Tyre wear measurement approaches

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Our Belief

When it comes to the pursuit for improved air quality, we believe in the power of clarity, transparency and integrity. With real-world data we can meet emissions challenges – instilling trust and confidence in our industry partners and public.

It's with our commitment and independence we are able to make a significant contribution toward positive change and to achieve enduring results.

Agenda

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EQUA real-world test database

Research questions

- What organic chemicals are tyres currently on the market made up of?
- With what certainty can they be identified?
- How can the amounts present be quantified?
- How potentially toxic are these compounds?
- How can the total amount of these compounds released into the environment be estimated?

Concept

Tyre wear rate

x

Chemical speciation

x

Compound hazard

=

Potential environmental impact

Sampling equipment

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On-vehicle sampling – principles

- Universal fitment across vehicles
- Fits to any and all wheels on a vehicle
- No vehicle modification required
- Articulates as the vehicle steers
- Safe and road-legal
- Low-loss sample line
- Can be coupled with any detector
- And collected plates/receptacle

➢ Mass, number and physical collection

On-vehicle sampling – measurements

- Sample point close to tyre (~1 cm) in rooster tail to minimise interferences
- Fixed with reference to tyre for consistency
- Low-loss sample line with smooth routing
- Losses must be characterised for each set-up
- Example detector – Dekati ELPI+ for real-time size distribution within certain ranges
- Example collection – size-denominated plates
- Example scales – for wheel masses

Chemical fingerprinting

- Two-dimensional gas chromatography with mass spectrometry
- INSIGHT flow modulator from SepSolve Analytical for separation
- BENCH-TOF time-of flight mass spectrometer
- Multi-stage pyrolysis method

Sampling options

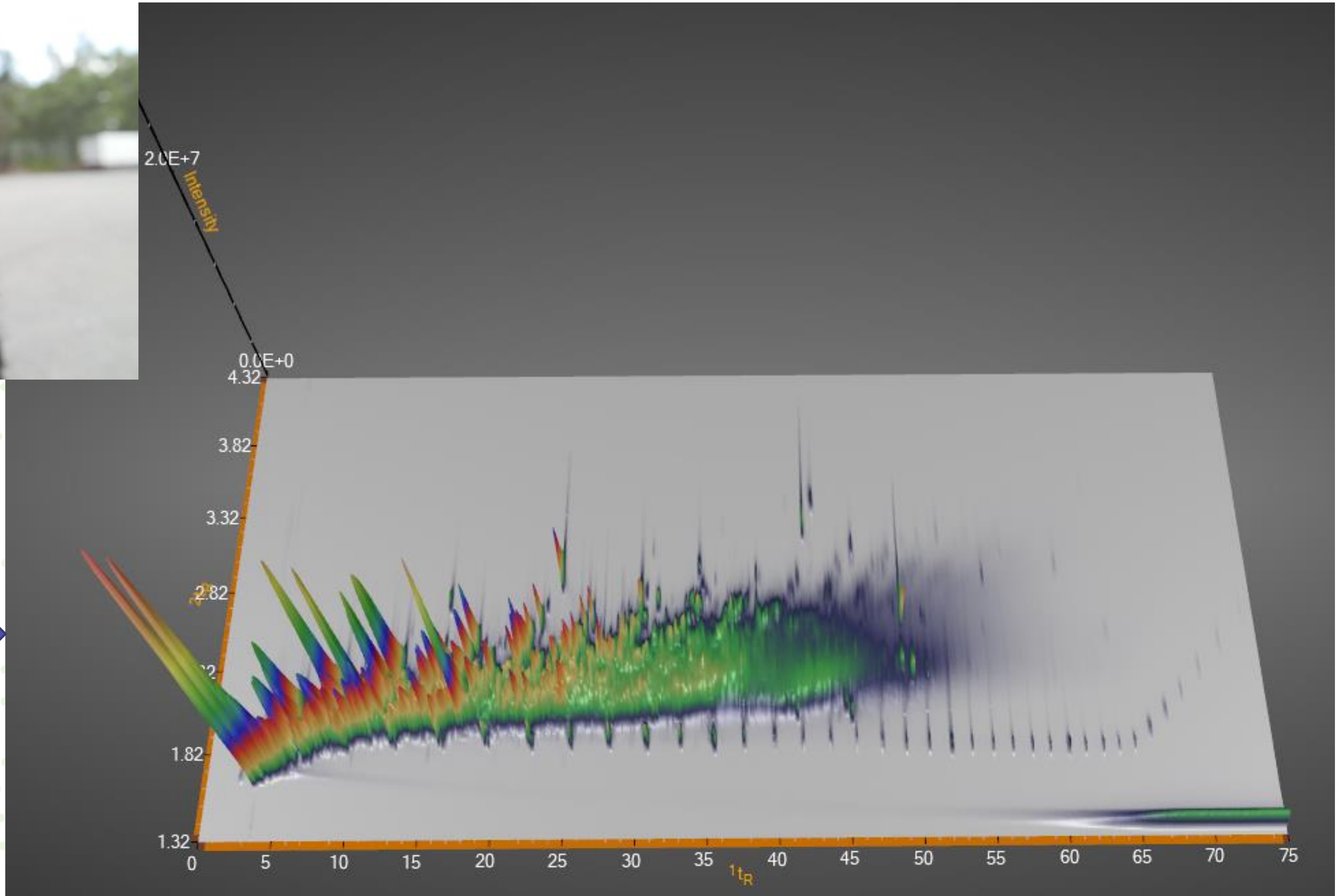
- Original tyre
    - Sidewalls
    - Inside tread
    - Outside tread
    - Central band
- Tyre wear emissions collected
- Environmental samples

Analytical methodology

- *Are the compounds measured really in the originally tyre?*
- *Does the high temperature of the pyrolysis lead to compounds breaking down?*

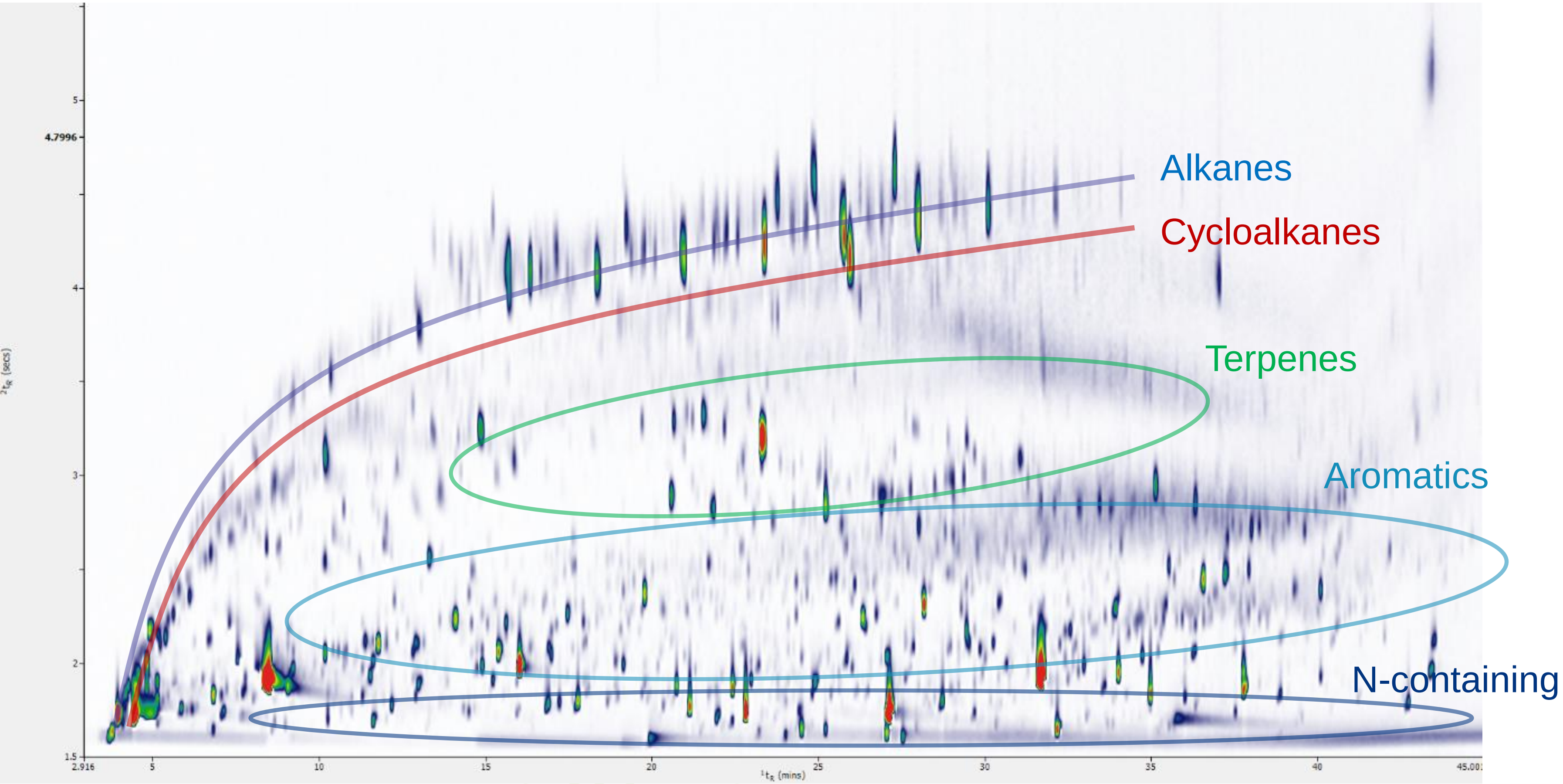
- Due to the very rapid heating and then flushing out of the hot zone, the pyrolysates are likely to remain unchanged, with secondary reactions and pyrolysate aggregation occurring rarely (Shin Tsuge, 2012) (Xiao-Ming Ma, 2014).
- The degradation process is useful for understanding the structure of the polymer but also for determining what smaller molecules could possibly be formed and for example, leach into the environment (Ladak, 2021) (Greta Biale, 2021).

Two-dimensional pyrolysis chromatogram



TEMS tyre emissions measurement system

Functional group classification



- Wide-ranging analytes identified
- Alkanes: lungs, liver, kidney, brain
- Cycloalkanes: headaches, dizziness
- Terpenes: aromas
- Aromatics: carcinogens
- N-containing: carcinogens

TEMS tyre emissions measurement system

Tyre wear results

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EQUA real-world test database

Comparative tyre wear results

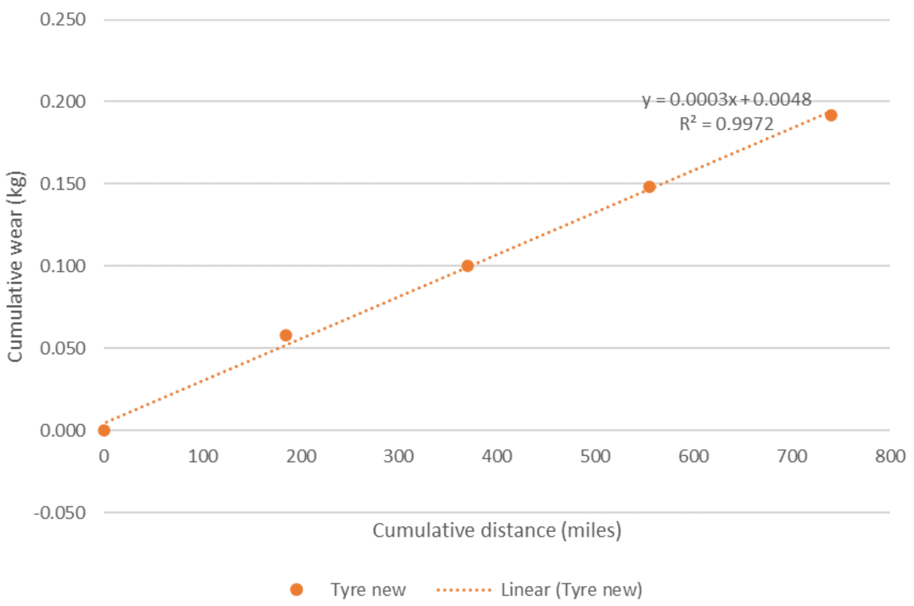
- 14 different models of tyre
- Tested from new
- 90% motorway driving by distance
- Public highway
- Average total distance 4,500 km

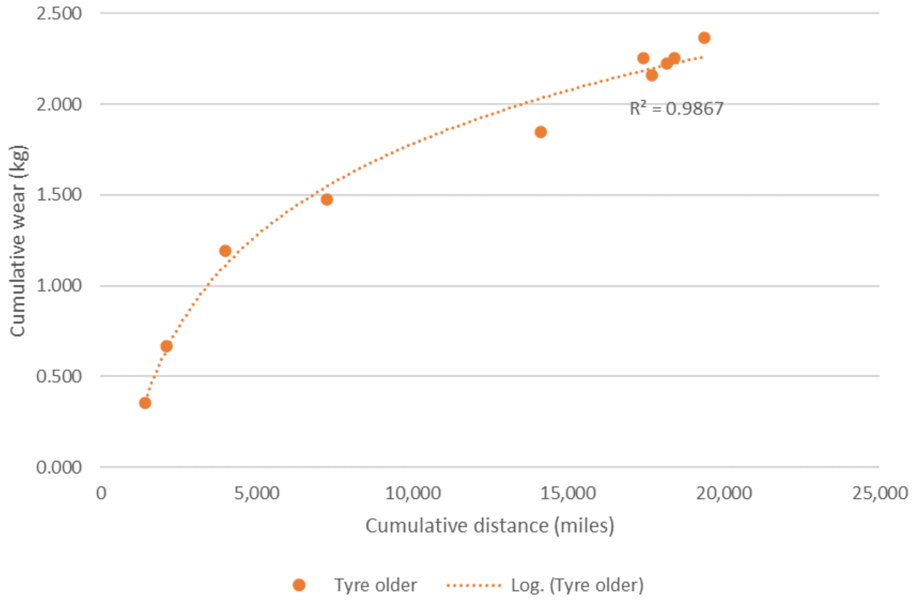
- 73 mg/km mean

Tire #	Make	Wear rate (mg/km)
1	Continental	161
2	Michelin	61
3	Sumitomo	38
4	Firestone	73
5	Avon	45
6	Kumho	75
7	Yokohama	89
8	Goodyear	75
9	Apollo	61
10	Kumho	51
11	Michelin	81
12	Hifly	76
13	Rotalla	66
14	Taurus	70
	Average	73

Longitudinal results

- Continental Contisport 6 tyres on Mercedes C-Class/unladen
- Tyres tested from new
- Wear rate linear up to ~1,000 km
- Then approximately logarithmic trend up to ~30,000 km
- Shape of cumulative wear differs between models





TEMS tyre emissions measurement system

Chemical speciation

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Speciation

- Toluene equivalence used for quantification
- Proportion of the most toxic group – the aromatics and PAHs – varies between 25% and 80% across 100 tyres

Mass in sample (µg)	Group 1 Acids, Amine and Alcohols	Group 2 Alkanes, Alkenes, Alkynes, Cyclo, Aldehyde and Ketone	Group 3 Aromatics and PAH
UKT003	4.9	40.6	178.6
UKT009	2.2	66.1	65.0
UKT012	2.2	57.9	58.4
UKT013	2.4	119.2	98.4
UKT014	4.5	116.6	87.0
UKT016	4.9	132.8	73.3
UKT022	8.4	156.2	83.6
UKT023	2.6	95.6	69.8
UKT024	1.7	65.7	63.2
UKT025	8.9	194.9	69.9

Compound	Match Factor	Area %	Mass (ng)	Concentration (ng/mg)
1,3-Pentadiene	817	9.83	24,884	23,476
D-Limonene	789	6.58	16,660	15,717
Cyclohexene, 4-ethenyl-	667	4.95	12,526	11,817
Toluene	781	4.19	10,619	10,017
9,12,15-Octadecatrienoic acid, methyl ester, (Z,Z,Z)-	729	3.05	7,727	7,290

Uncertainty budget

Quantity	Relative uncertainty
Mass of tyre analysed	0.7%
Peak area of sample – ion current	3.5%
Compound extraction efficiency	3.0%
Matrix match bias	2.0%
Peak area of standard – ion current	2.6%
Concentration of compound in stock solution	1.5%
Volume of calibration compound on TD tube	5.0%
Drift of instrument calibration	44%
Uncertainty total (k=1, 68%)	23%
Uncertainty total (k=2, 95%)	47%

- On parts-per-billion concentrations
- Analagous to the 1.5 RDE Conformity Factor

Already significantly reduced

Wear rates by brand

Compound release (µg/km) =
Tire wear rate (mg/km) x Compound concentration in sample (µg/mg)

- Distance-specific wear derived by brand and functional group
- Sevenfold difference in alkanes between highest and lowest
- Fourfold difference in aromatics across the range

Mass emissions (mg/km) Brand ID	Group 1 Acids, Amine and Alcohols	Group 2 Alkanes, Alkenes, Alkynes, Cyclo, Aldehyde and Ketone	Group 3 Aromatics and PAH
1	0.339	2.823	12.407
2	0.162	5.780	5.262
3	0.328	8.507	6.346
4	0.332	8.968	4.947
5	0.370	9.391	5.057
...			
36	0.208	9.515	7.282
37	0.382	14.397	12.456
38	0.306	9.103	5.828
39	0.357	8.513	5.557
40	0.326	7.969	12.468
Average	0.286	8.050	9.088
Minimum	0.087	2.396	4.947
Median	0.247	7.739	8.037
Maximum	0.970	17.005	20.951

Compound hazard

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Hazards

Hazard code	Description
H300	Fatal if swallowed
H301	Toxic if swallowed
H302	Harmful if swallowed
H303	May be harmful if swallowed
H304	May be fatal if swallowed and enters airways
H305	May be harmful if swallowed and enters airways

- Globally Harmonized System of Classification and Labelling of Chemicals (GHS) – United Nations' standardised system
- Compounds identified CAS Registry Number, unique identifier assigned by US Chemical Abstracts Service
- European Chemicals Agency database of manufacturer disclosures
- 'Hazard codes' described different effects, from irritants to carcinogens
- Each compound can have multiple hazard codes
- Different manufacturers can make different disclosures

Toxicity potential factor

$$\text{Overall toxicity factor} = \sum_{i=1}^{n} \text{Number of hazard codes}_i \times \text{Compound concentration in sample } (\mu g/mg)_i$$

- Over 250 tyres now tested
- 410 organic compounds separated on average
- 46 hazard codes cited
- Challenge of compound identification
- 78 organic compounds identified using NIST library
- Needs bespoke spectral library

Targeted screening

- Compounds regulated under REACH, found in tyres
  - ($C_{18}H_{12}$) Chrysene
  - ($C_{18}H_{12}$) Benz[a]anthracene

- Other compounds of concern found
  - ($C_{18}H_{24}N_2$) [6PPD] 1,4-Benzenediamine, N-(1,3-dimethylbutyl)-N'-phenyl-
  - (C_7H_5NS) [BTZ] Benzothiazole
  - ($C_{15}H_{18}N_2$) [IPPD] 1,4-Benzenediamine, N-(1-methylethyl)-N'-phenyl-
  - ($C_7H_5NS_2$) [MBTZ] 2-Mercaptobenzothiazole
  - ($C_{18}H_{16}N_2$) [DPPD] 1,4-Benzenediamine, N,N'-diphenyl-

Summary

- Real-world, real-time measurement is viable, calibrated to total mass loss
- Wear rates differ significantly between tyre makes and models
- Wear rates decline as tyres age
- Organic composition can be almost fully resolved
- Potential toxicity can be assessed

➢ Wear, speciation and hazard all need to be evaluated

Thank you.

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