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An Investigation in to the cleaning mechanisms of liquid jets and sprays used in batch cleaning

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Aims and objectives

- The primary aim of the project is to characterise the cleaning mechanisms of jets and sprays used in batch cleaning processes in the pharmaceutical industry, particularly spray mechanisms which remain relatively unexplored.

- Cleaning is an important part of the manufacturing cycle and is a large source of inefficiency in the pharmaceutical industry, the research will aim to seek more optimal flow conditions in batch cleaning processes to help minimise these inefficiencies.

Introduction

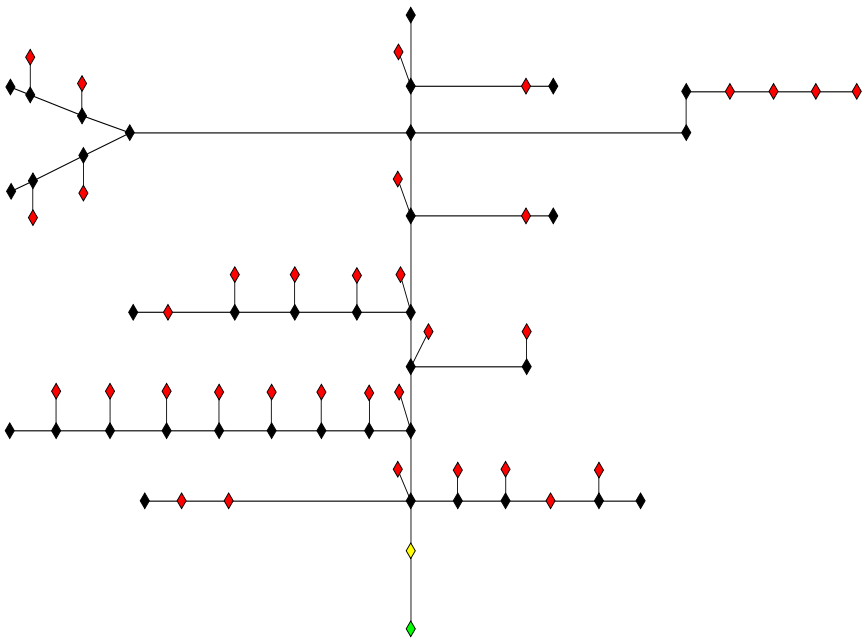
- For batch processing, production equipment is commonly disassembled in to its constituent parts which are then loaded on to a washing rack for cleaning out of place.

- Each rack comprises a series of pipes and nozzles through which a mixture of heated water and surfactant passes.

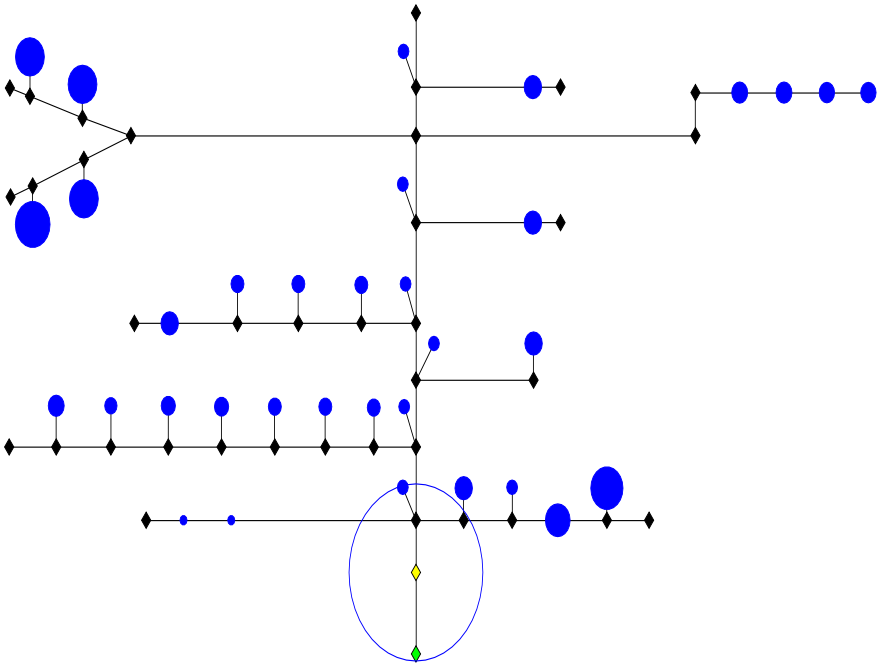
- The nozzles are positioned such that the fluid flow cleans the loaded components via a jet or spray.

- Residual films on components are often such that they do not meet acceptance criteria set out by regulatory bodies.

Flow network analysis



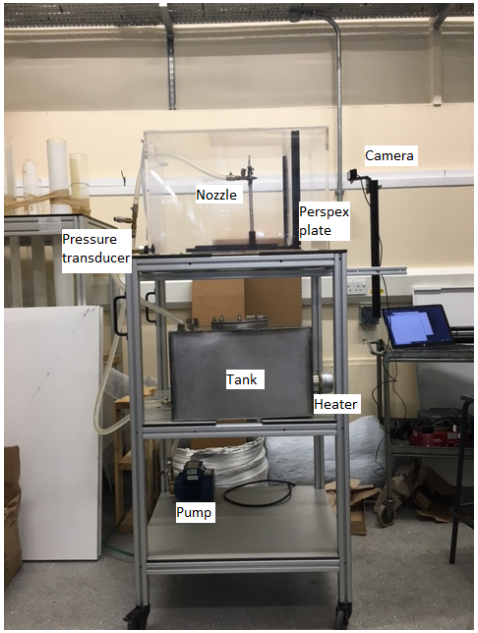
- EPANET was used, an open source software developed by the Environmental Protection Agency (EPA) to model hydraulic and water behaviour in water distribution systems.
- Idealised flow network of wash rack, where pipes and connecting sections are black, nozzles red, pump green and the coupling yellow.
- Pipes are assigned a flow coefficient and an elevation from manufacturer data sheet.
- Conservation of mass and momentum applied under steady state conditions.

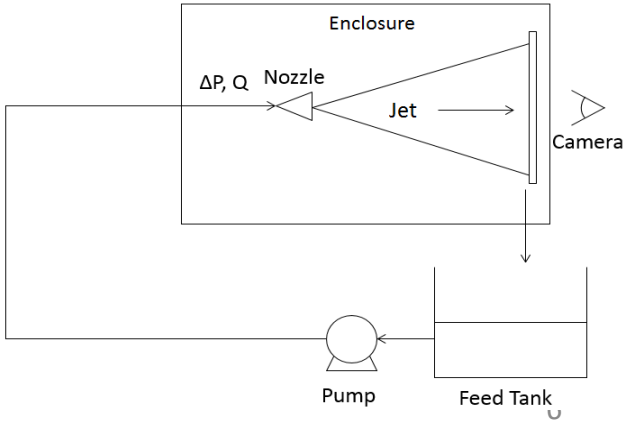


- Bubble plot of flow distribution through wash rack.
- Areas of bubbles are proportional to the flow rate through them, the coupling is left unfilled.
- Certain nozzles are left under or over supplied with fluid, nozzle selection can be optimised for improved flow distribution.
- Flow rates vary from 1.8 - 42.6l/min.
- Due to pump limitations on the rig the lower boundary was explored; 1, 2.5 and 4l/min.

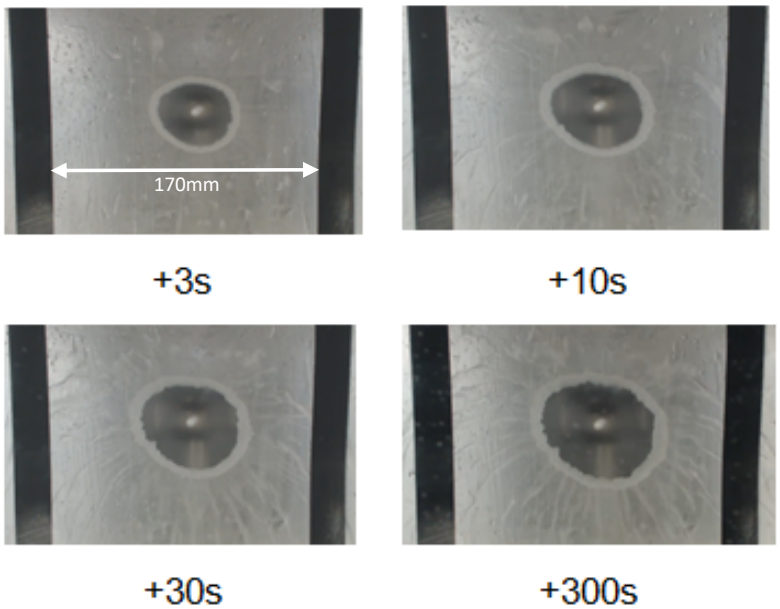
Experimental setup

- Test rig built in Leeds with impinging jet/spray on to a vertical Perspex wall.
- Wall coated with film of white soft paraffin (WSP), an excipient commonly used in the pharmaceutical industry.
- Film thickness, nozzle standoff distance, WSP yield stress, water temperature and flow rate are controlled variables. Experiments thus far have been conducted at room temperature to view cleaning from a purely mechanical aspect.
- Process filmed with camera positioned behind the Perspex wall.





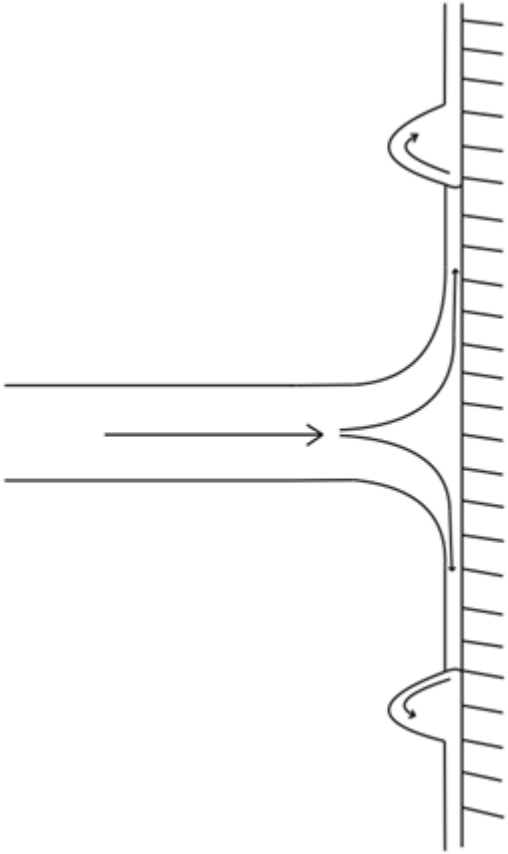
Jet results



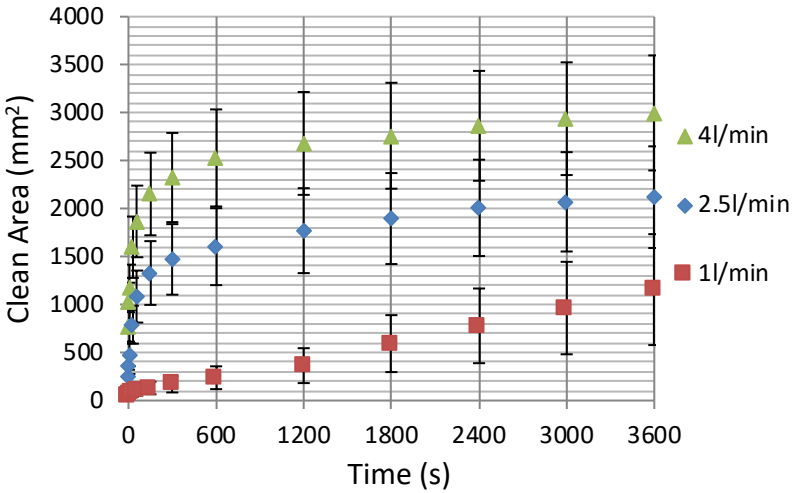
- Removal is rapid in the early stages of the cleaning process and then the clean area growth begins to plateau.
- A ridge of WSP forms on the perimeter of the clean area, where it accumulates as the WSP is displaced radially outwards.
- The ridge grows with time and acts as a resistance to clean area growth.

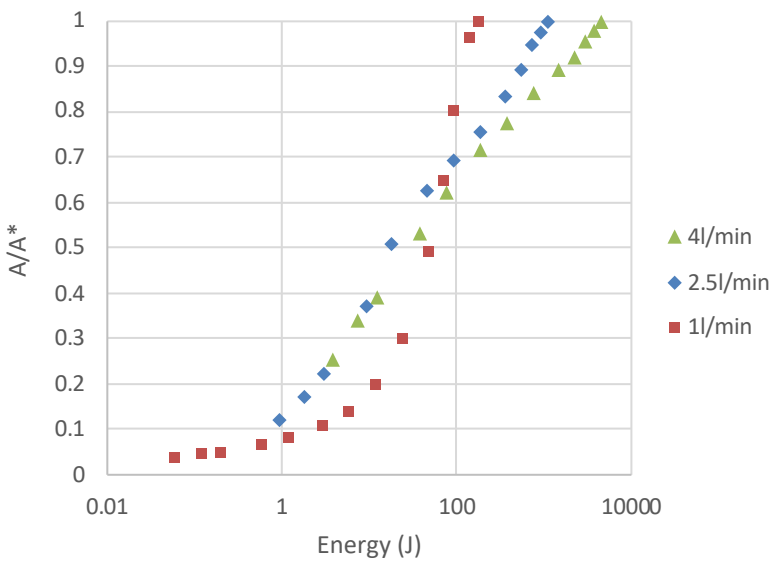
Soil removal mechanism study

- After a minute of cleaning the ridge of WSP was dyed with oil soluble dye to track how the WSP was displaced.
- The jet was then continued for a few minutes and stopped again.
- It can be observed that the dye has moved to the back of the ridge and later submerged by more WSP.

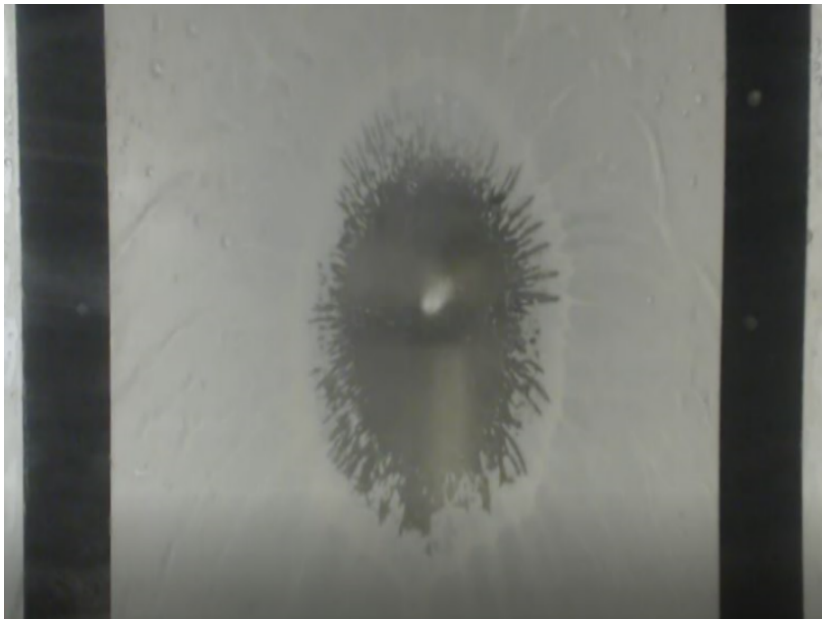


- This suggests the WSP at the perimeter of the clean area is forced over the ridge in a rolling motion and the ridge continues to grow in size as more WSP is removed.
- Mass balance before and after process showed only 17% of the WSP was removed so most of the material is simply transported to the ridge.
- As the ridge grows in size the shear stress required to displace it increases and ultimately the final clean area A* is reached.
- A* is a function of the WSP yield stress, the film thickness, the flow rate of the impinging jet and the surface material properties.





- Clean area vs time shows how the vast majority of the cleaning is achieved in the first 300s of the process for the two higher flow rates and then the curves plateau.
- The 1l/min jet shows a linear increase in clean area.
- A/A* vs energy shows how the two higher flow rates adhere approximately to a common curve.
- Using two 2.5l/min jets for an extended time would be more efficient in energy terms than using a 4l/min jet for a shorter time, however time is money on plant.

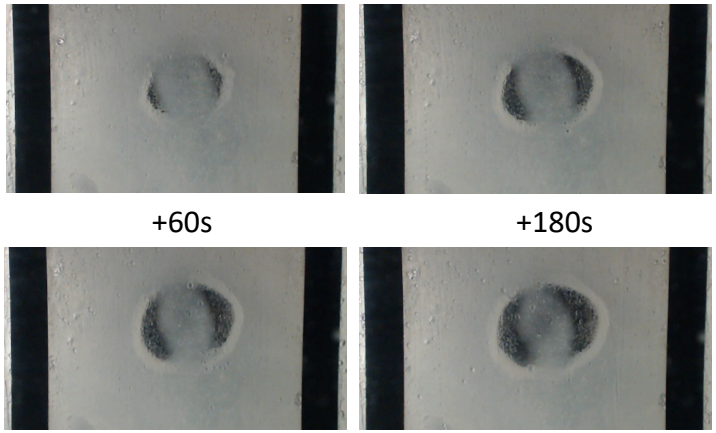


- When a WSP with a higher yield point is used the clean area produced is less of a uniform circle than the previous sample.
- The ridge contains several fragments but due to the higher yield of the WSP the jet is unable to displace as much material.

- The effects of the falling film can be observed on the softer sample. The shear stress exerted on the film in this case exceeds the adhesive force between the film and the surface and displaces it.
- The clean area resembles a tear drop shape and the rate of removal is far greater than the higher yield samples.

Spray results

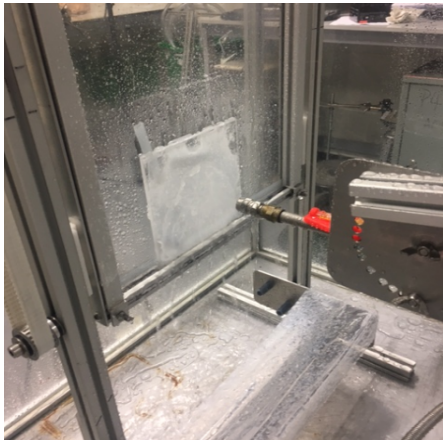
- The spray shows a very small growth in clean area in comparison to the jet.
- The perimeter of the cone is cleaned first and the central uncleaned region slowly reduces with time.
- The ridge of WSP on the perimeter can still be observed suggesting material is displaced radially outward as with the jet.
- A thin residual film was still present on the surface after cleaning.

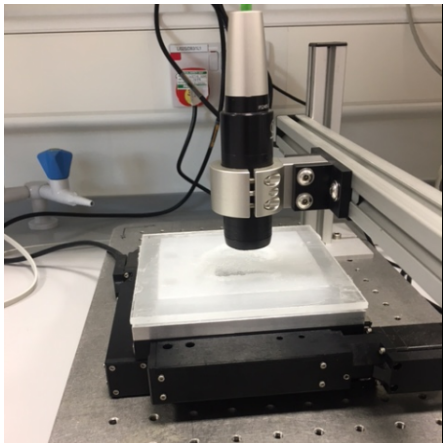


+60s +180s

+300s +600s

Short research visit

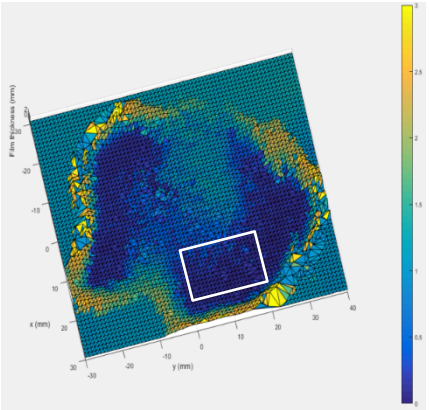


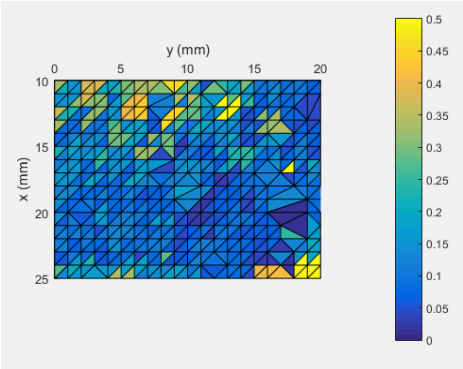


- Two week research visit to Cambridge through SIG 10 primarily to use confocal thickness sensor (CTS).
- CTS can be used to measure very thin residual films on surfaces such as those left after spray cleaning.
- Sample is mounted on to an x-y stepper motor positioning table which allows the entire surface to be measured.
- Polychromatic white light focused on to the target and a specific distance to the target is assigned to each wavelength via a factory calibration.
- Deviation from the distance to clean surface represented the thickness of film on the surface.

5 minutes cleaning

- 1mm film was cleaned for 5 minutes with a 4l/min spray from a 50mm standoff distance and then measured with the CTS.
- The CTS shows that at its peak the ridge of WSP on the perimeter of the clean region is ~3mm.
- There is a large uncleaned region in the centre that has approximately the same thickness as the surrounding film.

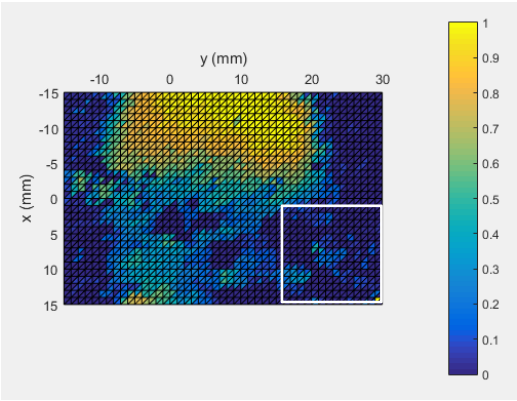


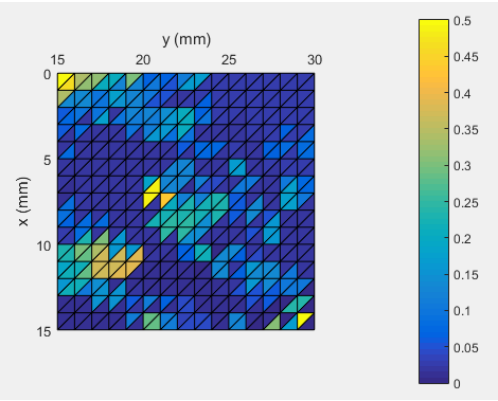


- When focusing on an area that appears clean to the naked eye the presence of a residual film becomes clear (~0.1-0.2mm thick).
- Very few pixels are fully clean.

15 minutes cleaning

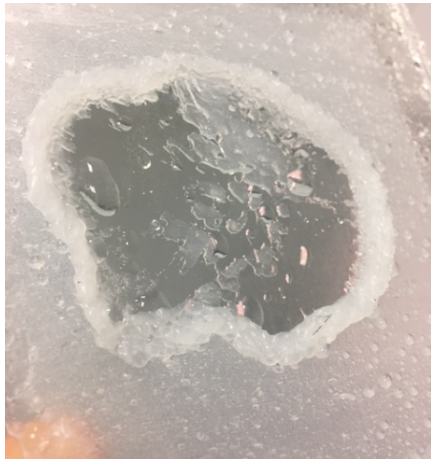
- A new sample was then cleaned for 15 minutes under the same conditions and measured with the CTS.
- There is still a large area that is uncleaned of approximately the same thickness as the surrounding film.
- Again focusing on an area that appears clean to the naked eye there still appears to be a residual film present of at least 0.05mm.



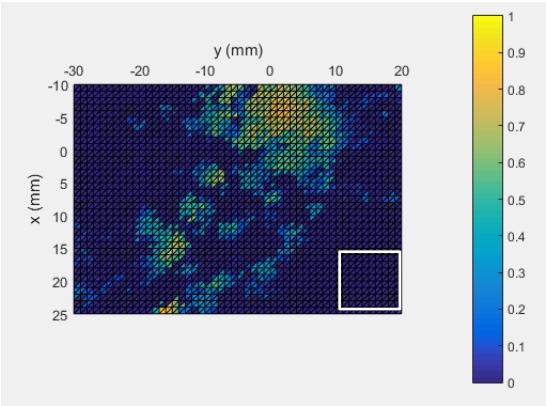


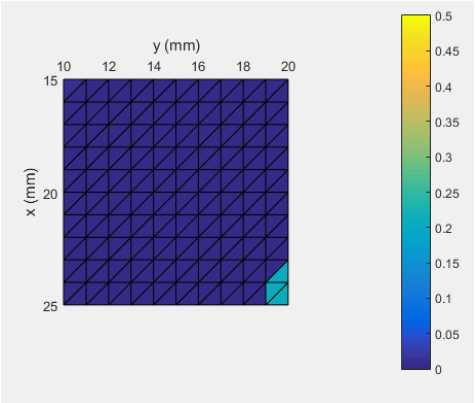
- Despite being far cleaner than the 5 minute sample still very few pixels are fully clean.

45 minutes cleaning



- Finally a sample was cleaned for 45 minutes and measured by the CTS.
- Although reduced in size and thickness a relatively large residual film is present in the centre of the cleaned area.
- Focusing on an area that appears clean to the naked eye in this case also appears clean from the CTS results.





- Heat and surfactant are required to fully remove the residual film in the centre.

Conclusions and future work

- Jet cleaning mechanism study showed how the medium yield WSP is rolled over the ridge at the perimeter after it is adhesively removed.

- Energy efficiency comparison between flow rates showed how using multiple lower flow rates is more efficient but cost of time needs to be quantified.

- The effects of temperature need to be studied; batch cleaning is conducted at ~90°C on plant, temperature ramp will show if this can be lowered for certain films. Energy may be being wasted beyond certain temperatures.

- Despite covering a larger area than the jet, the spray left a residual film on the surface whereas the jet did not. The power consumption for the same flow rate of the spray is 4.6 times greater than the jet, however temperature effects must again be explored.

- Spray cleaning mechanism is to be captured in more detail through use of high resolution imaging and droplet impacting on film simulations on Comsol.