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PLASMA PERFORATION OF TIPPING PAPER – A NOVEL METHOD TO GENERATE VENTILATED FILTER CIGARETTES

Michael LINDNER, TANNPAPIER GmbH, AUSTRIA
Renata Raunić Vadanjel, TDR d.o.o.

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INTRODUCTION: FILTER VENTILATION METHODS

- Types of Tipping perforation:
  - Online-laser perforation on finished cigarettes inside the cigarette maker
  - Pre-perforated Tipping Paper (offline perforation):
    - Electrostatic perforation (EP)
    - Laser perforation (LP)

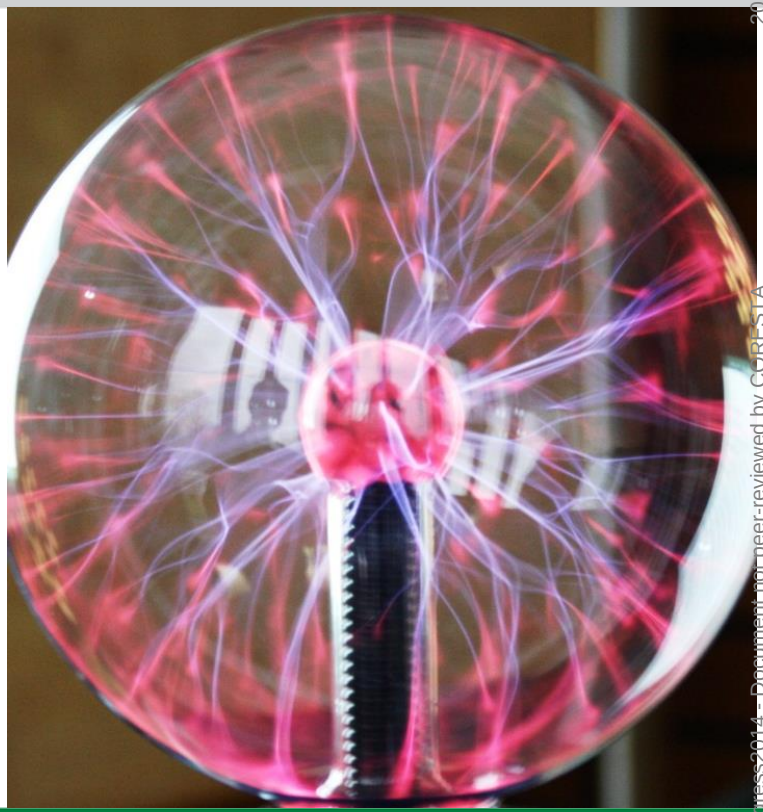
- Advanced technology to realize pre-perforated Tipping Paper: **Plasma Perforation (PP)**

WHAT IS PLASMA?

- Plasma is a quasi-neutral particle system consisting of gaseous and fluid-like mixtures of free electrons, ions and neutral particles

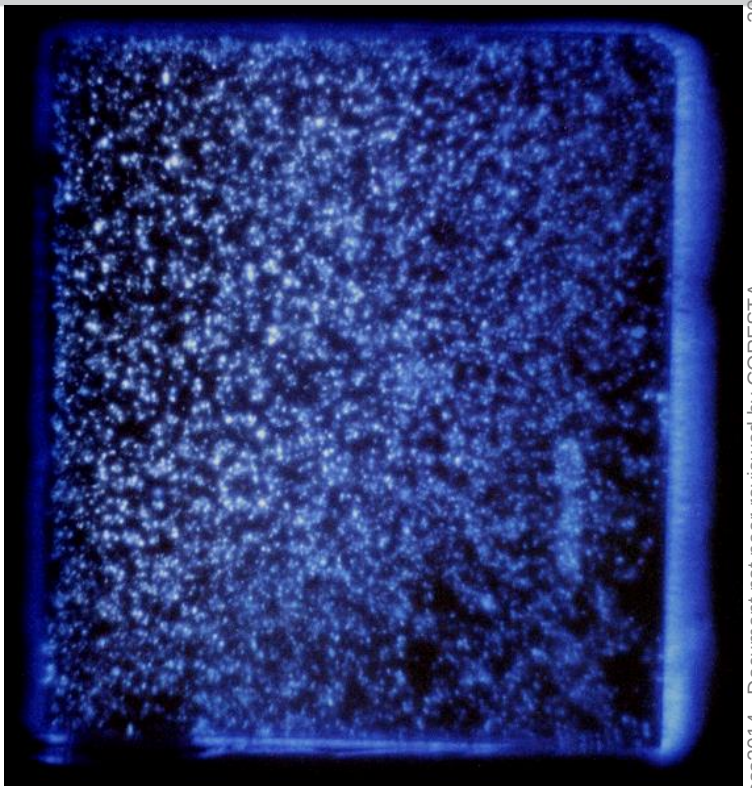
- Plasma = 4^{th} state of matter

- The mean kinetic energy of plasma components lies between 0,2 eV and 2 MeV per particle



PLASMA GENERATION

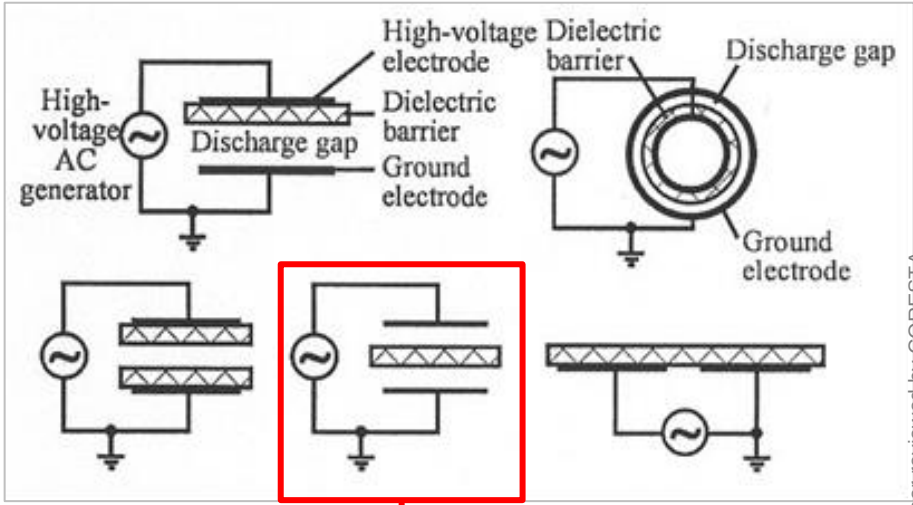
- Plasma is generated by high-voltage dielectric barrier discharges (DBDs) which are self-sustained electrical micro-discharges accompanied by the emission of short light pulses from the discharge gap
- Depending on the temperatures of electrons and ions, plasmas can be divided into low- and high-temperature plasmas
- DBDs can be carried out either under atmospheric conditions or within inert gas environment



STRUCTURES OF DBDs

- DBDs are characterized by insulating layers on one or both electrodes or by dielectric layers inside the discharge gap

- Materials for the dielectric barriers can be glass, quartz, ceramics, silicon rubber, polymer films or cellulose materials (e. g. paper)



Plasma Perforation

PLASMA PERFORATION IS PERFORMED WITH LOW-TEMPERATURE PLASMA AND WITHIN INERT GAS ENVIRONMENT

- Dielectric barrier: **Tipping Paper**
- Generation of **invisible** perforation holes by means of **material evaporation** (no burning process)
- Perforation in bands or on the **entire** Tipping Paper **surface**
- Realization of **small hole diameters** down to 0,01 mm together with **high hole densities**

QUASI-DIFFUSION SIMULATION MODEL

- Diffusive influence from ventilation processes via Tipping Paper perforation: Quasi-diffusion effect co-determines the control of CO
- Perforation and Tipping Paper parameters + Hagen-Poiseulle law + Darcy's law + Fick's first law = calculation of the quasi-diffusive flux:

$$J_{quasi} = -\frac{\sqrt{P^3 p^{\nu-1}}}{\kappa n r^4} \qquad \kappa = \frac{\pi}{8\eta}$$

- P… air permeability (CU), Δp… open pressure drop, ν… empirical permeability exponent, η… dynamic viscosity of air, n… perforation hole density, r… mean perforation hole radius

SAMPLE SELECTION: CIGARETTE SAMPLES FROM TDR D.O.O. (ROVINJ / CROATIA)

Sample Number	Perforation Type	Permeability [CU]	CoV of Perm. [%]	Hole Diameter [mm]	Open Pressure Drop [mm H_2O]	CoV of Open PD [%]	Filter Ventilation [%]	CoV of Filter Vent. [%]
1	Electrostatic	50	3,50	0,035	113,30	4,10	7,15	41,84
2	Electrostatic	100	4,00	0,060	109,15	4,30	13,52	18,47
3	Electrostatic	200	2,47	0,118	96,85	2,90	24,73	8,11
4	Electrostatic	400	2,17	0,257	86,90	3,60	37,32	5,64
5	Laser	50	5,98	0,419	113,55	3,00	6,91	21,05
6	Laser	100	4,48	0,674	107,65	7,60	15,11	27,20
7	Laser	200	3,36	0,509	99,80	5,10	23,95	7,41
8	Laser	400	3,26	0,747	89,45	4,05	37,27	4,50
9	Plasma	50	3,25	0,027	115,10	3,30	8,80	10,08
10	Plasma	100	2,58	0,030	109,40	2,85	16,09	5,58
11	Plasma	200	1,92	0,032	96,40	3,45	28,83	5,83
12	Plasma	400	1,52	0,038	79,80	3,10	49,80	3,89

- American Blend Tobacco
- 120 CU banded (LIP) cigarette paper
- 24000 CU plug wrap paper
- Adhesive-free area under-neath the Tipping Paper is 8 mm wide

CLASSIFICATION OF CIGARETTE SAMPLES

- Cigarettes are equipped with Tipping Paper with the same specifications
- Separation according to the three types of perforation which respectively comprise four levels of air permeability
- The three classes of cigarette samples are marked in the table with equal color shades

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EXPERIMENTAL RESULTS

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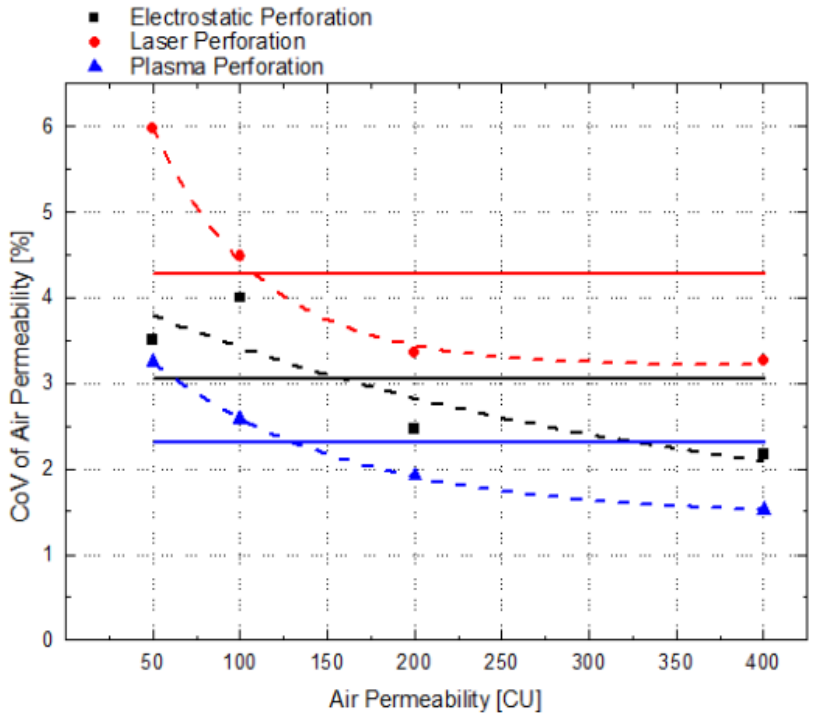
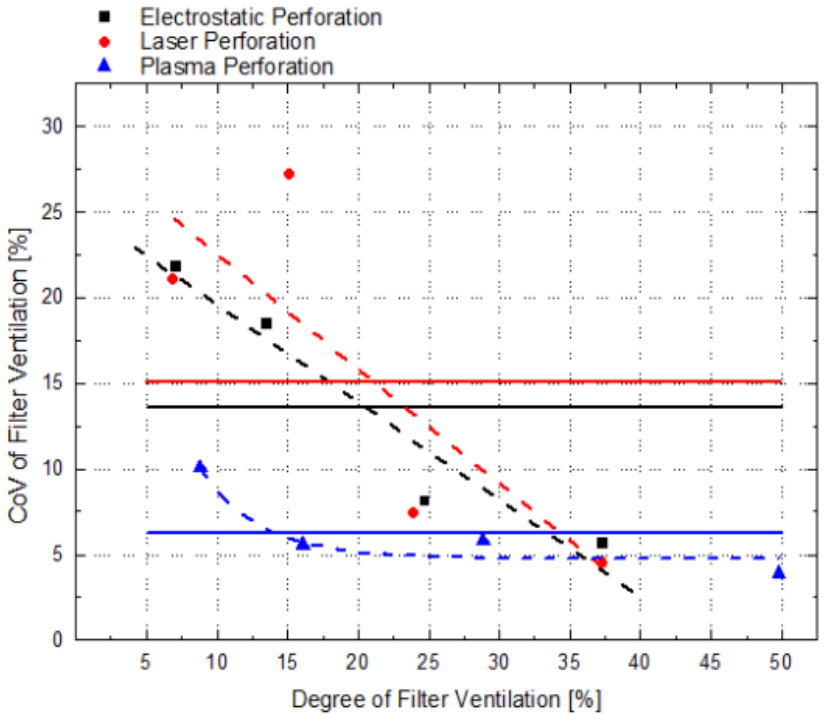
RESULTS: STABILITY OF AIR PERMEABILITY



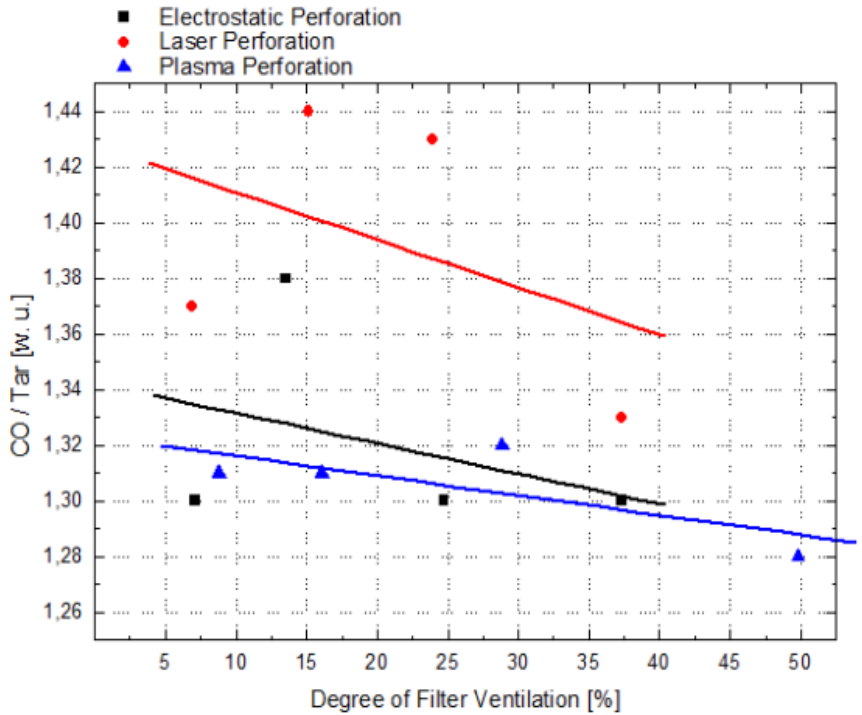
- **Highest stability with PP**
- Average CoVs shown by straight lines
- More stable distribution of the hole size and density with PP than with standard perforation methods

RESULTS: STABILITY OF FILTER VENTILATION



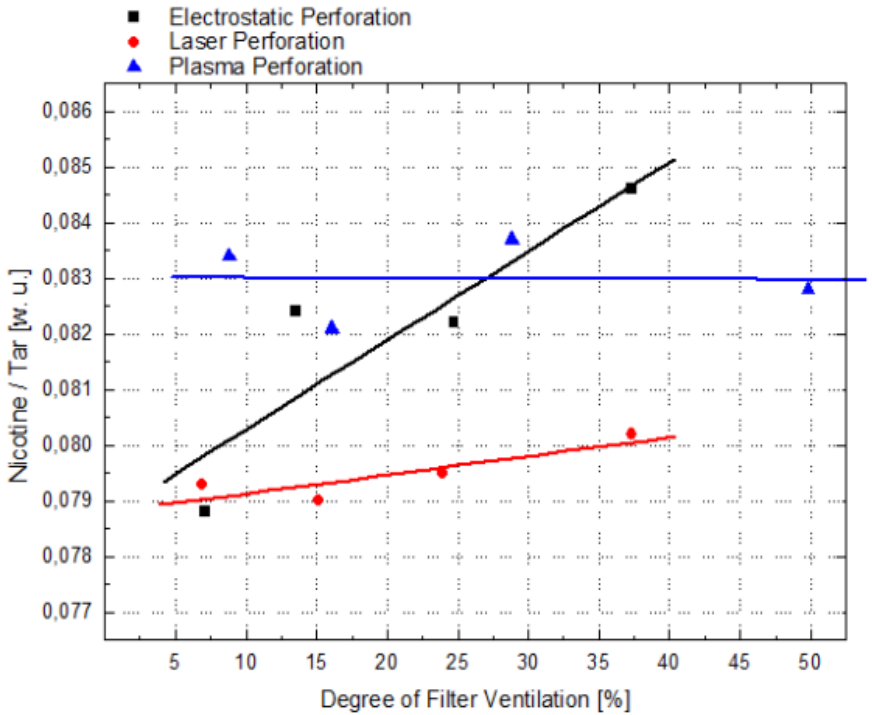
- Mean hole diameters:
  - EP: 0,118 mm
  - LP: 0,587 mm
  - **PP: 0,032 mm**
- CoV of hole density:
  - EP: 6%
  - LP: > 40%
  - **PP: 3%**
- **Lowest variation (only 6%) with PP**

CO / TAR RATIO = ESSENTIAL PARAMETER TO DESCRIBE SMOKE QUALITY
RESULTS: CO / TAR vs. FILTER VENTILATION



- EP and PP are roughly at the same level
- LP refers to high ratios
- High perforation hole densities + small hole dimensions generate quasi-diffusion effects
- Difference between EP and PP is unexpectedly small (tinier holes = lower CO / tar ratios!?)

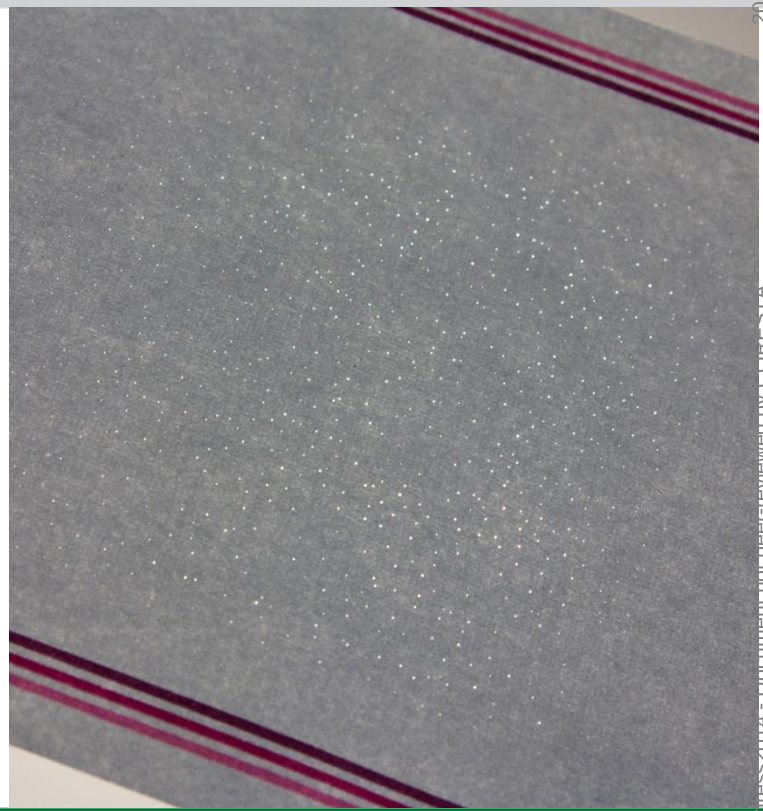
RESULTS: NICOTINE / TAR vs. FILTER VENTILATION



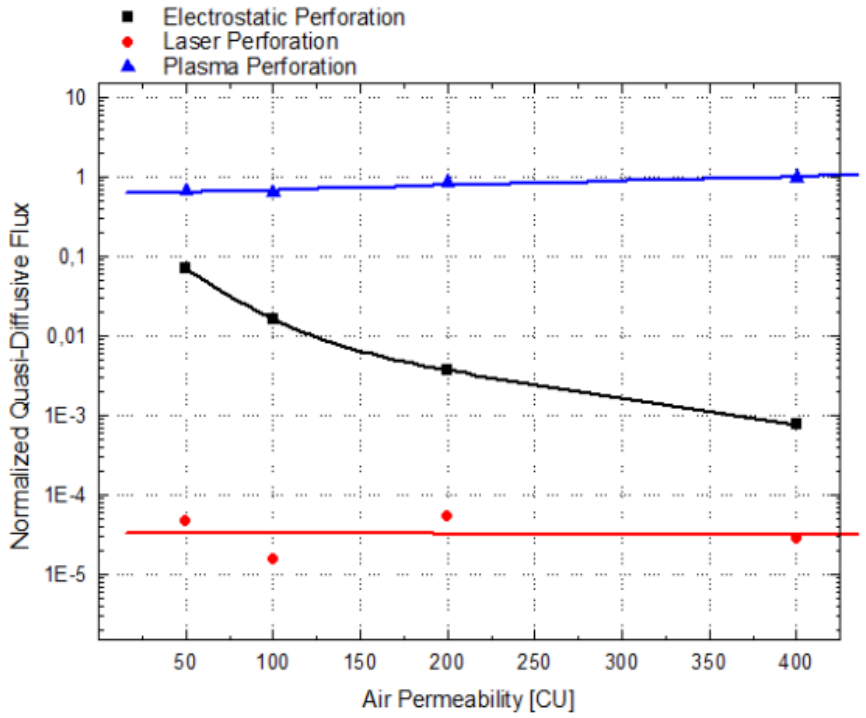
- Target is to achieve high values to indicate a stable nicotine output and efficient tar reduction
- PP tends to provide the most promising results, but again, the observed differences are not significant
- Further investigation of the smoke yields topic must be carried out!

RESULTS: RELATIONSHIP BETWEEN AIR PERMEABILITY AND FILTER VENTILATION

- At a defined permeability level, the corresponding filter ventilation is larger for PP than for EP and LP
- In average, 25% higher filter ventilation can be gained with an 8 mm wide adhesive-free zone
- With the same air permeability, in average, up to 8% lower CO and tar yields are recorded with PP

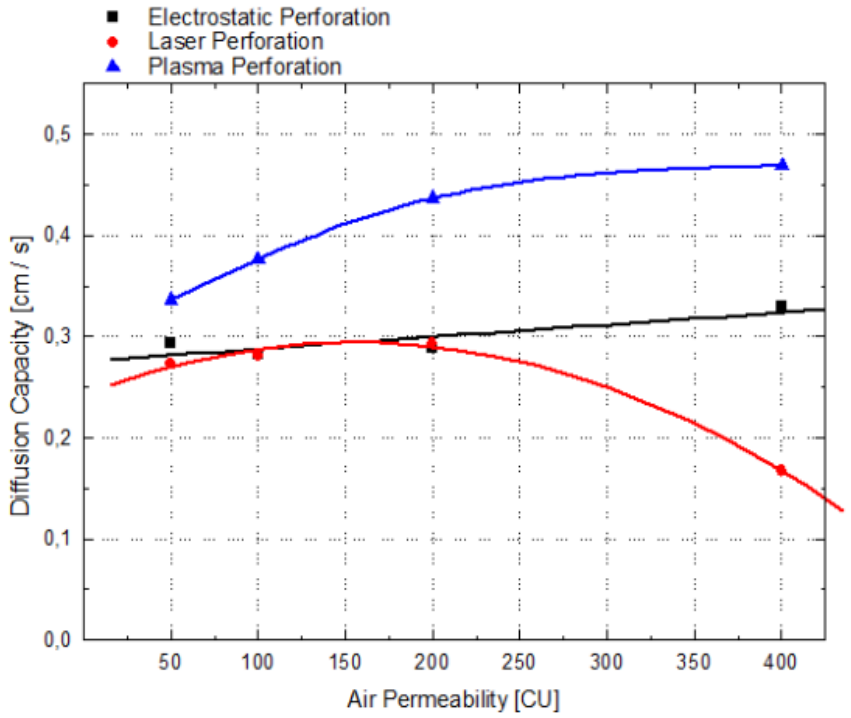


RESULTS: CALCULATED QUASI-DIFFUSIVE FLUX vs. AIR PERMEABILITY



- The data is normalized and plotted on a logarithmic scale
- Strong exponential decay for EP towards a low level
- Linear & constant behavior for LP at a negligible level
- Exponential increase for PP at a high level: Potential for huge CO reduction capability

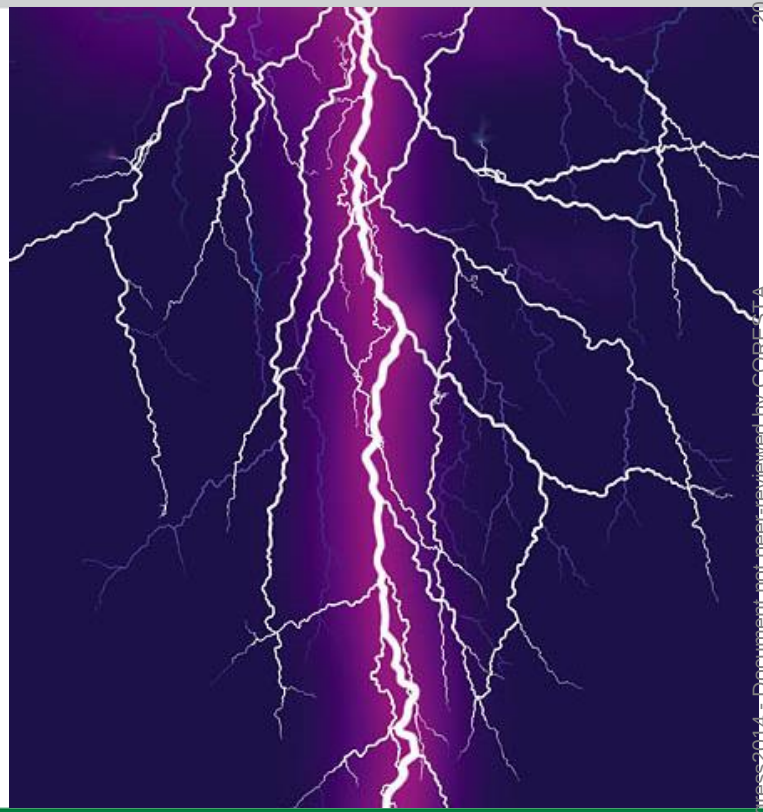
RESULTS: MEASURED DIFFUSION CAPACITY vs. AIR PERMEABILITY



- According to CRM 77
- Diffusivity drops quickly for LP
- Diffusivity grows slowly for EP
- Higher average level of the diffusion capacity for PP ending up in a linear increase
- PP delivers 1/3 or 1/4 of the diffusion capacity of non-LIP cigarette paper

SUMMARY & CONCLUSIONS: PLASMA PERFORATION

- Improved method for the generation of pre-perforated Tipping Paper
- Low-temperature dielectric barrier plasma discharges within an inert gas surrounding
- Micro-evaporation events either in bands or on the entire Tipping Paper surface
- Formation of tiny perforation holes with high hole density



SUMMARY & CONCLUSIONS: FEATURES & ADVANTAGES

- Highest stability of air permeability and filter ventilation for PP compared with EP and LP
- Higher efficiency in ventilation rates and smoke yields reduction
- More homogeneous air flow through the ventilation zone
- Confirmed superior quasi-diffusive and diffusive contributions to the dilution process

FURTHER NOTES & OUTLOOK

- Studies performed with test cigarettes other than used in the present contribution reveal **significant differences** in the CO / tar and nicotine / tar ratios between the perforation types
- Experiment: Random smokers were provided with two cigarette samples (185 CU EP & 100 CU PP Tipping Paper);
  Result: Smokers reported a much **smoother, softer and more natural taste** of the PP cigarettes
- Research on PP needs to be proceeded (cigarette design, control of smoke yields & sensory properties of cigarette smoke)
- PP has huge potential to achieve reliably specific regulatory targets and for supporting banded cigarette paper

THANK YOU FOR YOUR VALUABLE QUESTIONS & FEEDBACK!