AN INVESTIGATION INTO THE SPRAY PATTERNS OF BITUMEN PRODUCTS

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ABSTRACT

This paper presents the results of a test program that investigated the spraying behaviour of various binders and emulsions. A laboratory spraying simulator was used to determine the transverse spray pattern of products through a single nozzle.

Traditional sprayer calibration practice relies on the use of simple oils to validate their performance, which at comparatively low temperatures match the viscosity of bitumen at spraying temperature. However, the non-Newtonian flow properties of polymer modified binders (PMB) and emulsions are not able to be adequately represented by such oils, and as such must have their performance validated by other means.

The results will be used to update the national bitumen sprayer calibration test methods, with greater and updated understanding of the performance and repeatability of the nozzles, and the properties of sprays with alternative materials.

INTRODUCTION

Traditional sprayer calibration practice relies on the use of calibrating oils to validate their performance, which at comparatively low temperatures match the viscosity of bitumen at spraying temperature. However, the non-Newtonian flow properties of polymer modified binders (PMB) and emulsions are not able to be adequately represented by such oils, and as such must have their performance validated by other means.

Main Roads Western Australia (MRWA) has provided ARRB with a single jet laboratory spraying simulator, which can be used to investigate the transverse spray pattern of a single nozzle. The aim of this project is to provide recommendations to Austroads, via the Bituminous Surfacings Research Reference Group (BSRRG) and Pavement Technology Review Panel (PTRP), for updated national bitumen sprayer calibration test methods, with greater and updated understanding of the performance and repeatability of the nozzles, and the properties of sprays with alternative materials.

This report details the testing conducted with calibration oil and bitumen products, and the development of a software package to simulate a full spray bar.

DESCRIPTION OF EQUIPMENT

The device includes a 15 litre storage tank fitted with temperature and pressure controls, and provisions for fitting and testing one nozzle at a time. The discharge from the nozzle is collected in a set of 20 mm wide troughs, the measurement of which enables the transverse spray pattern to be determined accurately across its fan.

The storage tank is fitted with a stirrer to maintain the uniformity of the binder to be sprayed, which is particularly important for binders that contain products that settle upon standing.

The nozzles used for this testing were standard Copley AN18 type. Six nozzles were chosen randomly from a set of 50 for testing. The nozzle is positioned 260 mm above the top of the troughs, which is the same height used in historical investigations with the spray facility in WA, and is representative of typical spray bar heights in practice.

The oil selected for the experiments is BP Enerpar 11, which meets the requirement of Austroads test method *AGPT/ T536 Viscosity of test fluid determination* (Austroads 2005). The oil at low temperature has viscosity equivalent to bitumen at the much higher spraying temperature.

METHOD

Nozzle Repeatability

Tests were conducted under the following conditions to ascertain the repeatability of the spray distribution:

Temperature	20 ˚C
Product pressure	82 kPa
Product	Enerpar 11
Spray period	50 s

The nozzles used for this testing were standard Copley AN18 type, as seen in Figure 1 ARRB randomly chose six nozzles for testing, with each given a letter prefix (D, E, J, P, Q, T).

Copley AN18

18.0 L/min at 80 kPa

Figure 1: Copley AN18 nozzle

Each of the six nozzles was tested with three repeats, using calibration oil.

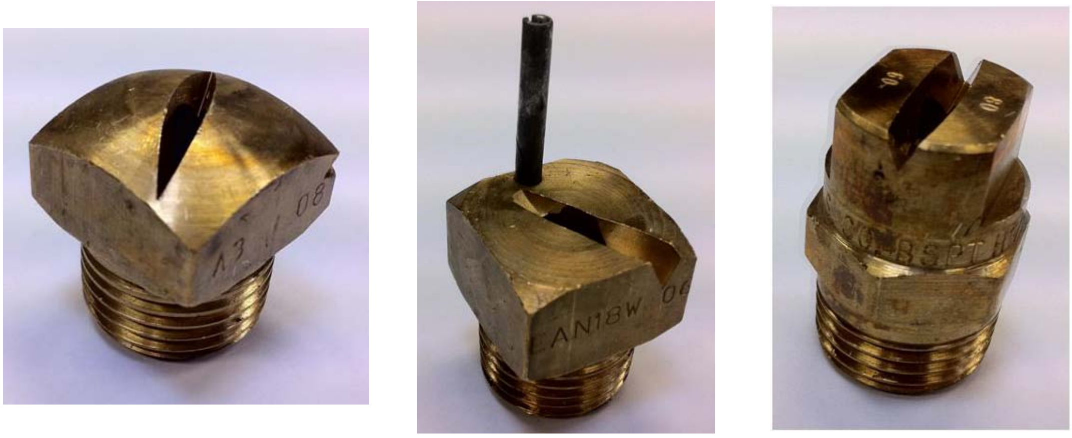
Alternative Nozzles

As well as determining the profile for a ‘standard’ Copley AN18, three alternative nozzles were tested using calibration oil:

These include:

- Copley A3
- Copley AN18W (end)
- VeeJet H1/2U.

Photos and flow rate information are included in Figure 2.



Copley A3	Copley AN18W	VeeJet H1/2U
13.5 L/min at 80 Kpa	18 L/min at 80 KPa	3.9 L/min and above up to 280 kPa

Figure 2: Alternative nozzles for testing

Effect of Pressure

The experiments were conducted with the sprayer pressure set to 87 kPa for a Copley AN18 type nozzle, with an expected flow rate of 18 L/min (with a ± 5% tolerance, or 17-19 L/min range).

Products for Testing

Experiments were conducted using various unmodified and modified bitumen products to compare against the results found with calibration oil, and also to determine the spray profiles of non-Newtonian bitumen products.

The products listed below for testing are defined in AS 2008–1997 *Residual bitumen for pavements* (Standards Australia 1997) and AGPT/T190 *Specification framework for polymer modified binders and multigrade bitumens* (Austroads 2010).

- C170
- C320
- S20E
- S25E
- S35E
- S15RF
- Emulsion.

Simulation Program

In order to understand the effects of the differences in spraying profile between products, a computer program that can perform simulations of a spraybar with many nozzles was developed to demonstrate the cumulative effect of the nozzle profiles on on-road spray performance.

The software allows the user to select the following variables, and observe their effect on total spray pattern:

- binder type
- nozzle spacing
- number of nozzles.

PROBLEMS OVERCOME

Measurement Method

A ‘dipstick’ type method can be used to determine the transverse distribution from the sprayer nozzle. A dipstick is placed into each of the troughs following a test run, measuring the height and volume of product in that trough.

This method was trialled by placing quantities of oil into a number of the trays, and then taking measurements of the volume of this oil indicated by the dipstick. The results of this testing are shown in Figure 3.

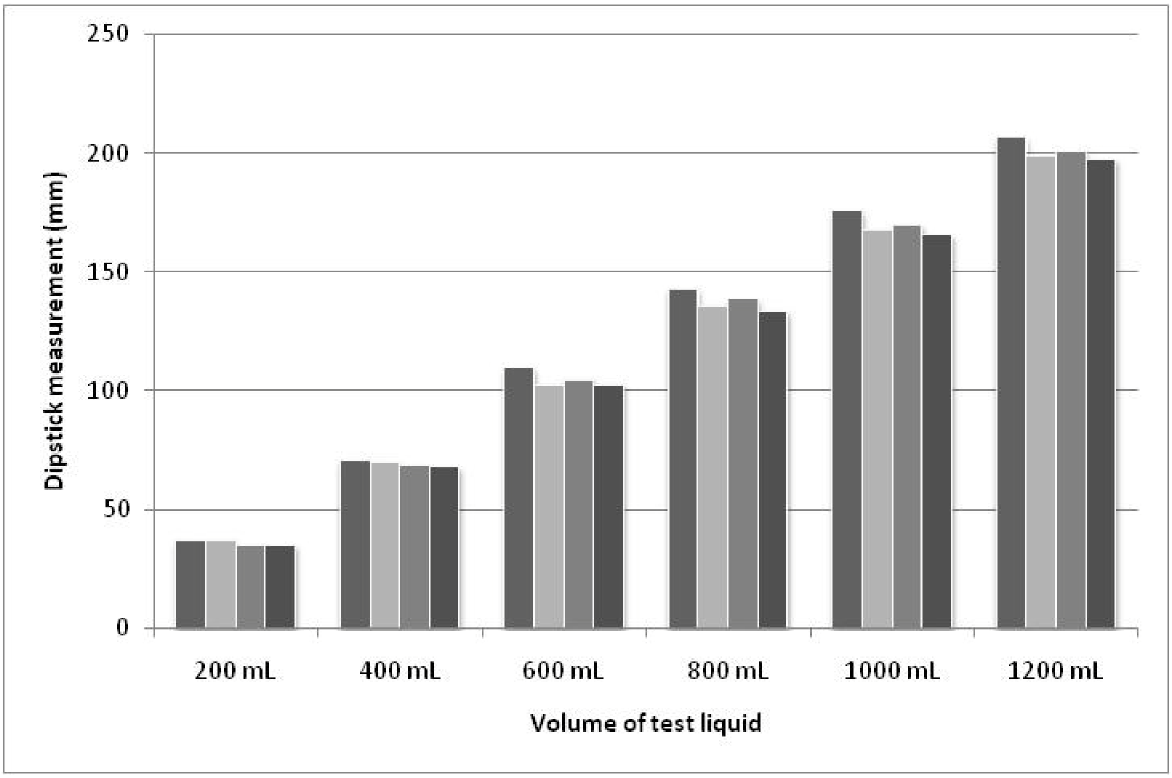


Figure 3: Dipstick measurement repeatability

It is evident from these results the dipstick does not provide an accurate and consistent measurement for the small volumes of product involved in the calibration process.

To improve accuracy and productivity it was decided to determine the spray distribution by weighing each trough immediately before and after the tests, as done by Tredrea (2001). The initial measurement is to ascertain the tare weight of the trough, which must be repeated for each test run to account for any movement in the tare (caused by detritus or remaining product from a previous run). Weighing the trough after the test provides a comparative indication of the proportion of the spray collected by that trough.

Symmetry

The design of the spray nozzle is such that a symmetrical pattern should be expected as its output. However, testing results indicate there is somewhat of a skew around the centre when using this apparatus, with more of the sprayed product falling to the left of the centre than the right.

Two experiments were conducted in an attempt to source the cause of this lack of symmetry. Firstly, the origin of the nozzle was reversed 180 degrees, to investigate whether the source of the skew was the nozzle. The results of this testing can be seen in Figure 4.

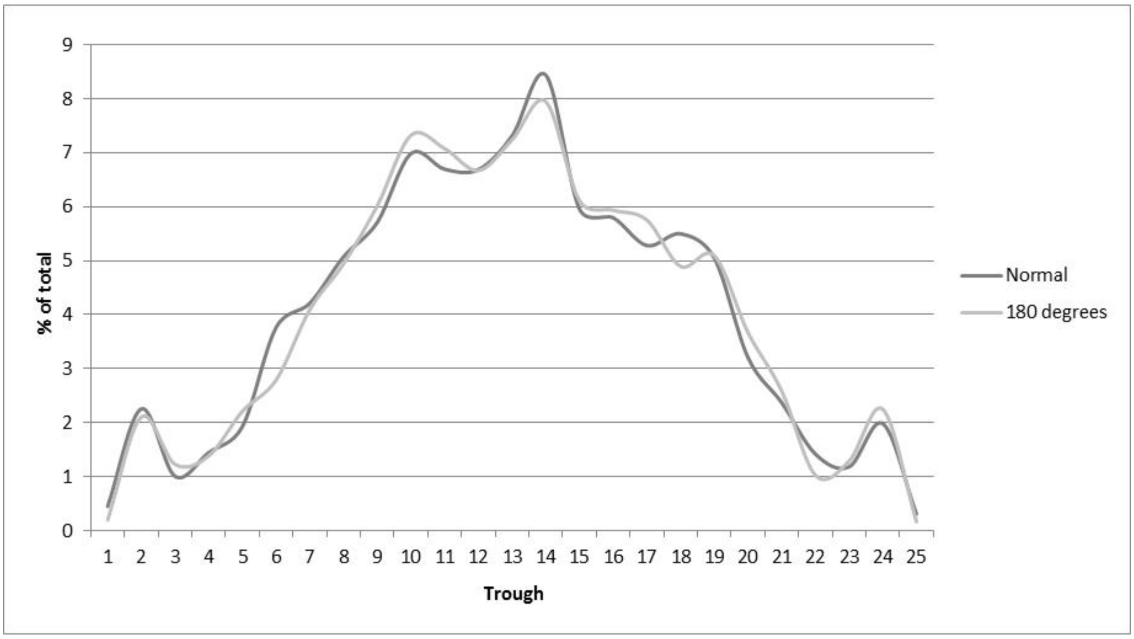


Figure 4: Nozzle J with standard and reversed orientation

It can be seen the profiles are very similar, and thus not dependent on the orientation of the nozzle, with the skew around the centre present in both spray profiles.

The nozzle was removed from the apparatus to determine the spray pattern of just the rig alone, and test if the skew was still present. The results of this testing can be seen in Figure 5.

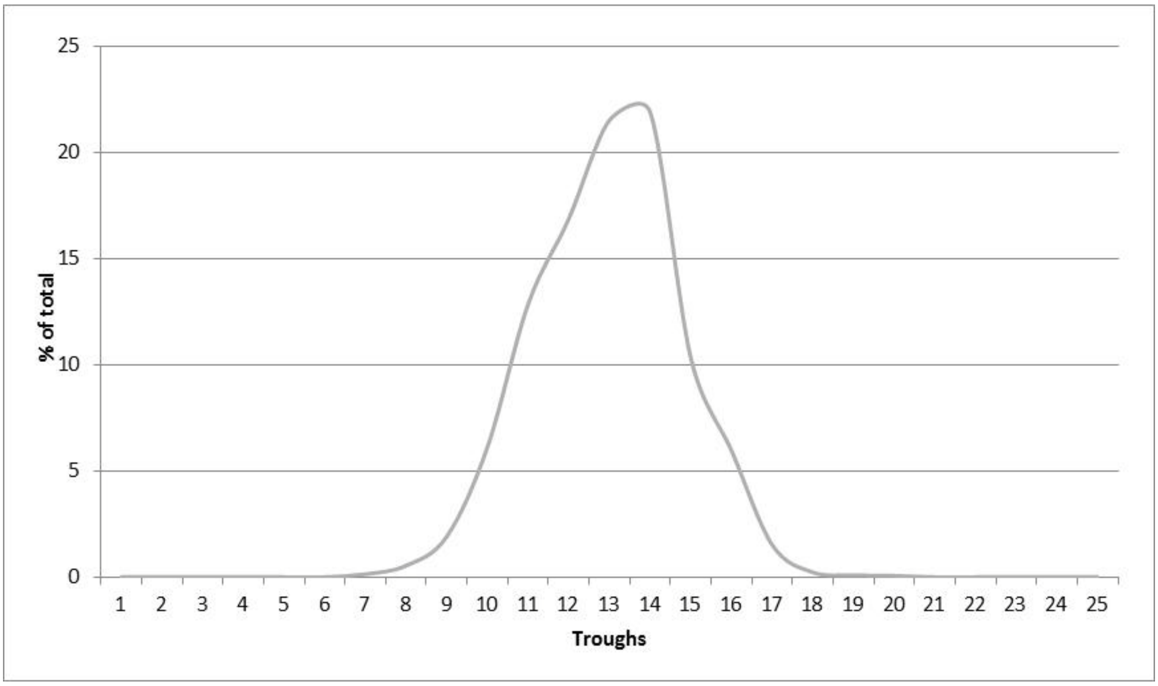


Figure 5: Spray pattern with no nozzle

It is apparent that the skew reducing the amount of the product falling to the right of centre compared to the left is still present. This indicated the skewing is caused by some inherent property of the test apparatus itself.

The nozzle attachment apparatus was removed from the rig for inspection, as seen in Figure 6.

Figure 6: Nozzle apparatus with valve open

There are no noticeable overlaps or inconsistencies present when the valve is in the fully open position.

Upon further inspection, some burrs and inconsistencies were noted around the circumference of the internal edges (Figure 7). It is reasonable to expect that inconsistencies such as this will impact on the shape of the spray profile, and may be a cause of some of the turbulence witnessed in the spray. However, it does not provide sufficient evidence to place it as the cause of the skew.

Figure 7: Burrs on the valve

RESULTS

Between-Nozzle Variation

In order to determine the spray pattern of the AN18 nozzle, six were tested three times each, Comparisons of these indicate the repeatability expected between different nozzles of the same type.

A plot of the averaged nozzle outputs is seen in Figure 8.

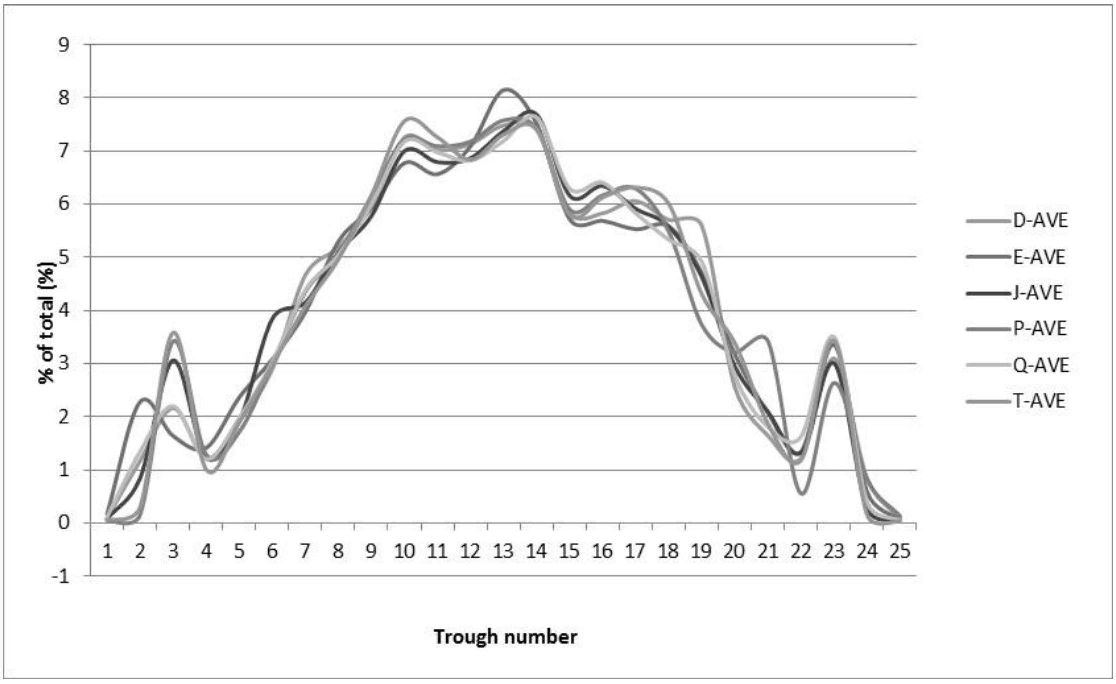


Figure 8: AN18 nozzle spray distributions

A distinct three peaked pattern can be observed for all nozzles. The spray pattern can be observed to be quite consistent in the middle region, but more variable towards the outer extents.

Quantifying Variation

In order to quantity the variation in the spray pattern around the mean expected values, the pattern was broken into three sections, one in the middle and another on each edge. The variability of each section was assessed. Table 1 lists the variability around the mean expected for two standard deviations, or approximately 95% of all likely results.

Table 1: Spray variability (95% confidence) across trough sections

Trough	1-7	8-18	19-25
Variability	56%	7%	57%

This shows the outer regions can expect the spray to vary approximately 50% from their mean values. However, the middle region experiences significantly less variation and can be expected to only alter 7% from its mean value.

The absolute outer troughs gather the least product, and are subject to considerably more variation than the troughs closer to the middle. If the last three troughs on each edge are excluded from the results, the variability for the outside regions is reduced greatly, as indicated in Table 2.

Table 2: Spray variability (95% confidence) across reduced trough sections

Trough	3-7	8-18	19-23
Variability	27%	7%	37%

In Figure 9 the averaged pattern for AN18 nozzles is plotted with a thick black line, with the two thin grey lines bounding two standard deviations, or 95% of the expected variation around the mean (in this case simplified to 7% in the middle section, 32% on both sides).

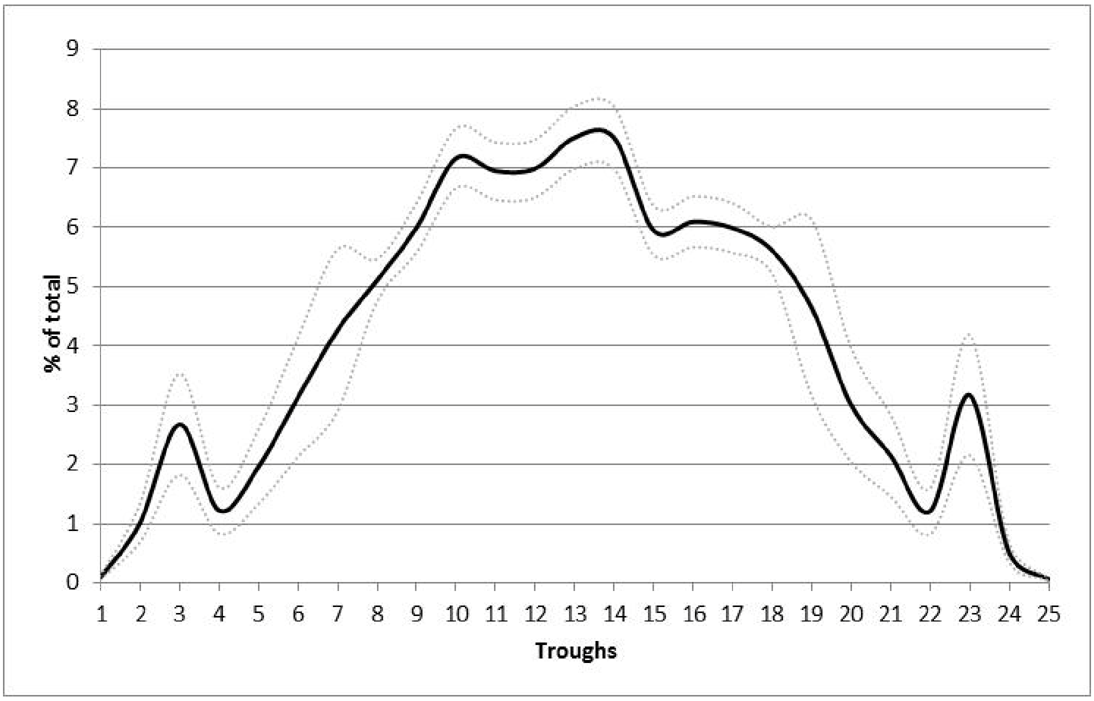


Figure 9: Average AN18 profile and confidence bounds

Effect of Pressure

In order to understand the effect of the pressure on the resultant spray pattern, a set of runs were performed with Copley AN18 nozzle 'J' at a pressure of 110 kPa.

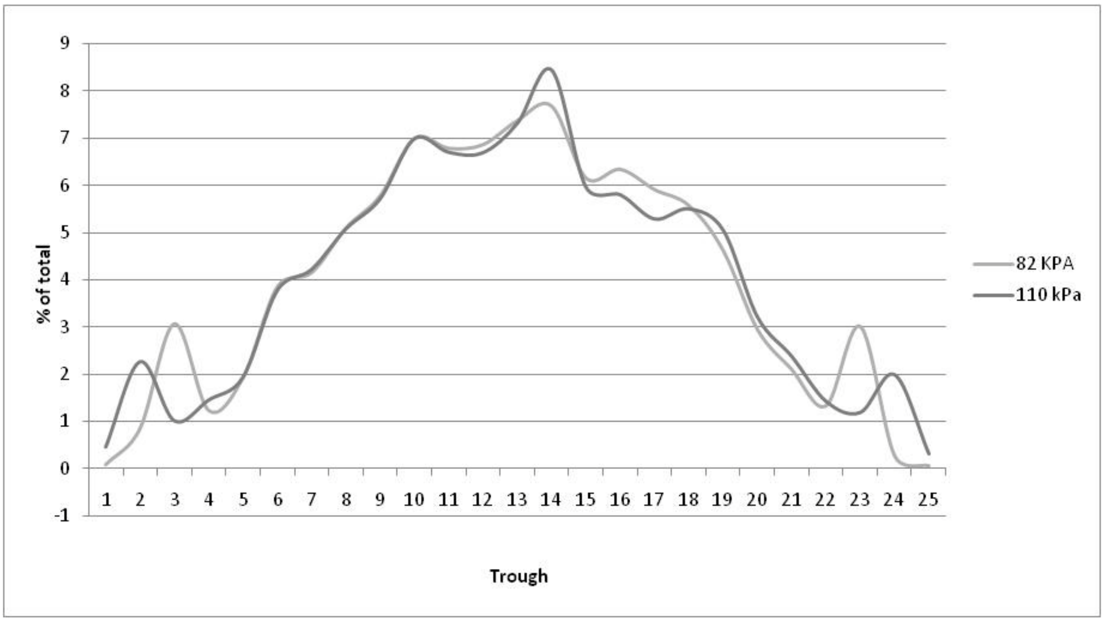


Figure 10: Nozzle J with different pressures

Figure 10 shows that the overall profile shape is not affected significantly by the change in pressure. Especially in the middle section of the spray, the two profiles are very similar to each other.

The difference comes in the location of the two outside peaks, with the higher pressure flow moving the peaks outwards. This indicates these peaks are generated by a turbulent region on the edges of the spray, where the film breaks up and does not distribute evenly at the edges. It can be seen in Figure 10 that the location of these areas is dependent on the pressure the material is forced through the nozzle.

These turbulent areas of the flow can be seen in Figure 11. The edges closer to the nozzle can be seen as quite strong and defined lines, and as it moves further way these lines break up and the flow becomes turbulent.

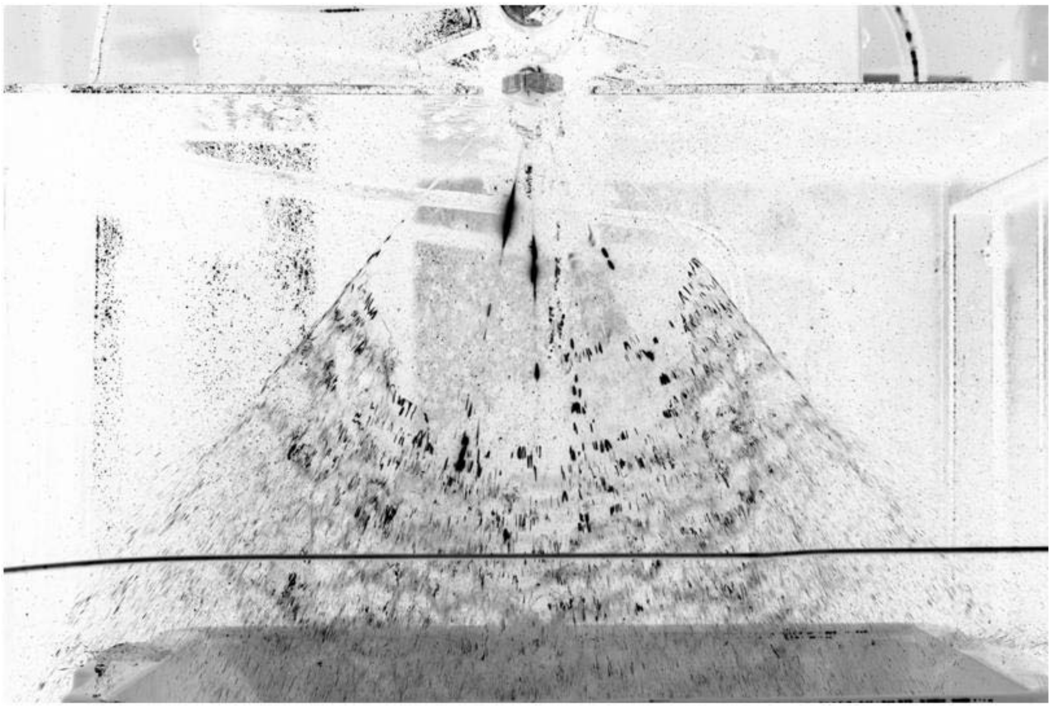


Figure 11: Photo (negative) of calibration oil sprayed at 110 kPa

Alternative Nozzles

The Copley AN18 is the accepted standard nozzle used for bitumen spraying in Australia. However there are a number of nozzles available, designed for an array of different applications and from different manufacturers.

The first alternative nozzle tested was an ‘end’ nozzle, the Copley AN18W. End nozzles are used at the extremities of a spray bar where the output from intermediate nozzles no longer overlaps. Also tested were the Copley A3, a similar but lower capacity nozzle to the AN18, and the VeeJet H1/2U, another standard fan nozzle.

The results of this testing can be seen in Figure 12.

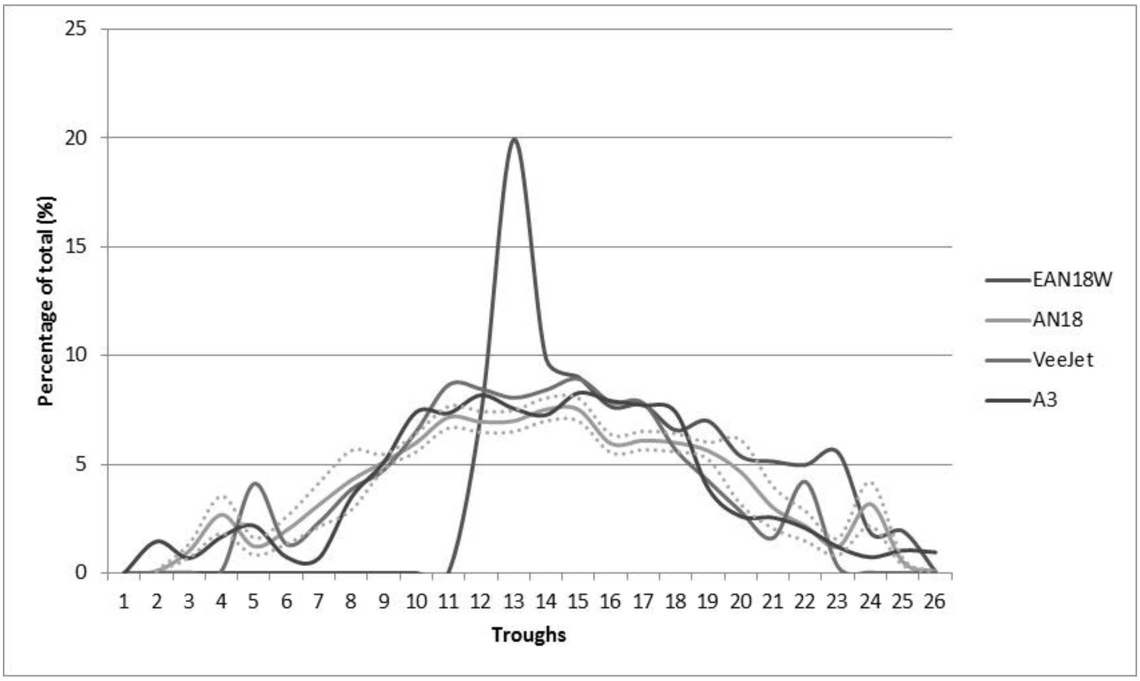


Figure 12: Spray profiles of alternative nozzles

The EAN18W can be seen to deliver a 'half pattern' spray, with product being sprayed over only about half of the width of a standard nozzle. The profile delivered on the 'active' side of the nozzle follows reasonably close to that expected for the AN18.

As for the other nozzles, there are small differences evident in the shape of the profiles, but with the same major features, being a peaked centre and small peaks due to turbulence at the edges.

One of the alternative nozzles tested, the VeeJet had apparently less 'misting' of the calibration oil compared to the others, and the repeatability of the plots tends to indicate these nozzles provide a more uniform transverse distribution.

Bitumen Testing

In order to verify the results obtained with calibration oil, the C170 and C320 bitumen were tested and the spray profiles are plotted in Figure 13, from the average of three separate testing runs. The dotted lines indicate the expected pattern as taken from the calibration oil testing, as per Figure 9.

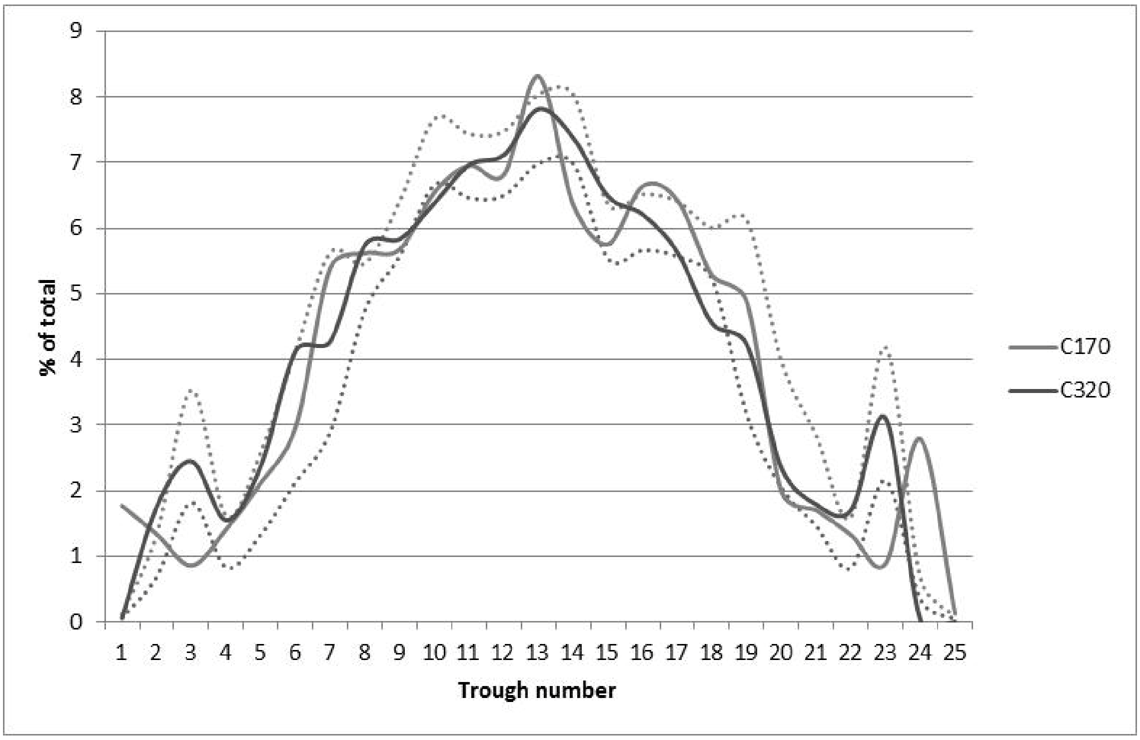


Figure 13: Spray profiles of bitumen products

For the C170, the profiles are seen to be mostly within the expected bounds displayed in the dotted black lines. The peak on the right-hand edge has shifted outwards.

The C320 shows a similar pattern, remaining within the expected bounds for most of its width.

PMB Testing

The profiles of the PMB products tested have been compiled together in Figure 14. The PMBs tested were:

- S35E – a binder intended for spray seal applications with a low level proportion of elastomeric polymer (such as a PBD or low molecular weight SBS). This type of binder is typically used for SAM applications.
- S20E – a binder intended for spray seal applications, and has been modified with a medium level proportion of elastomeric polymer (such as SBS). This type of binder is typically used for SAM applications.
- S25E – a binder typically used for SAMI applications, and has been highly modified with elastomeric polymer (such as SBS).

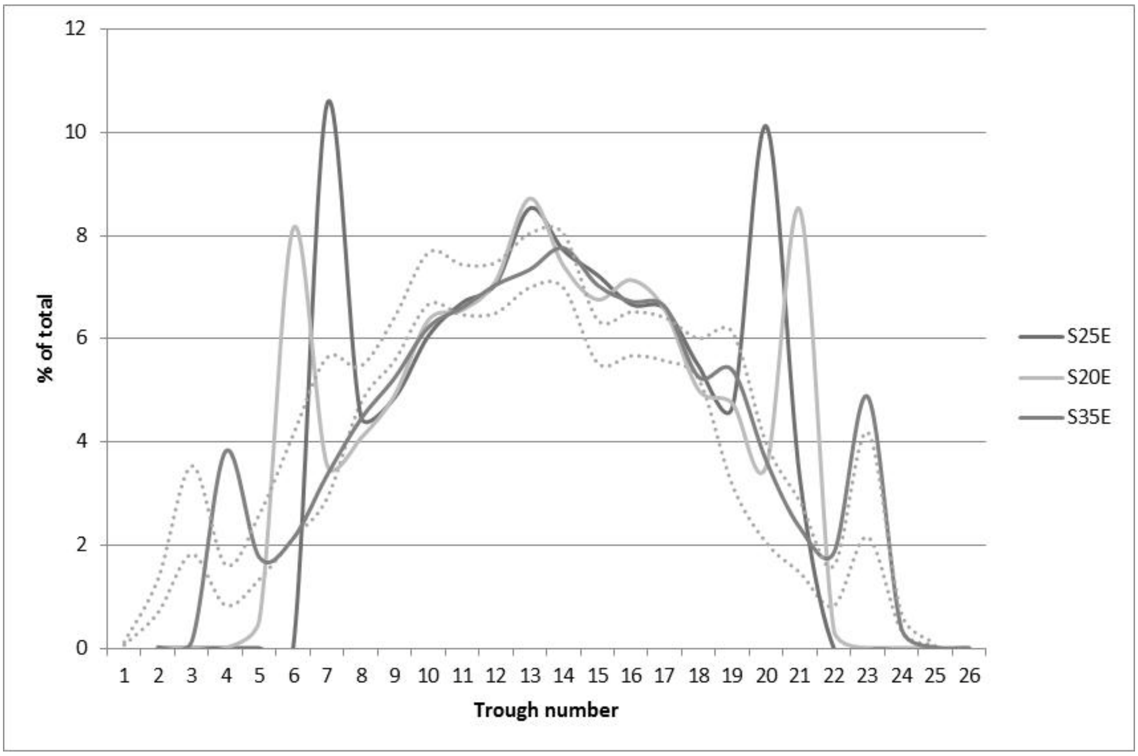


Figure 14: Spray profiles of PMBs

All products feature a similar shape in the centre of the profile, in the region closest to the nozzle. The central peak is about 8% of total delivered product in each case.

The outside peaks become more pronounced and closer to the nozzle as the concentration of polymer increases in the PMB type. Whilst the shape of the lowly-modified S35E product is quite close to that expected from standard bitumen (dotted lines), the two other products spray with a significantly narrower profile.

In the case of S25E, the nozzle shape is so restricted the outer peaks exceed the level of the central peak.

Other products

The spray profile of field produced crumb rubber, S15RF, and an emulsion product are seen in Figure 15.

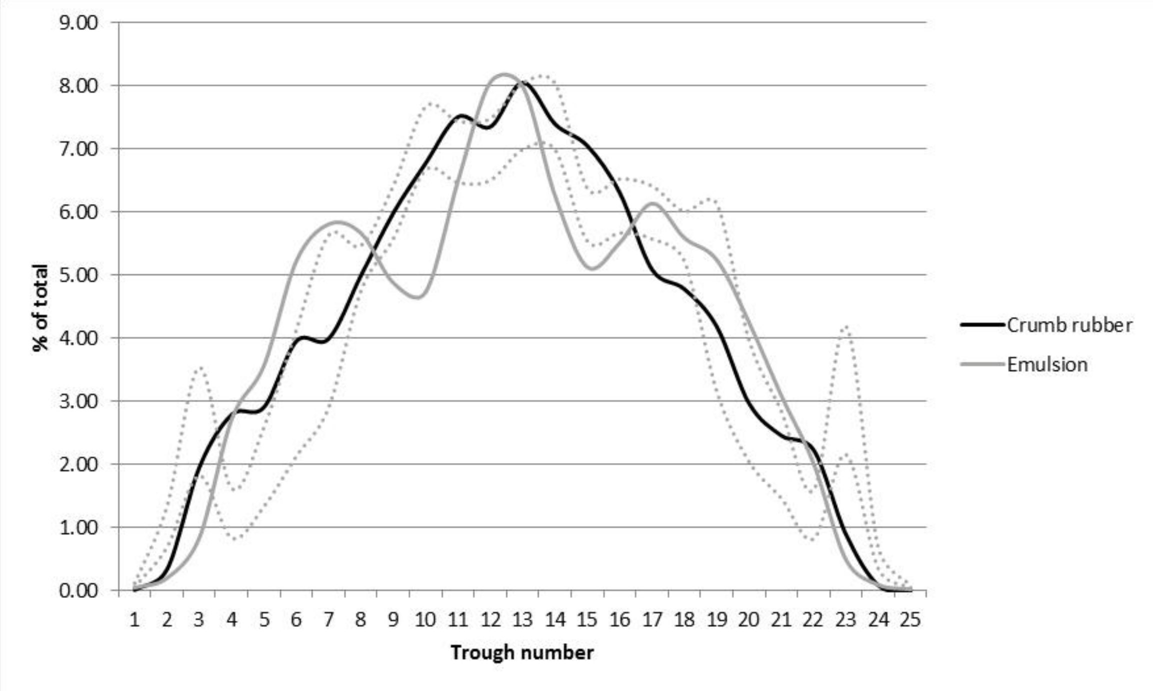


Figure 15: Spray pattern of other products

The profile of the crumb rubber and emulsion follows that of the conventional bitumens (indicated by dotted lines) quite well. They are notably wider than the PMB products.

Viscosity

Brookfield viscosity tests were performed on each of the sprayed products, at the spraying temperature used for that product. The S20E and S25E PMBs were tested at two temperatures each.

The results are shown in Table 3.

Table 3: Brookfield viscosity tests

Sample	Temperature of test (C)	Brookfield viscosity (Pa.s)
S35E	186	0.124
S25E	186	0.312
S25E	196	0.233
S20E	186	0.244
S20E	201	0.161
C170	180	0.0628
C320	182	0.0699
Emulsion	33	0.0276

The viscosity results have been plotted against the width of the spray profile (Figure 16), which was taken to be the distance measured between the two outside ‘peaks’ of each spray profile.

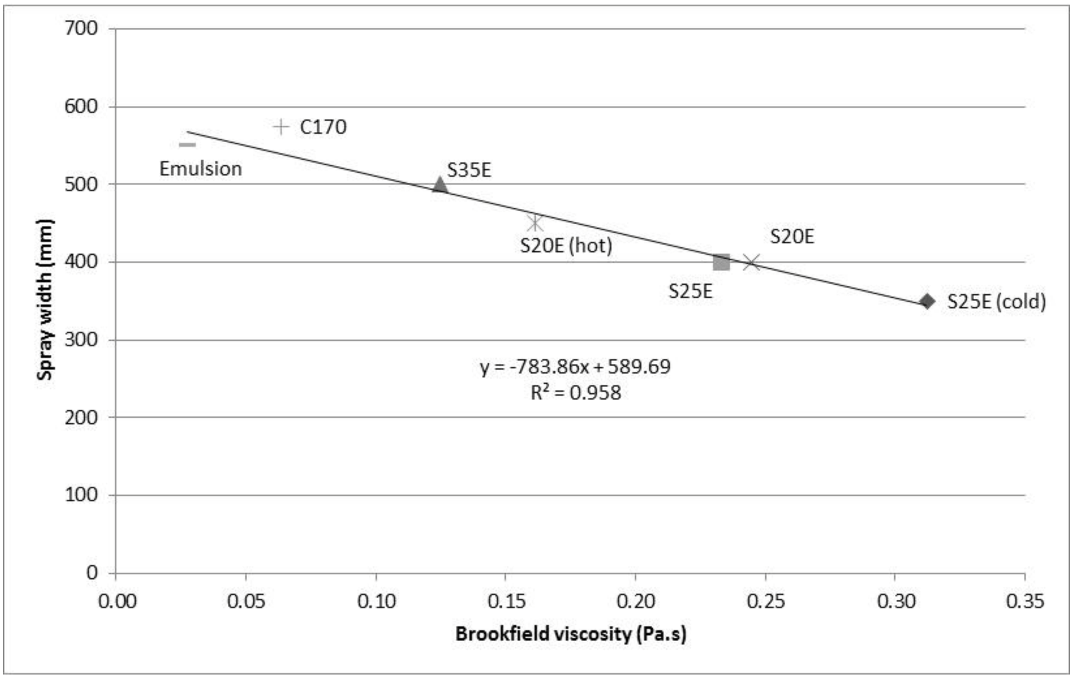


Figure 16: Brookfield viscosity results of sprayed products

A linear line of best fit has been applied to the data generating the following relationship between spray width and product viscosity:

$$Spray\ width = -783.86 \times Viscosity + 589.69$$

This relationship returns a coefficient of determination R^2 of 0.958. This shows a strong relationship between the viscosity and spray width of the tested products.

This relationship allows a practitioner to predict the spray profile width of a product based on its viscosity at spraying temperature.

Simulation Software

In order to understand the effects of the differences in spraying profile between products, simulations of a spraybar with many nozzles can be undertaken to determine the cumulative effect.

Spraybars are designed to deliver a consistent and uniform amount of bitumen across their length, with the output of a nozzle overlapping the output of its neighbouring nozzles. As such, any change to the width and shape of a profile with affect the overlap and the uniformity of the transverse distribution. The software can be used to quantify this effect, and can simulate both commonly used 3-nozzle and 4-nozzle overlaps.

The spreadsheet to conduct full spraybar width simulations can be seen in Figure 17.

The software allows the user to select the following variables, and observe their effect on total spray pattern:

- binder type
- nozzle spacing
- number of nozzles.

All spray profiles measured in the testing are included, and additional profiles can be added as required.

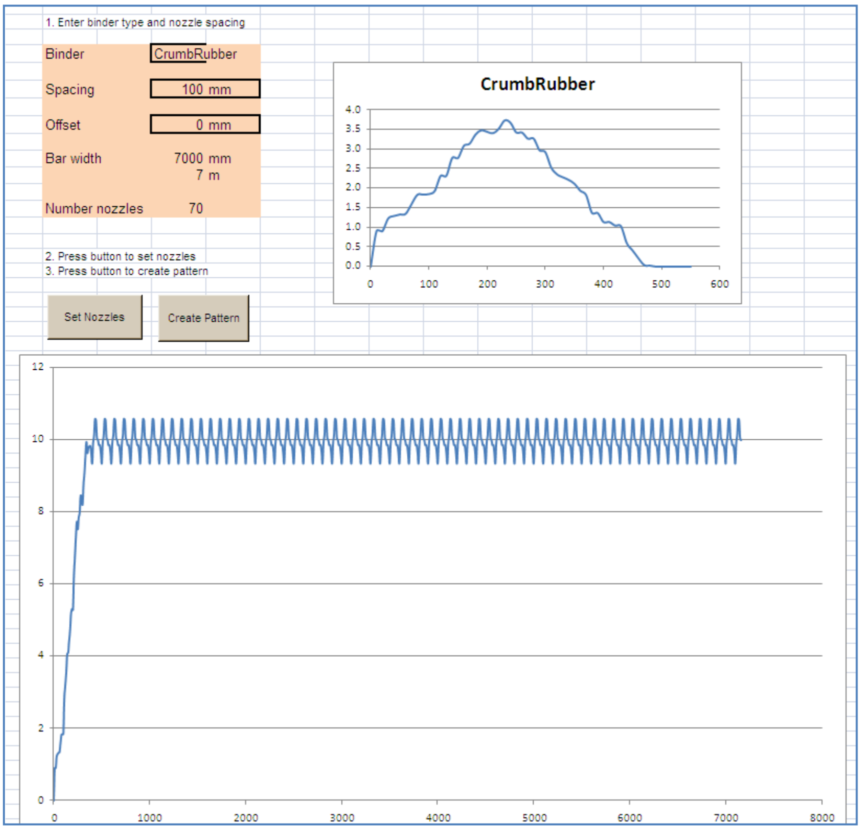


Figure 17: Simulation software

The spray bar output is presently represented by a dimensionless number, or a value without units, as the spray profiles have been generated in terms of '% of total spray', an absolute measure of output is not available.

The plots give an indication of the amount of variation around the average or mean output for that product and nozzle arrangement. It does not provide a measure of product placed on the ground as yet.

The software will be further developed to include end nozzles.

Comparison

The average output and standard deviations of the full spray bar simulations have been compiled in Table 4.

Table 4: Consistency of spray bar output

Binder	Nozzle spacing (mm)	Average	Standard deviation
C170	100	10.0	0.49
C320	100	9.99	0.64
S20E	100	9.98	1.19
S25E	100	9.98	2.29
S35E	100	9.98	1.12
S35E	90	11.10	0.72
S35E	110	9.10	0.78
Crumb rubber	100	10.0	0.46

In summary, the more modified the binder is, the more its spray pattern differs from that of conventional bitumen, and the more the overlap from the spray bar is affected.

It has been shown improvements in this variability can be made by moving the nozzle spacing, which changes the overlap of the spray from the nozzles. With the S35E product, changing the nozzle spacing by 10 mm both longer and shorter saw an improvement in variability around the mean.

An example of the outputs of a spray bar distribution test, in terms of variation from the mean, conducted as per *AGPT/T532 Calibration of bitumen sprayers Part 2: Transverse distribution by fixed pit facility* (Austroads 2006) is shown in Figure 18.

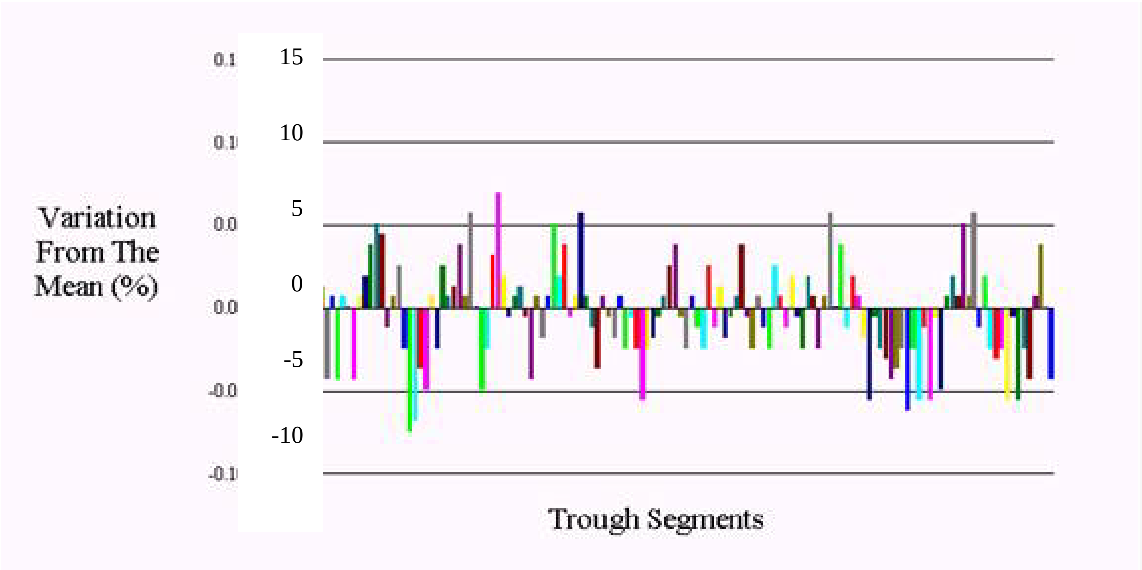


Figure 18: Example of typical transverse distribution from physical tests

The variation from the mean for a portion of the spray bar, with C170 product by the simulation program is seen in Figure 19.

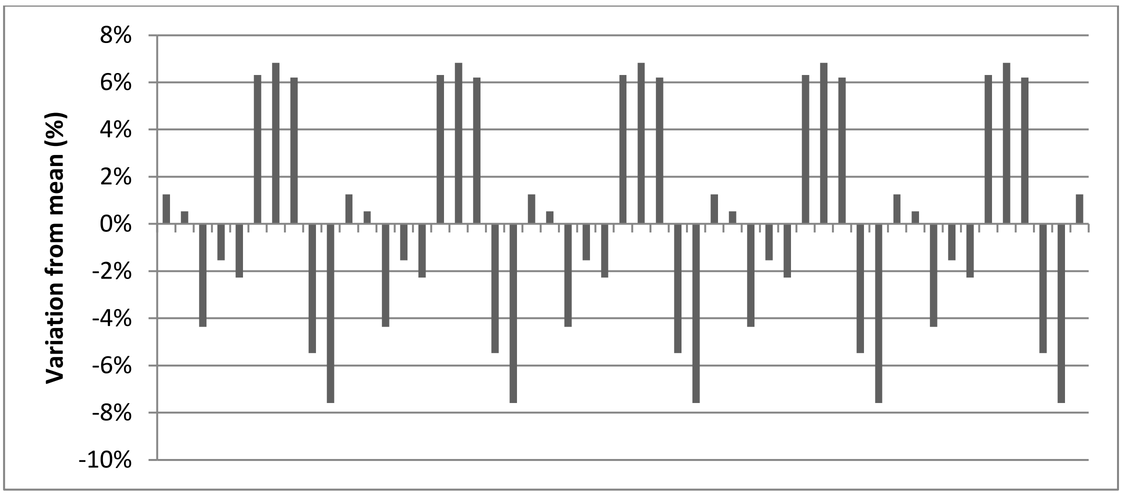


Figure 19: Example of transverse distribution from simulation

The plots generated by physical testing and the simulation program are very similar. The simulation does not include the variability in spray profile discussed earlier, and the repeating, identical spray outputs along the length causes its repeating, cyclic pattern. This transverse distribution meets the requirements for calibration laid out in *AGPT/T532* (Austroads 2006).

The ‘real life’ testing example in Figure 18 does not include the inherent variability of the spray nozzle pattern, and as such, the distribution has does not repeat exactly along the spray bar as does the simulated example.

WHAT NEXT

These findings will be used as a comparison and basis for more extensive testing of nozzle types and binders as part of Austroads project TT1357. It is expected these outcomes will also be used to guide the scope of further work, potentially including the development of new experimental equipment. The knowledge generated in this project has already been used to develop and update the Austroads Sprayer Calibration Testing methods.

The software used to simulate full bar spraying will be developed to simulate spraying scenarios of greater complexity, including end nozzles and variable spray bars.

CONCLUSION

This research paper reports on testing that has employed a single jet laboratory spraying simulator to investigate the transverse spray pattern of calibration oil and bitumen products through a Copley AN18 nozzle.

The Copley AN18 nozzle showed good repeatability, and produced patterns that were highly comparable to each other. Analysis of the spray shows that the middle most section is repeatable with 7% variability, yet the outside regions are more susceptible to variation and 32% can be expected. Three alternative nozzles have been tested, with an average expected profile generated for each.

Conventional bitumen products and PMBs have also been tested. The conventional bitumens conformed to the expected shape quite well, with the non-Newtonian PMBs showing more variation towards the outer edges of the spray, except in the case of crumb rubber which retained a very uniform fan shape.

Software has been created to simulate a spray bar with multiple nozzles, which will be used to investigate the effect of the different products. This software will also be used to explore the effects of nozzle spacing on a spray bar, and how these may be manipulated to cope with the changing spray properties of different materials, and how to best use and design equipment to ensure the more uniform distributions.

These findings will be used as a comparison and basis for more extensive testing of nozzle types and binders as part of Austroads project TT1357. It is expected these outcomes will also be used to guide the scope of further work, potentially including the development of new experimental equipment.

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AUTHOR BIOGRAPHIES

Steve Patrick completed a Bachelor of Engineering (Mech.) at the University of Melbourne in 2004, before commencing employment with ARRB Group later that year. After roles in the Data Collection and Heavy Vehicle Groups, Steve moved to the Bituminous Surfacings Group in 2009, where he participates in the Group’s research activities in sprayed sealing practices, bitumen sprayer calibration and skid resistance.

Walter Holtrop bio to come.