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Cold Plasma Technology for Industrial Odour Mitigation: Mechanisms, Pilot-Scale Applications and Full-Scale Industrial Validation

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Industrial odour emissions are characterised by complex mixtures, variable operating conditions and very low perception thresholds, so treatment performance cannot be assessed from total volatile organic compound (VOC) measurements alone. This work examines odour mitigation by non-thermal plasma (NTP) using an indirect dielectric barrier discharge (DBD) system. The pilot dataset comprised 19 paired inlet-outlet tests from bitumen membrane production, rubber processing, pouring of animal fat processing and wastewater treatment. Dynamic olfactometry and gas chromatography-mass spectrometry (GC-MS) were used to compare odour reduction, VOC removal and compositional changes. A separate full-scale case study at a bitumen membrane facility included two emission points with a combined airflow above 110,000 $m^3 h^{-1}$.
Pilot and full-scale results are reported separately, together with the observed formation of oxygenated intermediates, the electrical energy input and the main limitations associated with olfactometric uncertainty, ozone and incomplete carbon balances.

1. Introduction

Industrial odour nuisance may occur even when conventional emission limits are met because sensory impact is often governed by a limited number of compounds with very low odour thresholds. Total VOC concentration therefore provides an incomplete indicator of odour impact, particularly for variable industrial mixtures (Oliva et al., 2018). Conventional control options include absorption, adsorption, biological treatment and thermal or catalytic oxidation. Their applicability depends on pollutant load, airflow, variability, footprint, consumables and energy demand. NTP is of interest for dilute contaminants in large airflows because energy is transferred mainly to electrons rather than to the bulk gas (Kim, 2004; Kogelschatz, 2003).
This study investigates an industrial indirect-DBD system developed by Aerox B.V. The contribution is a cross-scale comparison between a multi-sector pilot dataset and one full-scale installation, using paired olfactometric and chemical indicators. The analysis focuses on the difference between odour and VOC removal, molecular transformation, measurement uncertainty and engineering performance.

2. NTP fundamentals

2.1 Plasma generation and oxidation mechanisms

NTP is a partially ionised gas in which electrons have much higher energy than ions and neutral molecules, while the bulk gas remains close to ambient temperature. Electron collisions with oxygen, nitrogen and water vapour generate ions, excited species and radicals. Industrial systems commonly use DBD or corona discharges; the system investigated here generates the discharge in a separate module and transfers reactive species to the polluted air stream (Fridman, 2008; Brandenburg, 2017). Reactive oxygen species (ROS) include hydroxyl radicals (•OH), atomic oxygen (O•), hydroperoxyl radicals and ozone (O_3).
Odorous compounds are transformed through both direct electron interactions and indirect oxidation reactions promoted by plasma-generated oxidants. Initial radical attack induces bond cleavage and formation of reactive

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intermediates, which may subsequently evolve into oxygenated compounds such as aldehydes, ketones, alcohols and organic acids. Performance depends on electrical input, gas distribution, reaction time, humidity and the chemical matrix; complete mineralisation to CO_2 and H_2O is not generally expected at industrial conditions. O_3 contributes to downstream oxidation but is also an undesirable and potentially harmful residual. O_3 was not systematically quantified in the archived pilot and full-scale campaigns; consequently, this dataset cannot support an outlet O_3 mass balance or a compliance conclusion.
Industrial applications should therefore verify residual O_3 under representative conditions and include additional residence time or polishing where required. The same precaution applies to NOx and organic by-products (Veerapandian et al., 2017).

3. Pilot-scale investigation

All results in Section 3 refer exclusively to the mobile pilot unit. The dataset contains 19 validated paired inlet-outlet comparisons obtained under real process conditions; the full-scale installation is described separately in Section 5.

3.1 Pilot setup and measurements

A representative side-stream of 100-200 $m^3\ h^{-1}$ was extracted from each industrial exhaust and treated by the indirect-DBD pilot unit. Simultaneous inlet and outlet samples were collected for each operating condition. Odour concentration was determined by dynamic olfactometry according to EN 13725:2022, while VOC composition was assessed by GC-MS; airflow, temperature and relative humidity were also recorded.
Dynamic olfactometry has a laboratory-specific, approximately lognormal uncertainty that must be considered when comparing individual results (Harreveld, 2021; Scolieri et al., 2021).
The archived campaign reports did not provide one homogeneous uncertainty parameter suitable for retrospective propagation across the entire dataset. Accordingly, the error bars in Figure 1 represent between-test standard deviation only, not combined measurement uncertainty; sector differences are interpreted descriptively rather than as statistically significant rankings.

3.2 Investigated sectors

The tests covered four industrial sectors with different dominant matrices and odour-generation mechanisms (Table 1).

Table 1: Pilot-scale sectors and characteristic emission matrices

Sector	Indicative compounds	Main issue
Bitumen membrane production	Heavy VOCs; aromatics; oxygenates	Persistent nuisance
Rubber processing	VOCs; sulfur compounds; additives	Variable process odours
Pouring of animal fat	Aldehydes; ketones; fatty acids	Intermittent peaks
Wastewater treatment	H_2S; NH_3; mercaptans	Low-threshold, corrosive odours

Inlet concentrations and compound distributions differed substantially among sites; therefore, cross-sector comparison was based primarily on paired removal efficiencies rather than on averaged outlet concentrations.

3.3 Pilot results

Across the 19 comparisons, mean odour removal was approximately 64%, whereas mean VOC removal was approximately 35%. Positive odour reduction was observed in all sectors, but variability was substantial and was influenced by inlet composition, operating conditions and the limited number of tests within each sector.
Figure 1 summarises sector means and between-test variability. Because olfactometric method uncertainty is not included in the error bars, the figure should be read as an overview of the pilot dataset, not as a formal comparison of sector performance.
The discrepancy between sensory and bulk chemical indicators was observed across different matrices. It is consistent with the possibility that a limited number of low-threshold compounds dominate odour perception, while total VOC includes many compounds with a smaller sensory contribution.

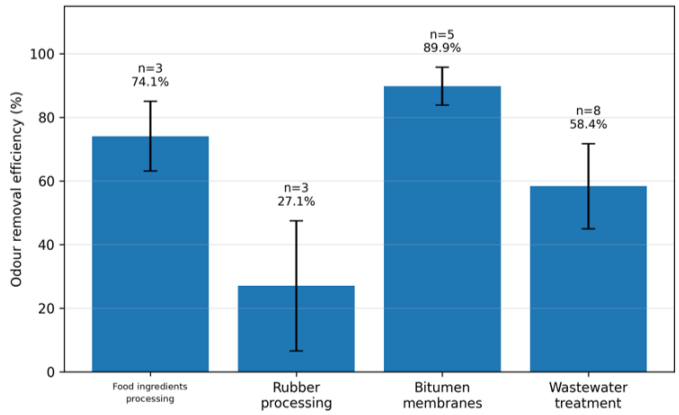

Figure 1: Pilot-scale odour removal by industrial sector. Bars show arithmetic means; error bars show the standard deviation among independent tests and do not include laboratory-specific olfactometric uncertainty.

Figure 2 compares paired VOC and odour removal. Three tests show negative apparent VOC removal, i.e. a higher GC-MS-derived VOC sum at the outlet than at the inlet. These values should not be interpreted as a complete mass-balance proof of VOC generation because the analytical sum does not represent all carbon species and is affected by the appearance of new intermediates and by analytical variability at low concentrations. In all three cases, odour removal remained positive.

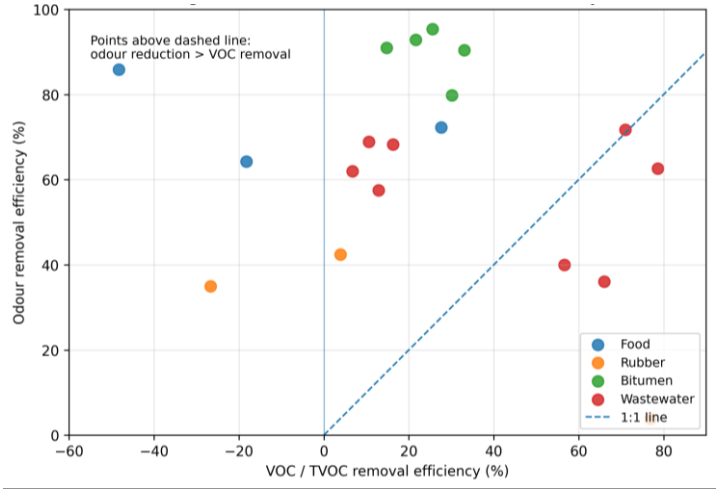

Figure 2: Pilot-scale VOC removal versus odour removal. The dashed line indicates equal removal; points above the line show greater odour reduction than VOC reduction.

The negative VOC points reinforce the need to combine compound-specific analysis, carbon balance and olfactometry. They do not by themselves demonstrate that the newly formed compounds are less hazardous or less odorous.

4. Molecular transformation and by-products

GC-MS profiles frequently changed after treatment: decreases in parent compounds were accompanied by the appearance or increase of aldehydes, ketones, alcohols and organic acids. These observations are compatible with radical attack, fragmentation and oxygen addition followed by further oxidation when reaction time and oxidant availability are sufficient. Partial oxidation cannot be assumed to reduce odour in every matrix. Some aldehydes and volatile fatty acids have lower odour thresholds than their precursors, and NTP can also generate O_3, NOx and secondary organic products (Veerapandian et al., 2017). The net olfactometric reductions measured here indicate that the overall sensory balance was favourable in the tested conditions, but this outcome should not be generalised without simultaneous inlet-outlet olfactometry and by-product assessment.

The recurrent difference between odour and VOC removal is therefore interpreted as evidence of selective molecular transformation, not as proof of complete mineralisation. Identification of the compounds driving the sensory response remains necessary for a predictive mechanistic model.

5. Full-scale industrial validation

5.1 Process and treatment configuration

The full-scale case concerns one European facility producing modified-bitumen waterproofing membranes. Heated bitumen handling, mixing, coating and finishing generate complex emissions containing heavy VOCs, aromatic hydrocarbons and oxygenated compounds. Two existing wet scrubbers, C45 and C46, were followed by indirect-DBD injection and approximately 1 s of downstream reaction time. The combined design airflow was 110,000 $m^3 h^{-1}$. All performance values in Sections 5.2-5.3 refer to this installation; the pilot reductions in Table 2 were used only for system selection.

5.2 Design basis and electrical input

Pre-installation pilot tests were performed at both emission points to select plasma capacity. Table 2 reports the design airflow, installed plasma power, specific input energy (SIE) and preceding pilot performance.

Table 2: Full-scale design basis and preceding pilot performance

Point	Q [$m^3 h^{-1}$]	P [kW]	SIE [Wh m^{-3}]	Pilot ηod [%]
C45	75,000	28	0.37	80-95
C46	35,000	14	0.40	91-93

5.3 Full-scale results

Following commissioning, paired olfactometric campaigns were conducted under different production conditions between 2025 and 2026 according to EN 13725:2022. At C45, odour removal ranged from approximately 64% to 93%; C46 showed values of approximately 86-89%. Although inlet concentrations varied with production, outlet concentrations occupied a narrower range, indicating attenuation of emission peaks. As for the pilot dataset, individual efficiencies remain subject to olfactometric measurement uncertainty and should be interpreted together with the complete campaign context.

The plasma generators required 28 kW at C45 and 14 kW at C46, corresponding to 0.37 and 0.40 Wh m^{-3} of treated air. These values provide a transparent volume-based benchmark, but not a complete plant energy balance: existing fan power and the existing scrubbers are excluded. Direct comparison with biofilters, scrubbers, adsorption and thermal oxidation is not robust without common boundaries for pressure drop, heating, consumables, pollutant load and target removal (Oliva et al., 2018). The full-scale observations are consistent with the pilot trend of odour reduction exceeding bulk VOC removal, while extending the evidence to a large and variable industrial airflow.

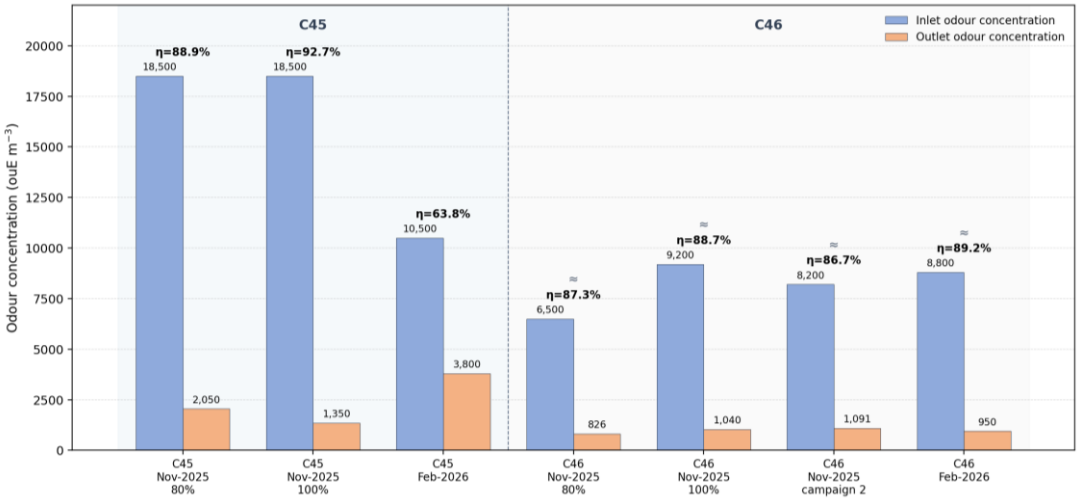

Figure 3: Full-scale inlet and outlet odour concentrations at C45 and C46 under different production conditions.

6. Discussion: cross-scale interpretation and engineering implications

The combined pilot and full-scale datasets provide complementary information on the behaviour of indirect-DBD treatment under industrial conditions. The pilot campaign covered four sectors and a wide range of emission matrices, while the full-scale case concerned one bitumen membrane facility operated at substantially higher airflow. The two datasets should therefore not be interpreted as directly equivalent. Nevertheless, a common trend was observed: odour removal was generally higher than bulk VOC removal. At pilot scale, mean odour and VOC removals were approximately 64% and 35%, respectively, while the full-scale installation achieved odour removals of approximately 64-93% depending on emission point and operating condition. This cross-scale consistency supports the use of odour concentration as an independent performance indicator rather than as a surrogate derived from total VOC measurements.

The observed behaviour is compatible with the chemical selectivity expected for NTP treatment. Total VOC concentration is a mass-based aggregate parameter, whereas odour perception depends strongly on compound-specific thresholds and mixture effects. Consequently, transformation of a relatively small fraction of the VOC mass may produce a larger sensory effect when the affected compounds have a disproportionate contribution to odour. Conversely, partial oxidation can also form aldehydes, ketones, alcohols and organic acids, some of which may themselves be odorous. The positive net olfactometric response observed in the present campaigns therefore reflects the overall balance of the treated mixtures and cannot be assumed for every industrial matrix. This interpretation is consistent with the need to assess NTP processes through combined chemical and sensory measurements and to include by-product monitoring where relevant (Kim, 2004; Veerapandian et al., 2017).

The pilot dataset also highlights an analytical limitation that is relevant to engineering assessment. In three paired tests, the sum of GC-MS quantified VOCs was higher at the outlet than at the inlet even though odour removal remained positive. Because the analytical sum does not represent a complete carbon balance, these cases cannot be interpreted as proof of net VOC formation. They may reflect conversion of non-quantified or poorly detected parent compounds into more readily quantified oxygenated species, together with analytical variability at low concentrations. For this reason, future campaigns should ideally combine compound-specific GC-MS analysis with a carbon-based indicator and, where possible, targeted quantification of the main reaction products.

The full-scale installation provides an additional engineering perspective. The two treatment lines operate at 75,000 and 35,000 $m^3\ h^{-1}$ with installed plasma powers of 28 and 14 kW, corresponding to specific electrical inputs of 0.37 and 0.40 Wh m^{-3}. The combined plasma power is therefore 42 kW for 110,000 $m^3\ h^{-1}$ of treated air. These values indicate that the relevant design parameter is not only the electrical power of the plasma source but the energy delivered per unit volume together with reaction time, pollutant matrix and upstream treatment. In the present case, the plasma stage was installed downstream of existing wet scrubbers, so the reported performance represents the behaviour of an integrated treatment train rather than an isolated plasma reactor. The approximately 1 s downstream reaction time is also part of the system configuration and should be considered when transferring the results to other applications. A further aspect emerging from the full-scale data is the narrower range of outlet odour concentrations compared with inlet values. This indicates attenuation of emission peaks under the investigated operating conditions and may be particularly relevant for industrial sources characterised by variable production cycles. However, the available number of campaigns is not sufficient to define a universal outlet concentration or to establish statistically robust performance guarantees. Dynamic olfactometry uncertainty, process variability and the absence of systematic residual O_3 measurements remain important limitations (Harreveld, 2021; Scolieri et al., 2021). From a design perspective, the results suggest that indirect-DBD technology should be evaluated as part of a treatment chain rather than as a stand-alone replacement for all conventional odour-control technologies. Selection should consider airflow, pollutant composition, inlet variability, required odour reduction, upstream particulate or soluble-pollutant removal, residual ozone and secondary products, as well as total energy and operating costs. Comparison with scrubbers, adsorption, biological treatment or thermal oxidation requires consistent system boundaries and cannot be based on electrical input alone (Oliva et al., 2018). The present study therefore supports a performance-based approach in which olfactometry, chemical characterisation, operating parameters and by-product control are assessed together before scale-up.

7. Conclusions

The 19 pilot-scale inlet-outlet comparisons yielded mean odour and VOC removals of approximately 64% and 35%, and an average odor outlet between 700-800 ou m^{-3}. The persistent difference between the two indicators shows that bulk VOC reduction alone is not sufficient to describe sensory performance for complex industrial mixtures. The sector averages are descriptive, because the available error bars represent inter-test variability

and a common retrospective olfactometric uncertainty could not be propagated. GC-MS results showed formation of oxygenated intermediates and, in three tests, negative apparent VOC removal despite positive odour reduction. This supports molecular transformation as a relevant mechanism but does not imply that partial oxidation is intrinsically beneficial: some intermediates may be more odorous or hazardous than their precursors. O_3 and a complete carbon balance were not systematically measured and remain limitations of the present dataset. At full scale, the two emission points treated a combined 110,000 $m^3\ h^{-1}$ and achieved odour removals of approximately 64-93%, with plasma-specific electrical inputs of 0.37-0.40 Wh m^{-3}. The combined pilot and industrial evidence supports the use of paired sensory and chemical monitoring for NTP assessment. Future work should include laboratory-specific uncertainty propagation, residual O_3 and by-product monitoring, and identification of the compounds controlling odour perception.

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References

Brandenburg R., 2017, Dielectric barrier discharges: progress on plasma sources and applications, Plasma Sources Science and Technology, 26, 053001.

CEN, 2022, EN 13725:2022 Stationary source emissions - Determination of odour concentration by dynamic olfactometry and odour emission rate, European Committee for Standardization, Brussels, Belgium.

Fridman A., 2008, Plasma Chemistry, Cambridge University Press, Cambridge, United Kingdom.

Harreveld A.P., 2021, Update on the revised EN 13725:2021, Chemical Engineering Transactions, 85, 115-120, DOI: 10.3303/CET2185020.

Kim H.H., 2004, Nonthermal plasma processing for air-pollution control: a historical review, current issues and future prospects, Plasma Processes and Polymers, 1, 91-110.

Kogelschatz U., 2003, Dielectric-barrier discharges: their history, discharge physics and industrial applications, Plasma Chemistry and Plasma Processing, 23, 1-46.

Meichsner J., Schmidt M., Schneider R., Wagner H.E., 2012, Nonthermal Plasma Chemistry and Physics, CRC Press, Boca Raton, USA.

Oliva G., Zarra T., Naddeo V., Munoz R., Lebrero R., Angeles R., Belgiorno V., 2018, Comparative analysis of AOPs and biological processes for the control of VOCs industrial emissions, Chemical Engineering Transactions, 68, 451-456, DOI: 10.3303/CET1868076.

Scolieri G., Invernizzi M., Sironi S., 2021, A crude Monte Carlo analysis for treating the influence of olfactometric uncertainty, Chemical Engineering Transactions, 85, 85-90, DOI: 10.3303/CET2185015.

Veerapandian S.K.P., Leys C., De Geyter N., Morent R., 2017, Abatement of VOCs using packed bed non-thermal plasma reactors: a review, Catalysts, 7, 113, DOI: 10.3390/catal7040113.