



## **Smoking machine design and yield errors under intense smoke regimes . Part 1: The influence of dead volume on yield.**

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# Agenda

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1. Introduction
2. Experimental
3. Results
4. Discussion
5. Conclusions
6. References and Acknowledgements



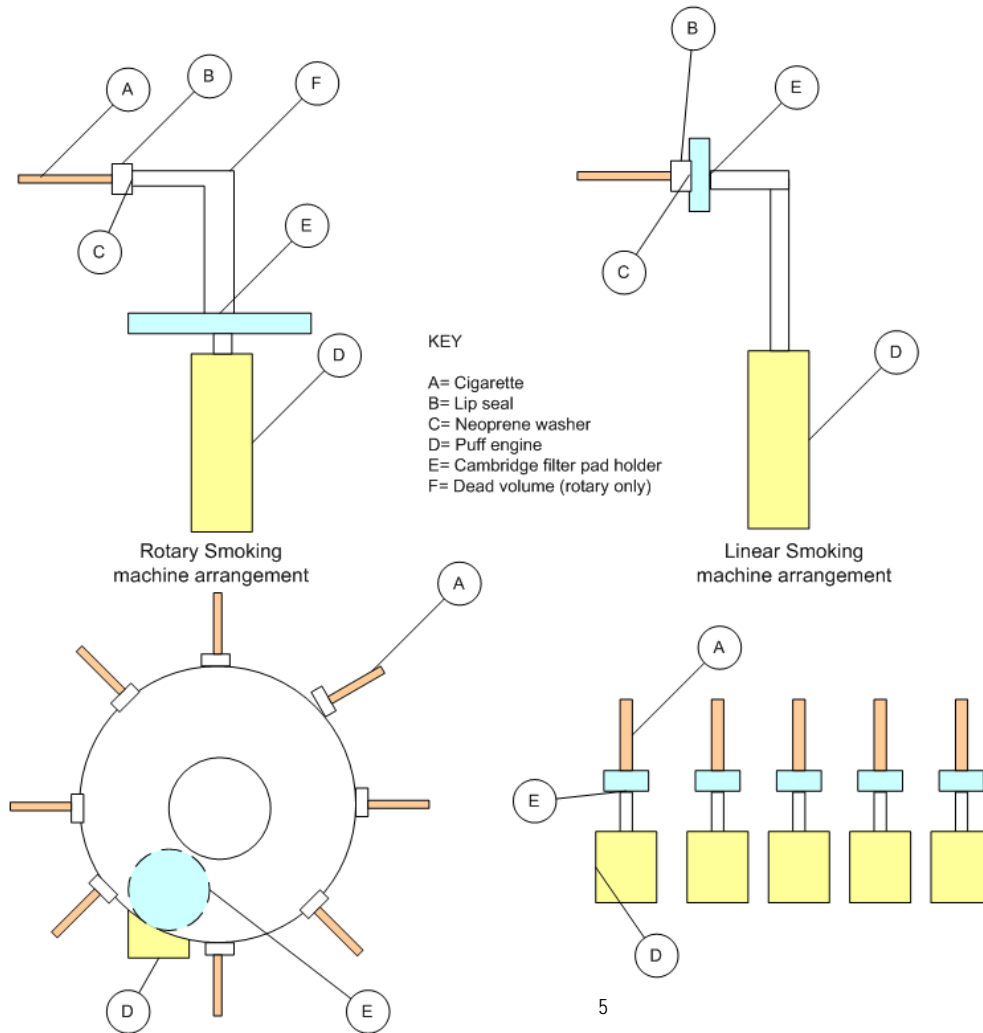
## 1. INTRODUCTION

## Rotary / Linear differences ISO and HCI

- Differences between rotary and linear machine yields are more prominent in HCI smoking

	ISO Linear - Rotary		CI Linear - Rotary		Increase in % ISO to CI
	Absolute mg/tp	% of mean	Absolute mg/tp	% of mean	
CO	-0.56	-3.9%	-0.73	-2.7%	1.2%
TPM	0.60	3.4%	5.47	12.8%	9.5%
NFDPM	1.00	7.0%	2.62	9.0%	2.0%
Water	-0.49	-26.0%	2.76	25.6	51.5%
Nicotine	0.06	4.6%	0.12	4.4%	-0.2%
Puff count	0.31	3.4%	0.22	1.8%	-1.5%

# The fundamental difference between Rotary and Linear machines



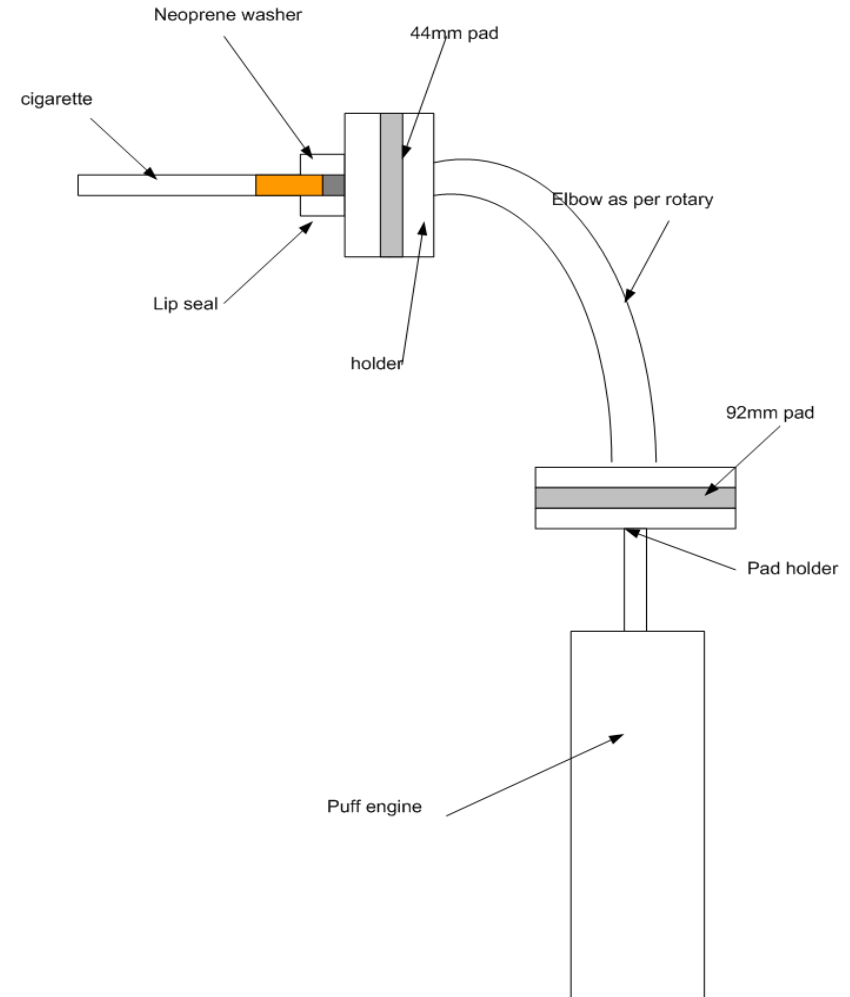




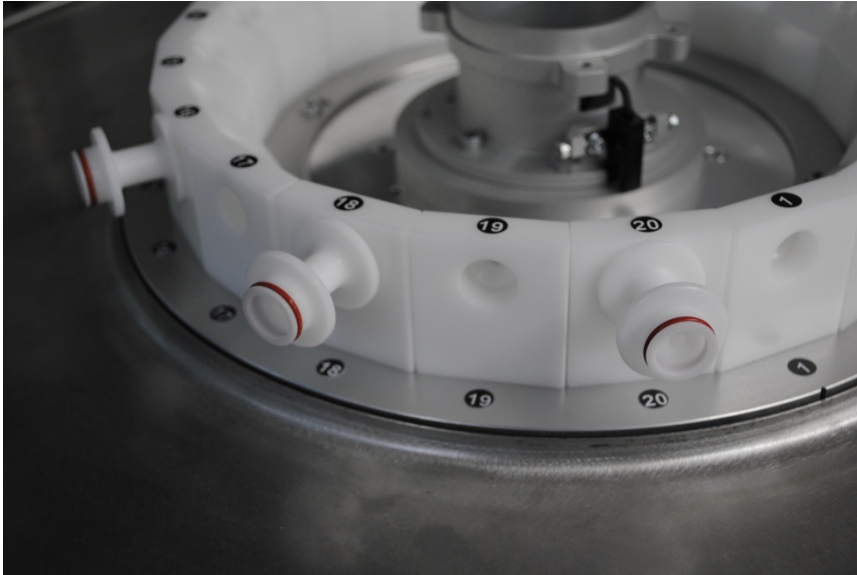
## 2. EXPERIMENTAL

## Experimental set up

- Conceptually identical in rotary or linear mode
- Capture pad can be immediately behind individual cigarettes or remote for a group of cigarettes
- A secondary trapping filter could be fitted for examining desorption experiments

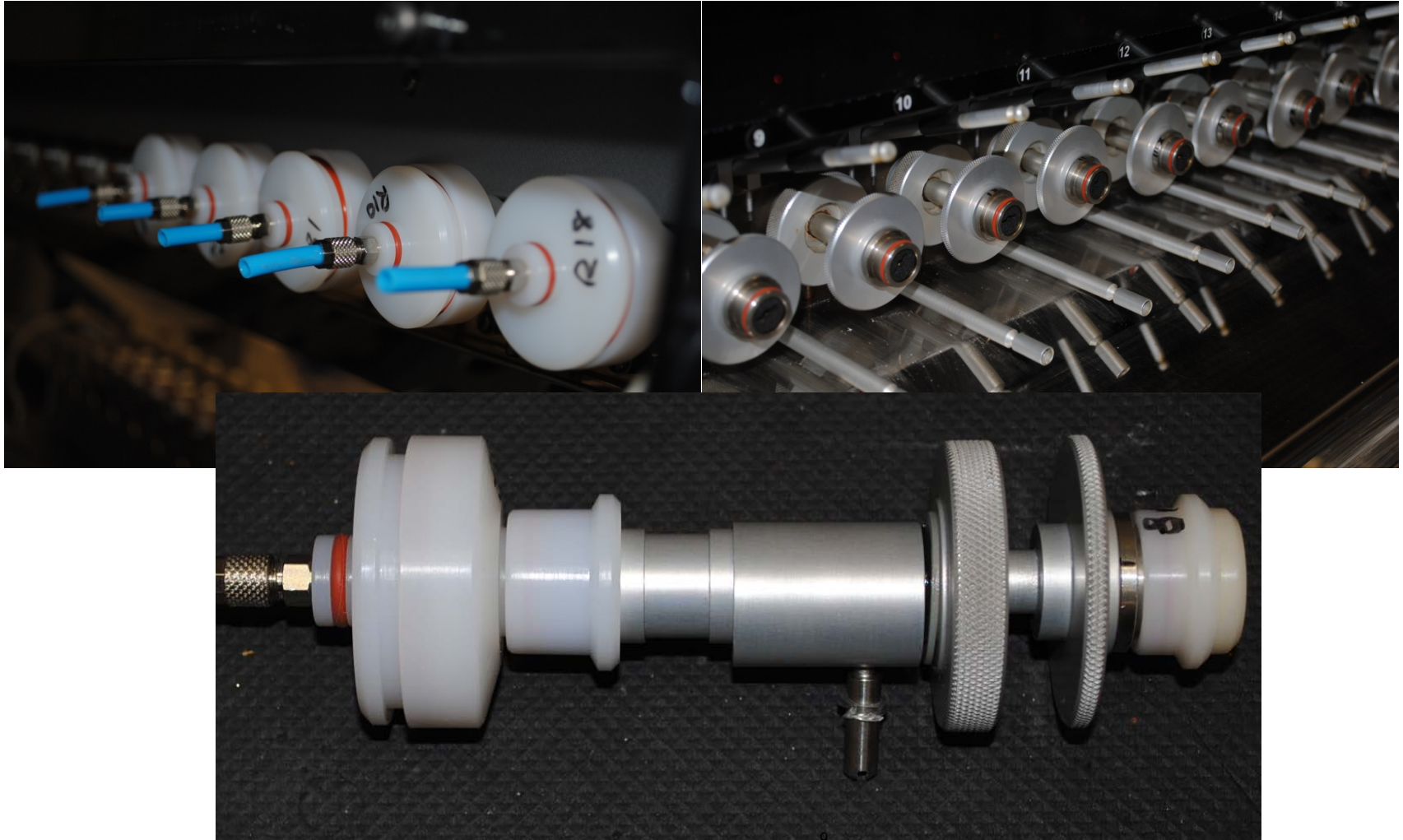


# Experimental equipment





# Experimental Equipment



## Experimental protocols

Objective	Experiment	Potential outcomes
1. Confirm that observed differences between machine types are a consequence of machine design and not of smoking conditions	Under both ISO and HCI conditions smoke into 44mm holder and 92mm holder on both machine types configurations TPM, puff and CO levels.	IF differences are not combustion related then CO concentrations should be consistent for 44mm and 92mm holders. ALSO under HCI 44mm holder TPM per cigarette > 92mm holder yields and in line with CORESTA study for similar products.
2. Identify sites for deposition of condensate within smoking machines	Smoke under both ISO and HCI on both machine types and deconstruct smoking machine as far as the puff engines determining the TPM deposited at each point within the smoking machine	<p>IF TPM is found in greater quantities before the capture pad for a 92mm holder under HCI compared with a 44mm holder then the capture dead volume is significant.</p> <p>IF TPM found between cigarette and 92mm holder capture pad is more significant under HCI than in ISO smoking then there are significant differences in the smoke matrix that initiate condensation</p> <p>IF TPM is found in significant quantities after the capture pad then desorption is taking place and this will contribute to the observed differences in TPM and NFDPM.</p>

## Experimental protocols

Objective	Experiment	Potential outcomes
3. Establish the relationship in between distance to capture pad from butt in terms of condensate deposition.	Extend distance between butt and capture pad (keeping cross sectional area and materials constant) and weigh TPM as a function of capture distance.	IF losses increase with distance between butt and capture then dead volume is a significant factor in the difference between machine type.
4. Establish the relationship between puff interval and condensate forming between butt and capture pad	On a modified linear machine with 92mm holder, keeping puff volume constant increase the puff interval and determine the levels of TPM deposition between butt and capture pad as a function of dead time.	IF there is a time based phenomenon then as dead time increases then deposition should increase. IF deposition is near instant deposition sites (nucleation sites for the smoke matrix) may be significant.



### 3. RESULTS



## Experiment 1

- Are observed differences between machine types a consequence of machine design and not of smoking conditions?

	ISO difference CORESTA	ISO difference 44 – 92 on Rotary	ISO difference 44-92 on Linear	HCI difference CORESTA	HCI difference 44 – 92 on Rotary	HCI difference 44-92 on Linear
TPM	0.60mg	0.40mg	0.77mg	5.47mg	5.68mg	4.15mg
CO	-0.37mg	-0.35mg	-0.06mg	0.73mg	0.41mg	0.32mg



## Experiment 1

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- As the differences between yields on the 44mm pad and 92mm pad locations are comparable to the differences between machine types in a collaborative study a reasonable conclusion is that it is not the combustion conditions in the machine types that is primarily responsible for the difference in yield
- Using the rotary machine in a “linear mode” (44mm pad) or a linear machine in a “rotary mode” (pad moved remotely) is to a first approximation equivalent in yield
- The method of using a rotary machine with 44mm pads as a linear machine “comparator” is shown to be valuable in comparison studies
- The use of the linear machine with remote capture has been shown to mimic a rotary system set up with a remote pad and again can be used for comparison experiments.

## Experiment 2

- Where are the sites for deposition of condensate within smoking machines?

	CI smoking (mg/tp) TPM yield		ISO smoking (mg/tp) TPM Yield	
	92mm pad	44mm pad	92mm pad	44mm pad
C (washer)	0.50		0.2	
C+E (washer +44CFH)		42.30		17.10
F (elbow)	5.67	0.28	1.16	0.0
E (92 mm CFH)	36.61	0.63	16.71	0.19
G (connector to PE)	0.46	0.40	0.26	0.01
Total mass balance	43.24	44.13	18.13	17.30

## Experiment 2

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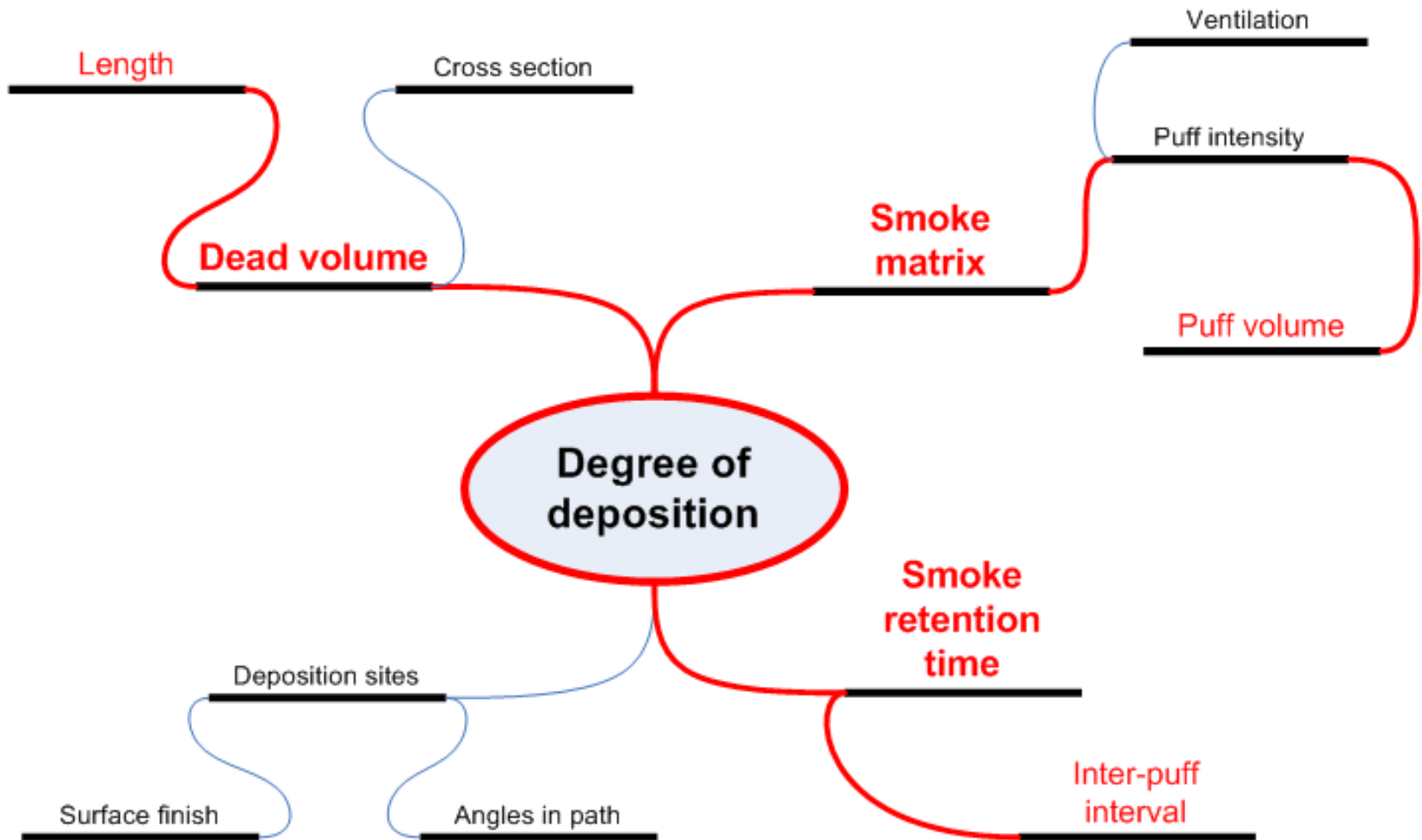
- There is an approximate mass balance in observed weights
- Most of the observed differences between 44 and 92mm capture are losses before the 92mm pad is reached
- Condensate forms between test piece and capture pad on 92mm pad capture system.
- The dead volume is significant
- Some condensate passes through 44mm and 92mm pad

## Experiment 2

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- There is a greater proportion “lost” in the HCl system compared to ISO for the 92mm capture pad
  - The smoke matrix differs between the two smoking regimes
- There are errors inherent in calculating NFDPM
  - Neoprene washer is included in TPM on linear machines and not on rotary
  - Gives rise to a 0.5mg offset in TPM and NFDPM
  - Condensate on the holder front imperfectly extracted for nicotine and water determinations
  - Rear of holder not extracted for nicotine and water determinations

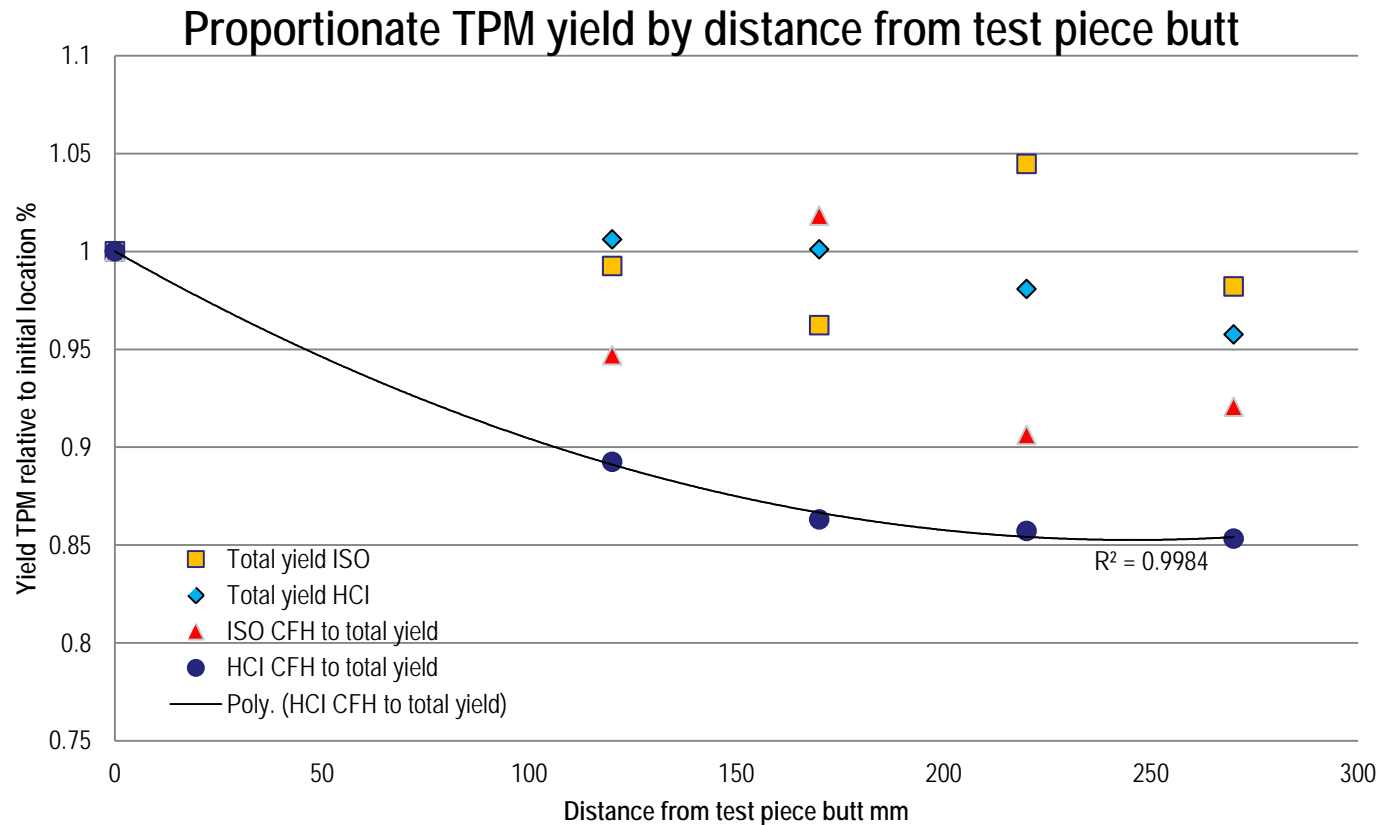
# What factors may influence the amount of deposition/loss?





## Experiment 3

- What is the relationship in between distance to capture pad from butt in terms of condensate deposition?



## Increasing dead volume

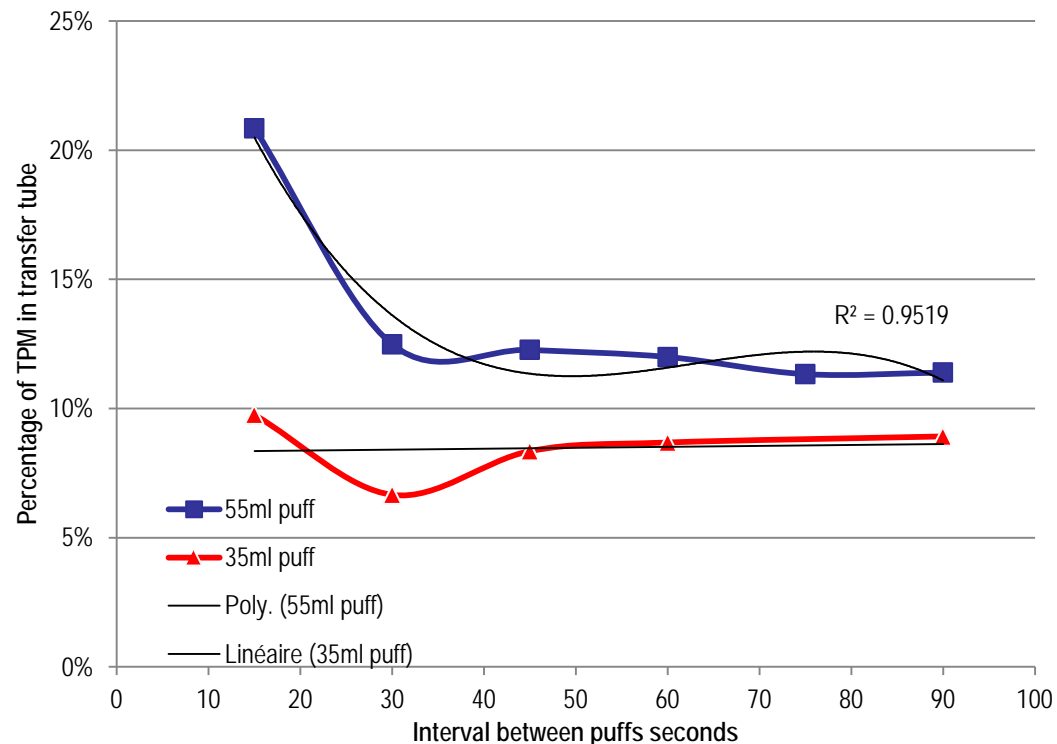
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- There are some losses in ISO smoking as the distance between capture pad and cigarette butt is increased but these are relatively small (2-5% for 170mm distant pad)
- In contrast HCl smoking has higher losses over the same distances, 14%
- The incremental loss as the capture pad moves away from the test piece decreases in HCl smoking (second order curve fit)
- The loss immediately behind the butt (first 20mm) is approximately 3% of the total regardless of the regime smoked.

## Experiment 4

- What is the relationship between puff interval and condensate forming between butt and capture pad?

Ratio of TPM Deposited before CFH to total TPM  
for remote CFH



## Experiment 4

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- Absolute yields decrease markedly with puff interval
- The relative deposition in the transfer tube for 55mL puff is constant from 30sec interval onwards
- The 15second puff interval results in a marked increase in transfer tube deposition for the 55mL puff
- The 35mL puffs show almost constant proportion of deposition in the transfer tube.
- The ratio of deposition of TPM in the dead volume to that on the pad is generally independent of puff interval
- But very short intervals change the smoke matrix



## 4. DISCUSSION



## A note about the ISO method applied to HCl

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- Neoprene washer not included for 92mm pad smoking
  - Up to 0.5mg/test piece offset in TPM and NDPM as always included in 44mm pad smoking
- Wiping out of only the front of the CFH
  - Only 30 to 70% effective in removing all deposits
  - 3 times as much material per test piece deposited on the front of the 44mm CFH compared with the 92mm CFH
  - 40% more deposition on the front of the CFH under HCl than under ISO
  - Rear of CFH not wiped out and deposits considered to be NFDPM
  - Greater per test piece deposition in HCl and on 44mm pad.
  - Lab to lab, machine to machine and method to method variability in Nicotine, NFDPM and water increased
- Loss of volatile components on opening
  - The time to “cap” could be significant in determining TPM and NFDPM

## Dead volume

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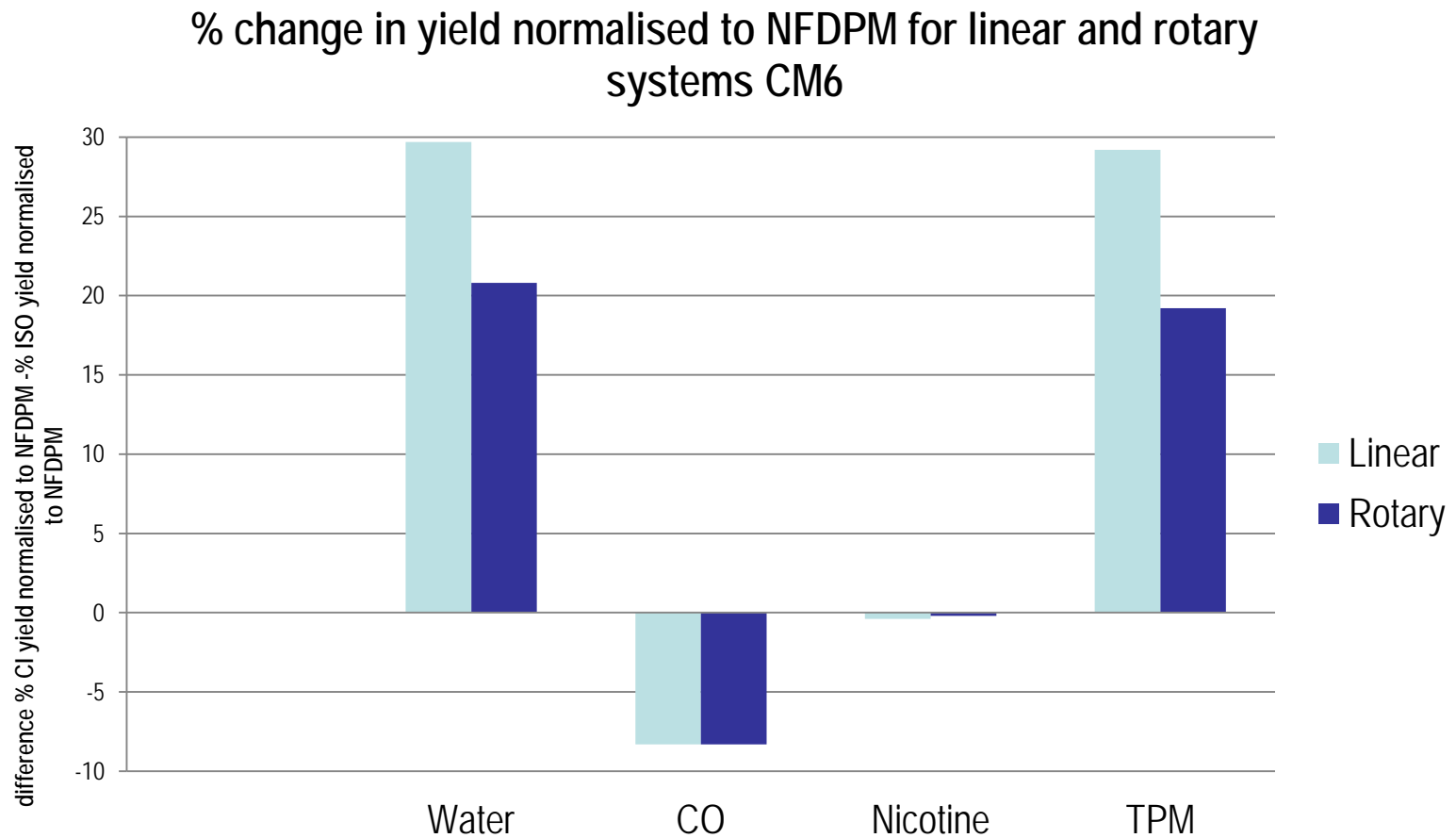
- The greater dead volume in the rotary system contributes significantly to the difference between results observed in collaborative studies under HCl conditions
- This difference is not so marked for ISO condition smoking and the losses due to dead volumes are greater in HCl smoking
- As the dead volume increases the loss in TPM also increases (constant cross section of dead volume) for HCl smoking
- This increase is proportionately larger in the first 100mm from the butt than in the next 100mm

## Smoke matrix

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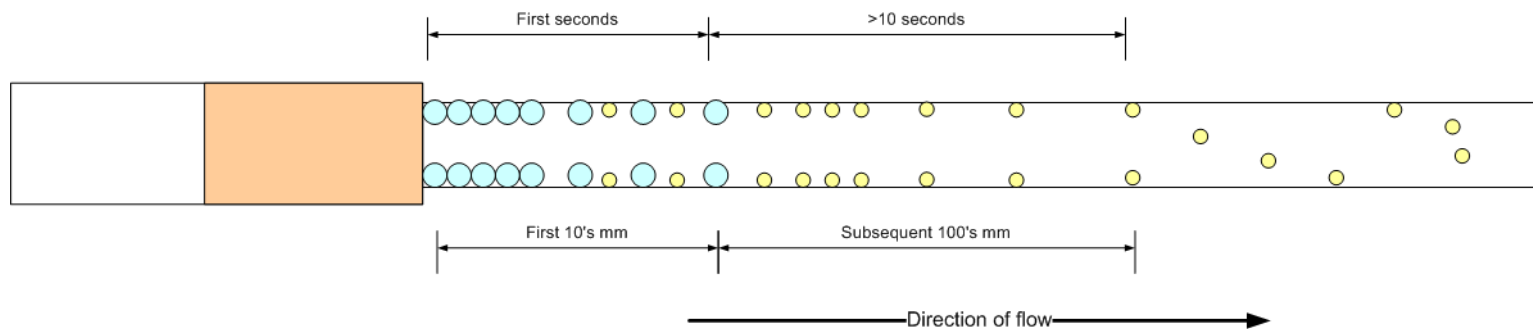
- The difference in TPM loss behaviour observed between the ISO and HCI intense regime is significant and appears entirely related to the conditions of the regime
- As these experiments were conducted upon an unventilated product the issue of ventilation can be placed to one side
- Two factors could be in play, the time that the smoke is resident in the dead volume and the composition of the smoke matrix being more susceptible to condensation
- The smoke matrix differs in that more water is present as determined by HCI smoking on a 44mm pad where as we have seen a greater proportion of TPM is captured
- The matrix does have significance as more intense (hotter) smoking increases the deposition in the dead volume – lower interval or bigger volume
- It has been shown that higher temperature pyrolysis increases the water content of the smoke matrix and this could be related to the levels of deposition in the transfer tube

## Offsets



## Possible mechanism

- As deposition in the transfer tube is characterised by:
  - Longer lengths = increasing deposition
  - Dead volume proportionately greater deposition close to butt
  - NOT time dependant as a first approximation
  - Coal temperature dependant (puff volume)
- Deposition is essentially a “time of flight” process
  - Large particles are formed in the smoke matrix at the butt
  - These impinge on transfer tube walls in the first few seconds of the puff
  - Smaller particles can travel further into the transfer tube but also will impinge on the transfer tube walls and distance travelled is critical







## 5. CONCLUSIONS

## From experiment

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- There are some systematic errors with the ISO methodology when applied to HCI smoking in the way that condensate is treated on the front of the holder, the omission of the holder rear from extraction and analysis, and the omission of the neoprene washer from the calculation.
- However we can say that although these effects are non zero the majority of the difference between the two pad locations is caused by the condensate initially not reaching the pad.
- We have seen that not all the TPM is reaching the pad when it is situated further away from the smoking cigarette. This accounts for the majority of the difference in observed TPM yield between the two smoking machine types.

## From experiment

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- In HCl smoking the larger dead volume between cigarette and capture pad the lower the yield. This is not so pronounced in ISO smoking
- The majority of deposition is immediately behind the cigarette and occurs immediately after the puff is taken
- Some condensate passes through the capture pad and is lost to the NFDPM/Water/Nicotine determination
- The differences in ISO and HCl loss in the transfer tube of a rotary smoking machine is a function of the smoke matrix

## How might these differences be mitigated

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- Locating the capture pad close to the cigarette will minimise the effect of dead volume on HCl smoke losses
  - Already possible with some rotary machines and on all linear machines
- Modify the extraction/capture/calculation method to include all condensate in the CFH and either exclude the washer totally or extract the washer in BOTH smoking systems
- Changing the cross sectional area of the rotary transfer tube?
- Changing materials in the rotary smoking transfer tube?
  - Could be counterproductive as “carry over” between runs may increase



## 6. REFERENCES AND ACKNOWLEDGEMENTS



- The authors would like to acknowledge the support of Cerulean and Molins PLC in the preparation of this paper
- We would also like to thank Mr Peter Jordan for performing experiments and providing data with both diligence and patience
- Further reading / source documents
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