Delavan Nozzle Characterization at CINVESTAV

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1 Footprint Measurements 4
1.1 Obelisk Distribution 4
1.2 Nozzles 5
1.2.1 Delavan 3.5-90 5
1.2.2 Delavan 3.5-60 8
1.2.3 Delavan 3.0-80 10
1.2.4 Delavan 51474-1 13
1.2.5 Delavan 51468-1 15
1.2.6 Delavan W19813-1 17
1.2.7 Delavan W19813-3 19
1.2.8 Delavan W19813-5 21
1.2.9 Delavan W19822 23
1.3 Operating Diagrams 27
1.4 Conclusions 27

1 Footprint Measurements

Numerical integration of all measured footprints were made using obelisk shape distribution. Results are presented in the following figures with original water measurements, corresponding calculated values using obelisk distribution, contour plots of these data, and a contour plot of difference in each collector location. Used measurement results are modified by not taking into account scattered water volumes clearly outside the footprint area. The existence of water in collectors far from main footprint indicates random scattering of spray or water entering the collector bottles on the ground or both. Extra water can enter bottles by flowing on the tube and, as the insulation in the connection between the tube and the cap of the bottle is not tight, enter through the gap. Fig. 1 shows the water collector with tubes connected with collector bottles.

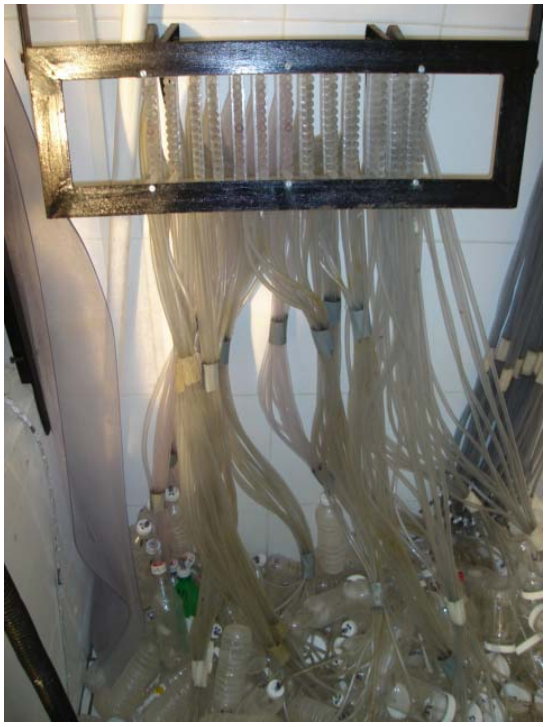

Fig. 1. Water collector used in the experiments.

1.1 Obelisk Distribution

Nozzle manufacturer's goal, when producing flat nozzles, is to produce a rectangular flow pattern making the impact density distribution seem like an obelisk (Fig. 2). After making this assumption it is possible to find calculated impact density profile and make the mass balance to match measured water flow Eq. (1).

Fig. 2. Schematic picture of an obelisk.

$$V = \frac{1}{6} h \left[(2a + a')b + (2a' + a)b' \right] \quad (1)$$

Volume of the obelisk is the flow rate of water in litres per minute and height h is the local impact density. Variables a and b are the boundaries of zero impact flux and a' and b' the boundaries of the area where the impact density is at the maximum value.

The calculation results have been converted into original measurements by using a simple technique illustrated in Fig. 3. At first the centre point of the collector in the model results need to be found in the accuracy of 0.5*Dx and 0.5*Dz. After the centre point is found to find locations as many grid points to each main direction (top, down, right, and left) as can fit in to the diameter of the collector. These five values are averaged. If the centre point is in the given calculation domain but some side is outside this outside value is dropped and value is only average of the rest of the values. If collector is partially in the calculation domain but centre point does not fall in the domain the biggest value inside the collector is found and divided by two to get impact density on that collector.

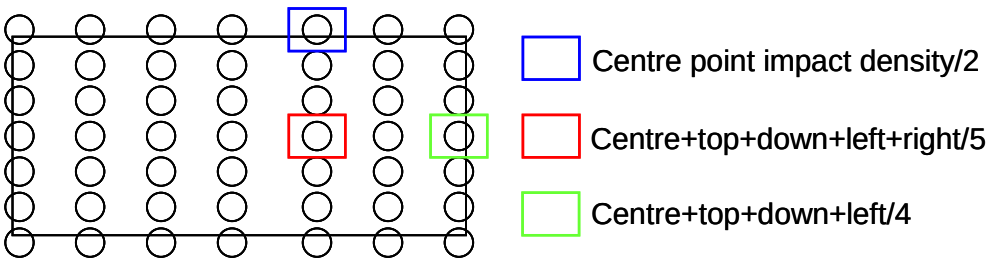

Fig. 3. Schematic description of finding comparable impact densities between the measurement's collectors and the model.

As later can be seen a new way has to be found in order to describe the some of the flow patterns with primitive shapes like obelisk form. Also it is clear that there is a problem with numerical integration or measurement method since it seems there is more water collected that would be possible with a nice continuous distribution of water. This will be shown later with examples.

1.2 Nozzles

Unfortunately the designated water distribution from the manufacturer is not available and only guide line that can be used is the caster blueprint obtained from Nucor steel plant. In this blueprint only width in the case of wide face nozzles or height in the case of narrow face nozzles can be seen.

The first row of nozzles in the wide face and all narrow face nozzles are hydraulic nozzles. The first is the wide face hydraulic nozzle and then narrow face hydraulic nozzles. All nozzles are presented in the order as they appear in the caster from top down.

In figures that show the contour plot with water collector tubes and the nozzle centre point the designed width in the blueprints is marked using a red arrow.

1.2.1 Delavan 3.5-90

Footprint shows that spray covers fully the area it should cover as given in the Fig. 4. In the numerical integration there is a problem since in Fig. 5. it can be seen that almost all difference is positive in favour of the original measurements. It means that we are collecting water on bigger area than measured, the flow values are too low or between collectors horizontally there are really low impact densities between the collectors (distance 20~25 mm). Also there is a slight inaccuracy since the impact density seems to be three spiked but assumption of a flat high impact density area is justified based on very stochastic behaviour of water sprays.

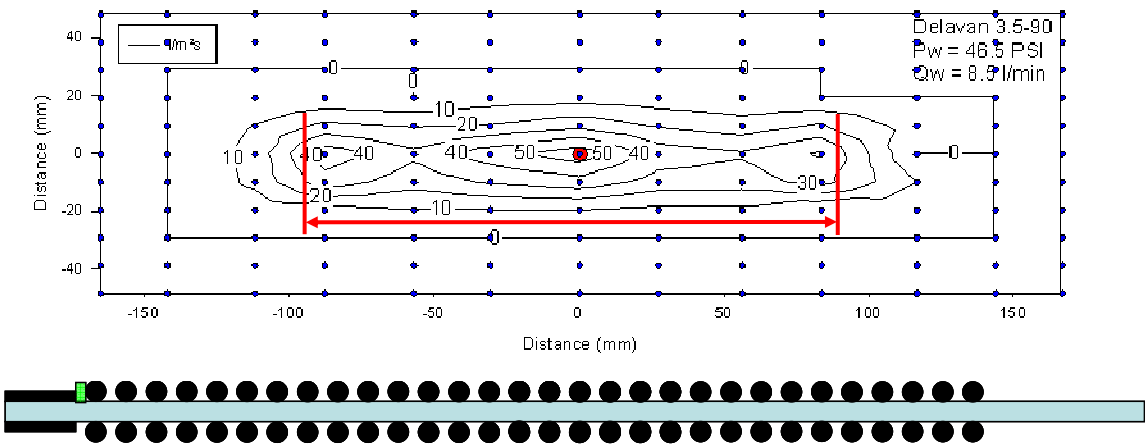

Fig 4. 3.5-90 measured footprint, designed footprint width and spray nozzle location in the caster. Red dot is the center of the nozzle, and blue dots are collector locations. Red lines are from the blueprints, and contours are processed from Table 1 measurements using Sigma-plot. The water pressure, Pw, and flow rate, Qw are the test conditions.

Table 1. Measured and calculated water fluxes and the difference between these two for 3.5-90.

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	0.75	1.16	0.00	4.23	5.45	3.71	3.59	0.00	0.00	0.00	0.00
9.75	0.00	0.00	10.44	22.03	18.55	20.29	26.67	18.55	13.33	20.87	5.04	0.00	0.00
0.00	0.00	0.00	13.33	46.38	32.47	45.80	56.24	35.95	31.31	41.16	0.00	0.00	0.00
-9.75	0.00	0.00	12.17	35.95	24.35	31.31	36.52	26.09	24.87	33.92	10.32	0.00	0.00
-19.50	0.00	0.00	4.75	6.96	9.86	9.97	10.32	7.54	8.00	0.58	4.41	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
19.50	0	0	1.81	1.99	1.99	1.99	1.99	1.99	1.99	1.99	0.84	0	0
9.75	0	0	5.17	17.61	17.61	17.61	17.61	17.61	17.61	17.61	1.94	0	0
0.00	0	0	5.17	27.08	29.32	29.32	29.32	29.32	29.32	29.23	1.94	0	0
-9.75	0	0	5.17	17.61	17.61	17.61	17.61	17.61	17.61	17.61	1.94	0	0
-19.50	0	0	1.81	1.99	1.99	1.99	1.99	1.99	1.99	1.99	0.84	0	0
-29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
-39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	-142.00	-112.00	-88.00	-57.00	-31.00	0.00	27.00	56.00	83.00	116.00	143.00	166.00
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	-1.06	-0.83	-1.99	2.24	3.46	1.72	1.60	-1.99	-0.84	0.00	0.00
9.75	0.00	0.00	5.27	4.42	0.94	2.68	9.06	0.94	-4.28	3.26	3.10	0.00	0.00
0.00	0.00	0.00	8.16	19.30	3.15	16.48	26.92	6.63	1.99	11.93	-1.94	0.00	0.00
-9.75	0.00	0.00	7.00	18.34	6.74	13.70	18.91	8.48	7.26	16.31	8.38	0.00	0.00
-19.50	0.00	0.00	2.94	4.97	7.87	7.98	8.33	5.55	6.01	-1.41	3.57	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

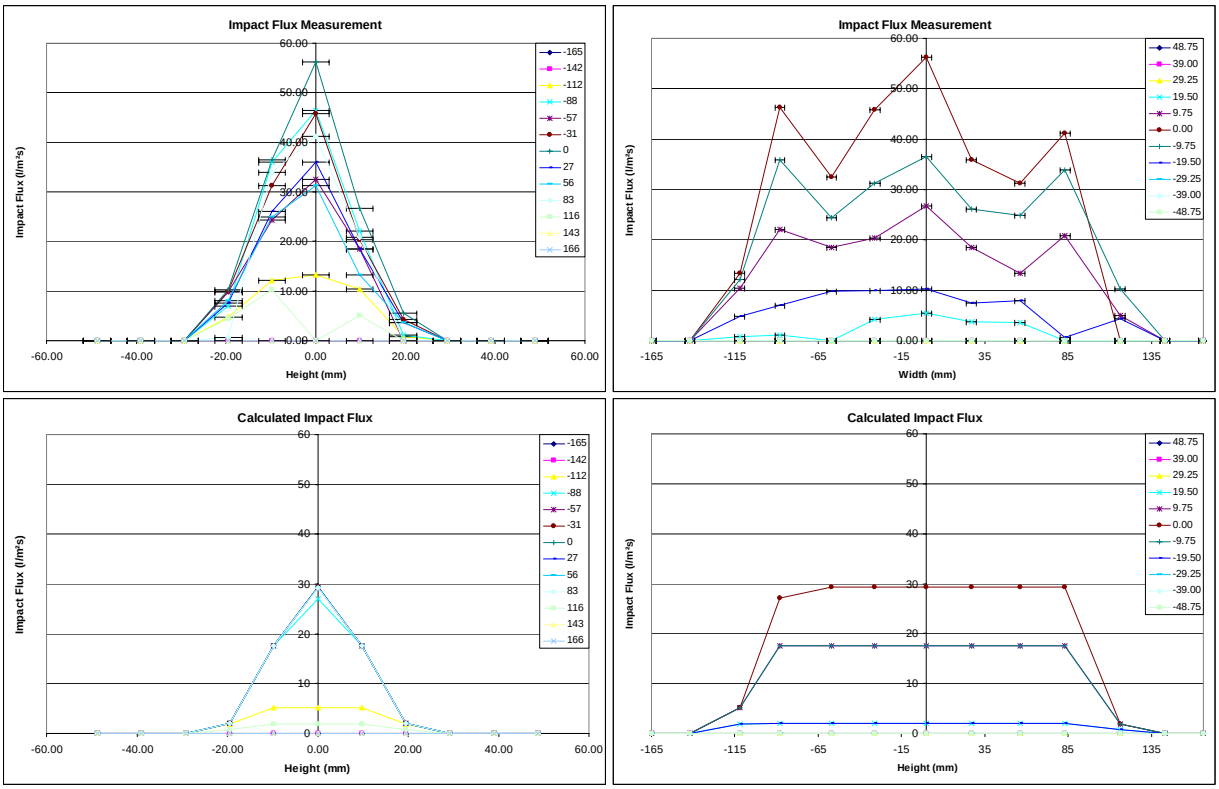

Fig. 5. Measured and corresponding calculated water flux values for nozzle 3.5-90.

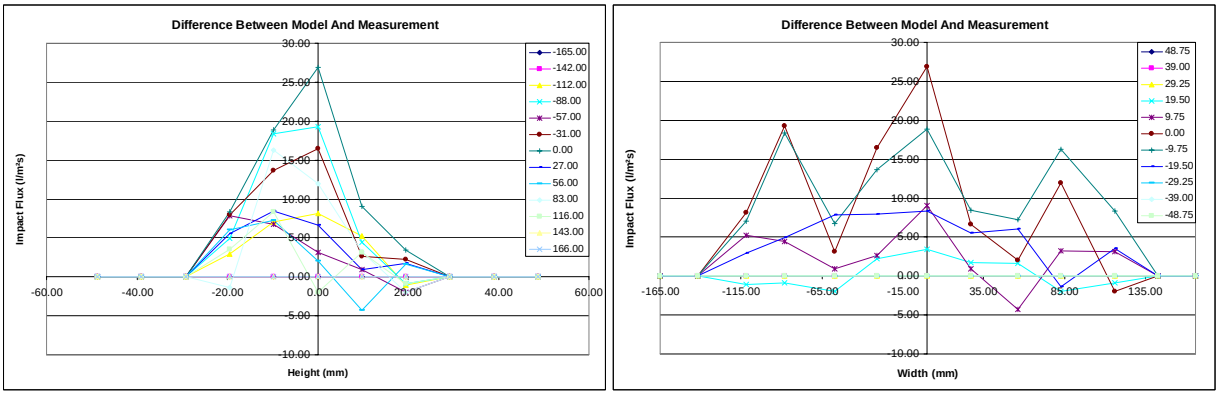

Fig. 6. Difference of water fluxes at each measured location.

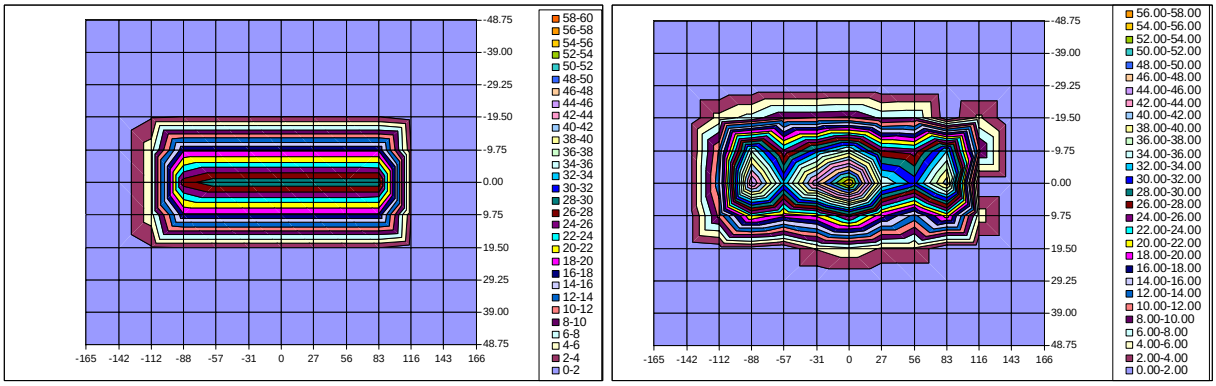

Fig. 7. Contour plots of calculated and measured footprint respectively.

1.2.2 Delavan 3.5-60

Fig. 8. Picture of the tested nozzle.

The flow pattern match very well to obelisk shape but the problem of water mismatch persists. The negative values in Fig. 11 should cancel the positive values but this is not true. The results are still better than with nozzle 3.5-90.

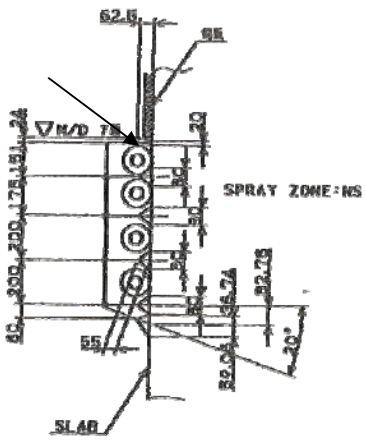

Fig. 9. 3.5-60 Nozzle spray nozzle assignment in the caster pointed by the arrow.

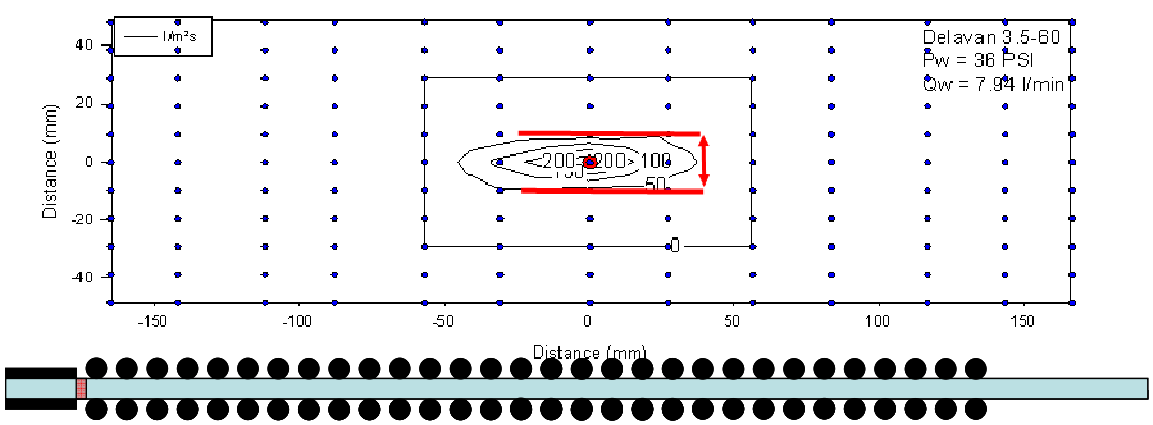

Fig. 10. 3.5-60 measured footprint, designed footprint height and spray nozzle location in the caster.

Table 2. Measured and calculated water fluxes and the difference between these two for 3.5-60.

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	0.00	0.00	0.00	4.64	1.91	3.88	0.00	0.00	0.00	0.00	0.00
9.75	0.00	0.00	0.00	0.00	0.00	8.70	19.13	37.10	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	113.05	243.50	77.11	0.00	0.00	0.00	0.00	0.00
-9.75	0.00	0.00	0.00	0.00	0.00	48.12	38.84	30.73	0.00	0.00	0.00	0.00	0.00
-19.50	0.00	0.00	0.00	0.00	0.00	5.39	1.16	3.01	0.00	0.00	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
9.75	0	0	0	0	0	33.43	33.43	33.43	0	0	0	0	0
0.00	0	0	0	0	0	73.78	152.65	106.33	0	0	0	0	0
-9.75	0	0	0	0	0	33.43	33.43	33.43	0	0	0	0	0
-19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
-29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
-39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	-142.00	-112.00	-88.00	-57.00	-31.00	0.00	27.00	56.00	83.00	116.00	143.00	166.00
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	0.00	0.00	0.00	4.64	1.91	3.88	0.00	0.00	0.00	0.00	0.00
9.75	0.00	0.00	0.00	0.00	0.00	-24.73	-14.30	3.67	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	39.27	90.85	-29.22	0.00	0.00	0.00	0.00	0.00
-9.75	0.00	0.00	0.00	0.00	0.00	14.69	5.41	-2.70	0.00	0.00	0.00	0.00	0.00
-19.50	0.00	0.00	0.00	0.00	0.00	5.39	1.16	3.01	0.00	0.00	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

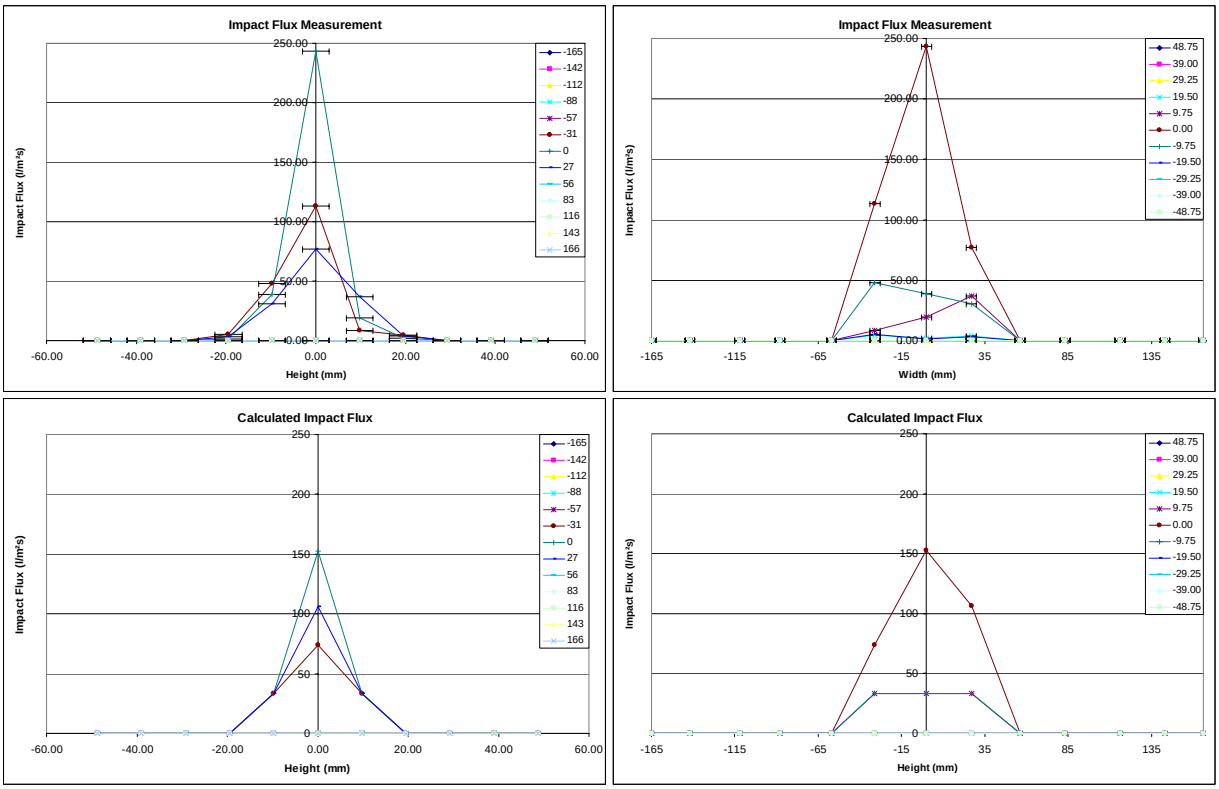

Fig. 11. Measured and corresponding calculated water flux values for nozzle 3.5-60.

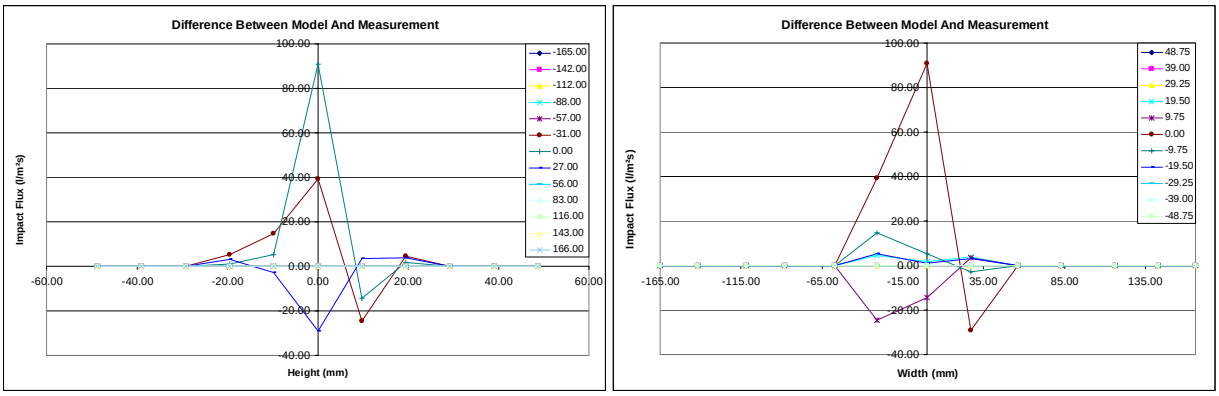

Fig. 12. Difference of water fluxes at each measured location.

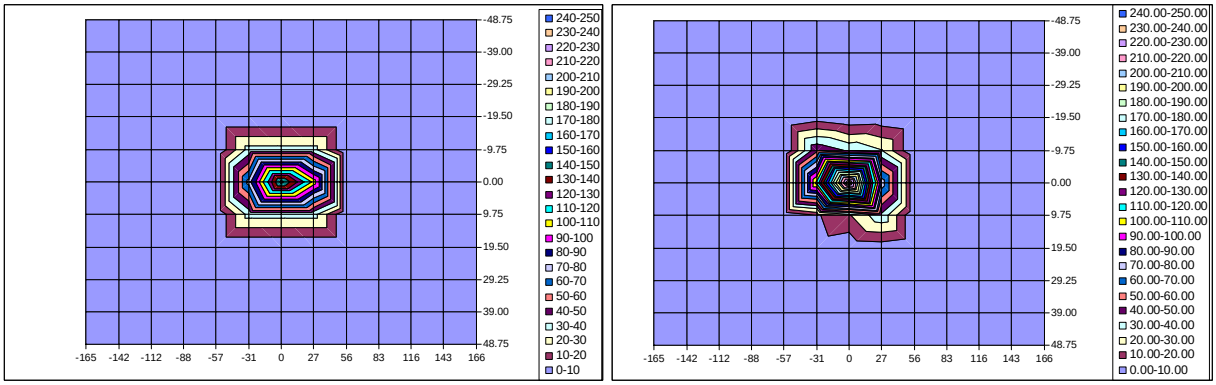

Fig. 13. Contour plots of calculated and measured footprint respectively.

1.2.3 Delavan 3.0-80

Fig. 14. Picture of the tested nozzle.

The nozzle seems to be a hollow cone type of nozzle where there is no water sprayed in the centre of the spray pattern and another primitive shape has to be used in describing the distribution in the numerical integration.

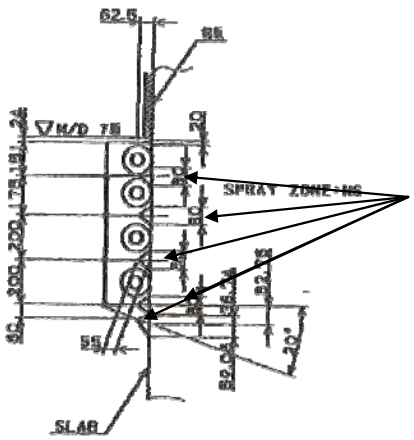

Fig. 15. 3.0-80 spray nozzle assignment in the caster pointed by the arrows.

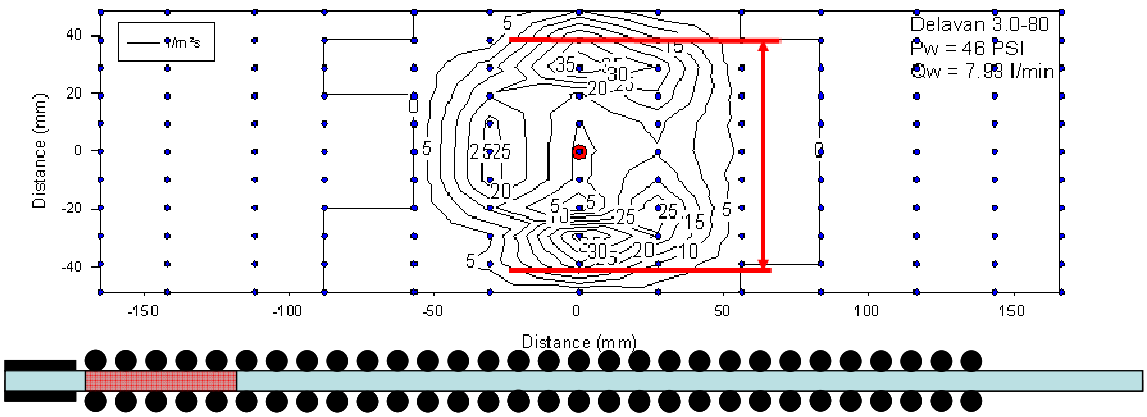

Figure 16. 3.5-80 measured footprint, designed footprint height and spray nozzle location in the caster.

Table 3. Measured and calculated water fluxes and the difference between these two for 3.0-80.

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	0.75	1.16	0.00	4.23	5.45	3.71	3.59	0.00	0.00	0.00	0.00
9.75	0.00	0.00	10.44	22.03	18.55	20.29	26.67	18.55	13.33	20.87	5.04	0.00	0.00
0.00	0.00	0.00	13.33	46.38	32.47	45.80	56.24	35.95	31.31	41.16	0.00	0.00	0.00
-9.75	0.00	0.00	12.17	35.95	24.35	31.31	36.52	26.09	24.87	33.92	10.32	0.00	0.00
-19.50	0.00	0.00	4.75	6.96	9.86	9.97	10.32	7.54	8.00	0.58	4.41	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
19.50	0	0	1.81	1.99	1.99	1.99	1.99	1.99	1.99	1.99	0.84	0	0
9.75	0	0	5.17	17.61	17.61	17.61	17.61	17.61	17.61	17.61	1.94	0	0
0.00	0	0	5.17	27.08	29.32	29.32	29.32	29.32	29.32	29.23	1.94	0	0
-9.75	0	0	5.17	17.61	17.61	17.61	17.61	17.61	17.61	17.61	1.94	0	0
-19.50	0	0	1.81	1.99	1.99	1.99	1.99	1.99	1.99	1.99	0.84	0	0
-29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
-39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	-142.00	-112.00	-88.00	-57.00	-31.00	0.00	27.00	56.00	83.00	116.00	143.00	166.00
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	-1.06	-0.83	-1.99	2.24	3.46	1.72	1.60	-1.99	-0.84	0.00	0.00
9.75	0.00	0.00	5.27	4.42	0.94	2.68	9.06	0.94	-4.28	3.26	3.10	0.00	0.00
0.00	0.00	0.00	8.16	19.30	3.15	16.48	26.92	6.63	1.99	11.93	-1.94	0.00	0.00
-9.75	0.00	0.00	7.00	18.34	6.74	13.70	18.91	8.48	7.26	16.31	8.38	0.00	0.00
-19.50	0.00	0.00	2.94	4.97	7.87	7.98	8.33	5.55	6.01	-1.41	3.57	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

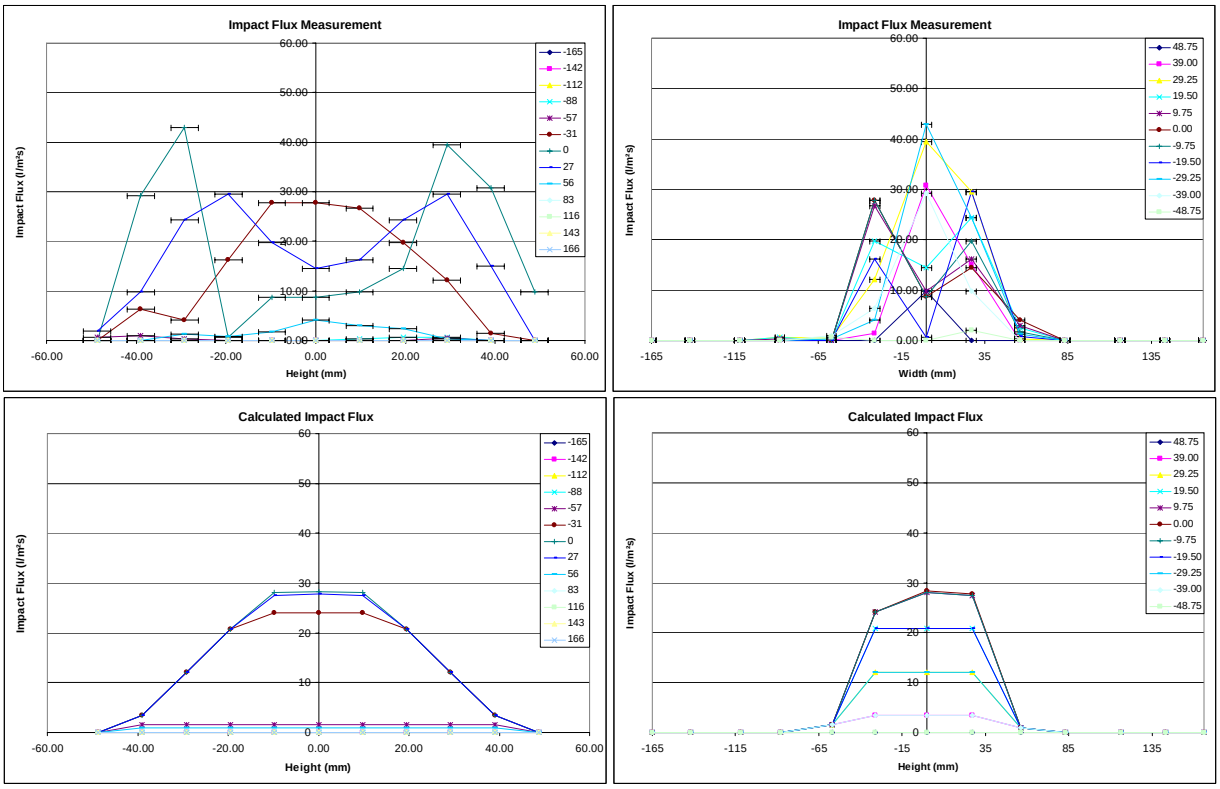

Fig. 15. Measured and corresponding calculated water flux values for nozzle 3.0-80.

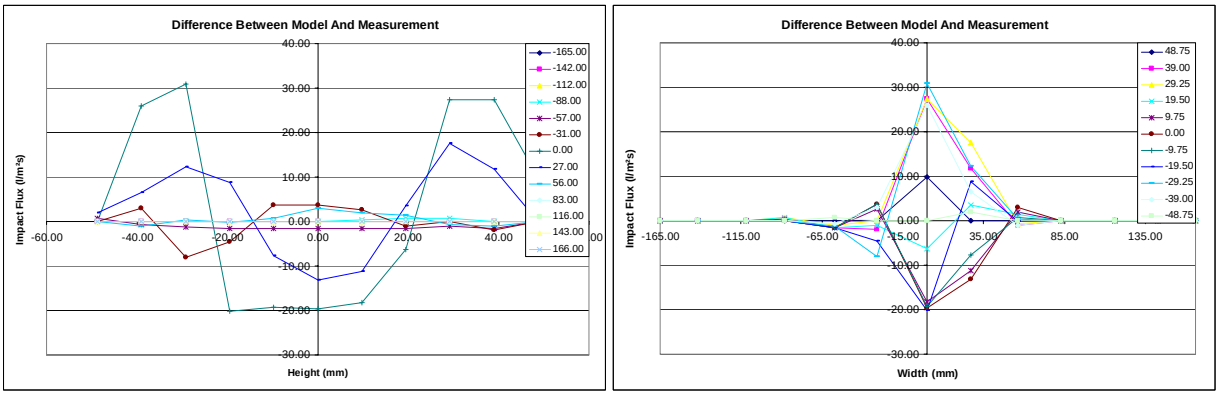

Fig. 16. Difference of water fluxes at each measured location.

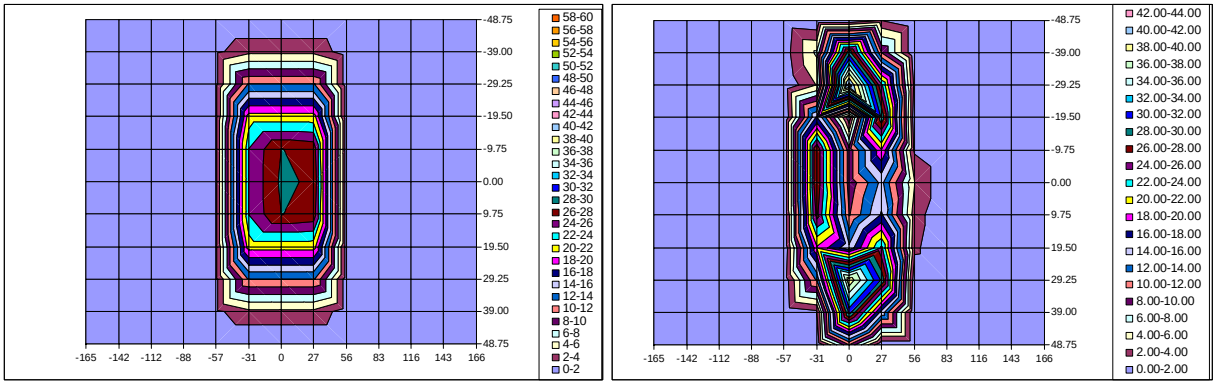

Fig. 17. Contour plots of calculated and measured footprint respectively.

1.2.4 Delavan 51474-1

Fig. 18. Picture of the tested nozzle.

Again the shape of obelisk distribution describes the measurements well but measurements indicate more water than registered from the flow meter. This can be caused by a problem with flow meter or more likely the there is excess water entering the collectors.

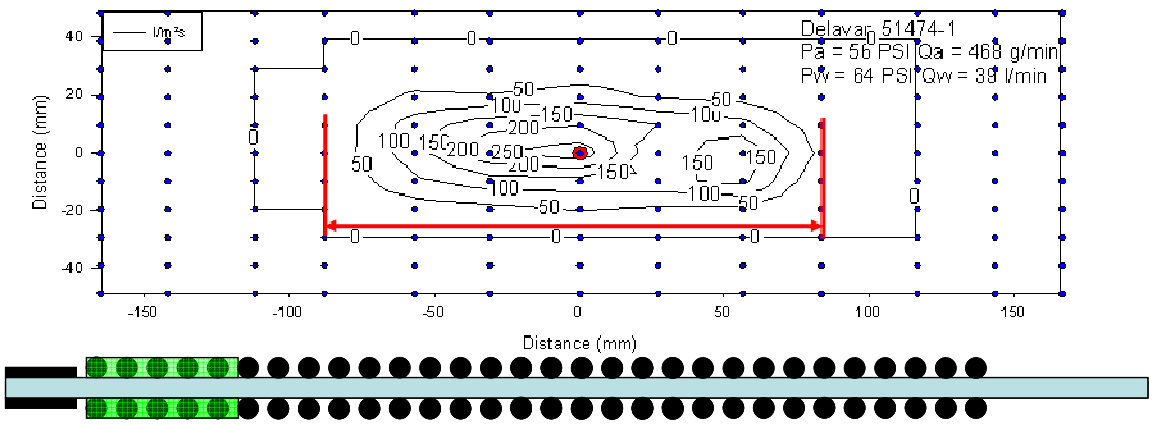

Fig. 19. 51474-1 measured footprint, designed footprint width and spray nozzle location in the caster.

Table 4. Measured and calculated water fluxes and the difference between these two for 51474-1

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	13.76	11.60	26.28	23.96	5.41	0.77	0.00	0.00	0.00
19.50	0.00	0.00	0.00	3.63	59.14	54.11	67.25	44.83	30.92	1.55	0.00	0.00	0.00
9.75	0.00	0.00	0.00	7.19	123.68	180.89	195.57	150.74	117.50	16.23	0.00	0.00	0.00
0.00	0.00	0.00	0.00	7.73	127.55	241.95	282.15	108.22	196.35	39.42	0.00	0.00	0.00
-9.75	0.00	0.00	0.00	2.86	89.67	127.55	131.41	135.28	166.20	2.32	0.00	0.00	0.00
-19.50	0.00	0.00	0.00	0.00	23.19	34.79	54.11	42.52	38.65	0.39	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
29.25	0	0	0	4.52	8.78	8.78	8.78	8.78	8.78	8.02	0	0	0
19.50	0	0	0	6.09	55.85	55.85	55.85	55.85	55.85	17.73	0	0	0
9.75	0	0	0	6.09	80.89	108.5	108.5	108.5	84.21	17.73	0	0	0
0.00	0	0	0	6.09	80.89	142.58	143.6	143.6	84.21	17.73	0	0	0
-9.75	0	0	0	6.09	80.89	106.9	106.9	106.9	84.21	17.73	0	0	0
-19.50	0	0	0	6.09	55.85	55.85	55.85	55.85	55.85	17.73	0	0	0
-29.25	0	0	0	3.5	7.18	7.18	7.18	7.18	7.18	6.83	0	0	0
-39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	-142.00	-112.00	-88.00	-57.00	-31.00	0.00	27.00	56.00	83.00	116.00	143.00	166.00
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	-4.52	4.98	2.82	17.50	15.18	-3.37	-7.25	0.00	0.00	0.00
19.50	0.00	0.00	0.00	-2.46	3.29	-1.74	11.40	-11.02	-24.93	-16.18	0.00	0.00	0.00
9.75	0.00	0.00	0.00	1.10	42.79	72.39	87.07	42.24	33.29	-1.50	0.00	0.00	0.00
0.00	0.00	0.00	0.00	1.64	46.66	99.37	138.55	-35.38	112.14	21.69	0.00	0.00	0.00
-9.75	0.00	0.00	0.00	-3.23	8.78	20.65	24.51	28.38	81.99	-15.41	0.00	0.00	0.00
-19.50	0.00	0.00	0.00	-6.09	-32.66	-21.06	-1.74	-13.33	-17.20	-17.34	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	-3.50	-7.18	-7.18	-7.18	-7.18	-7.18	-6.83	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

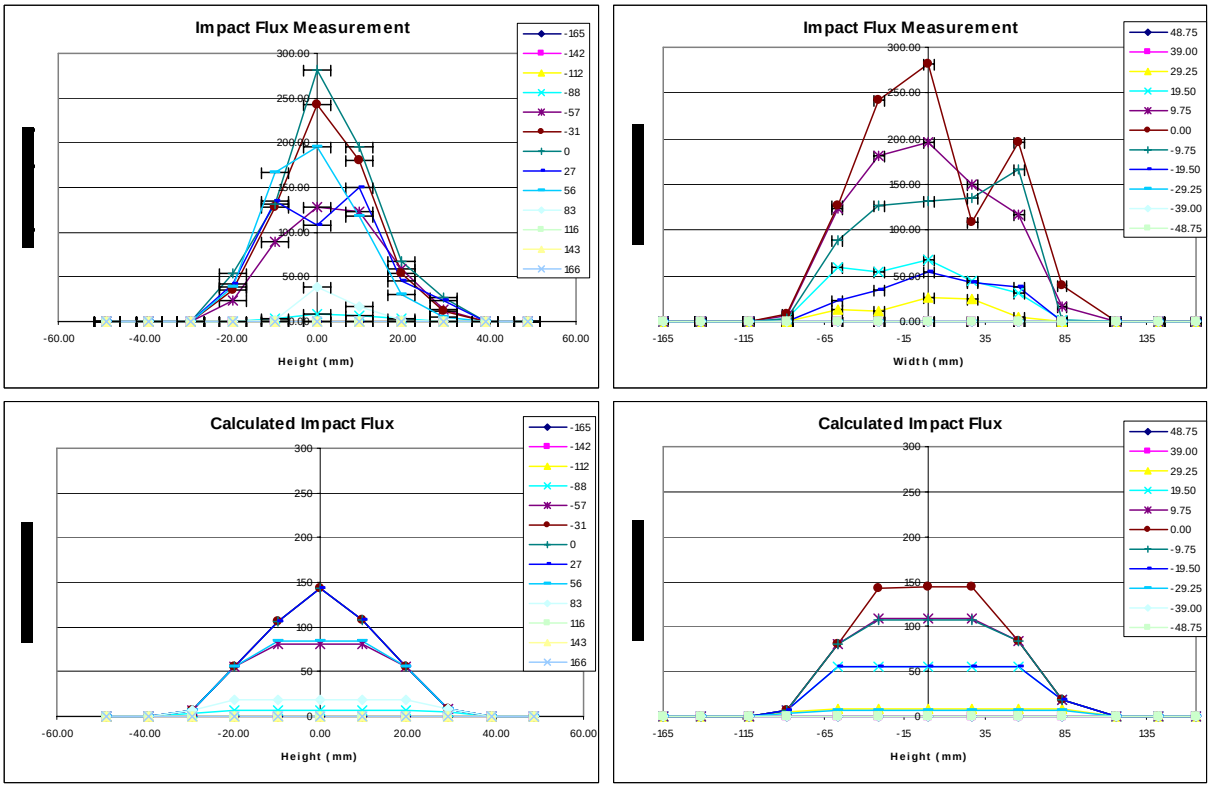

Fig. 20. Measured and corresponding calculated water flux values for nozzle 51474-1.

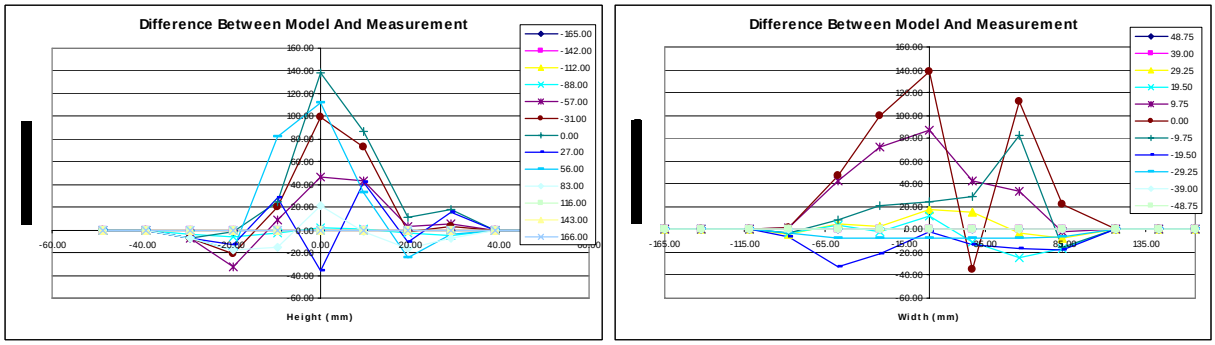

Fig. 21. Difference of water fluxes at each measured location.

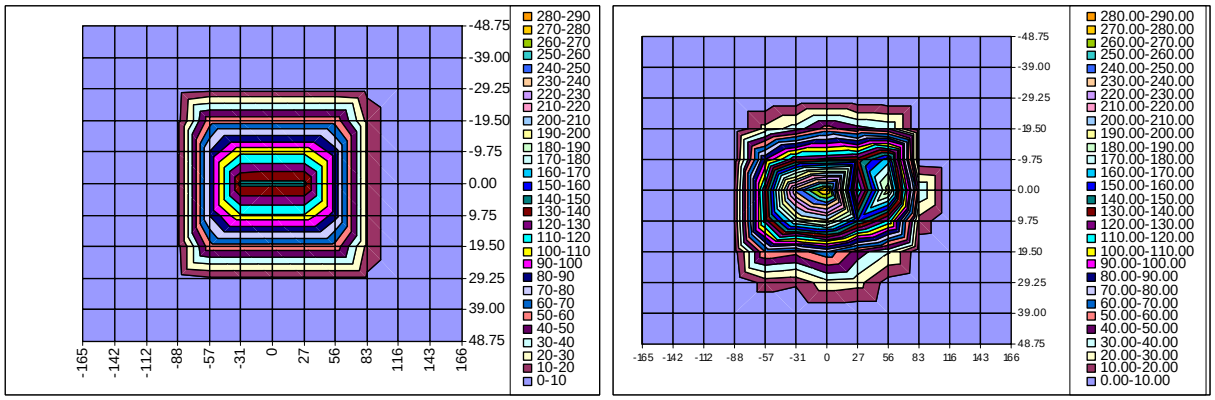

Fig. 22. Contour plots of calculated and measured footprint respectively.

1.2.5 Delavan 51468-1

Fig.23. Picture of the tested nozzle.

The results indicate the same as nozzle 51474-1. Calculated obelisk footprint shape is a good fit with measurements.

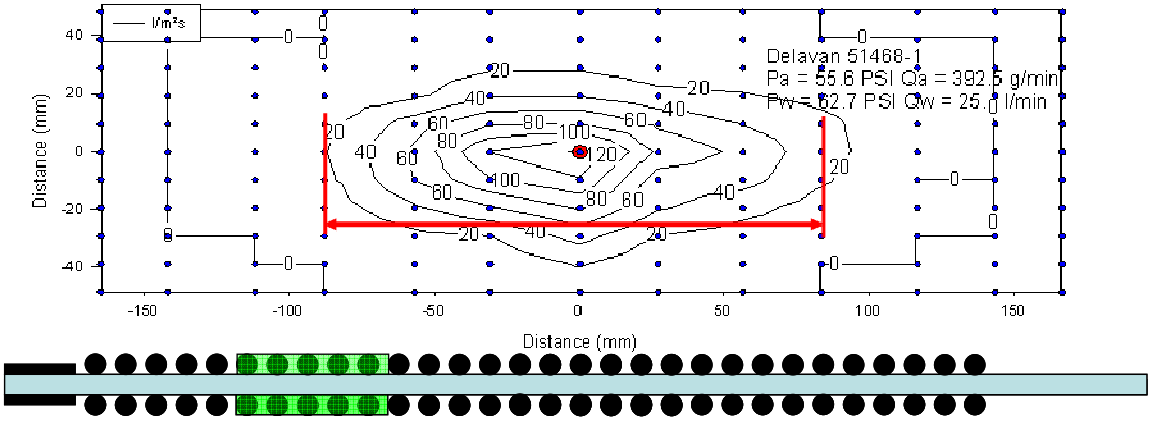

Fig.24. 51468-1 measured footprint, designed footprint width and spray nozzle location in the caster.

Table 5. Measured and calculated water fluxes and the difference between these two for 51468-1.

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	1.16	3.94	6.38	2.09	0.93	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.35	0.00	11.02	16.23	16.81	9.28	8.12	5.80	0.29	0.00	0.00
19.50	0.00	0.00	0.99	6.96	15.65	37.10	37.68	24.93	21.45	13.33	1.16	0.00	0.00
9.75	0.00	0.00	1.33	13.91	49.28	76.53	79.43	55.66	39.42	26.67	0.99	0.00	0.00
0.00	0.00	0.00	2.03	18.55	64.35	120.59	142.62	76.53	55.08	28.99	0.87	0.00	0.00
-9.75	0.00	0.00	1.39	13.91	60.30	97.98	118.27	49.86	48.12	23.19	0.00	0.00	0.00
-19.50	0.00	0.00	0.87	7.54	37.10	57.98	82.33	42.32	27.25	11.60	0.64	0.00	0.00
-29.25	0.00	0.00	0.00	0.52	14.20	19.71	47.54	19.42	11.89	4.06	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	1.74	6.38	21.45	5.74	1.80	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	1.51	7.54	0.81	0.00	0.00	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	1.49	2.54	2.54	2.54	2.54	2.54	2.54	2.54	0.34	0	0
29.25	0	0	2.43	15.69	18.26	18.26	18.26	18.26	18.26	17.36	0.41	0	0
19.50	0	0	2.43	16.23	33.13	34.49	34.49	34.49	33.38	19.2	0.41	0	0
9.75	0	0	2.43	16.23	34.35	48.93	51.39	50.34	34.89	19.2	0.41	0	0
0.00	0	0	2.43	16.23	34.35	49.5	65.06	51.93	34.89	19.2	0.41	0	0
-9.75	0	0	2.43	16.23	34.35	48.93	51.39	50.34	34.89	19.2	0.41	0	0
-19.50	0	0	2.43	16.23	33.13	34.49	34.49	34.49	33.38	19.2	0.41	0	0
-29.25	0	0	2.43	15.69	18.26	18.26	18.26	18.26	18.26	17.36	0.41	0	0
-39.00	0	0	1.49	2.54	2.54	2.54	2.54	2.54	2.54	2.54	0.34	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	-142.00	-112.00	-88.00	-57.00	-31.00	0.00	27.00	56.00	83.00	116.00	143.00	166.00
48.75	0.00	0.00	0.00	0.00	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	-1.49	-2.54	-1.38	1.40	3.84	-0.45	-1.61	-2.54	-0.34	0.00	0.00
29.25	0.00	0.00	-2.08	-15.69	-7.24	-2.03	-1.45	-8.98	-10.14	-11.56	-0.12	0.00	0.00
19.50	0.00	0.00	-1.44	-9.27	-17.48	2.61	3.19	-9.56	-11.93	-5.87	0.75	0.00	0.00
9.75	0.00	0.00	-1.10	-2.32	14.93	27.60	28.04	5.32	4.53	7.47	0.58	0.00	0.00
0.00	0.00	0.00	-0.40	2.32	30.00	71.09	77.56	24.60	20.19	9.79	0.46	0.00	0.00
-9.75	0.00	0.00	-1.04	-2.32	25.95	49.05	66.88	-0.48	13.23	3.99	-0.41	0.00	0.00
-19.50	0.00	0.00	-1.56	-8.69	3.97	23.49	47.84	7.83	-6.13	-7.60	0.23	0.00	0.00
-29.25	0.00	0.00	-2.43	-15.17	-4.06	1.45	29.28	1.16	-6.37	-13.30	-0.41	0.00	0.00
-39.00	0.00	0.00	-1.49	-2.54	-0.80	3.84	18.91	3.20	-0.74	-2.54	-0.34	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	1.51	7.54	0.81	0.00	0.00	0.00	0.00	0.00

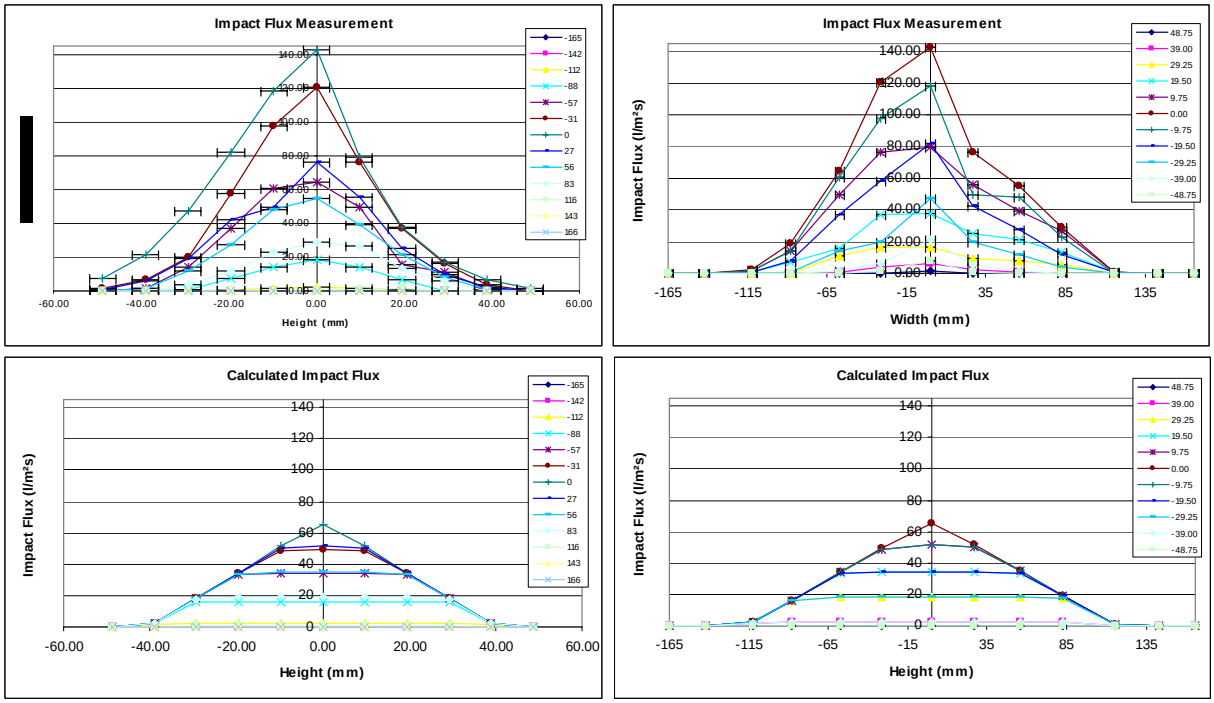

Fig.25. Measured and corresponding calculated water flux values for nozzle 51468-1.

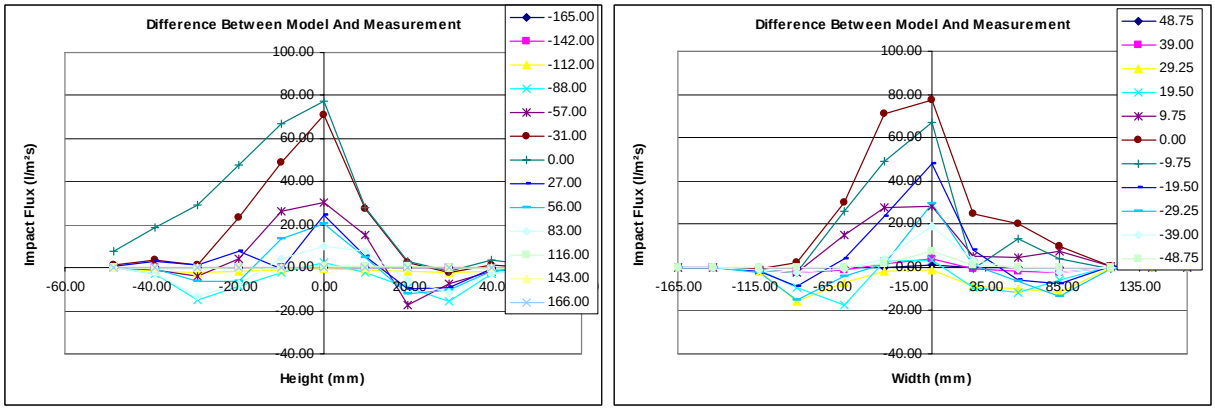

Fig.26. Difference of water fluxes at each measured location.

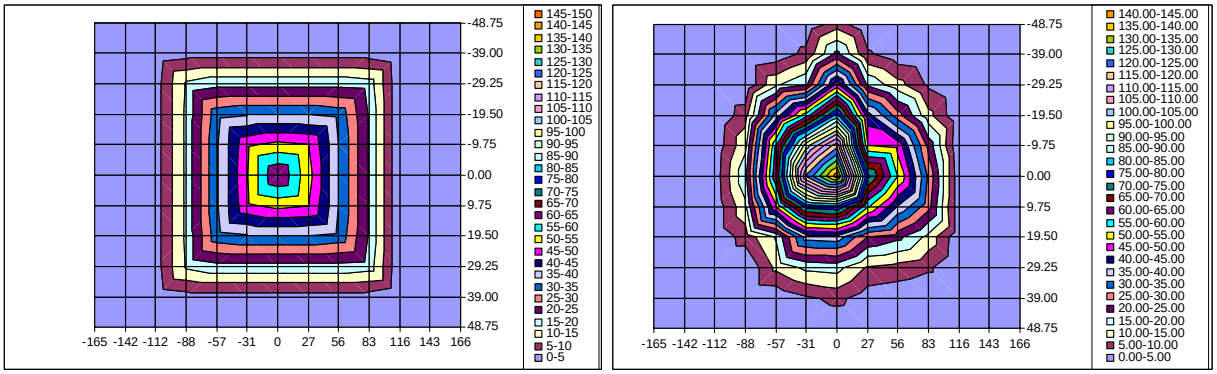

Fig.27. Contour plots of calculated and measured footprint respectively.

1.2.6 Delavan W19813-1

Fig.28. Picture of the tested nozzle.

A very close fit both numerically and in shape between calculated and measured footprints.

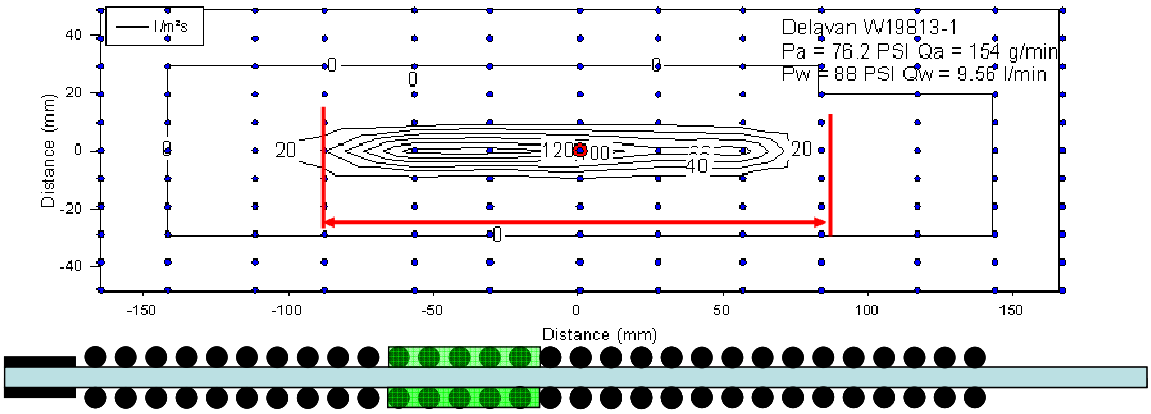

Fig.29. W19813-1 measured footprint, designed footprint width and spray nozzle location in the caster.

Table 6. Measured and calculated water fluxes and the difference between these two for W19813-1.

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	1.33	1.10	0.00	0.35	1.22	0.99	0.58	0.00	0.00	0.00	0.00
9.75	0.00	0.00	1.86	2.09	6.38	13.33	12.17	14.49	5.28	1.74	1.74	0.00	0.00
0.00	0.00	0.00	4.06	38.26	131.03	132.19	116.53	89.28	92.18	0.58	0.58	0.00	0.00
-9.75	0.00	0.00	2.20	9.57	10.44	1.74	17.39	8.12	8.70	0.29	0.29	0.00	0.00
-19.50	0.00	0.00	0.75	0.70	0.58	0.81	1.28	0.29	0.23	0.81	0.81	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
9.75	0	0	0	0	18.34	18.34	18.34	18.34	18.34	0	0	0	0
0.00	0	0	0	0	94.23	97.64	97.64	97.64	95.78	0.77	0	0	0
-9.75	0	0	0	0	18.34	18.34	18.34	18.34	18.34	0	0	0	0
-19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
-29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
-39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	-142.00	-112.00	-88.00	-57.00	-31.00	0.00	27.00	56.00	83.00	116.00	143.00	166.00
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	1.33	1.10	0.00	0.35	1.22	0.99	0.58	0.00	0.00	0.00	0.00
9.75	0.00	0.00	1.86	2.09	-11.96	-5.01	-6.17	-3.85	-13.06	1.74	1.74	0.00	0.00
0.00	0.00	0.00	4.06	38.26	36.80	34.55	18.89	-8.36	-3.60	-0.19	0.58	0.00	0.00
-9.75	0.00	0.00	2.20	9.57	-7.90	-16.60	-0.95	-10.22	-9.64	0.29	0.29	0.00	0.00
-19.50	0.00	0.00	0.75	0.70	0.58	0.81	1.28	0.29	0.23	0.81	0.81	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

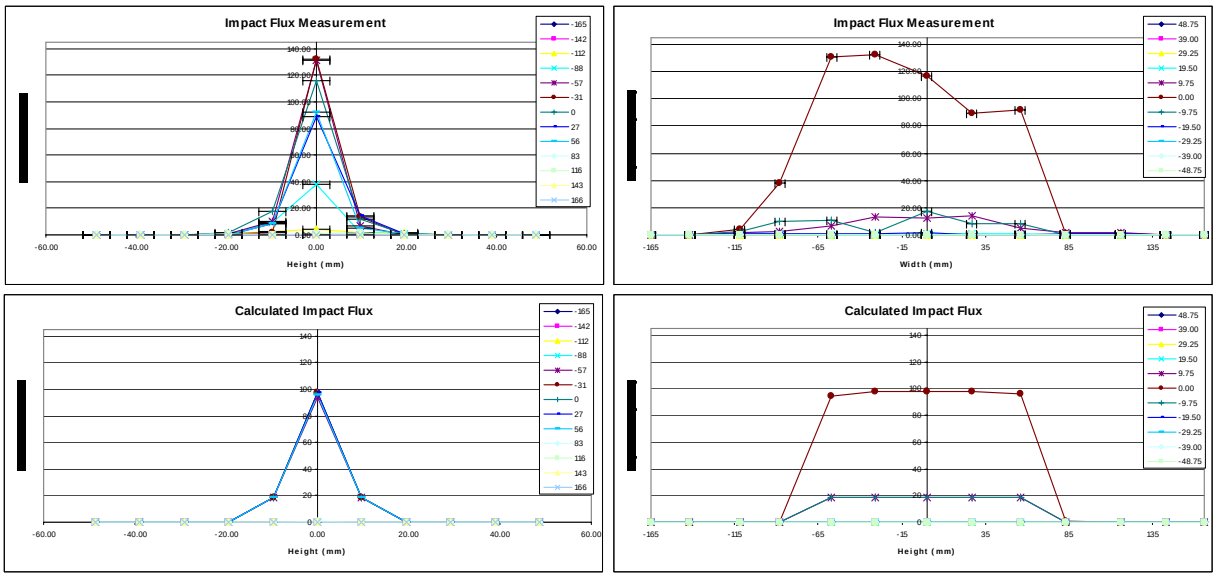

Fig.30. Measured and corresponding calculated water flux values for nozzle W19813-1.

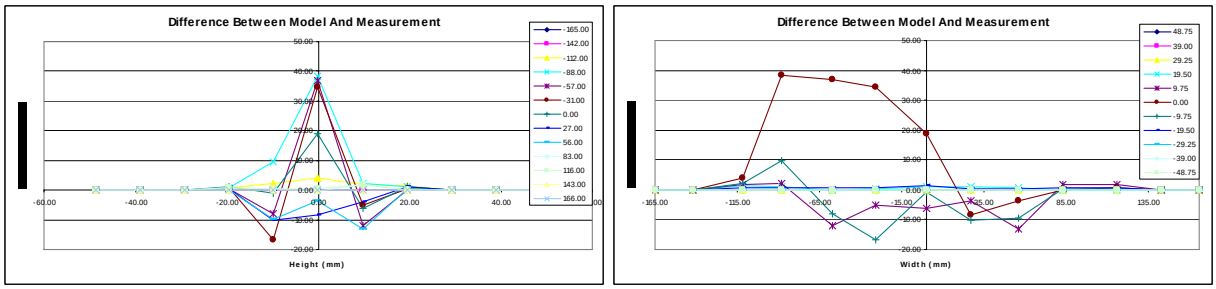

Fig.31. Difference of water fluxes at each measured location.

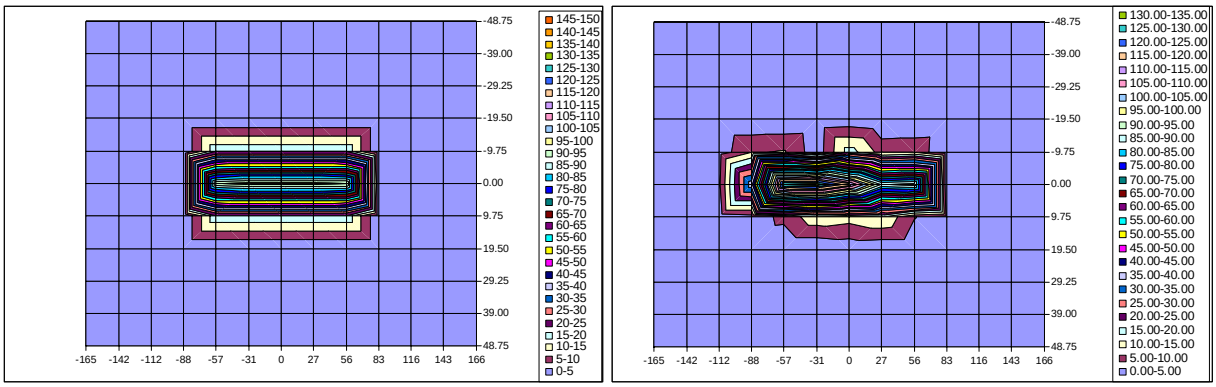

Fig.32. Contour plots of calculated and measured footprint respectively.

1.2.7 Delavan W19813-3

Fig.33. Picture of the tested nozzle.

This nozzle is very close match as the previous nozzle W19813-1.

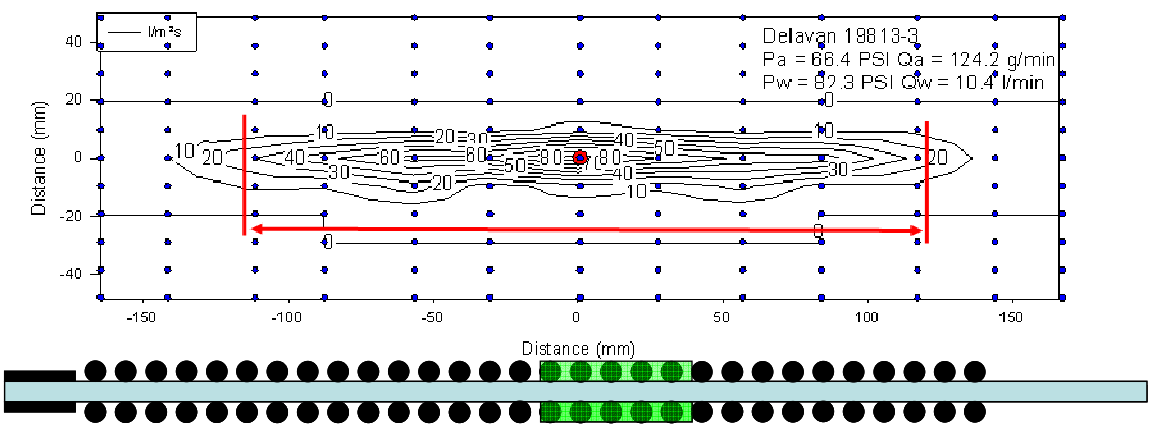

Fig.34. W19813-3 measured footprint, designed footprint width and spray nozzle location in the caster.

Table 7. Measured and calculated water fluxes and the difference between these two for W19813-3.

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.75	0.00	3.71	1.86	3.42	6.38	5.91	13.91	9.91	4.12	7.54	7.30	1.45	0.00
0.00	0.00	9.39	29.57	46.96	64.35	63.19	86.96	70.15	57.98	56.24	27.83	3.71	0.00
-9.75	0.00	3.01	11.60	10.67	24.93	4.06	16.23	11.60	22.61	6.38	8.00	0.87	0.00
-19.50	0.00	0.00	0.00	0.00	2.26	3.19	1.16	0.46	1.45	0.00	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
9.75	0	4.29	9.52	11.54	11.54	11.54	11.54	11.54	11.54	11.54	9.03	3.96	0
0.00	0	4.29	20.78	33.97	51.13	62.93	72.53	64.32	51.79	36.94	18.8	3.96	0
-9.75	0	4.29	9.52	11.54	11.54	11.54	11.54	11.54	11.54	11.54	9.03	3.96	0
-19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
-29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
-39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	**-142.00**	**-112.00**	**-88.00**	**-57.00**	**-31.00**	**0.00**	**27.00**	**56.00**	**83.00**	**116.00**	**143.00**	**166.00**
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.75	0.00	-0.58	-7.66	-8.12	-5.16	-5.63	2.37	-1.63	-7.42	-4.00	-1.73	-2.51	0.00
0.00	0.00	5.10	8.79	12.99	13.22	0.26	14.43	5.83	6.19	19.30	9.03	-0.25	0.00
-9.75	0.00	-1.28	2.08	-0.87	13.39	-7.48	4.69	0.06	11.07	-5.16	-1.03	-3.09	0.00
-19.50	0.00	0.00	0.00	0.00	2.26	3.19	1.16	0.46	1.45	0.00	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

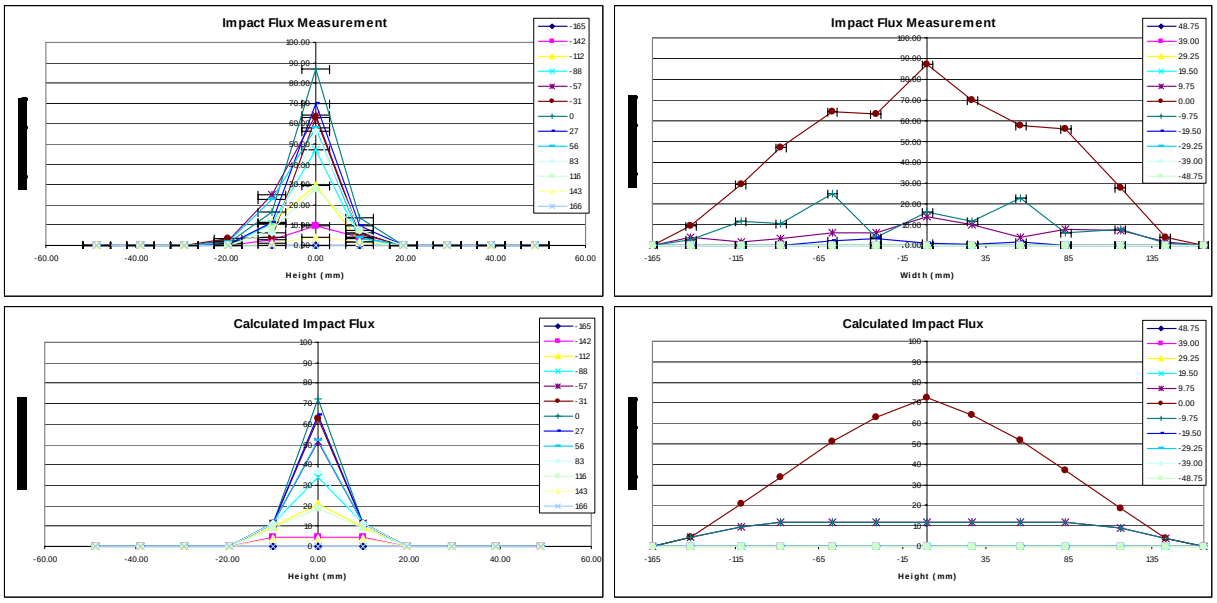

Fig.35. Measured and corresponding calculated water flux values for nozzle W19813-3.

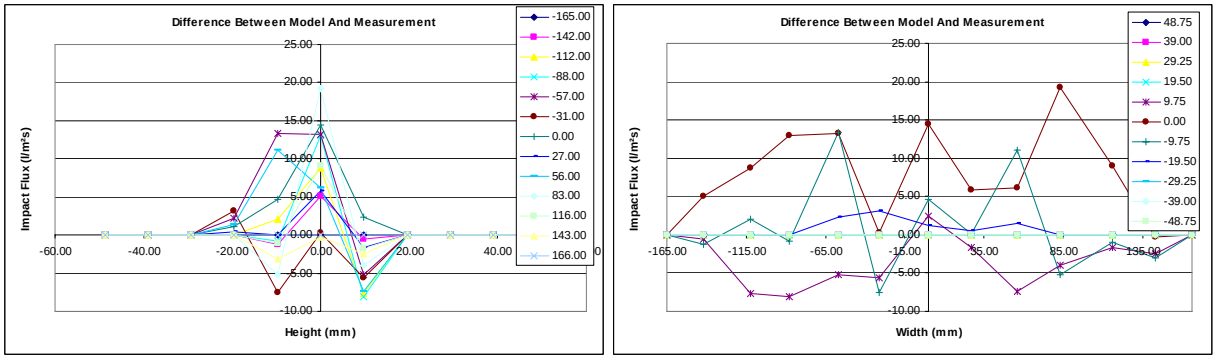

Fig.36. Difference of water fluxes at each measured location.

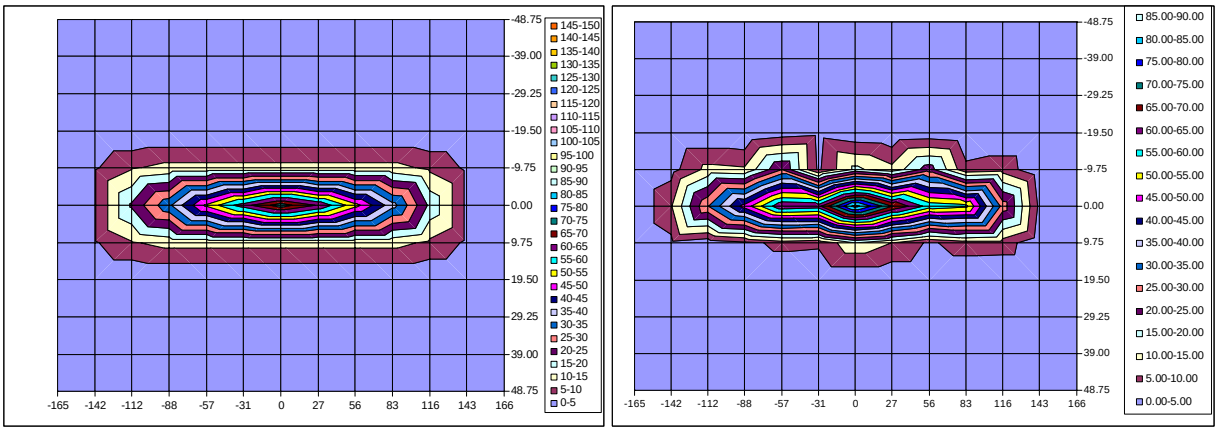

Fig.37. Contour plots of calculated and measured footprint respectively.

1.2.8 Delavan W19813-5

Mass balance is nearly achieved but there is difference in the distribution shape.

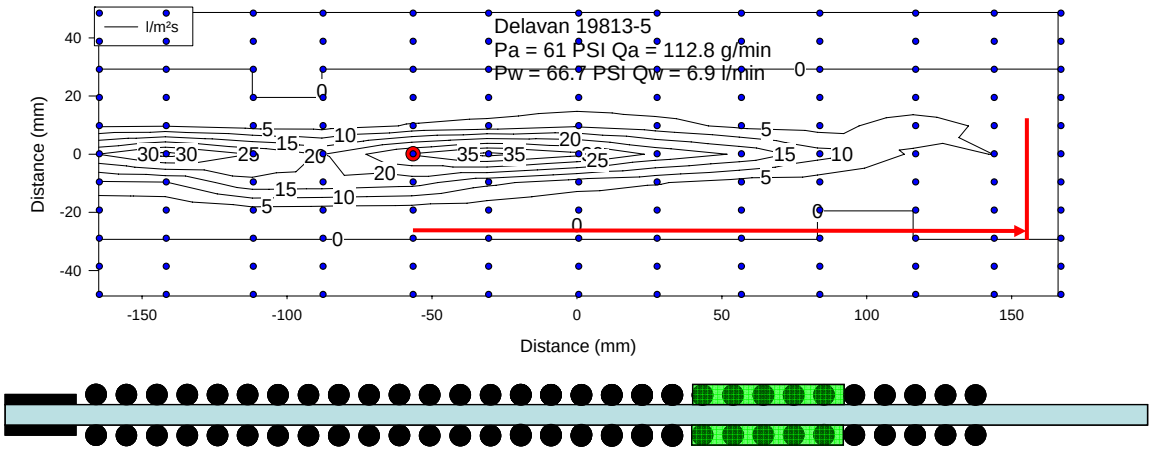

Fig.38. W19813-5 measured footprint, designed footprint width and spray nozzle location in the caster.

As clearly is visible in Fig. 38 the nozzle does not cover the whole area designed to be covered by the spray.

Table 8. Measured and calculated water fluxes and the difference between these two for W19813-5.

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.31	0.35	0.00	0.00	0.35	0.46	0.93	1.00	0.54	0.08	0.73	0.58	0.00
9.75	4.25	4.64	2.82	2.67	5.41	6.57	9.28	6.96	3.87	2.90	7.73	3.87	0.12
0.00	25.12	31.69	24.74	19.71	30.53	36.52	31.50	23.96	19.33	11.98	4.29	5.02	0.77
-9.75	9.28	9.66	18.94	18.55	17.01	11.21	7.34	5.41	2.94	2.47	0.85	0.27	0.00
-19.50	0.00	0.31	2.71	2.40	2.09	1.55	0.00	0.58	0.73	0.00	0.00	0.54	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
9.75	7.07	7.07	7.07	7.07	7.07	7.07	7.07	7.07	7.07	7.07	6.32	2.31	0
0.00	21.16	21.58	21.58	21.58	21.58	21.58	21.58	21.58	20.45	15.78	8.24	2.36	0
-9.75	7.07	7.07	7.07	7.07	7.07	7.07	7.07	7.07	7.07	7.07	6.32	2.31	0
-19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
-29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
-39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	-142.00	-112.00	-88.00	-57.00	-31.00	0.00	27.00	56.00	83.00	116.00	143.00	166.00
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.31	0.35	0.00	0.00	0.35	0.46	0.93	1.00	0.54	0.08	0.73	0.58	0.00
9.75	-2.82	-2.43	-4.25	-4.40	-1.66	-0.50	2.21	-0.11	-3.20	-4.17	1.41	1.56	0.12
0.00	3.96	10.11	3.16	-1.87	8.95	14.94	9.92	2.38	-1.12	-3.80	-3.95	2.66	0.77
-9.75	2.21	2.59	11.87	11.48	9.94	4.14	0.27	-1.66	-4.13	-4.60	-5.47	-2.04	0.00
-19.50	0.00	0.31	2.71	2.40	2.09	1.55	0.00	0.58	0.73	0.00	0.00	0.54	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

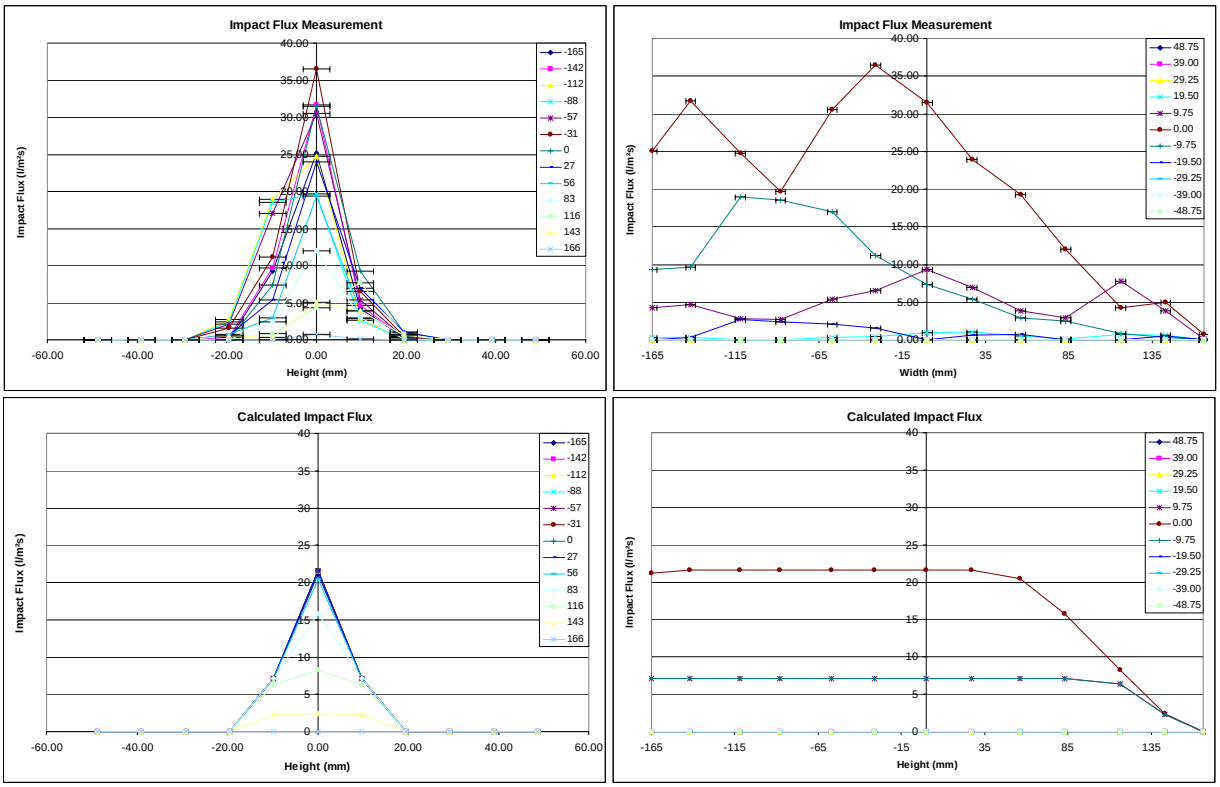

Fig.39. Measured and corresponding calculated water flux values for nozzle W19813-5.

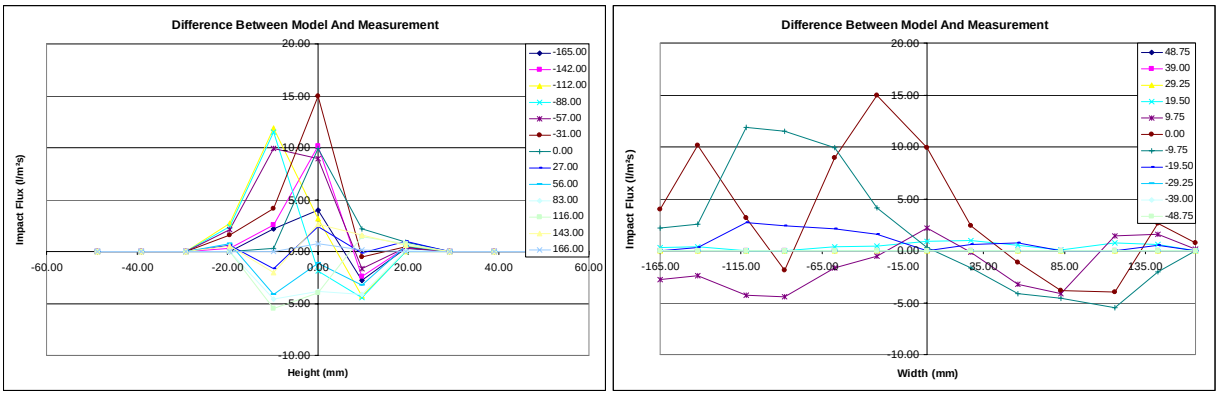

Fig.40. Difference of water fluxes at each measured location.

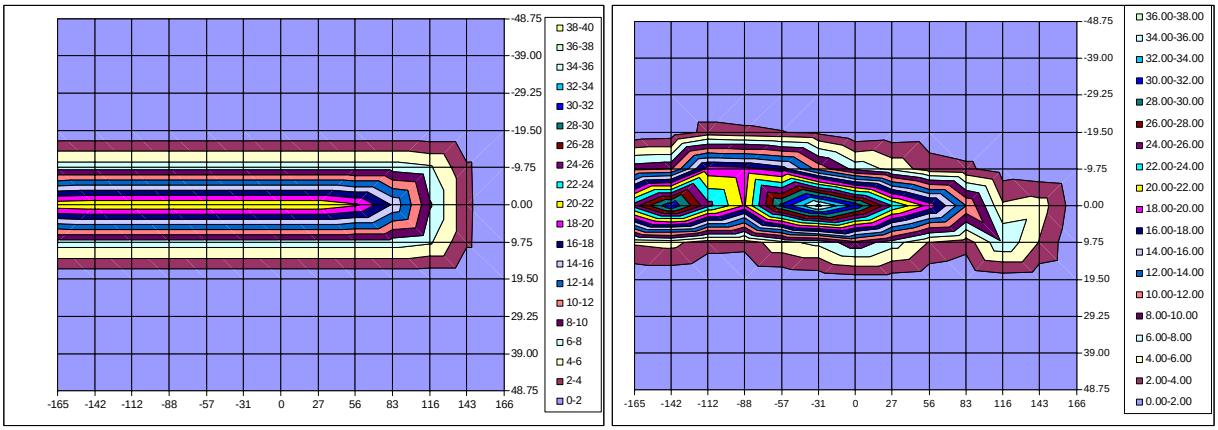

Fig. 41. Contour plots of calculated and measured footprint respectively.

1.2.9 Delavan W19822

Fig.42. Picture of the tested nozzle.

The same observations can be made with this nozzle as with all previous ones. The measurement was made twice and it shows the strong stochastic nature of the sprays. This measurement, as can be seen from the contour plot, is twisted clockwise.

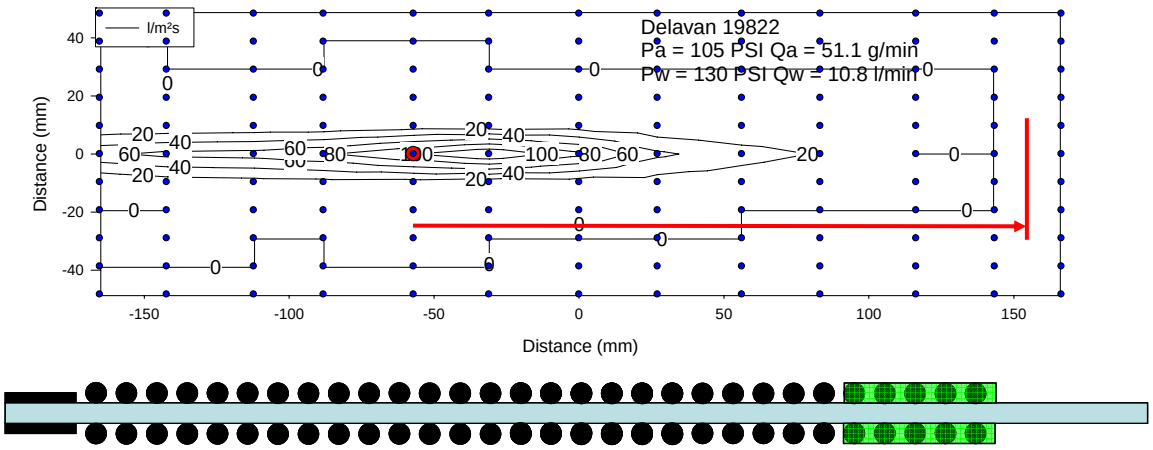

Fig.43. W19822 measured footprint, designed footprint width and spray nozzle location in the caster.

As in the case of the previous nozzle the footprint does not cover fully the area designed for the nozzle to cover.

1.2.9.1 Measurement 1

Table 9. Measured and calculated water fluxes and the difference between these two for W19822 test 1.

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00
9.75	1.39	4.35	2.26	3.07	9.16	22.03	24.93	9.28	7.54	11.60	4.64	0.00	0.00
0.00	23.77	38.26	38.26	57.40	99.72	91.02	57.98	52.18	27.83	9.86	7.54	0.00	0.00
-9.75	23.19	13.91	25.51	21.45	10.44	2.49	2.67	2.72	1.28	0.81	0.58	0.00	0.00
-19.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.22	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
9.75	6.56	6.56	6.56	6.56	6.56	6.56	6.56	6.56	6.44	4.29	1.76	0	0
0.00	27.28	34.64	44.14	51.5	60.39	53.03	43.53	34.94	25.75	17.17	7.05	0	0
-9.75	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.09	4.95	2.42	0	0
-19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
-29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
-39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	-142.00	-112.00	-88.00	-57.00	-31.00	0.00	27.00	56.00	83.00	116.00	143.00	166.00
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00
9.75	-5.17	-2.21	-4.30	-3.49	2.60	15.47	18.37	2.72	1.10	7.31	2.88	0.00	0.00
0.00	-3.51	3.62	-5.88	5.90	39.33	37.99	14.45	17.24	2.08	-7.31	0.49	0.00	0.00
-9.75	15.97	6.69	18.29	14.23	3.22	-4.73	-4.55	-4.50	-5.81	-4.14	-1.84	0.00	0.00
-19.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.22	0.00	0.00	0.00

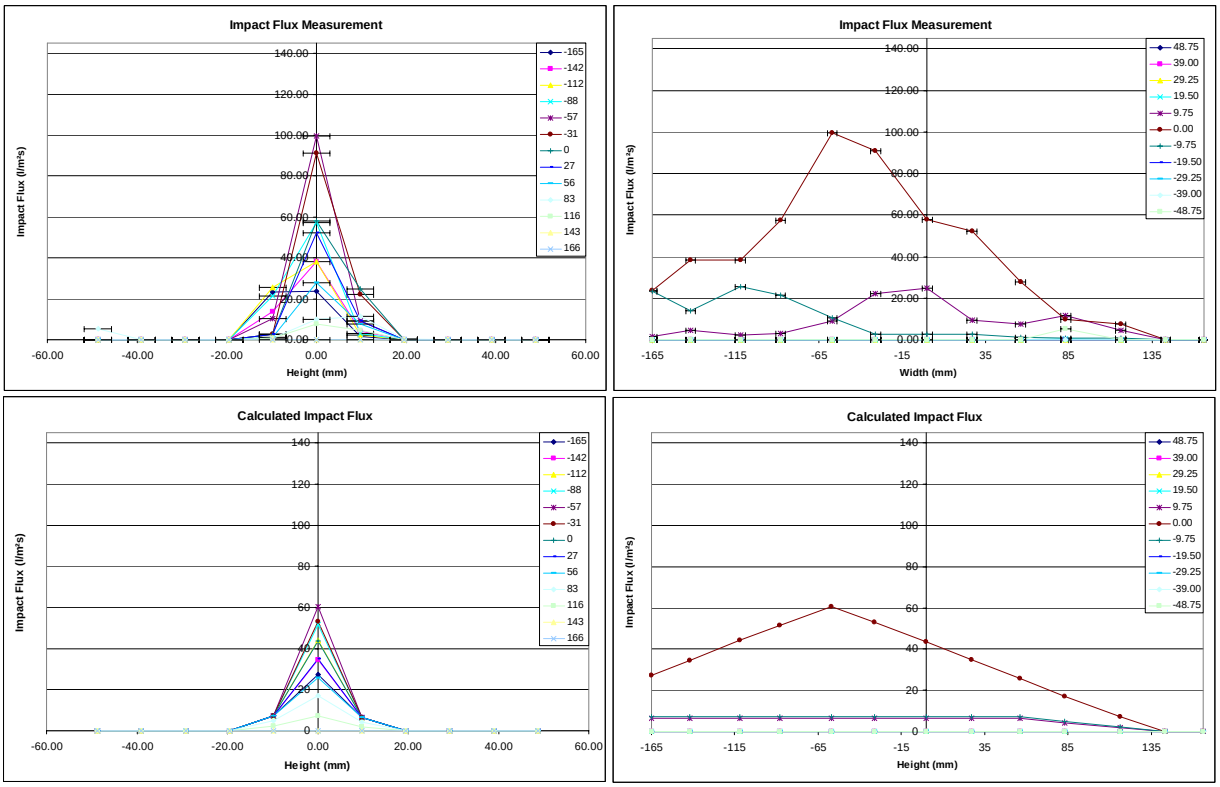

Fig.44. Measured and corresponding calculated water flux values for nozzle W19822 test 1.

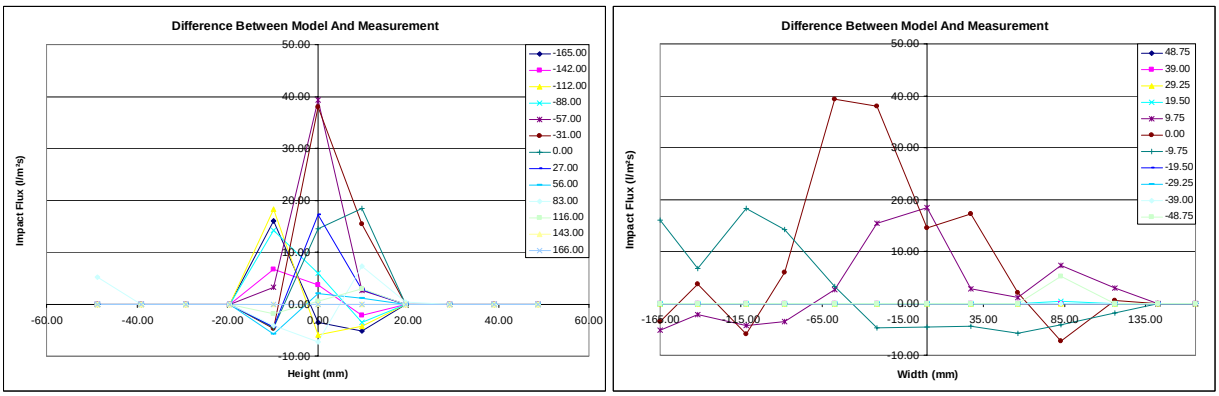

Fig.45. Difference of water fluxes at each measured location.

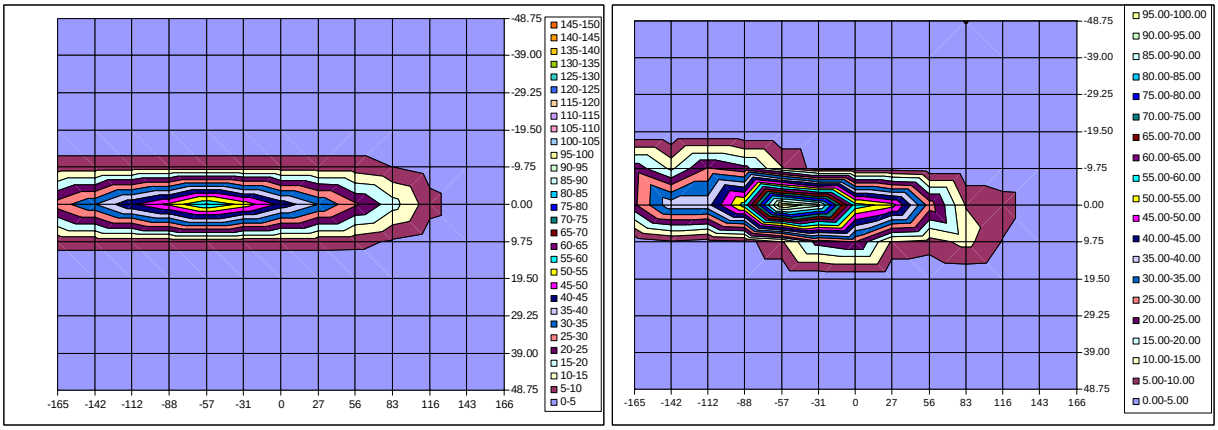

Fig.46. Contour plots of calculated and measured footprint respectively.

1.2.9.2 Measurement 2

Table 10. Measured and calculated water fluxes and the difference between these two for W19822 test 2.

Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.39	0.00	0.85	0.73	0.73	0.54	0.39	1.24	1.82	0.08	0.19	0.00	0.00
9.75	2.71	2.90	4.83	4.25	9.28	7.73	9.28	3.87	2.32	2.09	0.08	0.00	0.00
0.00	55.66	65.71	68.03	77.30	99.33	119.82	85.80	44.06	28.21	18.55	0.00	0.00	0.00
-9.75	2.28	9.28	11.98	13.14	11.98	7.73	9.66	11.21	8.12	1.47	4.64	0.00	0.00
-19.50	0.00	0.00	1.24	0.89	1.39	0.81	0.00	0.70	0.00	0.00	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Model Water Flux

	-165	-142	-112	-88	-57	-31	0	27	56	83	116	143	166
48.75	0	0	0	0	0	0	0	0	0	0	0	0	0
39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
9.75	5.58	5.58	5.58	5.58	5.58	5.58	5.58	5.58	5.58	4.05	0	0	0
0.00	33.77	46.26	58.3	65.02	65.02	65.02	57.74	46.72	30.99	16.19	0	0	0
-9.75	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14	4.61	0	0	0
-19.50	0	0	0	0	0	0	0	0	0	0	0	0	0
-29.25	0	0	0	0	0	0	0	0	0	0	0	0	0
-39.00	0	0	0	0	0	0	0	0	0	0	0	0	0
-48.75	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference Between Model And Measurements

	-165.00	-142.00	-112.00	-88.00	-57.00	-31.00	0.00	27.00	56.00	83.00	116.00	143.00	166.00
48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.50	0.39	0.00	0.85	0.73	0.73	0.54	0.39	1.24	1.82	0.08	0.19	0.00	0.00
9.75	-2.87	-2.68	-0.75	-1.33	3.70	2.15	3.70	-1.71	-3.26	-1.96	0.08	0.00	0.00
0.00	21.89	19.45	9.73	12.28	34.31	54.80	28.06	-2.66	-2.78	2.36	0.00	0.00	0.00
-9.75	-3.86	3.14	5.84	7.00	5.84	1.59	3.52	5.07	1.98	-3.14	4.64	0.00	0.00
-19.50	0.00	0.00	1.24	0.89	1.39	0.81	0.00	0.70	0.00	0.00	0.00	0.00	0.00
-29.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-48.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

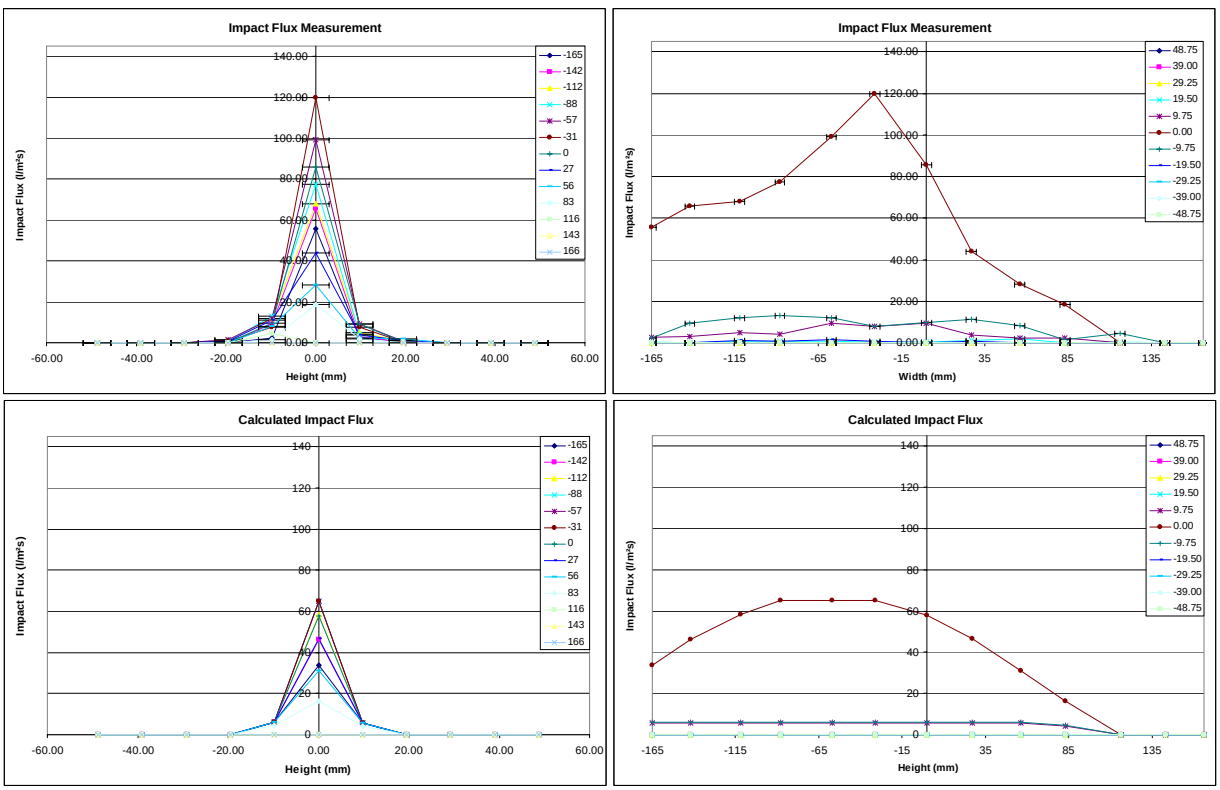

Fig. 47. Measured and corresponding calculated water flux values for nozzle W19822 test 2.

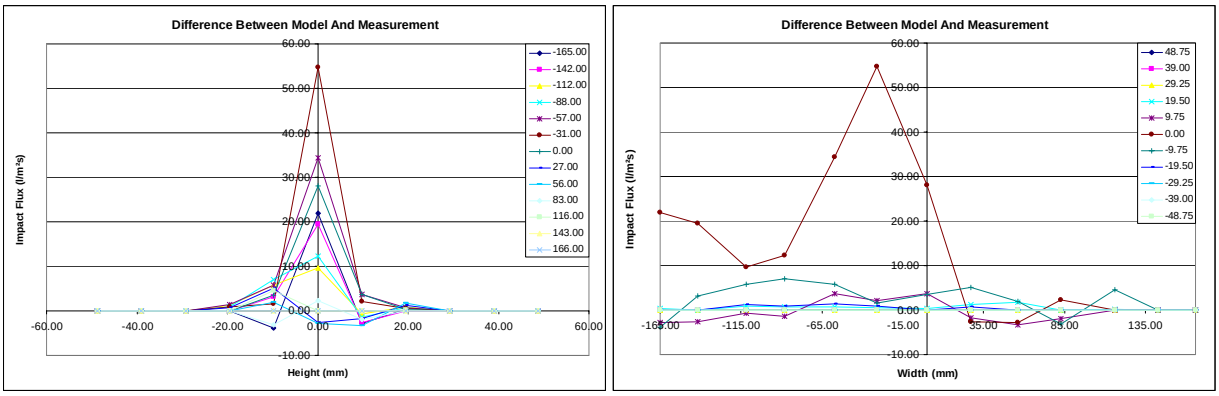

Fig. 48. Difference of water fluxes at each measured location.

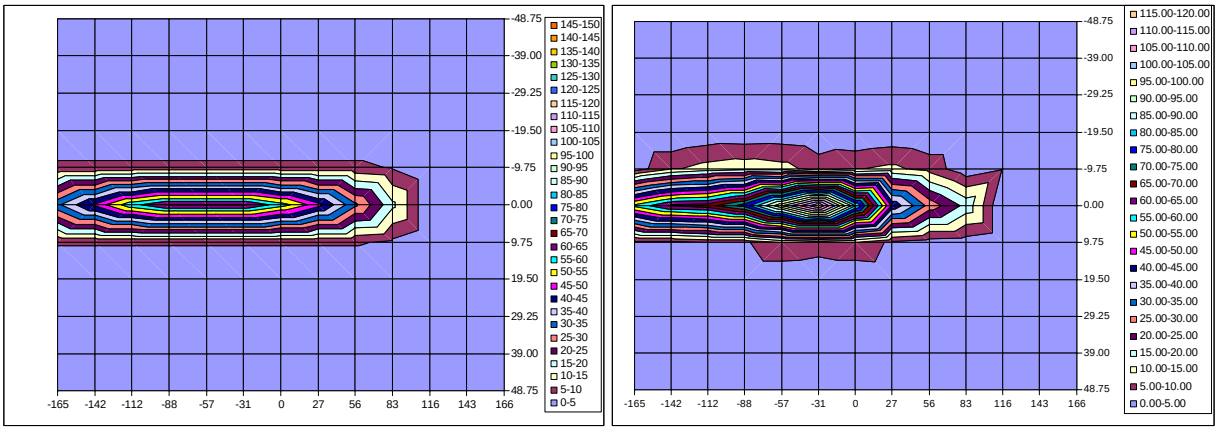

Fig. 49. Contour plots of calculated and measured footprint respectively.

1.3 Operating Diagrams

1.4 Conclusions

For the most of the nozzles obelisk shape is a good estimate for the impact density distribution but a problem can be found in one hydraulic nozzle with hollow cone distribution. Bigger question is what is causing the problem in numerical integration as the measured impact density values indicate a higher water flow rate. Modification of the measurement results before using the obelisk shape to describe the footprint included deleting measurement values usually between 0-5 l/m²s from up to 10 different collectors. Value as high as 14 l/m²s, corresponding to 25% of the maximum impact density for this case, was found outside of the footprint domain. The shape distribution obtained from these footprint measurements can be used in mathematical models qualitatively as they are but numerically the method is showing a very high uncertainty.

In Table 11 all obelisk parameters used and corresponding peak h-value for each nozzle are printed.

Table 11.a, a', b, b', (meters) and h (l/m²s) for all of the nine nozzles tested where direction of a is across the width and b is along the length of the caster.

Nozzle	a	a'	b	b'	h
3.5-90	0.235	.02	.04	.003	41.81386
3.5-60	.08	.04	.022	.003	162.7476
3.5-80	0.108	.054	.086	.0215	28.352

51474-1	0.18	.06336	.06	.006	143.6022
51468-1	0.232	.08	.000232	.00008	67.55093
W19813-1	0.165	0.113025	.016	0.006912	97.63731
W19813-3	.3	.003	.021	.00021	81.63580
W19813-5	0.42	.21	.028	.000028	23.55259
W19822 I	.39	.00585	.0195	.006045	60.38637
W19822 II	0.34	0.06936	.0195	0.0000195	73.64406

FUTURE WORK:

Operating diagrams from Delavan and our measurements

Equations in fortran code for full cone and hollow cone round nozzles for their distributions

Better summary for the nozzle parameters used in numerical integration