Study of Flow Patterns in An Automotive Paint Bath

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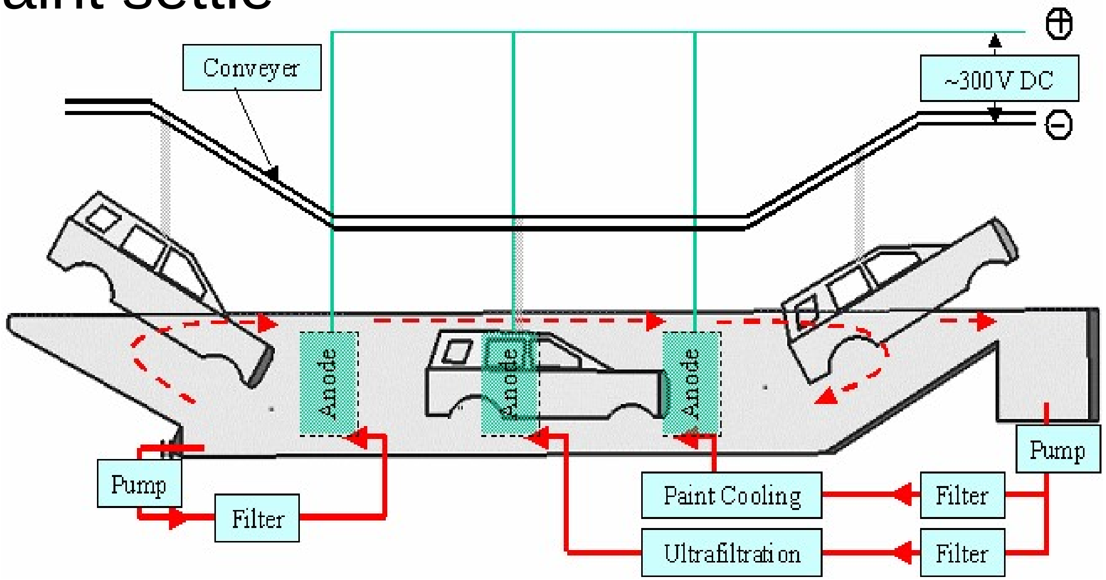
Background and Objective

- Automotive E-coating is the anti-corrosion layer on a vehicle body
- Operations are complex (dipping, heat and mass transfer during an electro-chemical process) and diverse (suppliers)
- To apply simulation technology to optimise flow design in the e-coating bath for a <u>dirt free e-coating</u>
- To develop predictive tool for new model design

Paint circulation

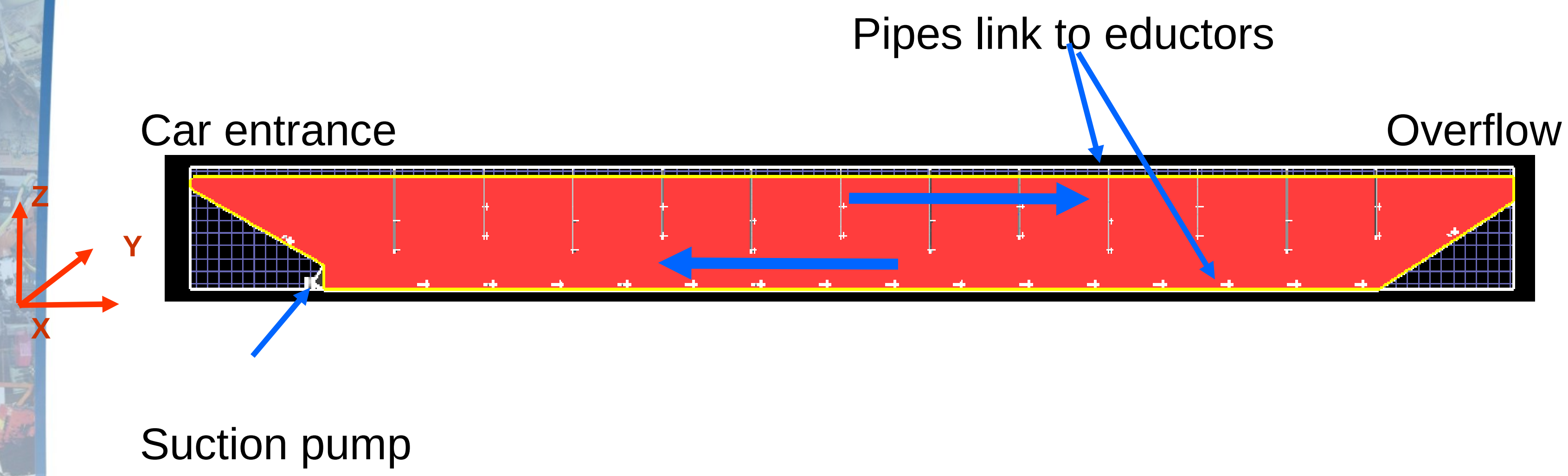
1. Mixing: Prevent paint settle



2. Dirt control
   - Prevent dirt deposition/embedding on the surface
   - Remove foreign dirt (heavy metallic dirt such as metal powders, weld balls brought in on the vehicle) from the suction pump at bottom of the bath
   - Remove floating dirt (generated by cataphoresis reaction) from the weir

3. Temperature control: to prevent over-coating

E-coating bath coordinate system



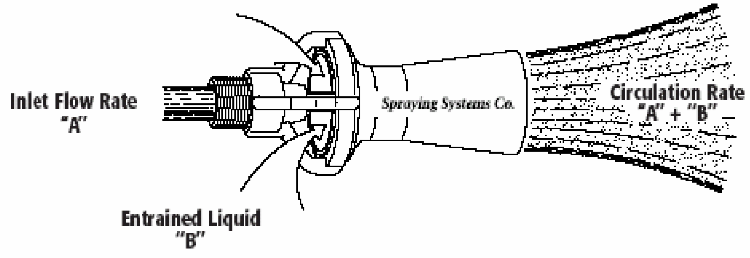
Outlets: suction pump and overflow weir

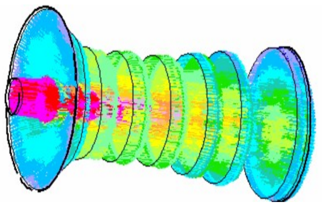
Inlets: eductors

X=0 left-hand-side, Y=0 middle-plane to far side, Z=0 bottom of the bath

bath~3000x3000x30000mm, eductor: R=21mm, L~160mm

Eductors


Inlet Flow Rate
"A"
Spraying Systems Co.
Circulation Rate
"A" + "B"
Entrained Liquid
"B"



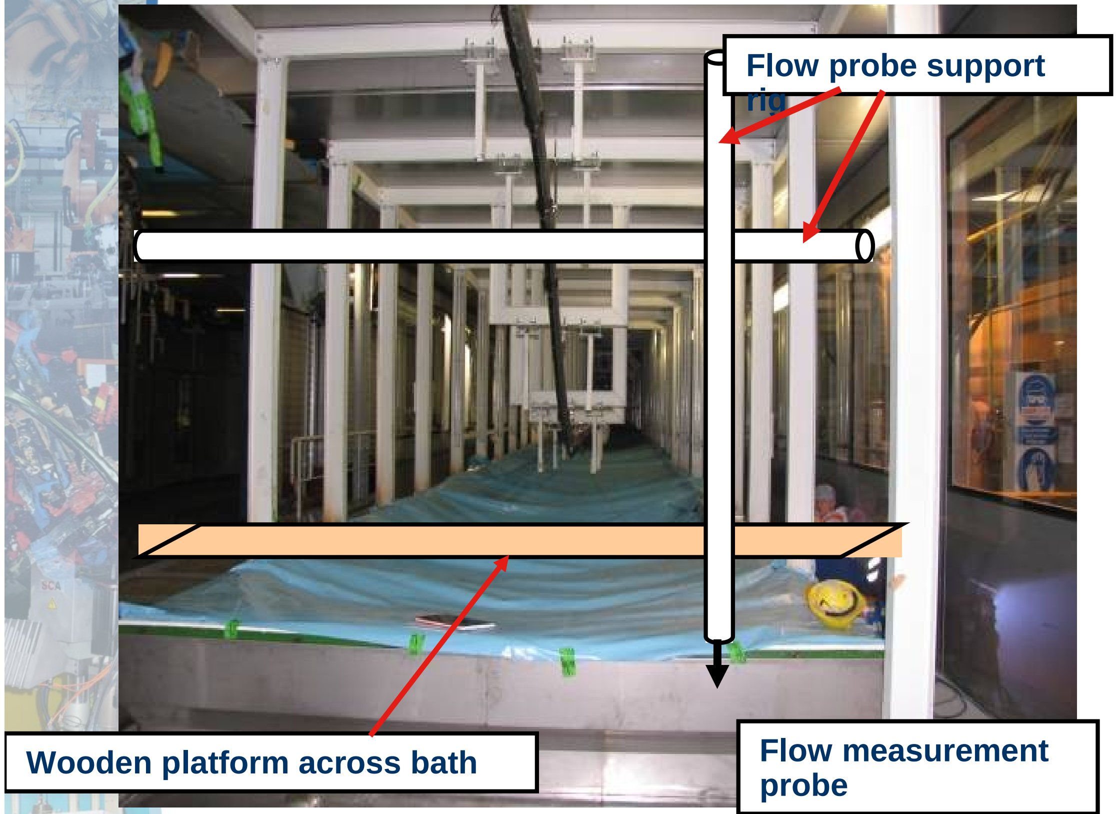
Measurements in an industry scale bath

Measurements made possible during the cleaning stages of a new e-coating bath (one week, in water). Aims to characterise the operating conditions and flow pattern in the bath

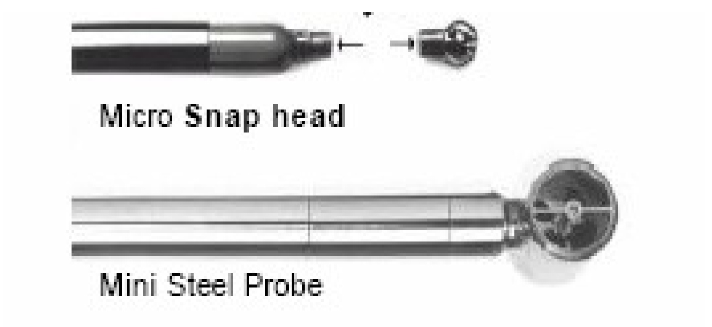
Process monitoring: Ultrasonic flowmeter for flow in the pipes, pressure readings at upstream of eductor pipes

- → Local average flow measurements using a vane anemometer
- → Surface flow measurements using floating ball and camcorder
- → Measurements of the local concentration build-up with time using a tracer.

Vane anemometer measurements



Water Probe	MiniWater20 Micro
Measuring range Flow	0.04 - 5 m/s
	0.05 - 10 m/s
Flow accuracy	2.0% fs
	3.0% rdg
Measuring range Temp.	0 to +70°C
Accuracy	+/- 0.5°C
Operating temperature	-30 to +70°C
Head dimension	∅ 11 x 15 mm
Access opening	16 mm
Length of probe	165 mm
Length of cable	5 m
Storage temperature	-65 to +150°C



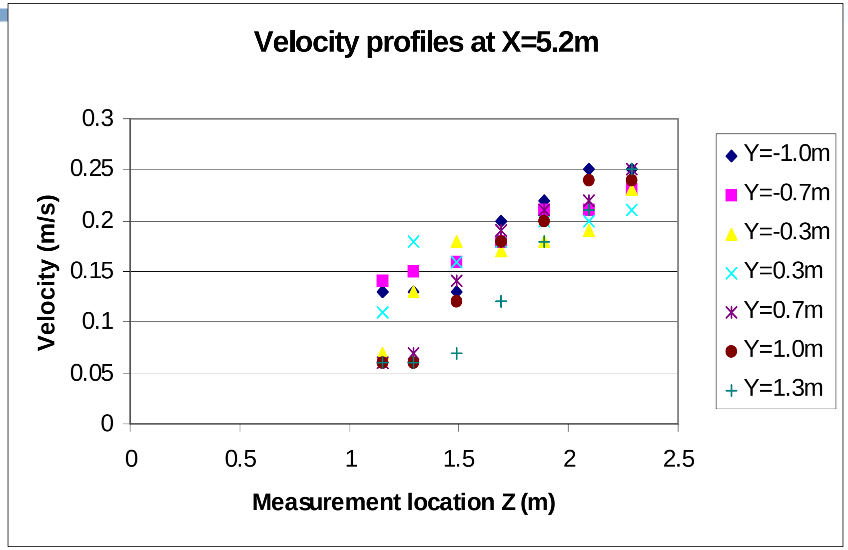
Flow measurements

550 locations are measured

in the front section of the bath.

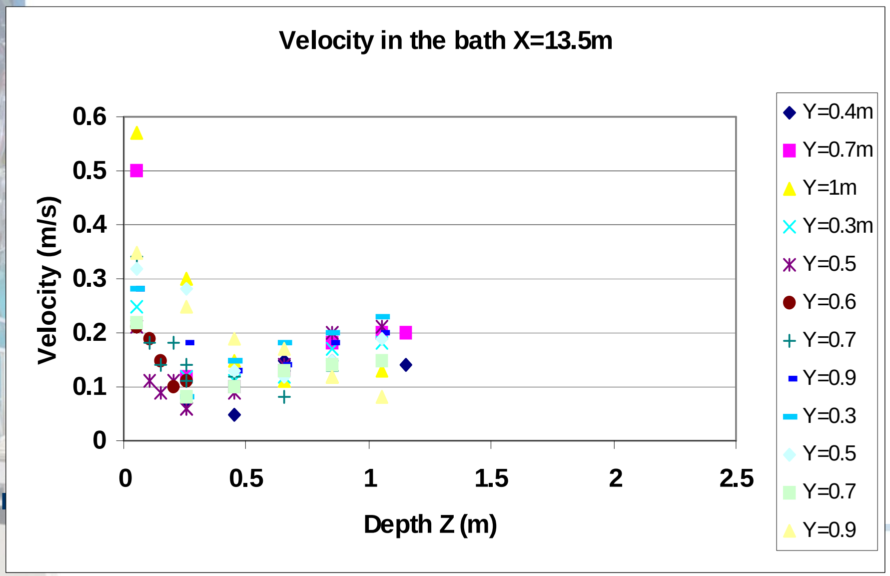
At X=5.2m (upper half of the bath only)

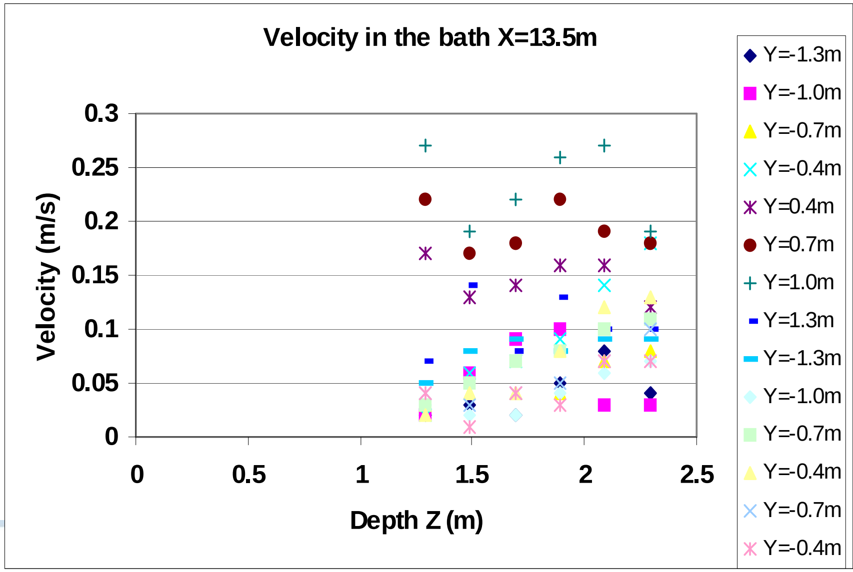
At X=13.5m



Lower half of the bath

Upper half of the bath



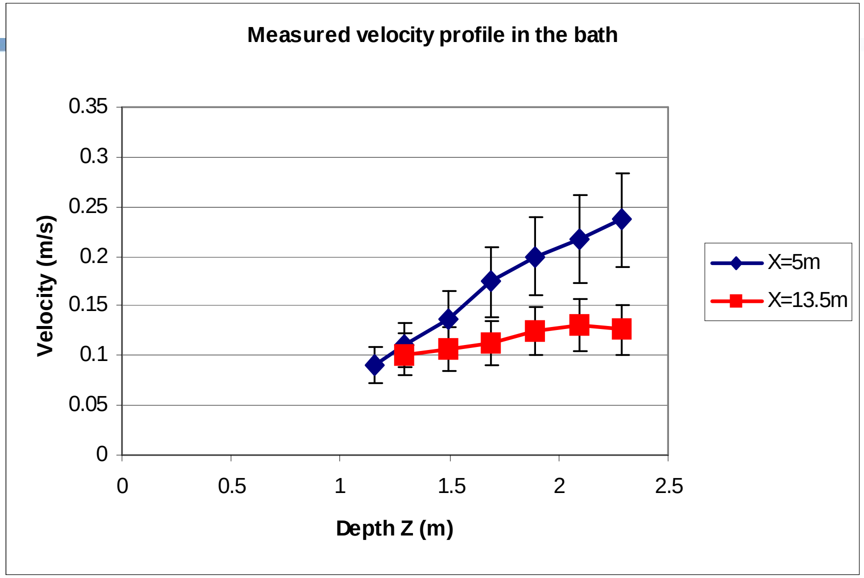


Flow measurements

Averaged value with 20% error bar

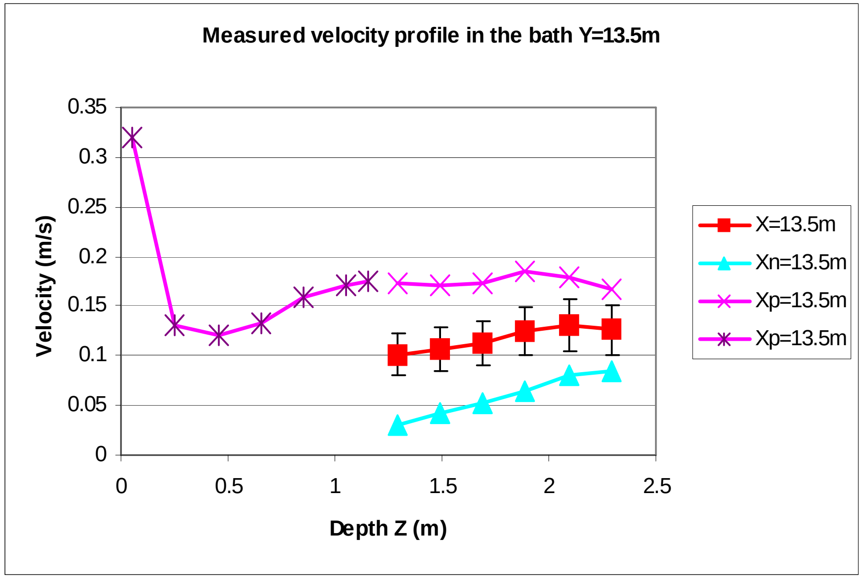
At X=5.2m and 13.5m

upper half of the bath



At X=13.5m

U(m/s), in X, Y and Z direction



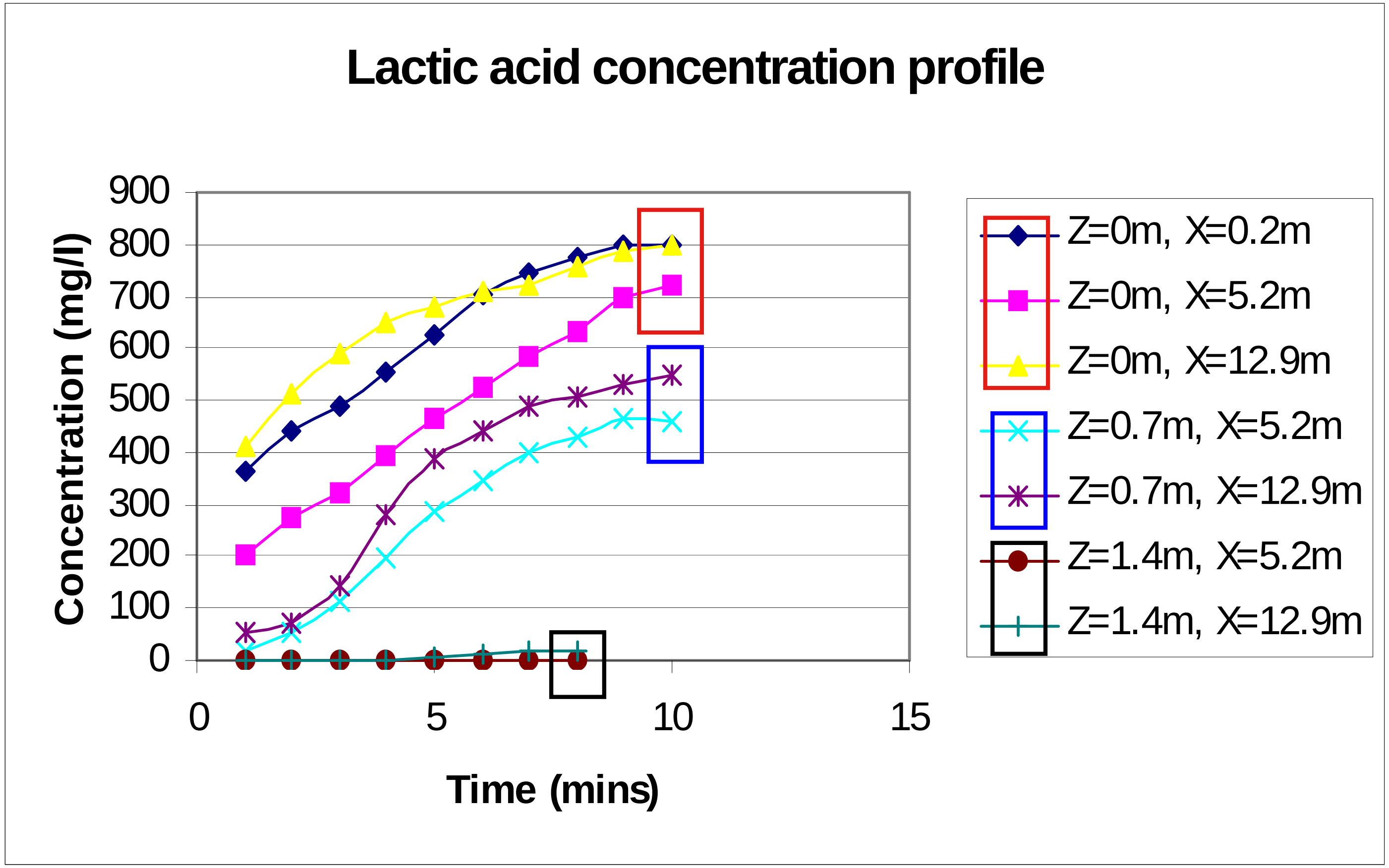
Surface flow measurements

Picture of floating body in the bath, from left, T=0s, T=0.25s, T=0.5s

The average velocity in streamwise direction is 0.2 to 0.23m/s.

The velocity is higher at X=6.1m than that of downstream location at X=14m

Concentration measurements
(Cleaning agent as a tracer)



Experimental Results

1. In the front section of the bath, the average velocity at free surface is about 0.2~0.3m/s. It decreases in the streamwise direction
2. A higher slope in the velocity profile at upstream location of X=5.2m than that of X=13.5m
3. The flow in the bath is highly turbulent. Also, the flow is not evenly distributed at a cross section at the free surface (channelling).

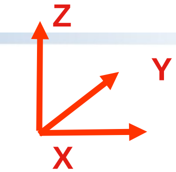
The experimental data acts to validate the numerical results qualitatively.

Simulation Methodology

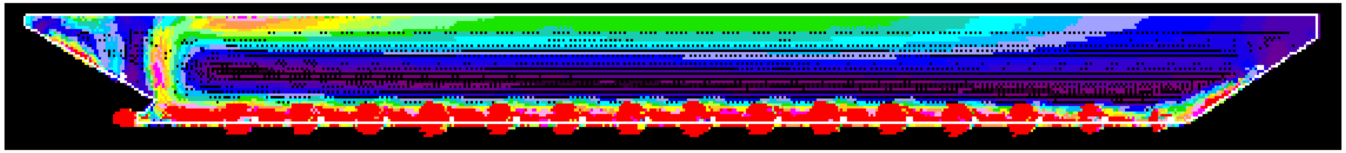
A single phase, steady state, isothermal turbulent flow with Newtonian fluid is solved with a commercial software Star-CD.

1. Mesh: Hex centered mesh with 2million cells, refined near eductor and inlets/outlets (bath~3000x3000x30000, eductor: R=21mm, L~160mm)
2. Turbulent models: high Reynolds number K-ε etc.
3. Eductor/nozzle angle and locations, inlet flow rate, outlet ratio
4. Scale-down (1/4 model).

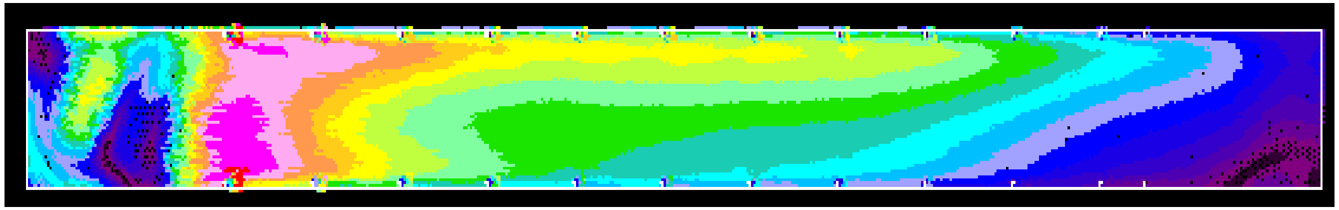
Simulation results

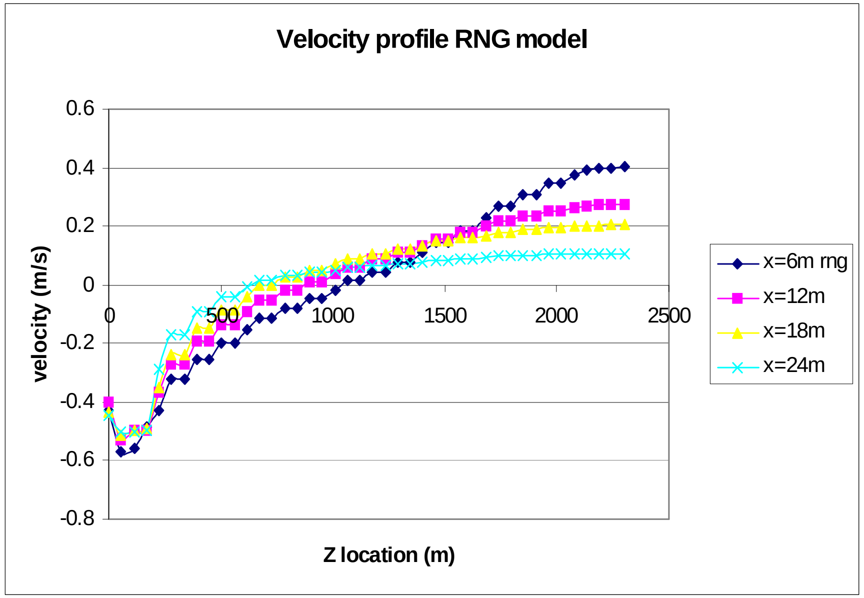


Side view at Y=0



Top view



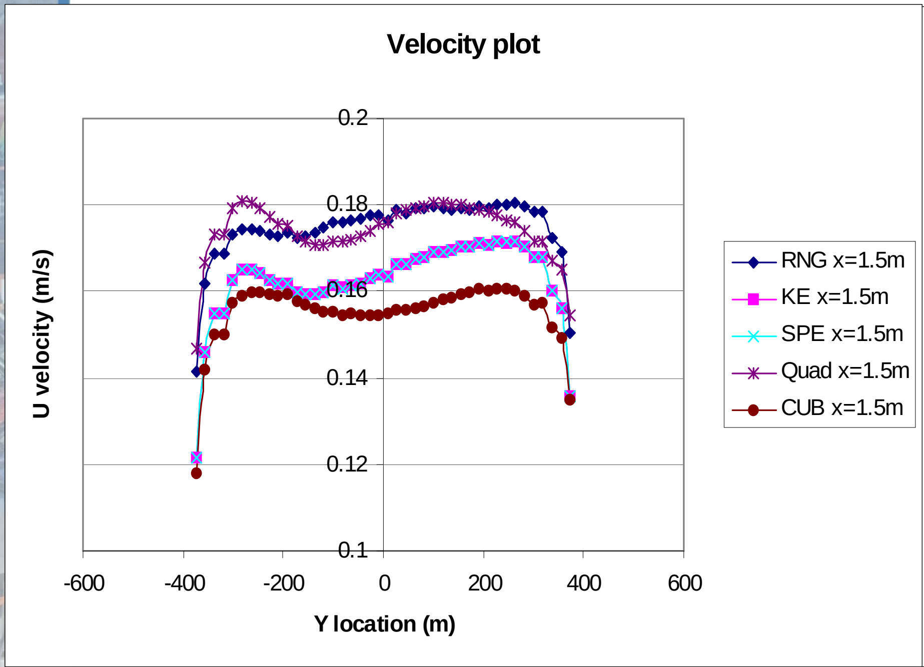


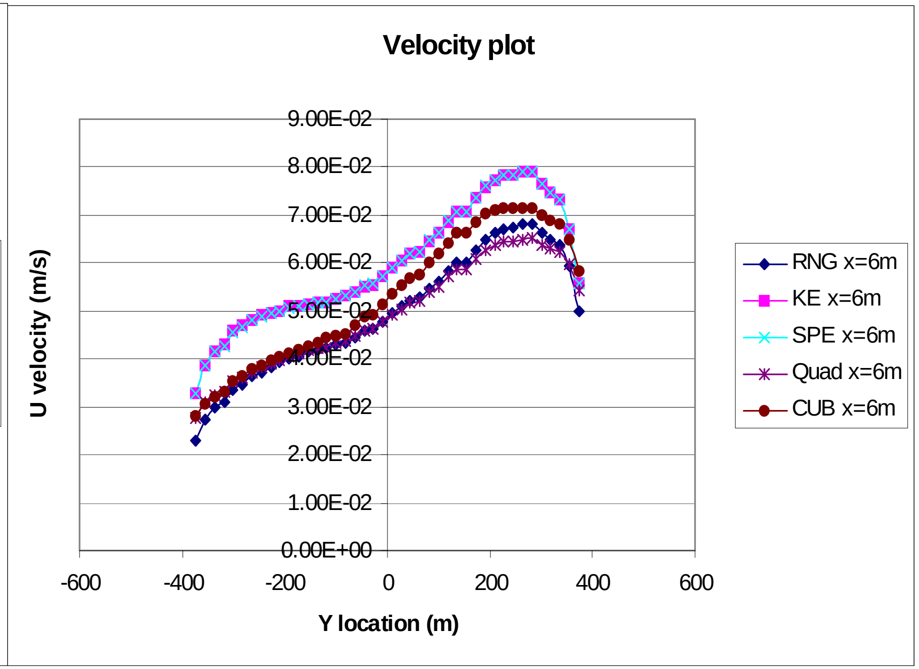
Simulation-Experiments Comparison

	Experimental	Numerical
Velocity at free surface	0.2~0.3m/s in the front section Reduce at downstream direction	0.2~0.4m/s in the front section (depend on operation pressure) Reduce at downstream direction
Velocity profile	A higher slope in the velocity profile at upstream X=5.2m	A higher slope in the velocity profile at upstream locations
Flow pattern in the bath	Channelling (uneven velocity profile) Stagnation zone in the front section (X~5.2m) at about half height of the bath	Channelling (uneven velocity profile) Stagnation zone in the front section at about half height of the bath. At downstream, the height of the stagnation zone moved closer to the bottom.

Very good consistency is obtained.

The effect of turbulent models





Scale down (¼)

Conclusions

1. Very good consistency between numerical and experimental results
2. CFD simulations provide valuable information for improving the flow in the e-coating bath
   - Low flow zones and channeling >> Adjust the angle and flow rate of floor/side eductors
   - Floating dirt accumulation near BIW entrance/exit >>Increase local flow near the weir by adding eductors
   - Heavy dirt suspended and recirculation in the bath >> Allow heavy dirt to settle near the discharge area

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