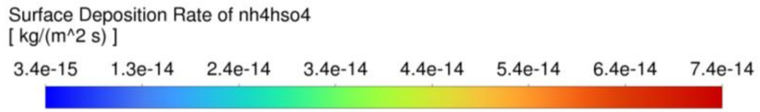
ABS formation in FN profiles was found to be different from that in the DU profiles.

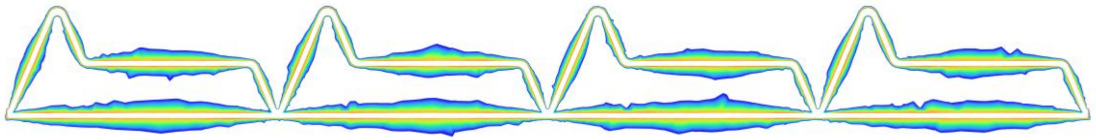
Results

ABS formation and deposition in FN profile of section plane

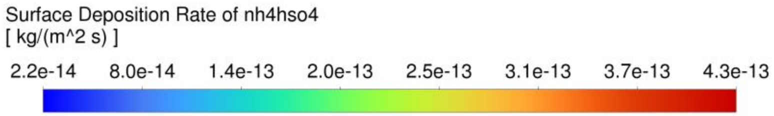


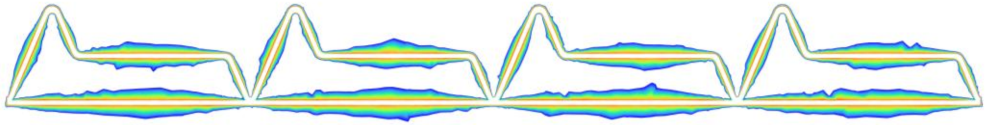
a) 460 K



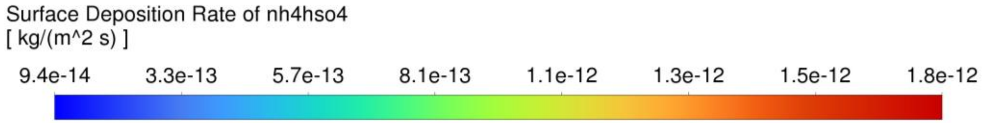


b) 510 K





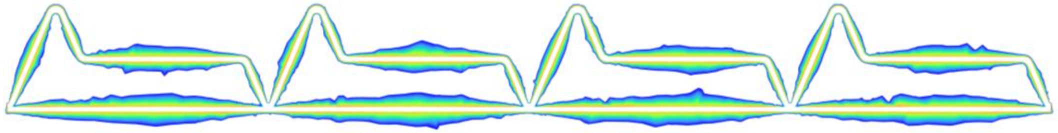
c) 560 K



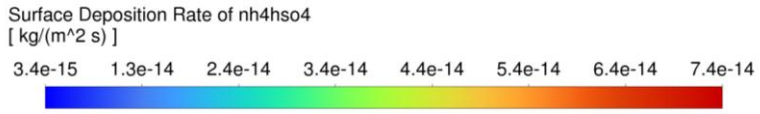
While the formation and distribution in the DU profiles were more balanced, it was observed that the formation was faster in the FN profiles at flat levels.

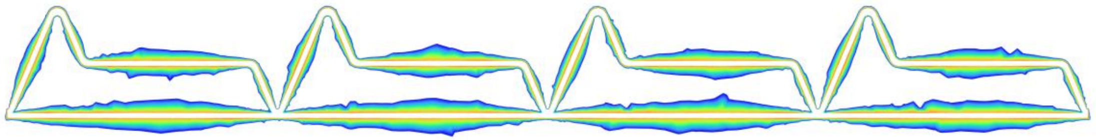
Results

ABS formation and deposition in FN profile of section plane

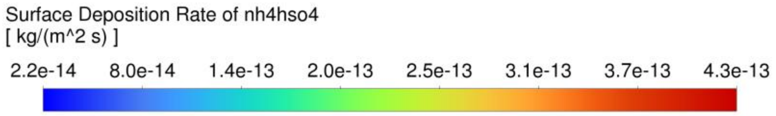


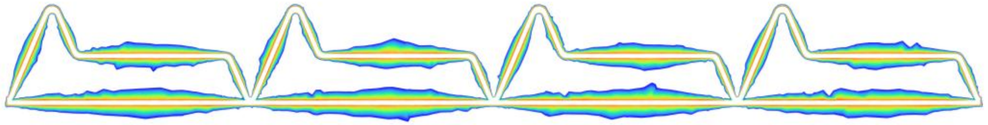
a) 460 K



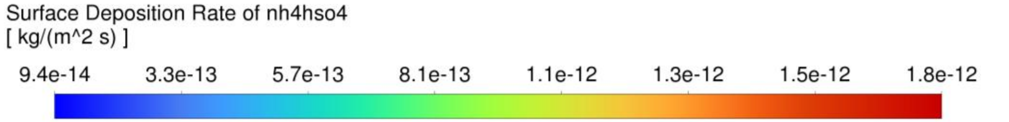


b) 510 K





c) 560 K



This was interpreted as a result of the shorter and narrower structure of the FN channel profiles.

Results

Comparison of ABS formation and deposition in DU and FN profiles

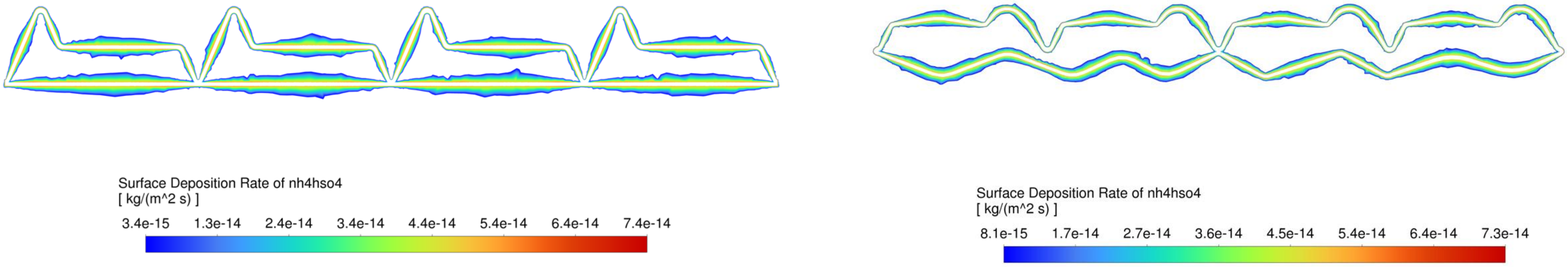


Fig. ABS formation on the surfaces for FN and DU profiles for 460 K – Cross-sectional view (z = 10 cm)

- The average ABS formation rates in the FN and DU profiles are similar. The main difference lies in the surface distribution of the deposits.

Results

Comparison of ABS formation and deposition in DU and FN profiles

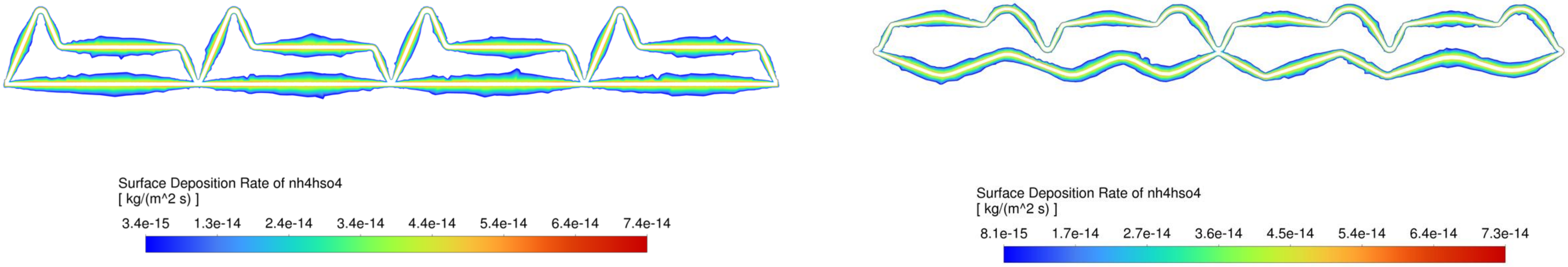


Fig. ABS formation on the surfaces for FN and DU profiles for 460 K – Cross-sectional view (z = 10 cm)

- In the DU profile, the ABS distribution shows a more balanced flow distribution due to wider flow channels, and the tendency for channel closure is lower.

Comparison of ABS formation and deposition in DU and FN profiles

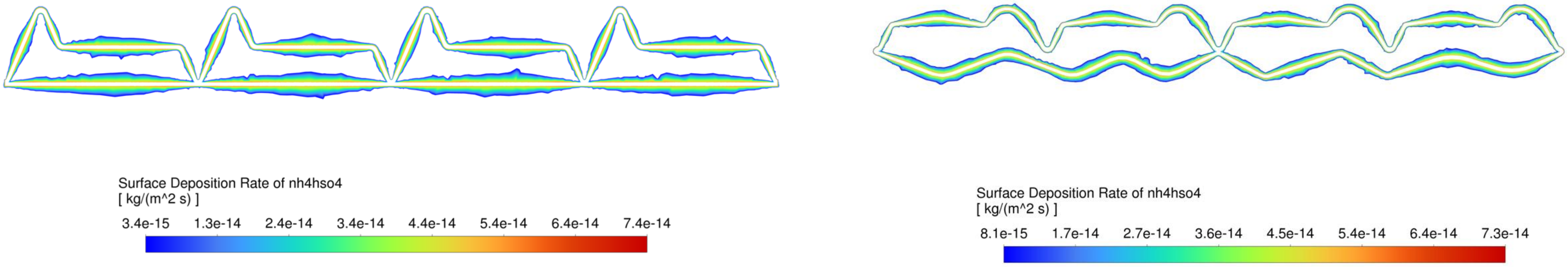
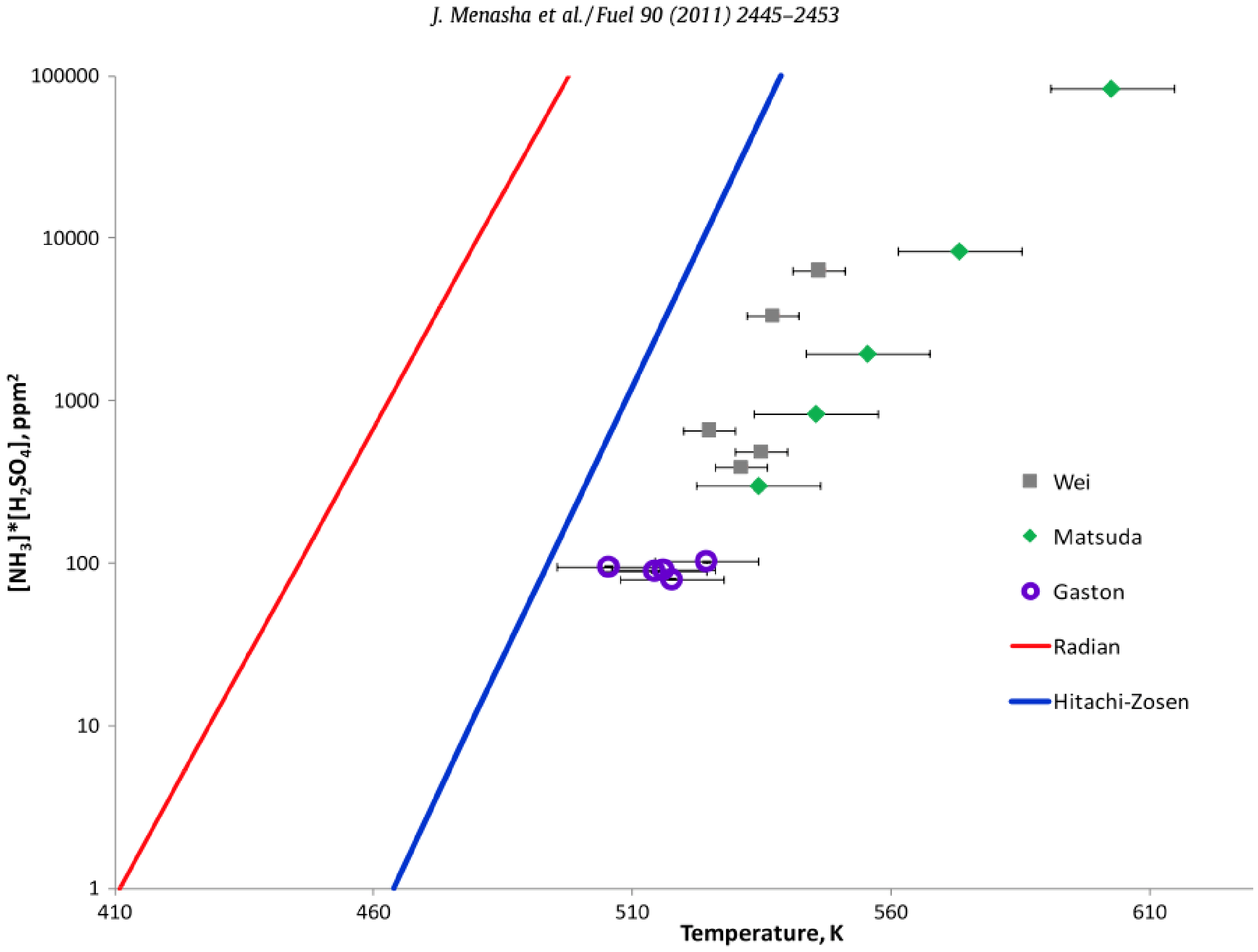


Fig. ABS formation on the surfaces for FN and DU profiles for 460 K – Cross-sectional view (z = 10 cm)

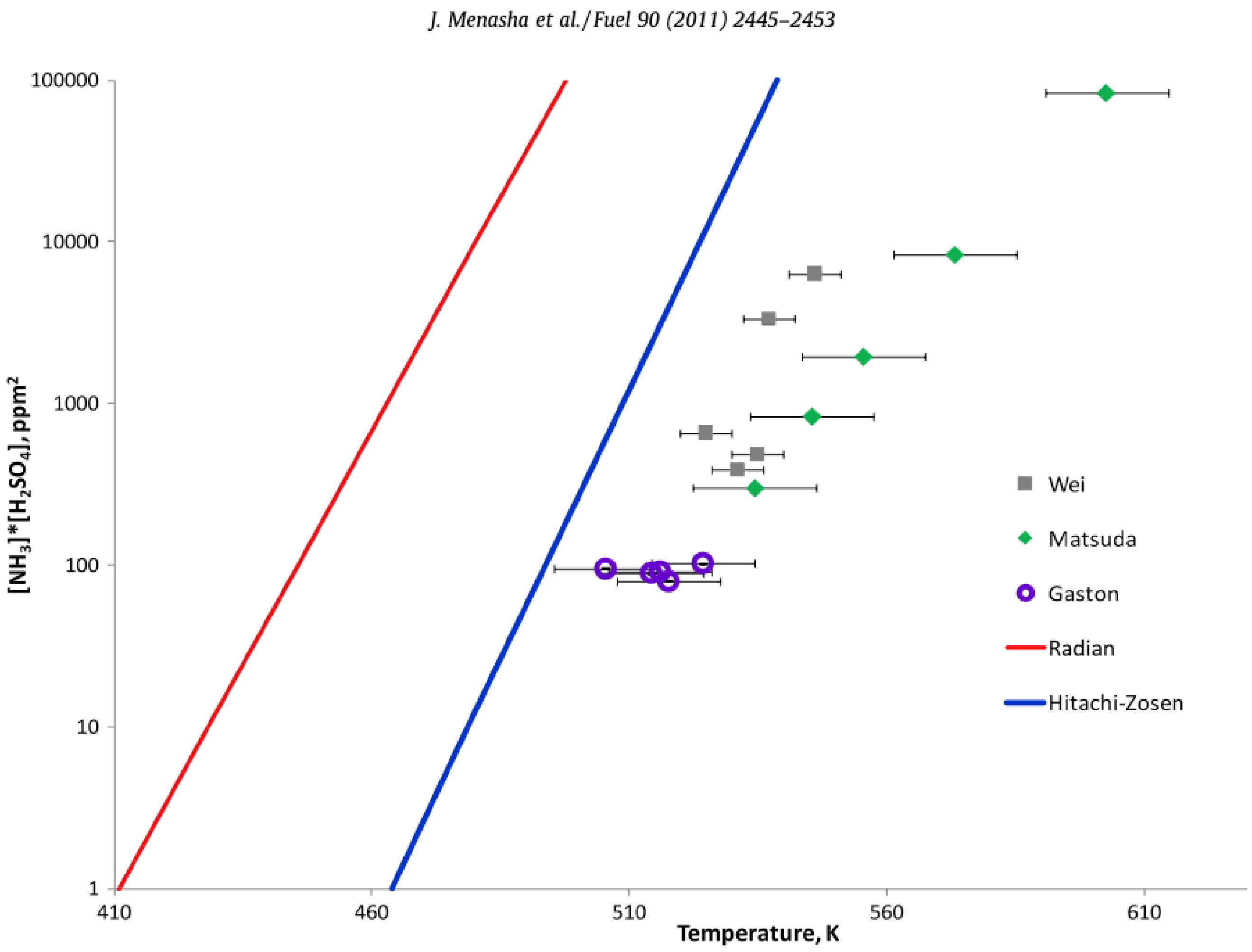
- In the FN profile, ABS accumulation is greater in flat areas, and the distribution is irregular. This increases the probability of local blockages and the risk of channel narrowing.

Compare with the literature



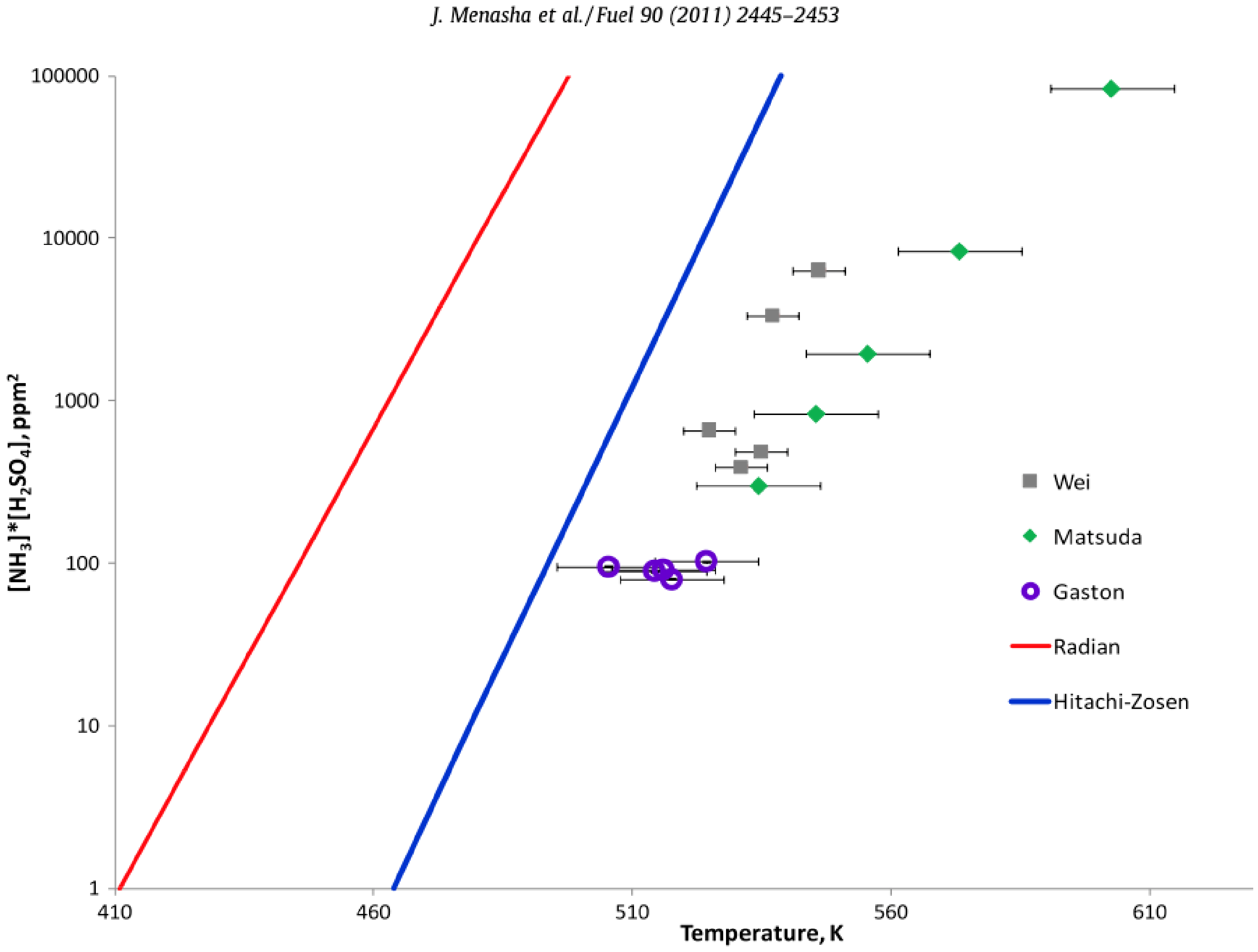
There is no information in the literature regarding the amount and timing of direct ABS formation, but there are some studies on the potential for ABS formation.

Compare with the literature



It has been reported that ABS formation is expected in the regions above the curves in the graph (critical/dewpoint-like threshold).

Compare with the literature

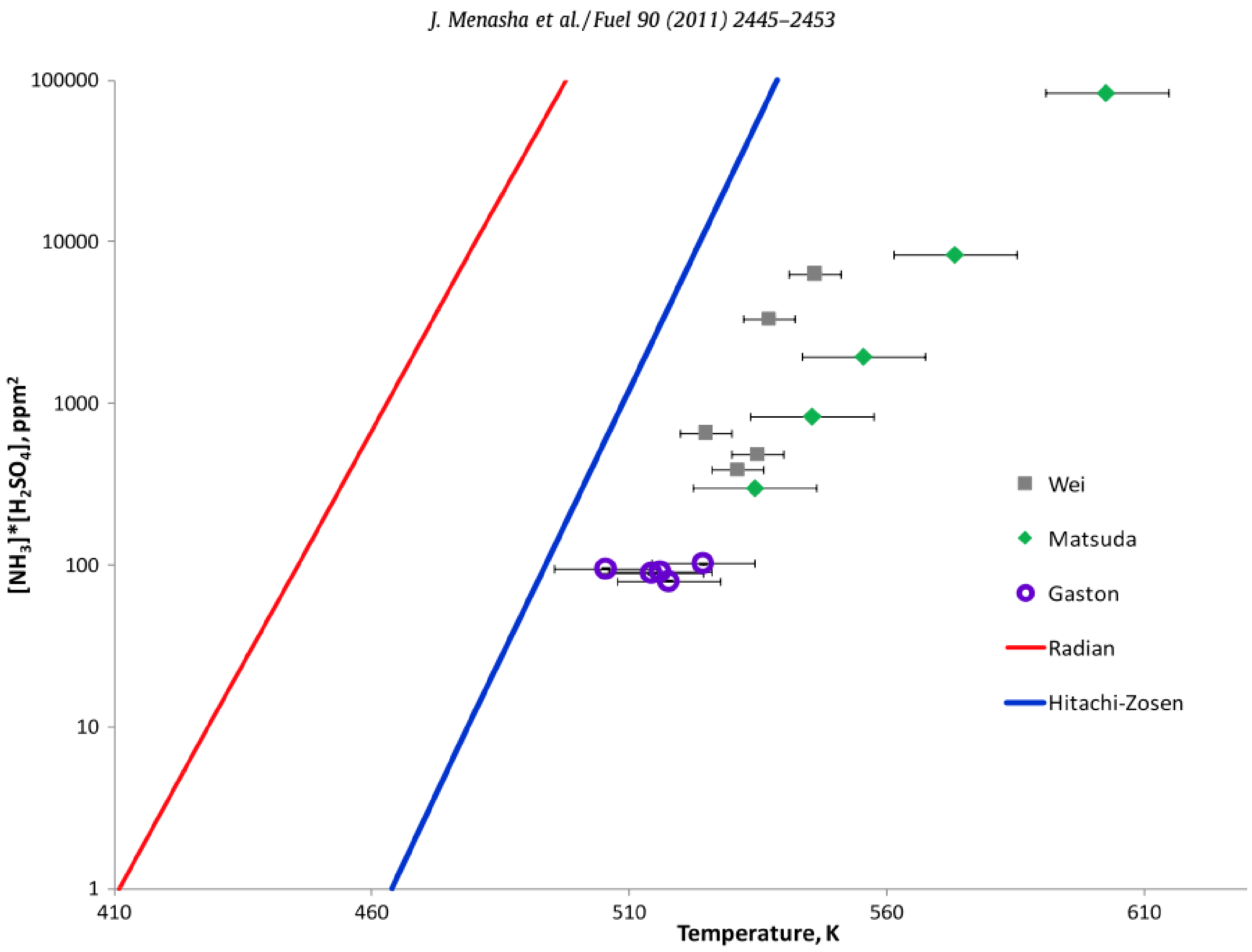


In this study, the rate and accumulation of ABS formation were numerically determined to increase rapidly with temperature

(460, 510, and 560 K)

(~10^{-14} → 10^{-13} → 10^{-12} $kg/m^2 \cdot s$).

Compare with the literature



In terms of the magnitude determined (kg/m^2.s), it is a contribution to the literature and confirms the usability of numerical modeling.

Conclusions

Geometry

- Similar average ABS accumulation rates are observed in the FN and DU profiles, but their surface distributions are distinctly different.
- In the DU profile, the density is higher in the regions close to the inlet; however, the channel narrowing progresses more slowly compared to the FN profile.

Conclusions

Temperature

- ABS accumulation sharply increases with temperature in the 460–560 K range; this is consistent with the intermediate temperature window reported in the literature.

- In this range, the tendency to adhere to surfaces increases and the likelihood of clogging rises.

Conclusions

Operational

- Average values alone are insufficient for design and operational decisions; the distribution of deposition determines the risk of pressure loss and clogging.

- Early narrowing in FN can cause an increase in ΔP and the risk of sudden stoppage; the cleaning plan should be optimized accordingly.

- In geometry selection, accumulation topology should be considered as much as heat transfer.

Conclusions

Modelling

- The developed CFD–species model is suitable for predicting ABS formation behavior and for preliminary design approaches.

- Converting the accumulation flow to mm/year will provide direct input for maintenance planning and life assessment.

Suggestions

- ABS formation can be expanded to the entire air preheater system
- For different geometries, the effects of ash load and dynamic conditions can be evaluated
- Strategies can be developed to extend maintenance intervals and increase efficiency

Thank you