CAQ III - Cabin air quality assessment of long-term effects of contaminants

CAC-Event Simulation & Chemical Characterization

Dr. Florian Mayer, Fraunhofer IBP, Holzkirchen
Dr. Sven Schuchardt, Fraunhofer ITEM, Hannover

CAC-Event Simulation & Chemical Characterization

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Objectives

- Generation of controlled and worst-case bleed air oil-contamination events in a simulator (BACS) to thoroughly characterize the fume composition and to allow exposure tests for toxicological assessment
- Selection of analytical methods based on already existing data on cabin air and oil analyses regarding expected contaminant concentrations
- Connection of the test bench (BACS) to the mobile toxicological laboratory (RIVM MAPCEL) via a transfer-line and proof that fume transfer works and oil fume composition remains the same
- Performance of pre-tests and dose range finding prior to main exposure test
- Use of BACS to simulate HEPA filter contamination by an oil related fume event and comparison with HEPA filters from real aircraft exposed / not exposed to a reported (oil) fume event

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Simulation of CAC events by use of a Bleed Air Contamination Simulator (BACS)

- BACS emulates the air supply system of an aircraft cabin
- Bleed air contamination events are simulated by dosing the contaminant (e.g. Mobil Jet Oil II) into hot (up to 590 °C), compressed (up to 8 bar) air and leading this through several expansion and cooling steps until the air has reached ambient conditions ("cabin" / sampling vessel)
- Bleed air dilution by recirculated air is omitted
- Focus will be put on engine oil contamination events as these are of biggest concern
- At ambient conditions the air will be thoroughly characterized by on-line monitoring and off-line analyses especially with regard to engine oil breakdown products
- Knowledge of the physico-chemical composition of the air is the pre-requisite for toxicological hazard identification and the targeted animal exposure studies in the RIVM mobile toxicological laboratory

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Advantages

- BACS allows the generation and measurement of possible bleed air contamination by an oil-related fume event independent from aircraft variables (age, type of engine, engine configuration, ECS, air distribution system, etc.)
- Potential contaminants can be introduced in a controlled way
- Sensors and measuring equipment along the air path allow thorough characterization

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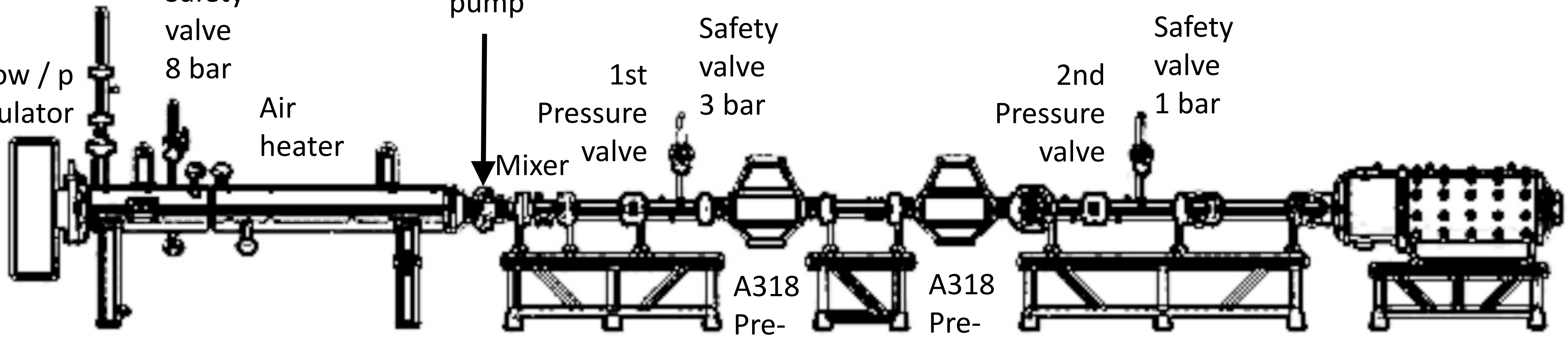
Bleed Air Contamination Simulator BACS



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Bleed Air Contamination Simulator BACS

- T possible up to 590 °C and p possible up to 8 bar
- Previous experiments:
  - Different oils (engine / hydraulic)
  - Amounts up to 80 mg/m³
  - Ideal for chemical analysis: 1 mg/m³
  - Most breakdown products at T = 350 °C
  - No to minimal influence of pressure

- ➢ BACS set point T = 350°C, p = 6 bar
- ➢ Mobil Jet Oil II (most commonly used)
- ➢ ACER/VIPR experiments dosed 6 mg/m³
- ➢ Range finding experiments planned to see effects
- ➢ Worst case starting point 50-100 mg/m³

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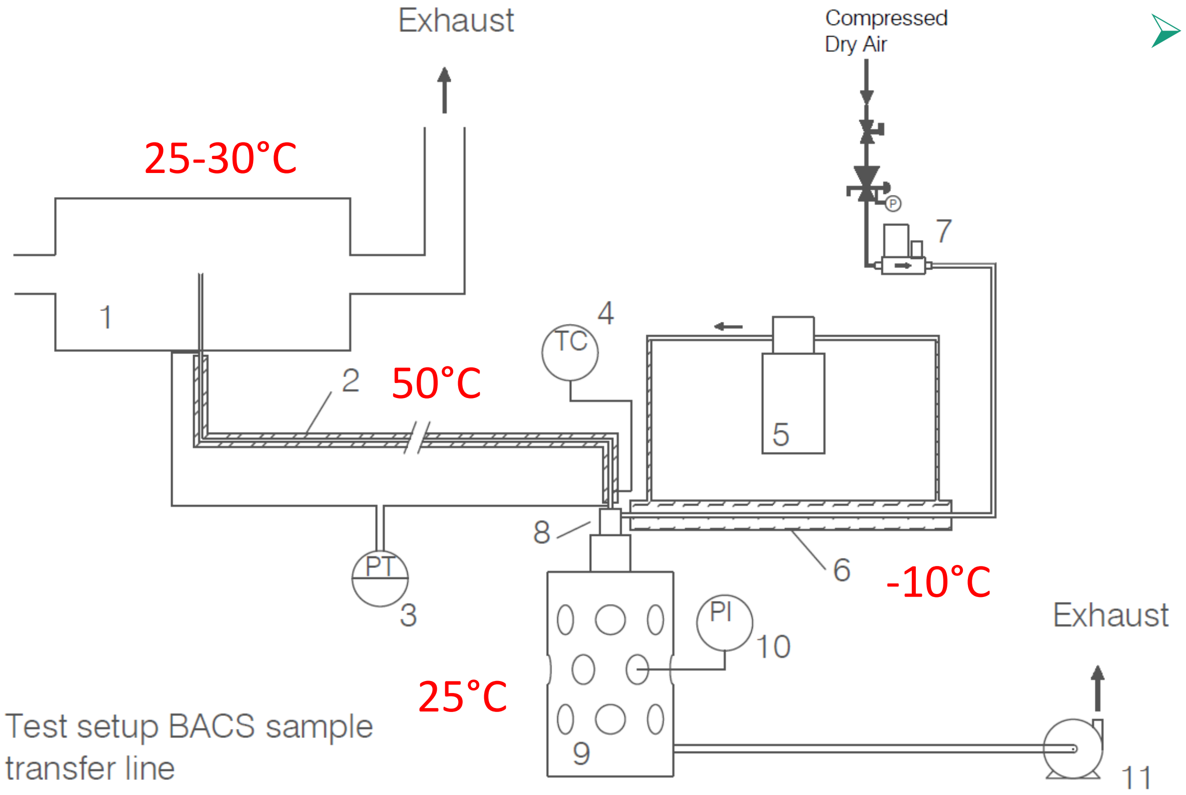
Connection of the exposure units in the MAPCELs to the BACS vessel via a transfer-line



Test setup BACS sample transfer line

- Are there any alterations in the oil fume composition caused by the transfer-line?

1: BACS sample vessel
2: sample line with electrical heating
3: pressure transmitter
4: temperature controller
5: cooling bath
6: heat exchanger
7: mass flow controller
8: eductor
9: inhalation unit
10: pressure indicator
11: pump

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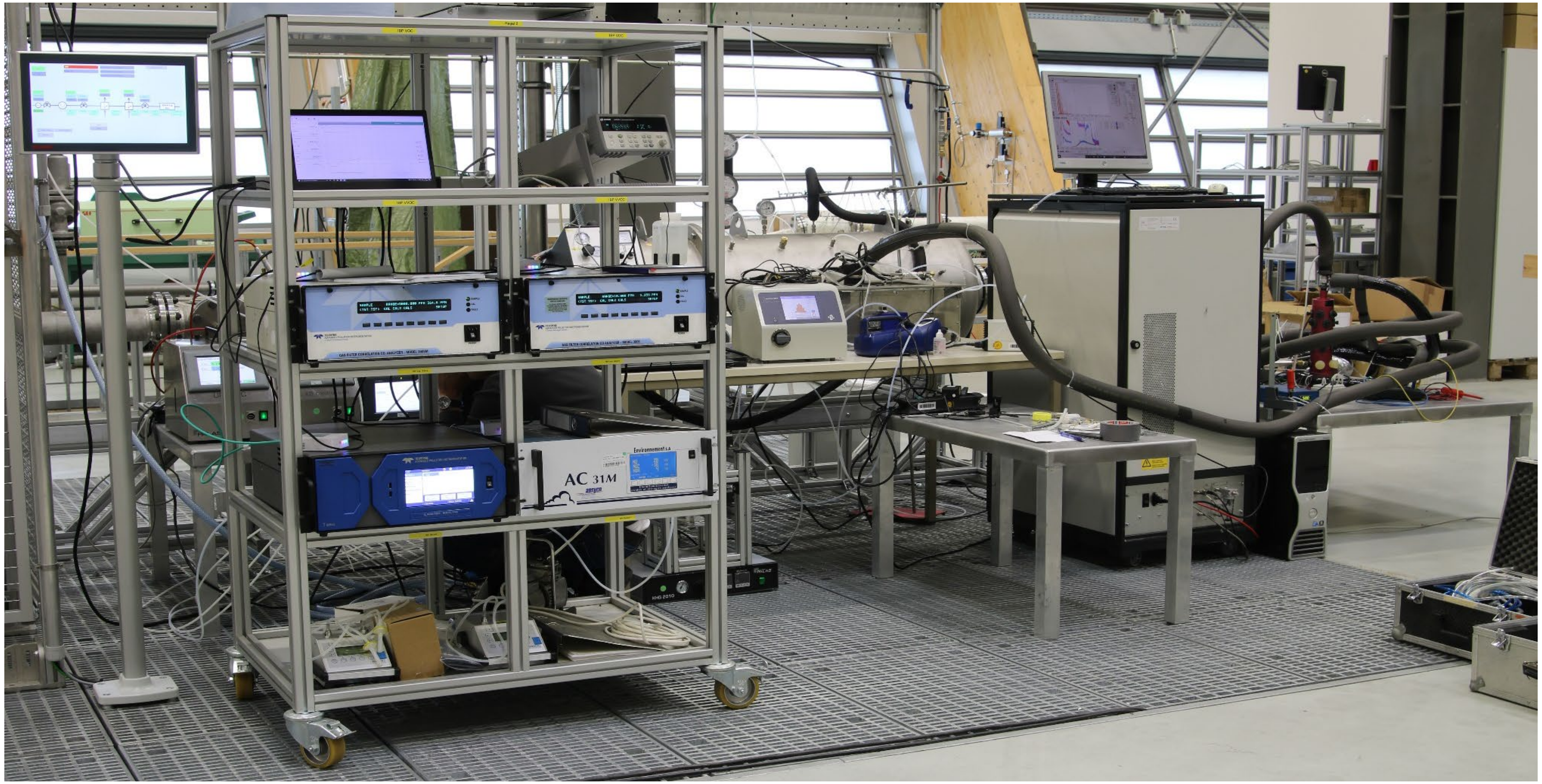
Instrument set-up around BACS during pre-tests



Worst case length of transfer-line from BACS to exposure unit in MAPCEL: 9 m

Rental PTR-MS from Ionicon, Innsbruck, with remote access from Airbus HH

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Pre-tests

- Dosing of MJO II to check whether at the end of the transfer-line after 1:1 dilution the oil vapour composition remains the same
- Dosed oil amounts: 1, 3, 5, 6, 10, 20, 30, 40, 50, 60, 100 mg/m³ (100 is the planned start concentration)
- Measurement locations:
  - BACS vessel (before transfer-line),
  - exposure unit after transfer-line and 1:1 dilution,
  - 1:10 dilution box (for PTR-MS at high oil concentrations)
- Sampling of VOCs, aldehydes, organic acids and organophosphates at BACS vessel before the transfer-line and after the transfer-line and 1:1 dilution for ITEM

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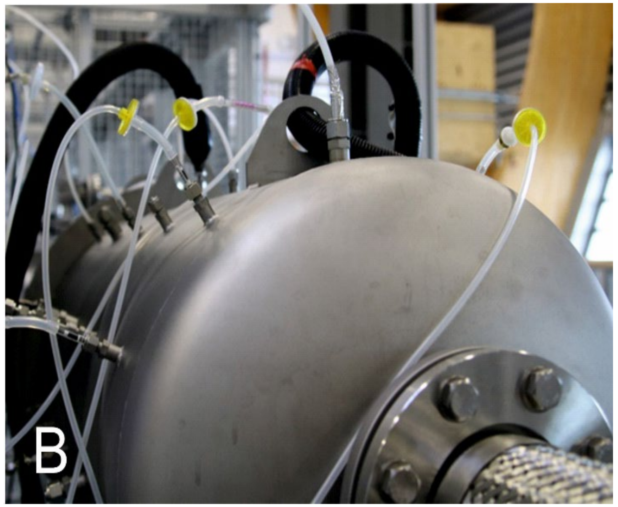

BACS on-line analytics

Compound	Measurement principle	Measurement range
Carbon monoxide CO	IR absorption	1 - 1000 ppb
Carbon dioxide CO_2	IR absorption	100 - 10000 ppm
Ozone O_3	UV Photometry (254 nm)	1 - 1000 ppb
Nitrogen oxides NO/NO_x	Chemiluminescence	1 - 1000 ppb
Total Volatile Organic Compounds (TVOC)	Flame Ionisation Detector FID or Photo-Ionisation-Detector PID	100 ppb - 100 ppm 1 - 10000 ppb
Selected Volatile Organic Compounds (VOCs)	on-line Proton-Transfer-Reaction-Mass-Spectrometry PTR-MS	1 ppt - 100 ppb
Aircraft operating fluids	Ion Mobility Spectrometer (Aerotracer), pattern recognition	Instrument own odor scale
Particulate Matter	different	10 nm – 20 µm

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On-line monitors

- Carbon monoxide (CO)
  - Measurement principle: IR at 4.7 µm
  - Interferences: CO_2 und H_2O - BACS air is dry, 0-1 % humidity
- Carbon dioxide (CO_2)
  - Measurement principle: IR at 4.3 µm
  - Interferences: H_2O - BACS air is dry, 0-1% humidity
- Nitrogen oxides (NO_x)
  - Measurement principle: Chemoluminiscence
  - Interferences: not known
- Ozone (O_3)
  - Measurement principle: UV at 254 nm
  - Interferences: SO_2, NO_2, NO, H_2O and aromatic hydrocarbon meta-xylene and mercury vapour (also other aromatic compounds? Particles?)

Since at 254 nm many compounds may absorb, we rather talk of an UV monitor!

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Particle counters for pre-tests

- TSI WCPC 3788 — 2.5 – 1000 nm, sampling rate 1.5 L/min
  (may be exchanged by a Butanol CPC if available from other project partners, Butanol CPC will be used in MAPCELs)
- TSI P-Trak 8525 — 20 – 1000 nm, sampling rate 0.1 L/min
- TSI Nanoscan SMPS 3910 — 10 – 421.7 nm, 13 channels, sampling rate 0.75 L/min
- TSI OPSS 3330 — 0.3 – 10 µm, 16 channels, sampling rate 1.0 L/min

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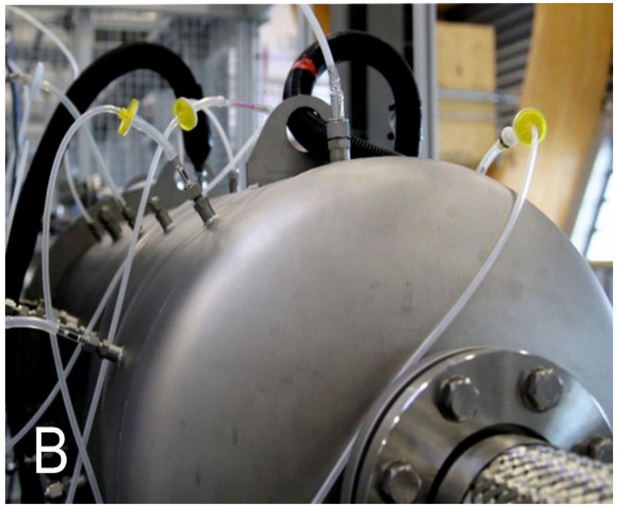

BACS off-line analytics (Fraunhofer ITEM)

Compound class	Method	Guideline	No of compounds covered	LOQ	LOD
VOCs	ATD-GC-MS	ISO 16000-6	> 150	0.05 - 0.3 µg/m³	0,01 - 0.2 µg/m³
Aldehydes / ketones	LC-UV (DNPH)	ISO 16000-3	15	~2 - 4 µg/m³	~1 - 2 µg/m³
Organic acids	GC-MS	OP-ITEM optimized for dust	12-14	0.1 µg/mL	0.03 µg/mL
Organo-phosphorus compounds	GC-MS	ISO 16000-31	22	2 ng/mL extract 25 ng ng/g dust	0.7 ng/mL extract 8.8 ng ng/g dust
Tri cresyl phosphates	GC-MS	OP-ITEM based on ISO 16000-31	10 isomers	1 ng/mL extract 13 ng ng/g dust	0.2 ng/mL extract 3 ng ng/g dust
Metals (Co, Be, Cr)	ICP-MS	OP-ITEM based on VDI 2267	3+x	~5 ng/g dust	~2.5 ng/g dust
Unknowns (all compound classes)	NMR / GC- and LC-MS / UV / IR	Fh-ITEM core competency	∞	not relevant	Approx. 50 µg absolute if NMR is applied

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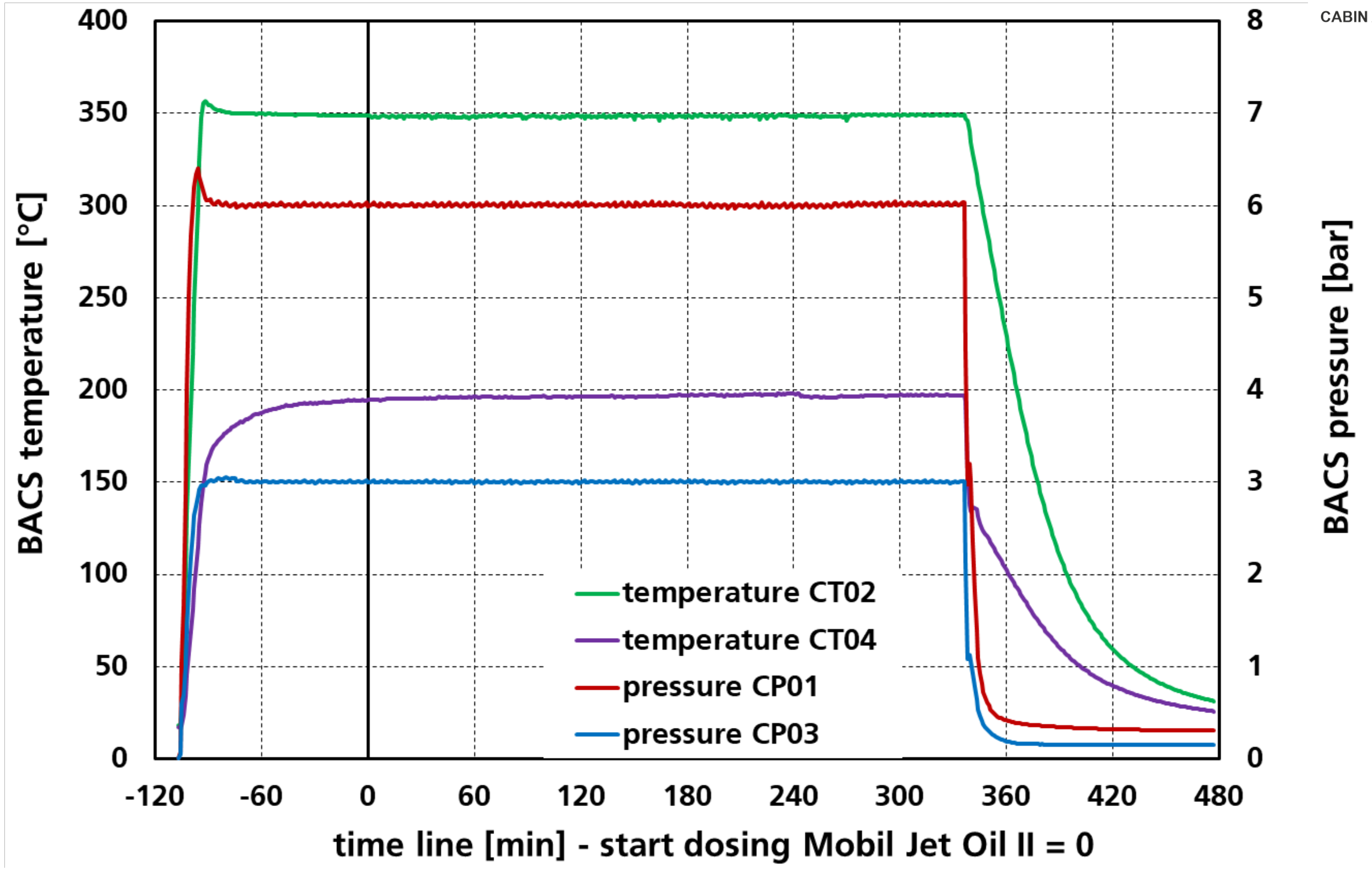
Stability of BACS T and p conditions over hours

Injection point
T = 350°C, p = 6 bar

Middle section
T = 200°C, p = 3 bar

Sampling vessel
T, p = ambient
T = 25-30°C
P = 0.92-0.96 bar



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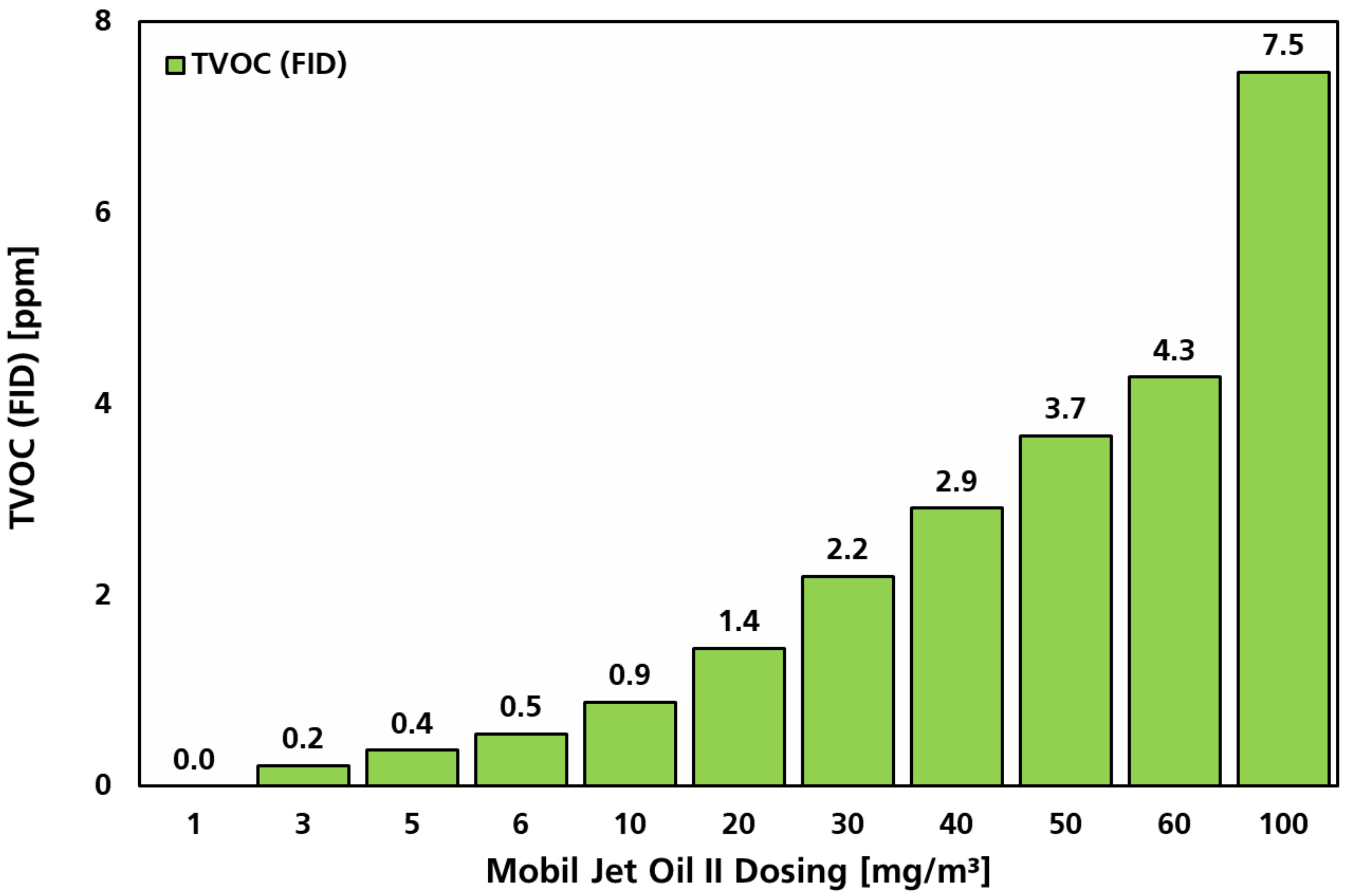
Flame Ionisation Detector (FID) reading depending on dosed oil amount



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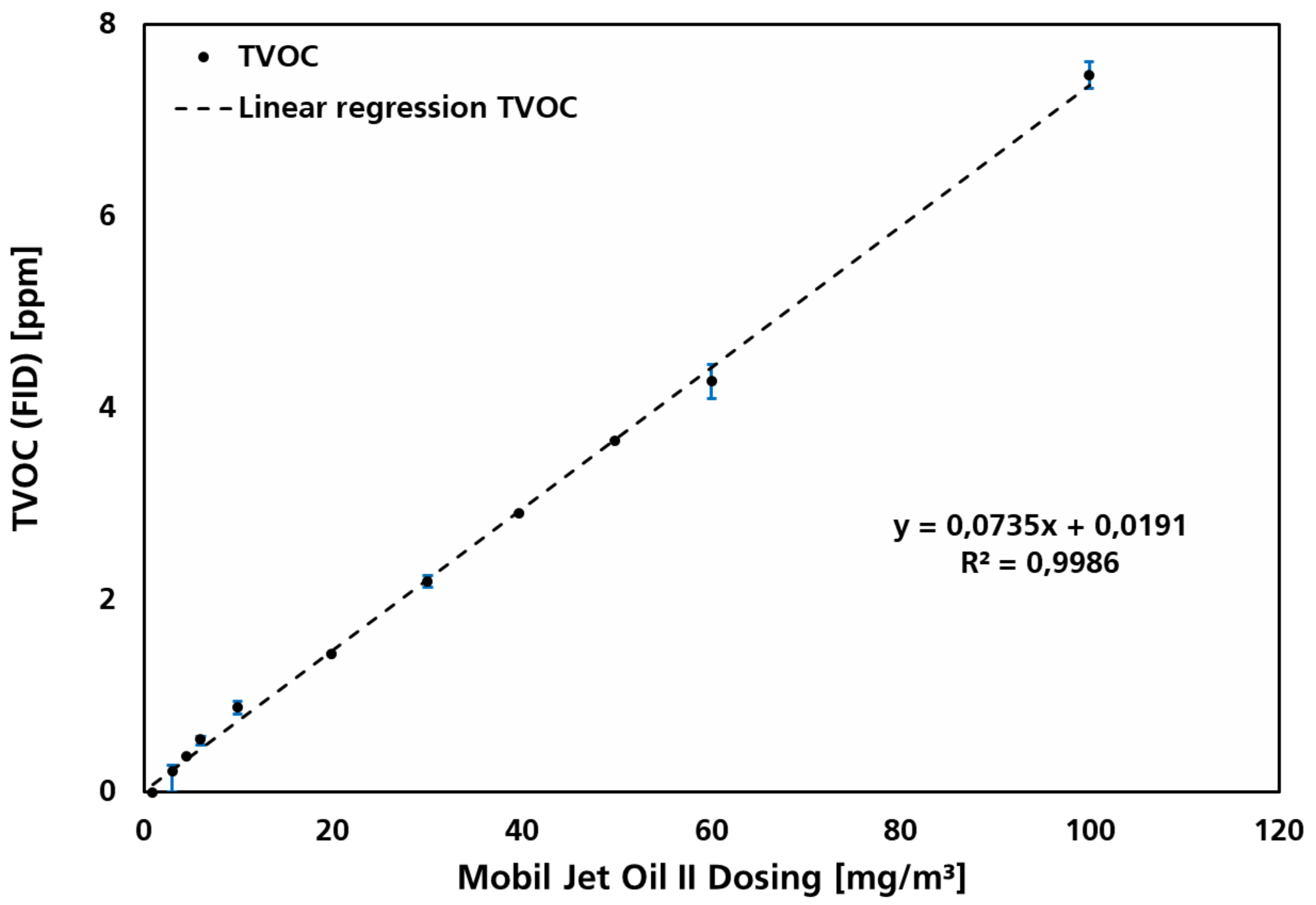
Linear regression FID



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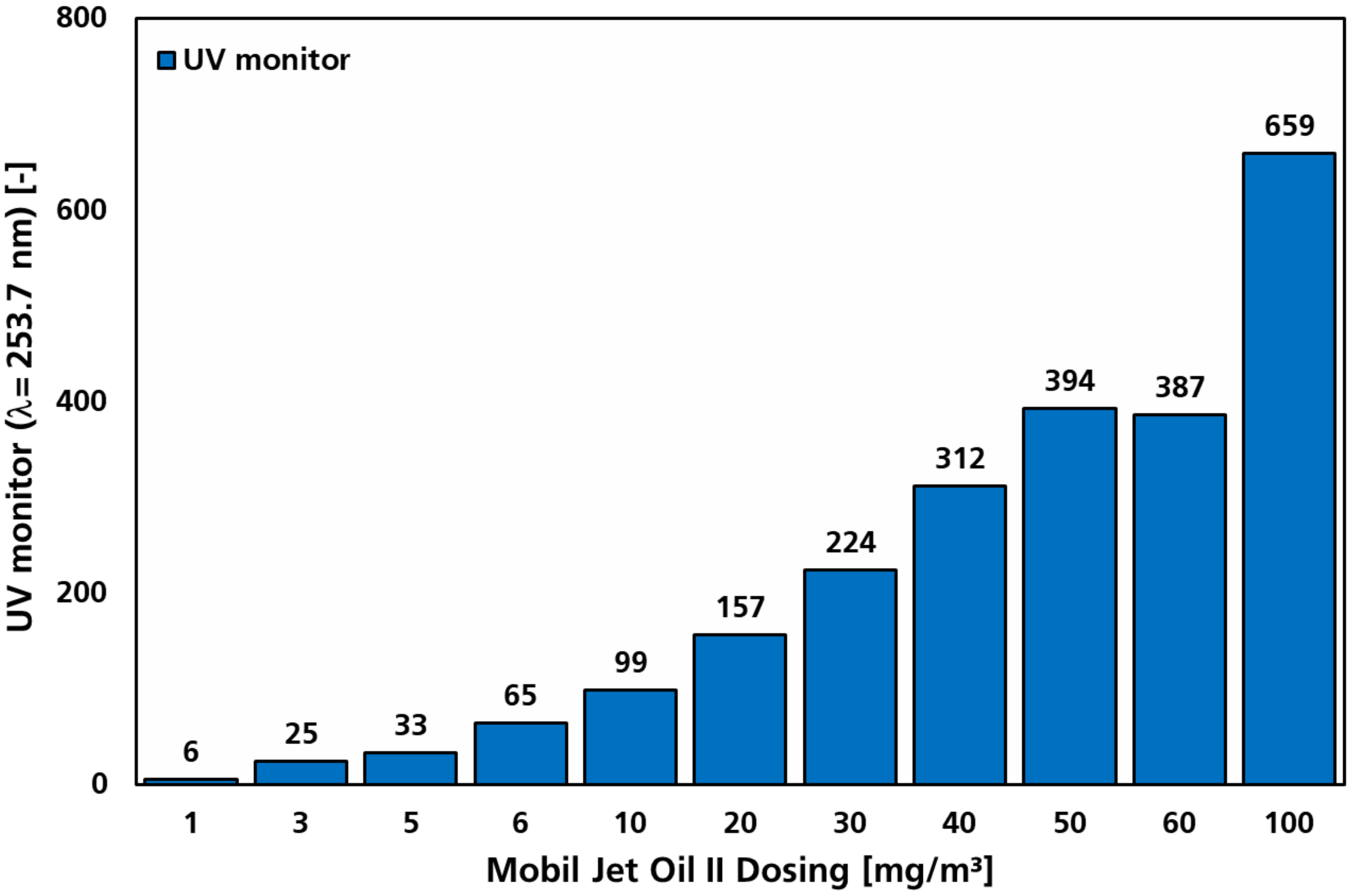
UV monitor reading depending on dosed oil amount



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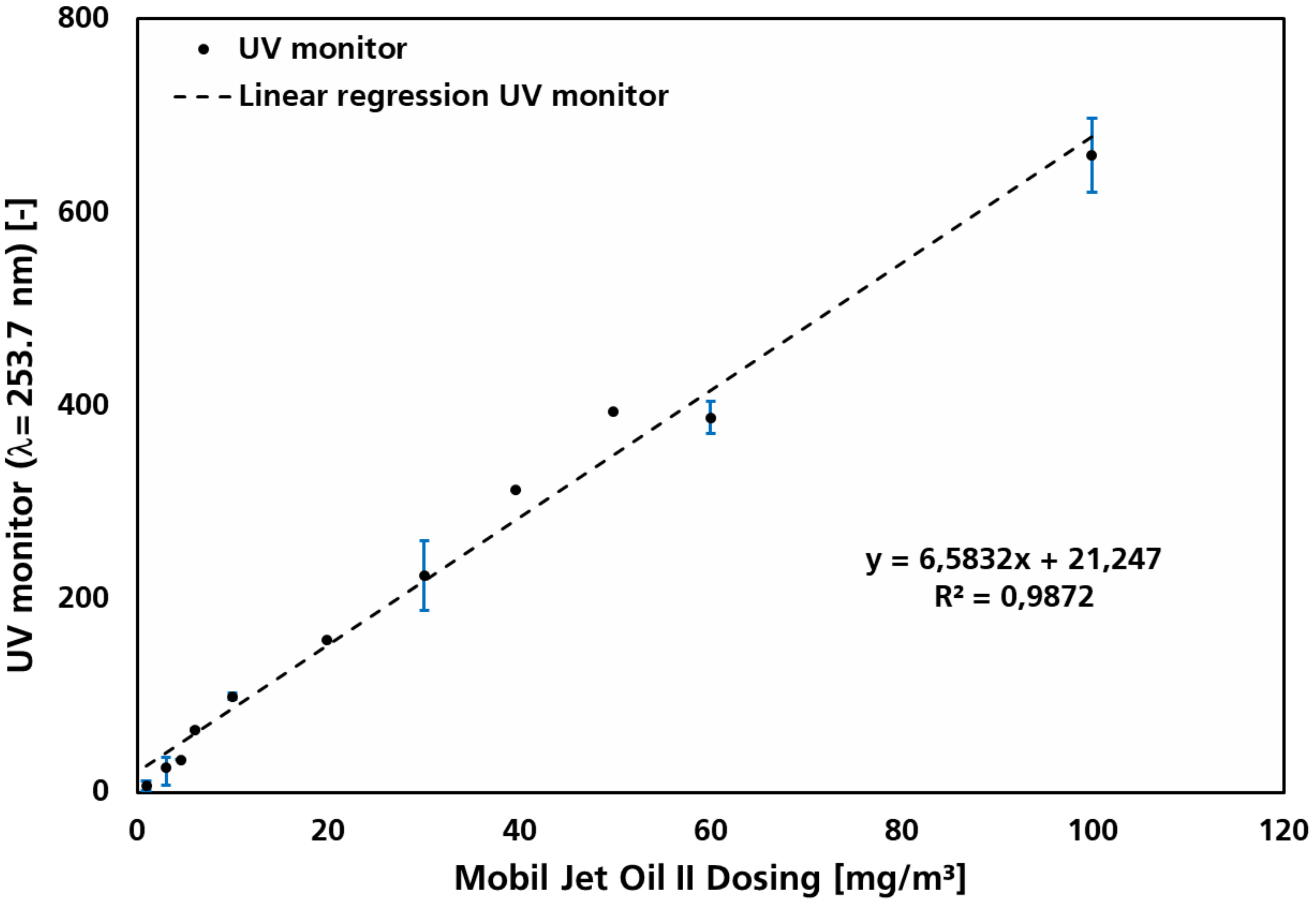
Linear regression UV-monitor



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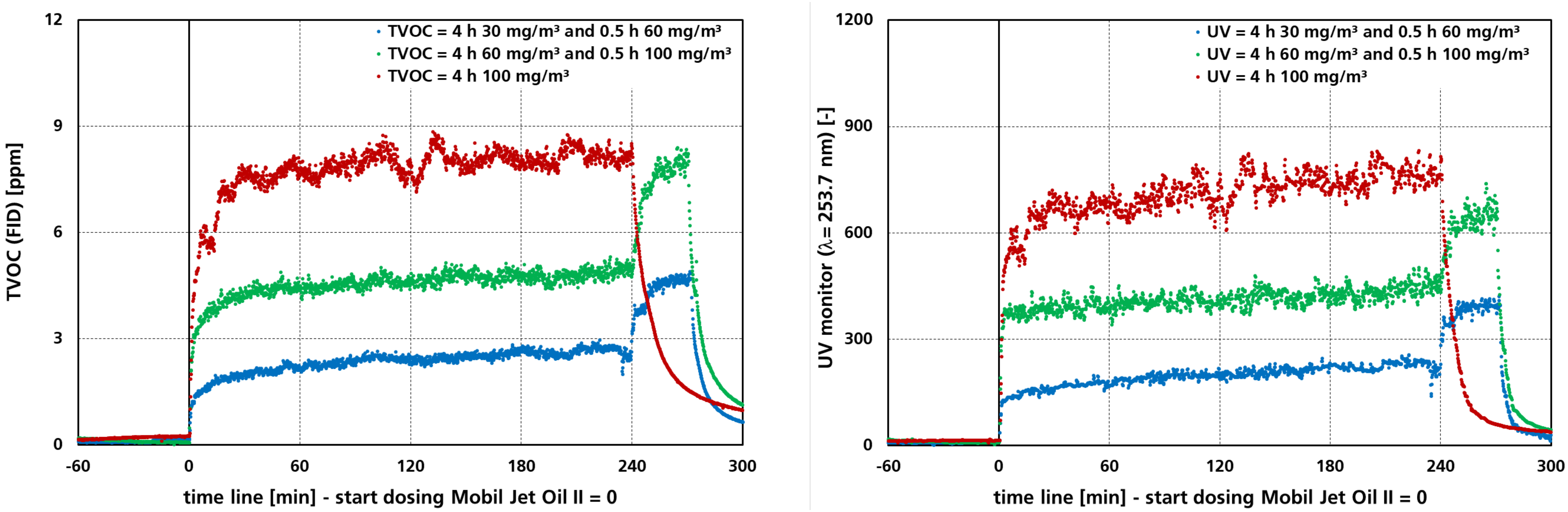
Monitoring stability and reproducibility when dosing high oil amounts over hours



- Oil dosing target concentration results in same monitor reading

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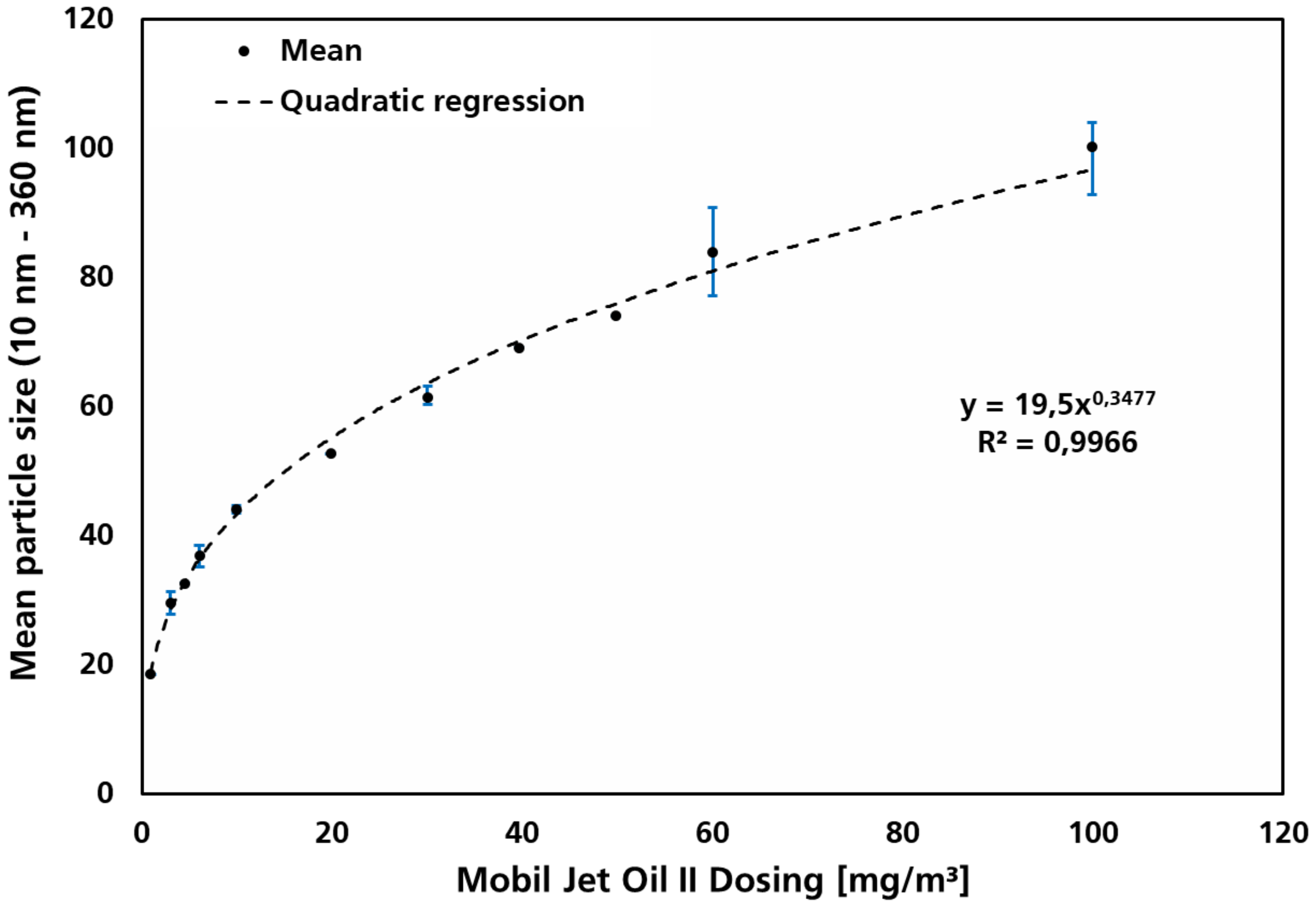

Max. mean particle size increases from ~20 to ~90 nm with dosed oil amount increase from 1 to 100 mg/m³

ASHRAE study at KSU on bleed air contamination with engine oils also showed that the max. particle size increases from ~50 to ~80 nm when injected oil amount is increased from 1 to 5 ppm

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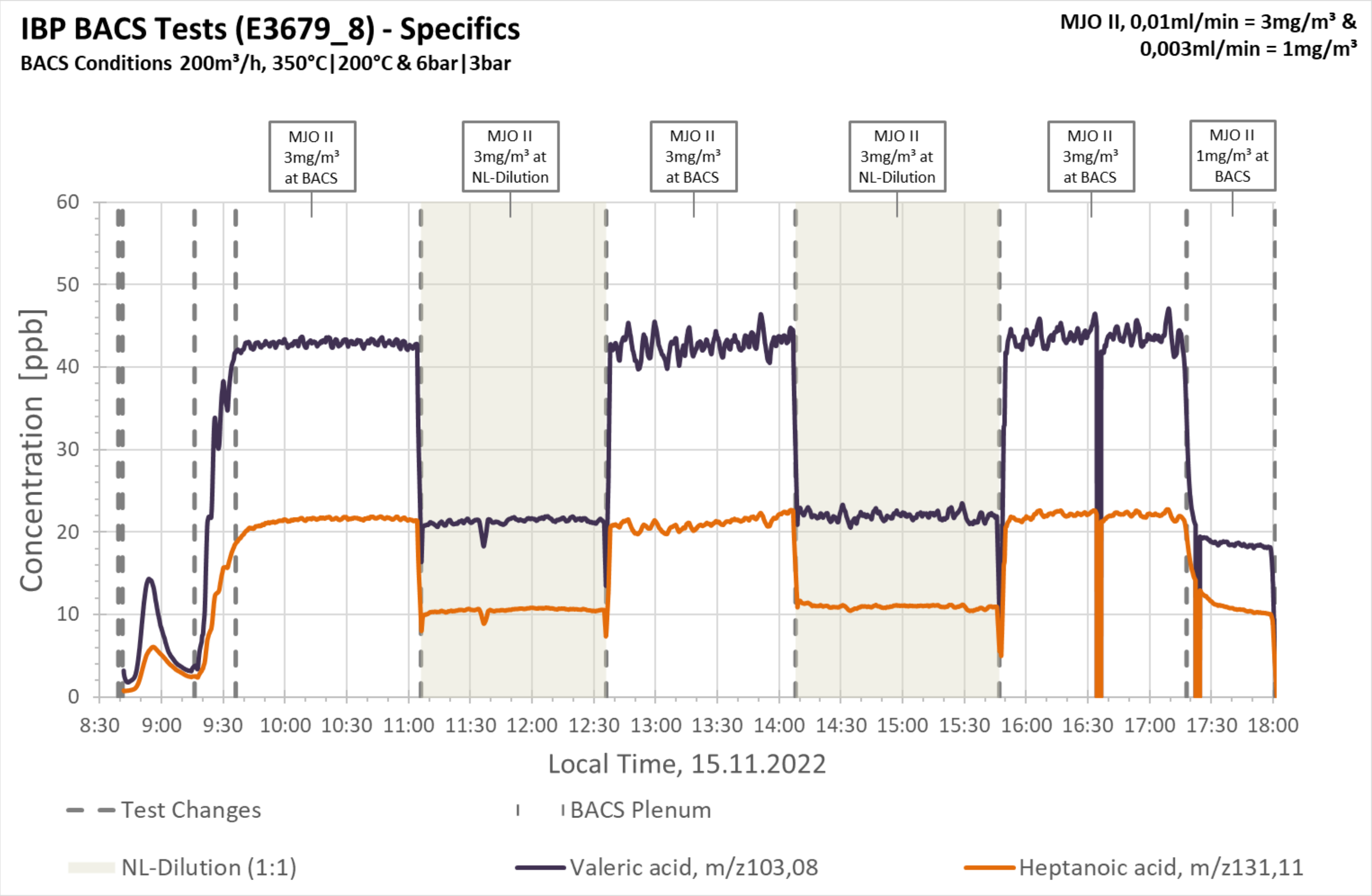
Dosing of MJO II to check whether at the end of the transfer-line after 1:1 dilution the oil vapour composition remains the same

PTR-MS results pre-tests Nov 15, 2022



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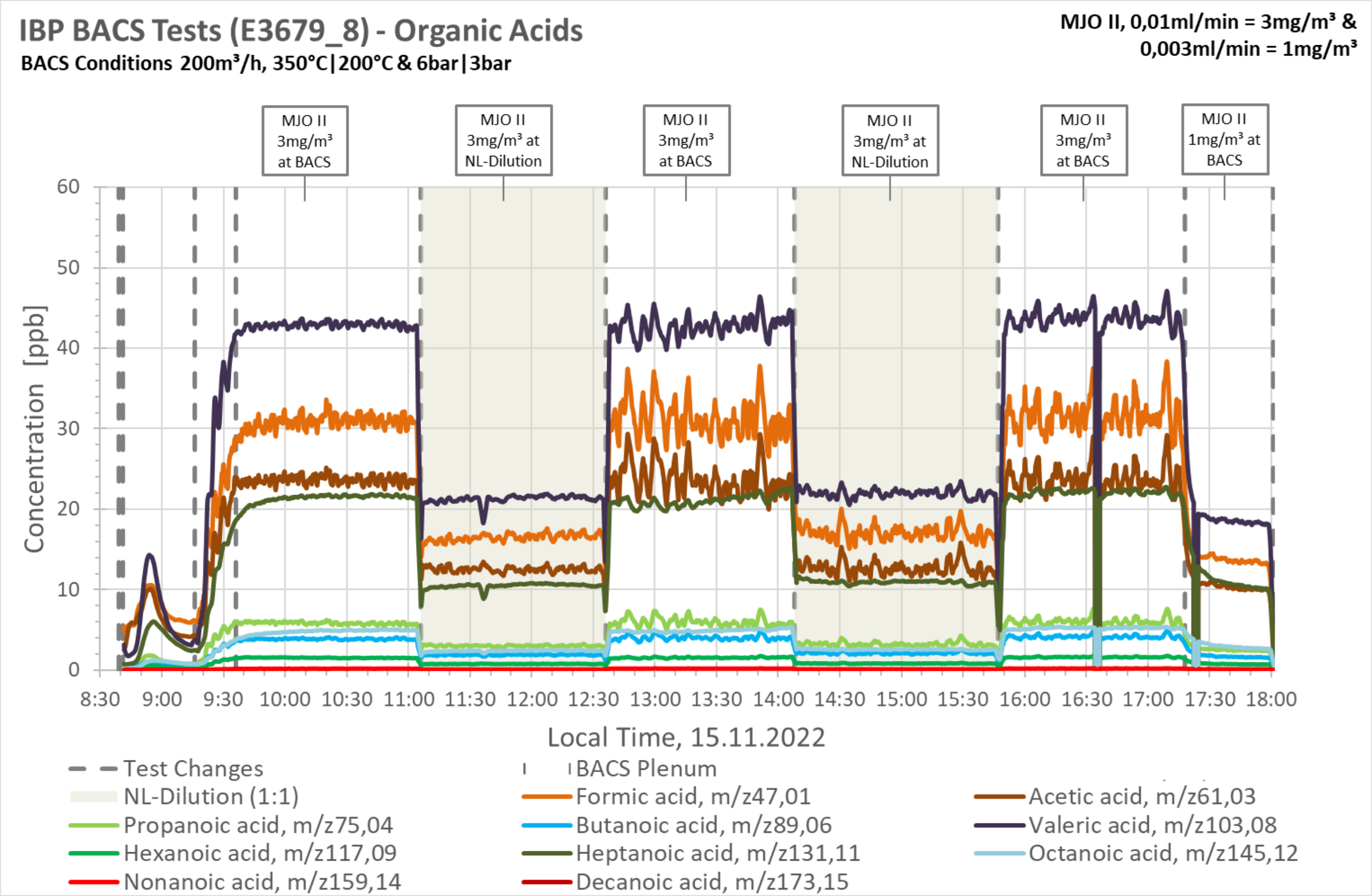

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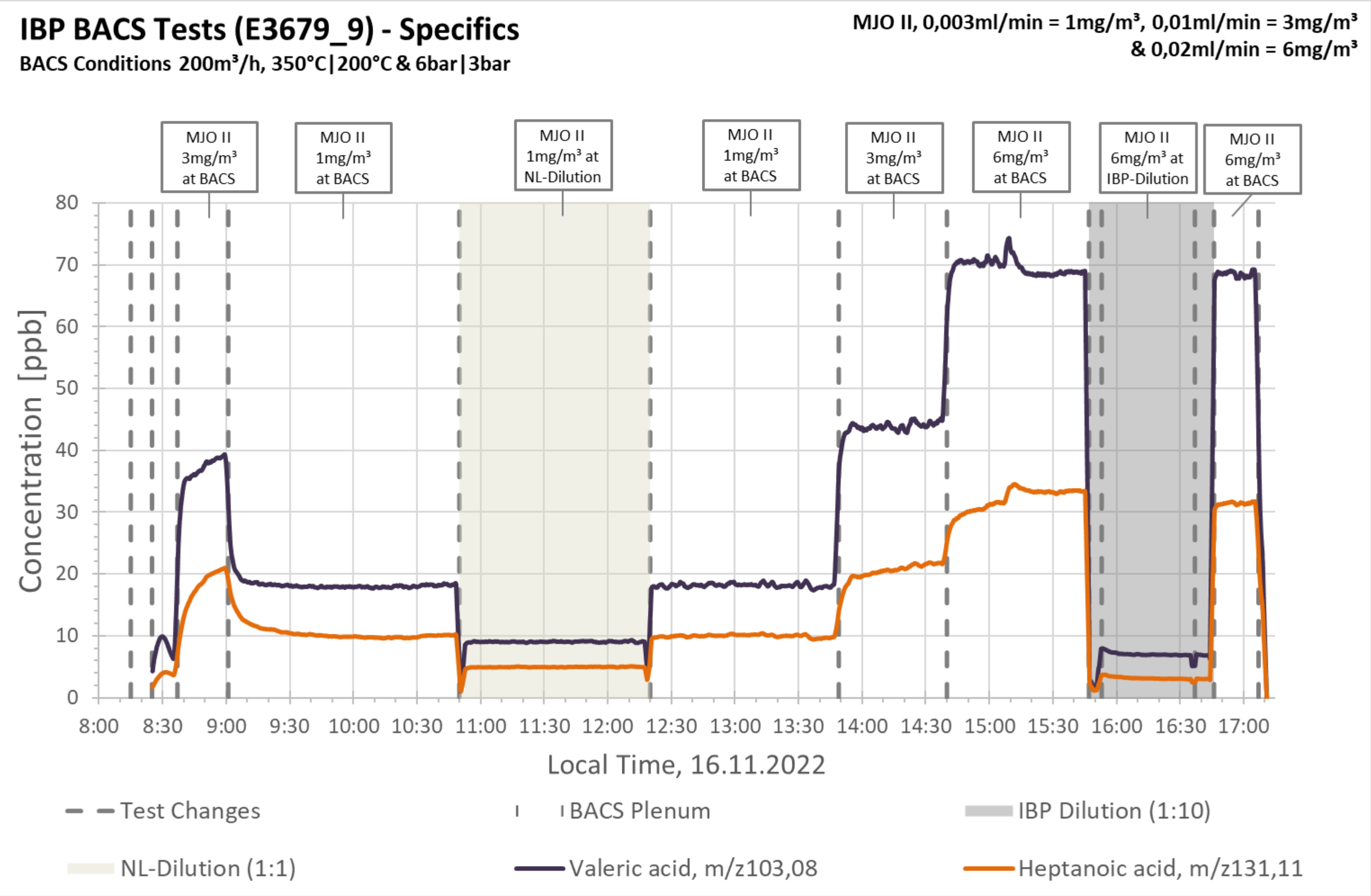
Dosing of MJO II to check whether at the end of the transfer-line after 1:1 dilution the oil vapour composition remains the same

PTR-MS results pre-tests Nov 16, 2022



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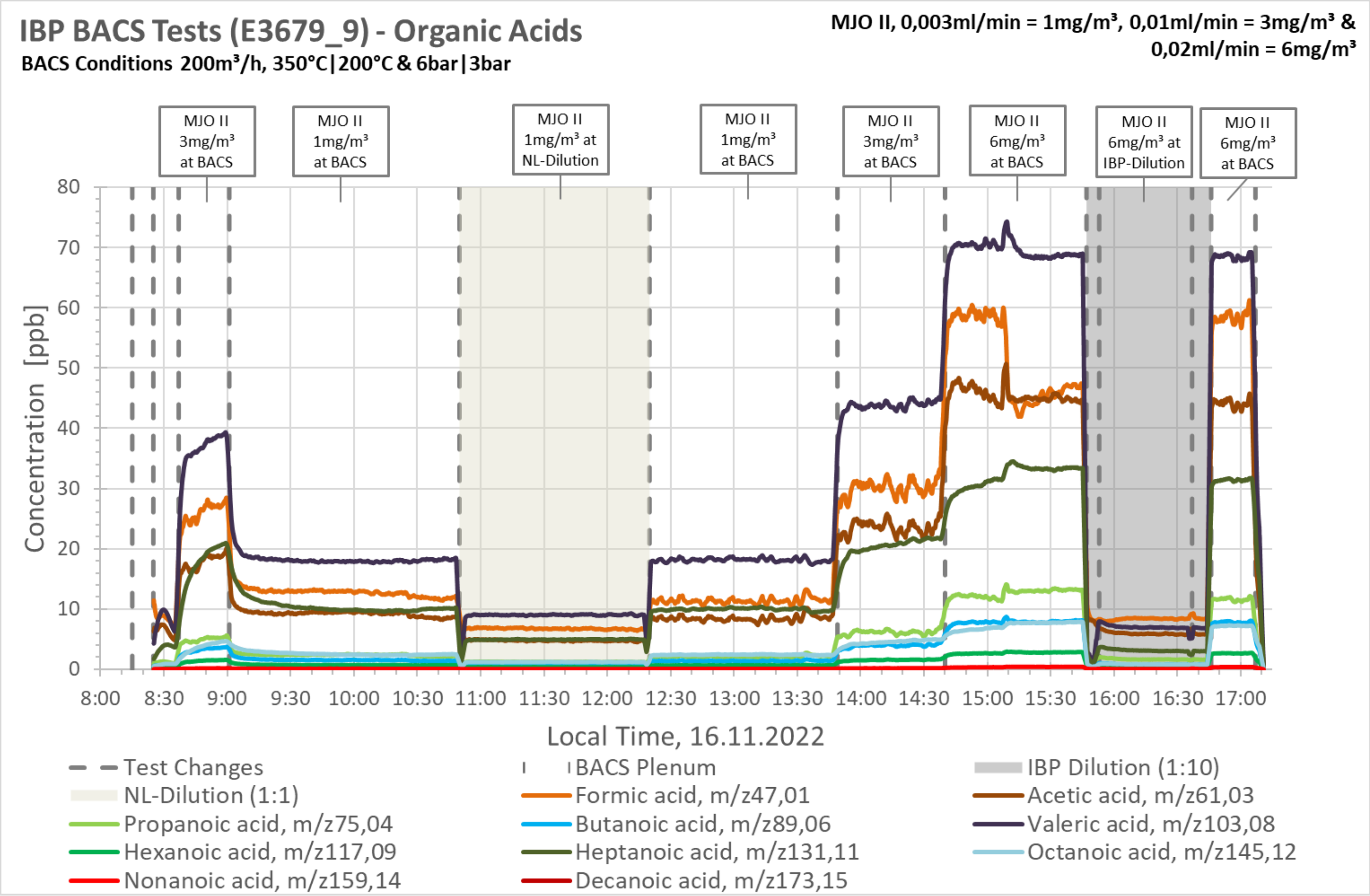

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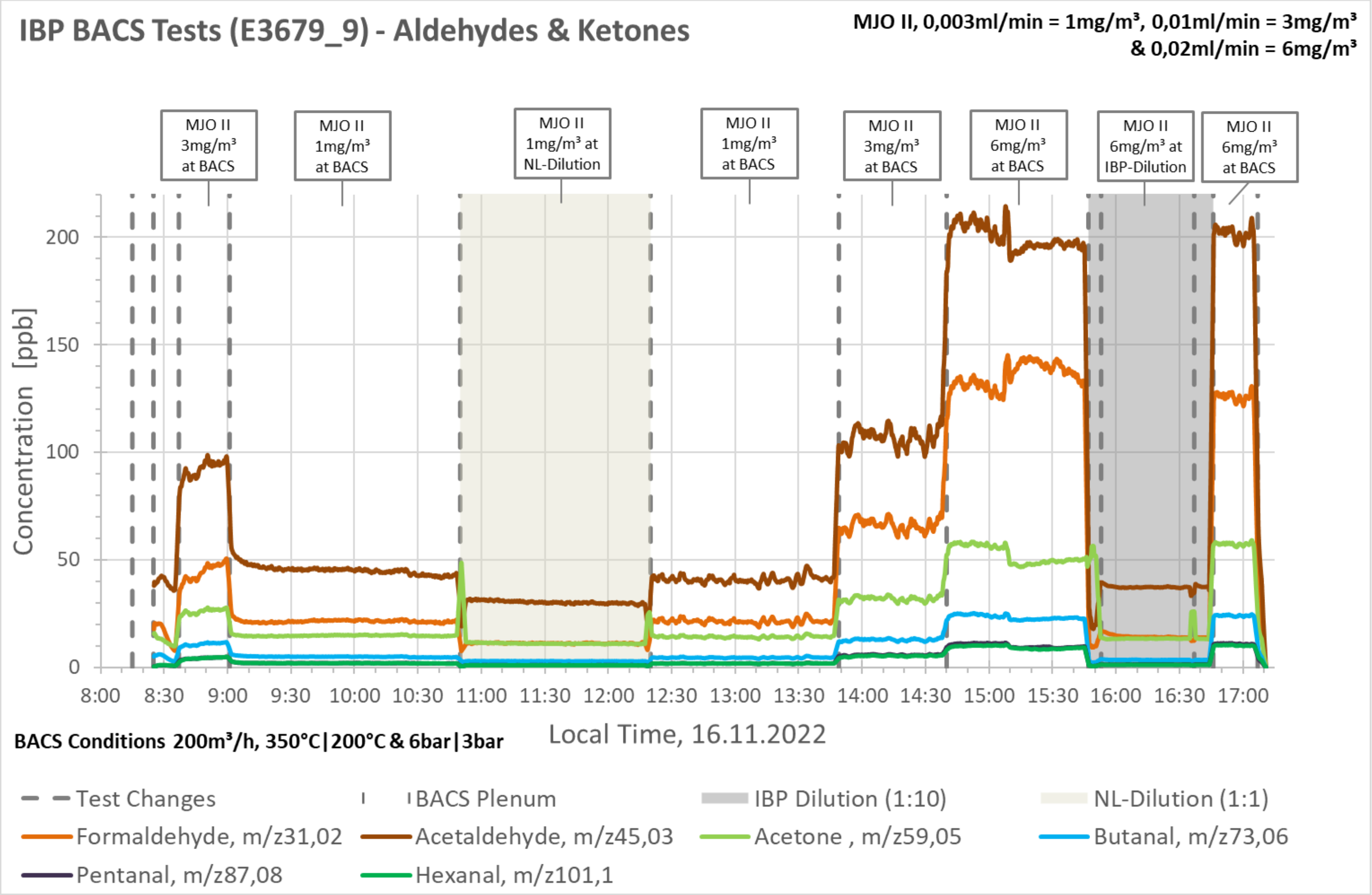

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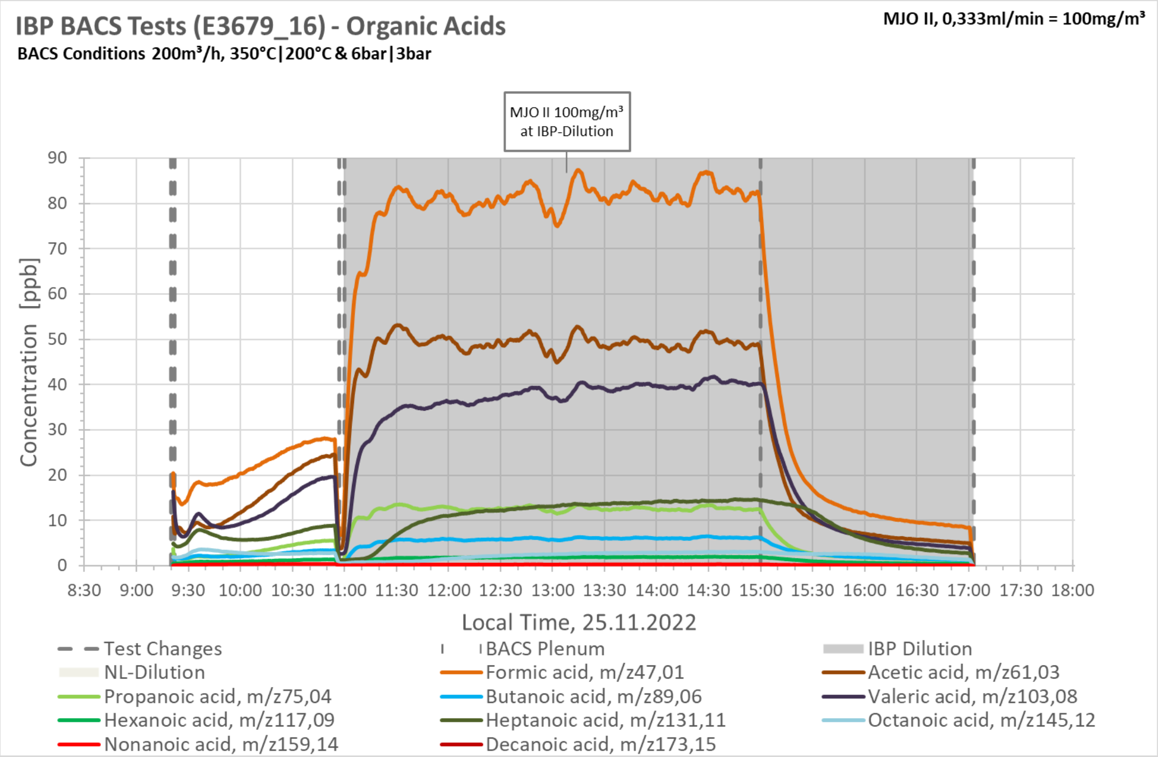
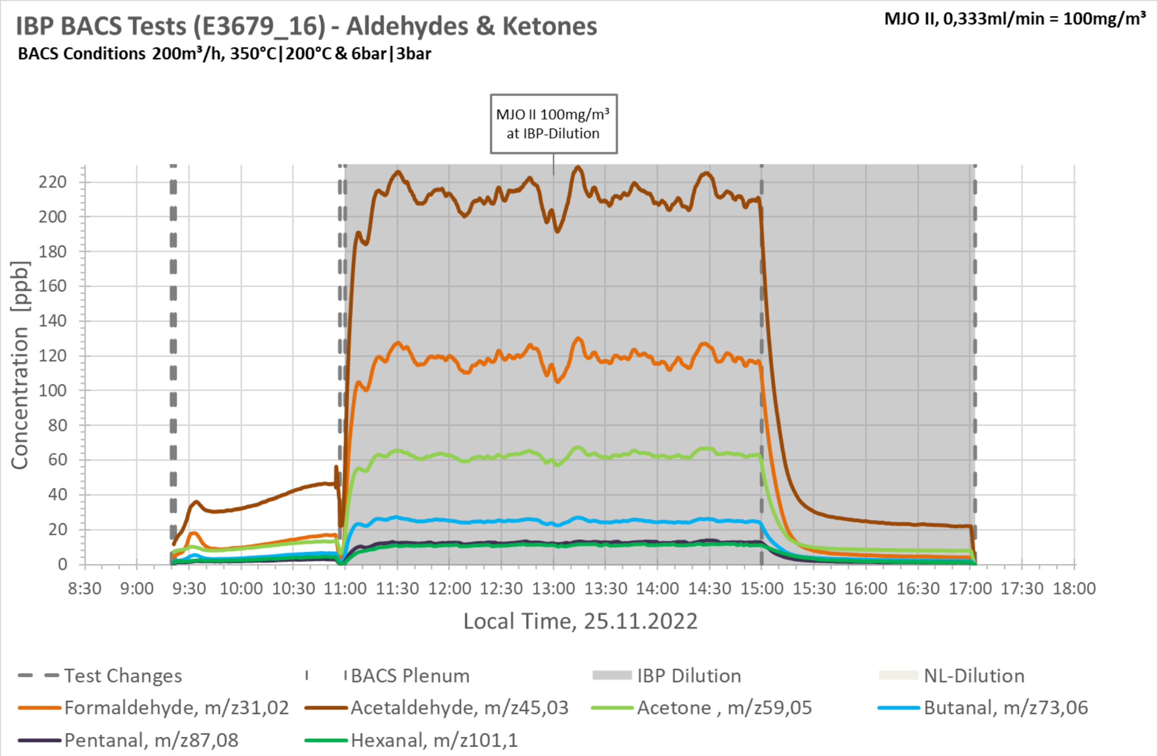
Dosing of high oil amounts over hours – 100 mg/m³ with PTR-MS at 1:10 dilution





- Note: sometimes more compounds show the same m/z fragment and cannot be differentiated ➔ Off-line analytics

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Dosing of MJO II to check whether at the end of the transfer-line after 1:1 dilution the oil vapour composition remains the same – pentanoic acid

Dosed oil amount	Pentanoic acid concentration [ppb] PTR-MS		
[mg/m³]	BACS vessel	Exposure unit after transfer-line and 1:1 dilution	1:10 dilution box
1	18	9	
3	42	21	4
6	69	34	7
10	89	44	9
20			12
30			16
40			18
50			22
60			25
100			40

Sampling of VOCs, aldehydes, organic acids and organo phosphates at BACS vessel and 1:1 dilution ➔ ITEM

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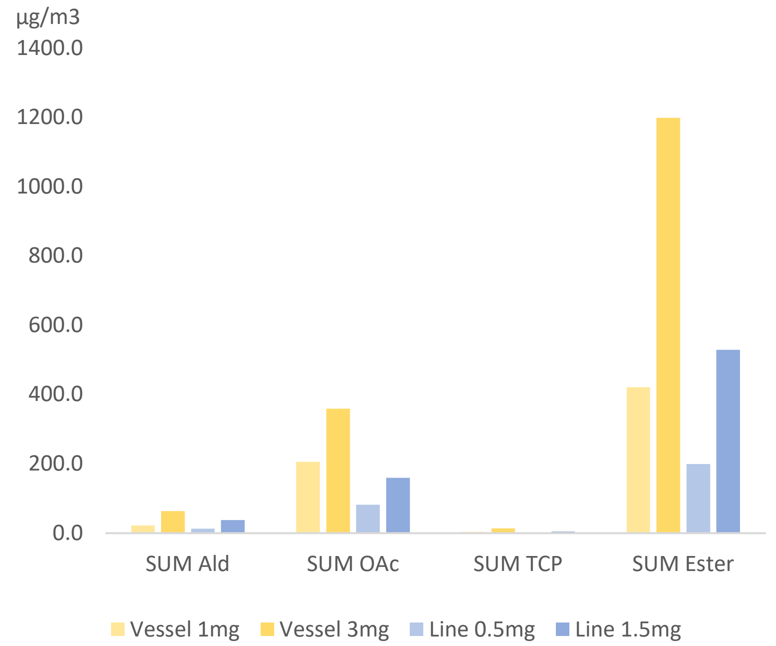
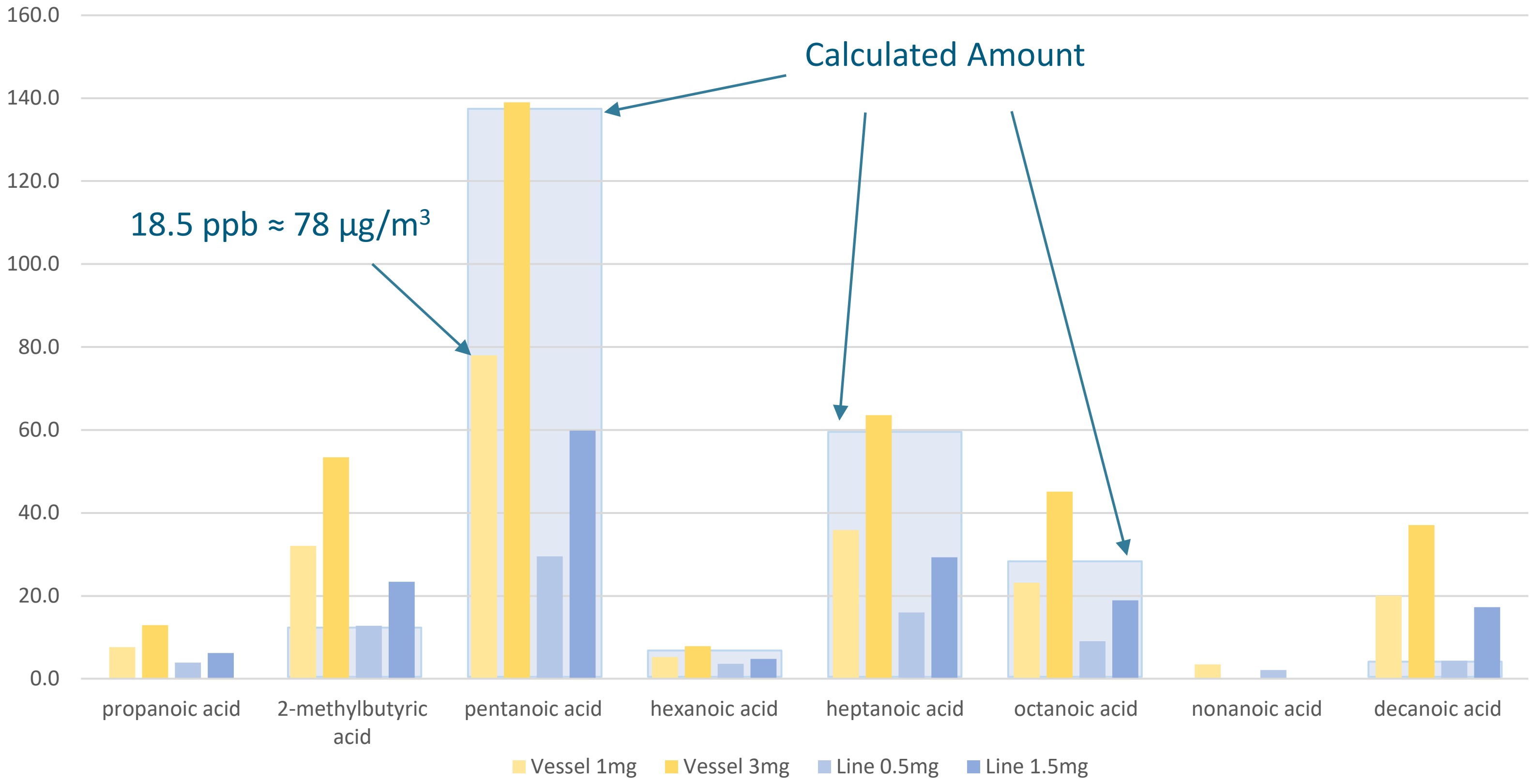
Sampling Vessel » Transferline (9m) » Line





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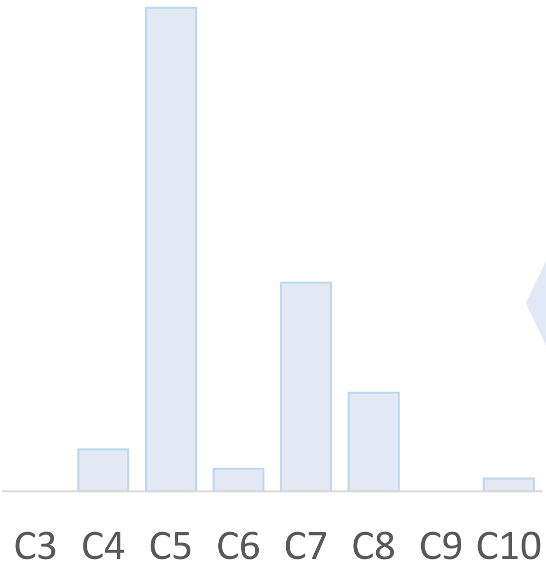
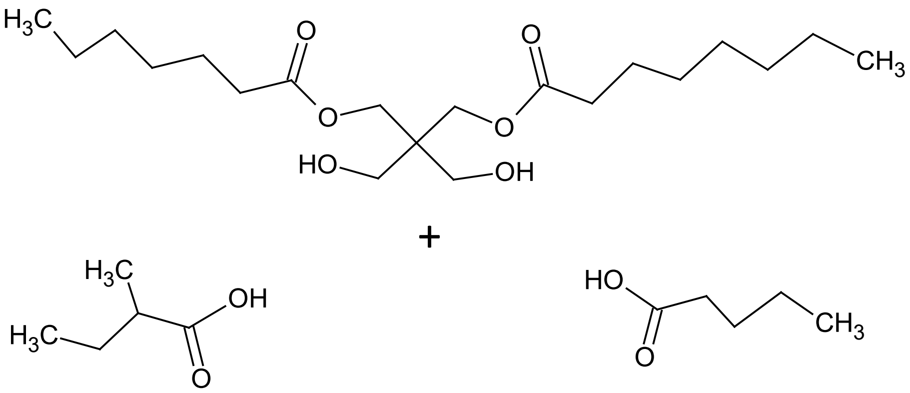
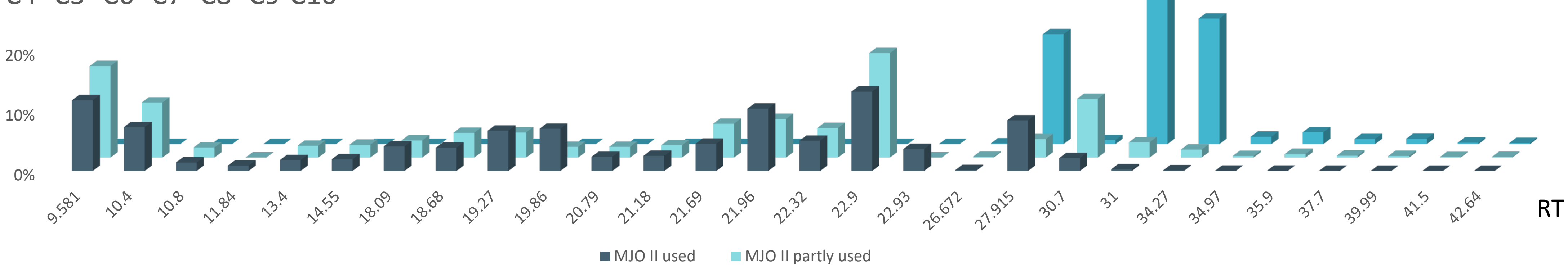




C4

C5



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Conclusions

- Composition and amount of the oil fume is not affected by the transfer-line
- The hydrolysis process of oil esters is in line with the known chemistry
- The oil fume is dominated by oil esters and carboxylic acids
- The formed carboxylic acids are most possibly the root cause of the oil smell

Thank you for your Attention!

National Research Centre for the Working Environment Copenhagen

RIVM
Rijksinstituut voor Volksgezondheid en Milieu
Ministerie van Volksgezondheid, Welzijn en Sport

GMC German Mouse Clinic

Fraunhofer IBP

HelmholtzZentrum münchen
German Research Center for Environmental Health

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ADSE CONSULTING AND ENGINEERING

Honeywell

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Back-up

- Particles

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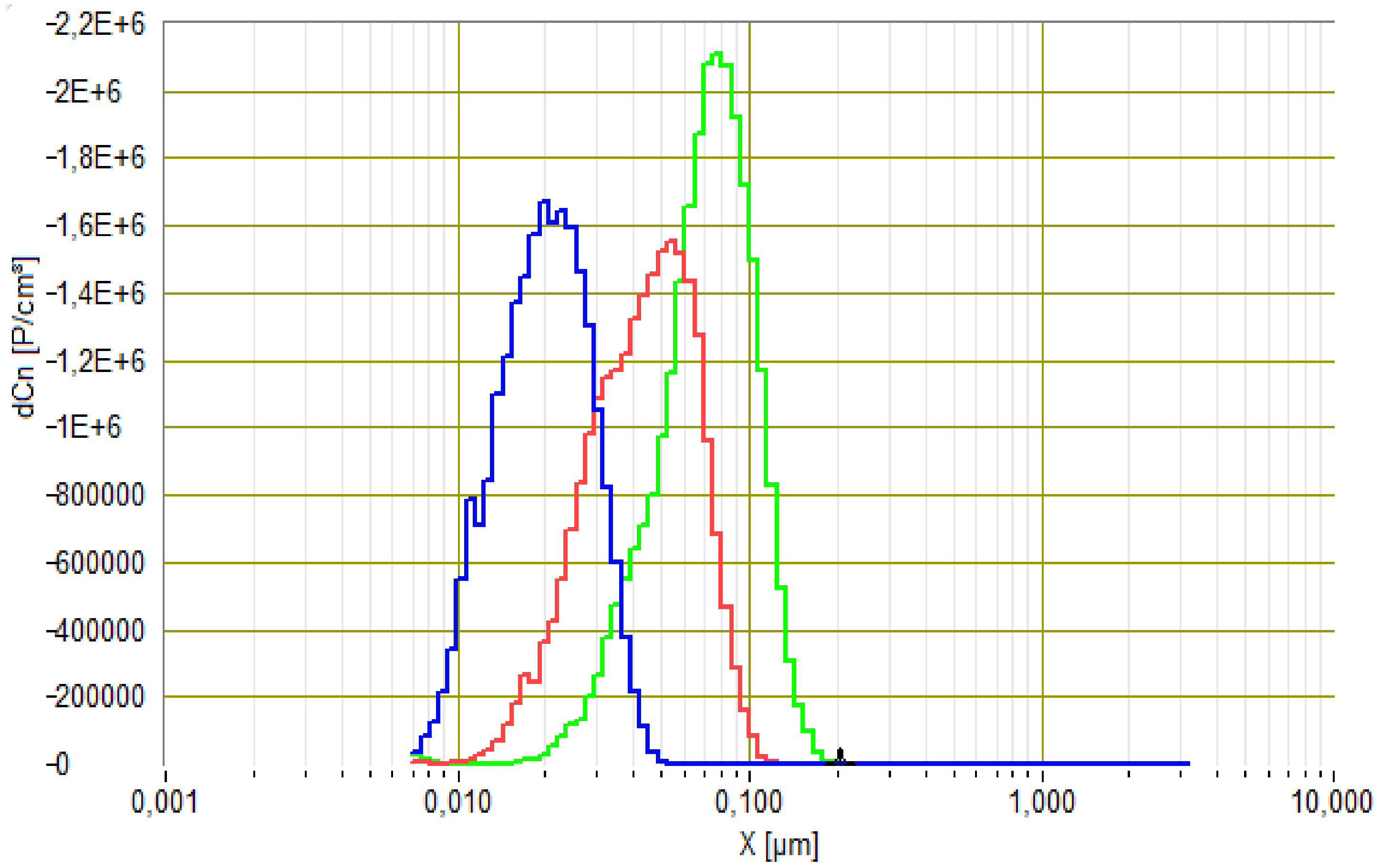

Measurement with rented Palas SMPS when 3, 30 and 60 mg/m³ of MJO II was injected:

Shift of the particle size maximum from 20 via 55 to 80 nm

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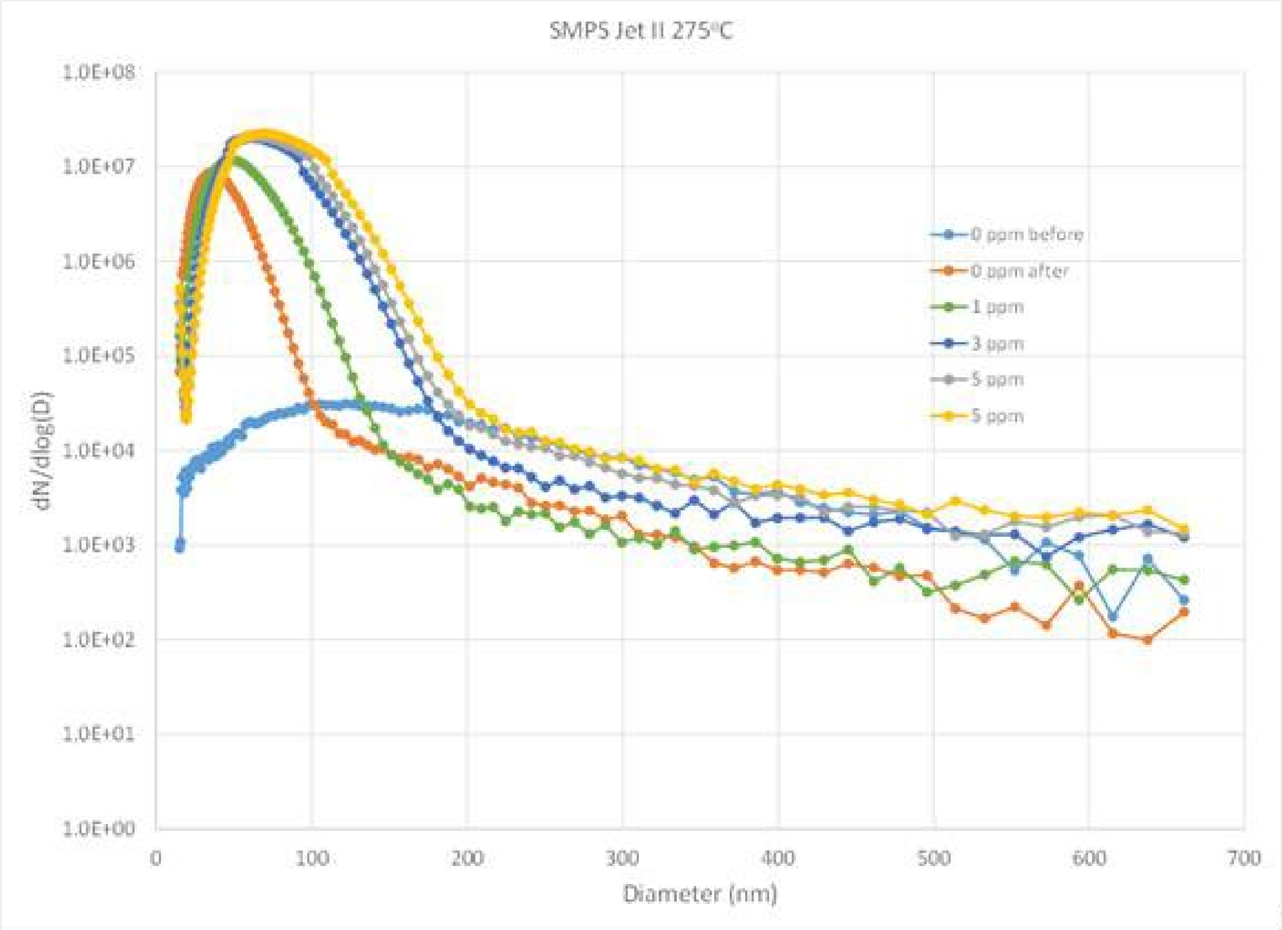

Figure 4.36. Size Distribution with Mobil Jet II as Measured by SMPS from Allison 250, 275°C Bleed Air, 2021-02-25.

Result from ASHRAE study at KSU on bleed air contamination with MJO II:

Max. particle size increases from ~50 to ~80 nm

when injected oil amount is increased from
1 via 3 to 5 ppm