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Temperature evolution in the spray zones: plant measurements and CON1D prediction

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- National Science Foundation
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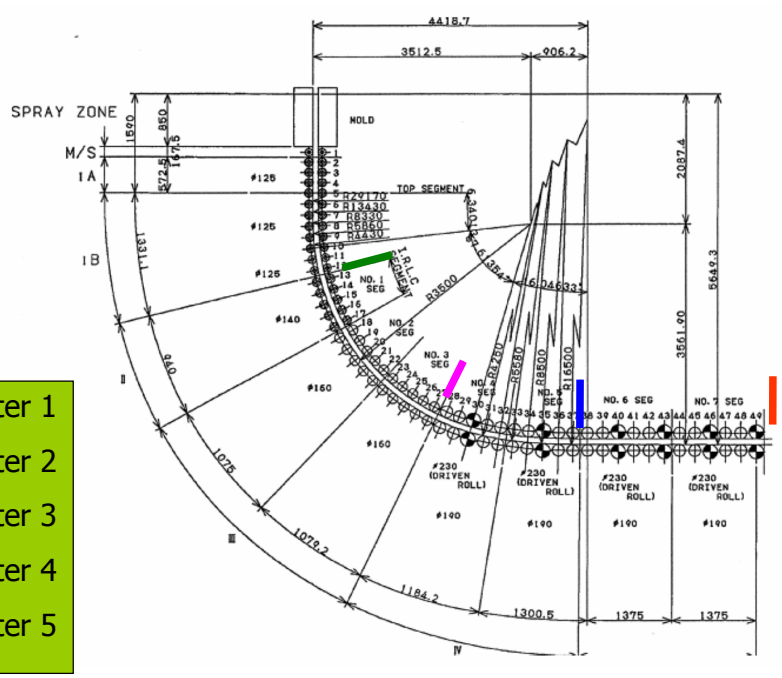
- Other graduate students, especially Huan Li and Bryan Petrus James.

Outline

- Nucor trials-pyrometer measurements
- Con1d prediction of Nucor trials
- Con1d prediction of whale formation
- Con1d tests of hysteresis
- Conclusions

Pyrometers location



- Pyrometer 1
- Pyrometer 2
- Pyrometer 3
- Pyrometer 4
- Pyrometer 5

Pyrometer Specifications

Model Name and Number	Modline® 5, 5R-141000, 4M5#25579
Length	1346 mm
Focus spot size	15.5 mm
Location of Pyrometer 1 from meniscus	11385 mm
Location of Pyrometer 2 from meniscus	8380 mm
Location of Pyrometer 3 from meniscus	6015.3 mm
Location of Pyrometer 4 from meniscus	3866.1 mm
Location of Pyrometer 5 from meniscus	13970 mm

Spray zones configuration in con1d input file

Zone No.	Zone Starts	# of Rolls	Roll Radius (m)
(1)	850	**1** (1)	0.062
(2)	940	**5** (2~6)	0.062
(3)	1767	**6** (7~12)	0.062
(4)	2823.3	**5** (13~17)	0.070
(5)	3773.6	**1** (18)	0.080
(6)	3968.6	**9** (19~27)	0.080
(7)	5903.6	**1** (28)	0.095
(8)	6130.3	**9** (29~37)	0.095
(9)	8260.0	**1** (38)	0.095
(10)	8495.8	**10** (39~48)	0.095
(11)	10995.8	**1** (49)	0.115

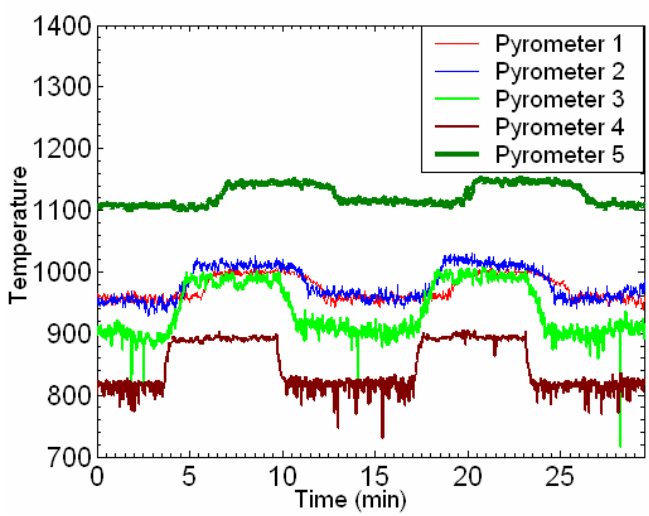
Case 4 13 Jan Transient (Low and High Spray)

Nucor experiment (from Amar's ccc meeting 2006)

Parameter	Value
Time of Experiment	Jan. 13, 2006, 1610-1640 hrs.
Casting Speed	142.1 ipm (3.61 m/min) (0.06 m/s)
Spray Pattern Number	4 to 7
Composition of Elements (%)	C .247 Mn 1.09 S 0.0019 Al 0.039 Ca .0018 Si .175 P .014 Cu .087 N (leco).0076
Caster	South
Pouring Temperature	1547.777 °C

- The casting speed kept constant.
- The spray pattern went like high-low-high-low-high.

Experimental Temperature Profile

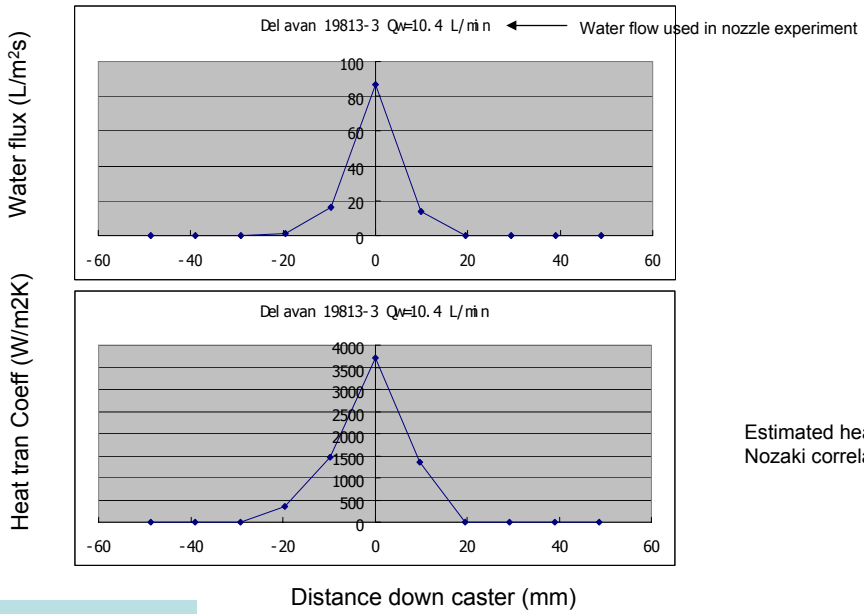


-Amar Behera's Nucor report

Characterize using CON1D

--from Vapalahti's 2006 ccc meeting report:

"Delavan Nozzle Characterization at CINVESTAV"



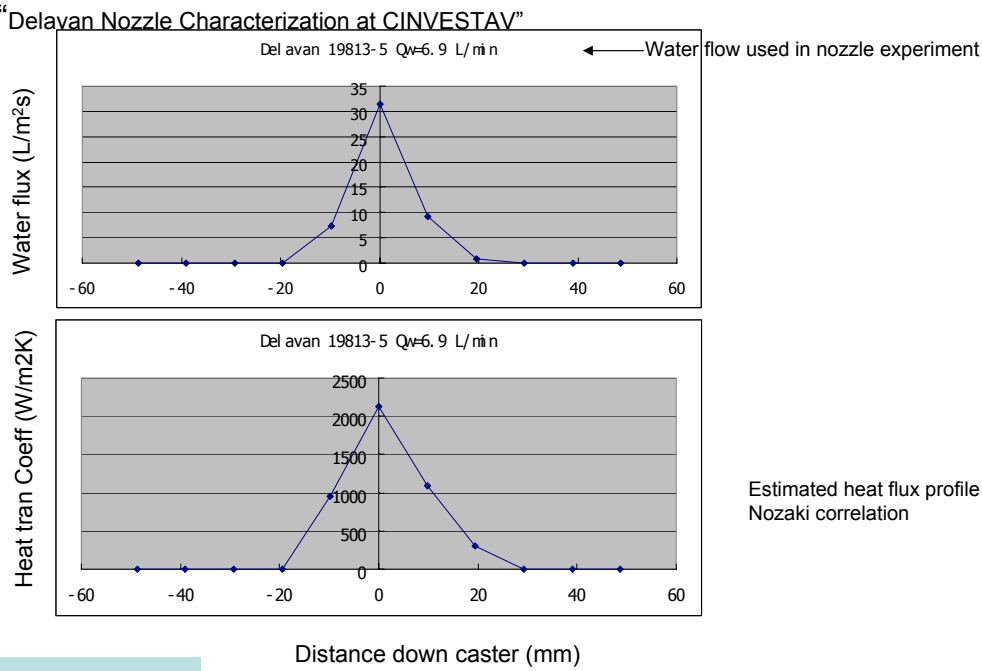
Estimated heat flux profile based on Nozaki correlation

Delavan 19813-3

Characterize using CON1D

--from Vapalahti's 2006 ccc meeting report:

"Delavan Nozzle Characterization at CINVESTAV"



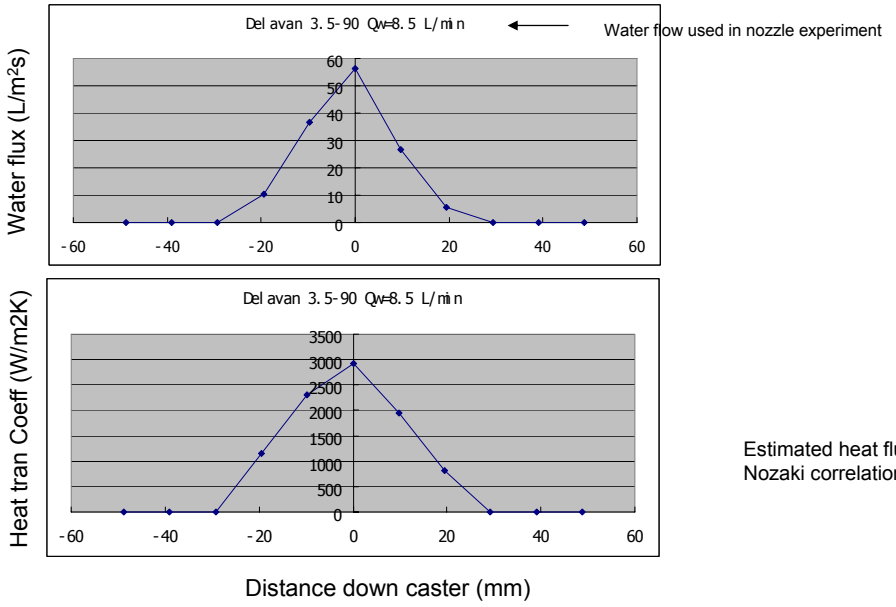
Estimated heat flux profile based on Nozaki correlation

Delavan 19813-5

Characterize using CON1D

--from Vapalahti's 2006 ccc meeting report:

"Delavan Nozzle Characterization at CINVESTAV"



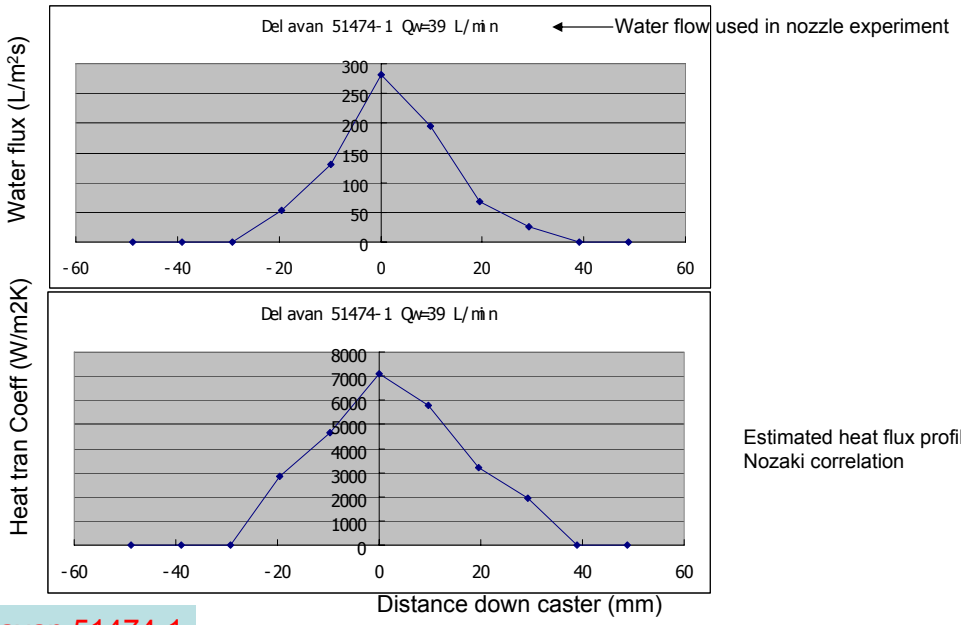
Estimated heat flux profile based on Nozaki correlation

Delavan 3.5-90

Characterize using CON1D

--from Vapalahti's 2006 ccc meeting report:

"Delavan Nozzle Characterization at CINVESTAV"



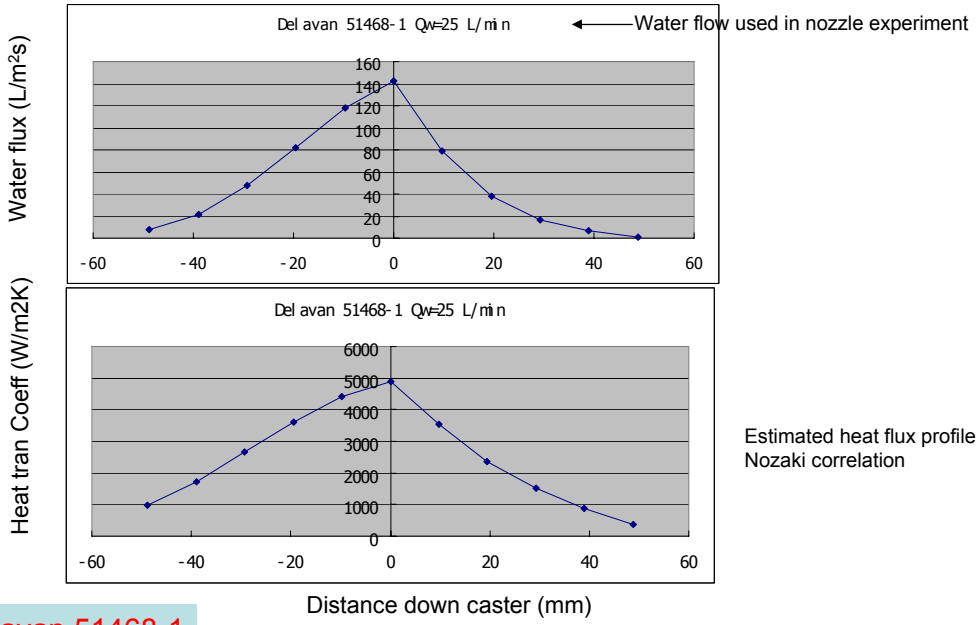
Estimated heat flux profile based on Nozaki correlation

Delavan 51474-1

Characterize using CON1D

--from Vapalahti's 2006 ccc meeting report:

"Delavan Nozzle Characterization at CINVESTAV"



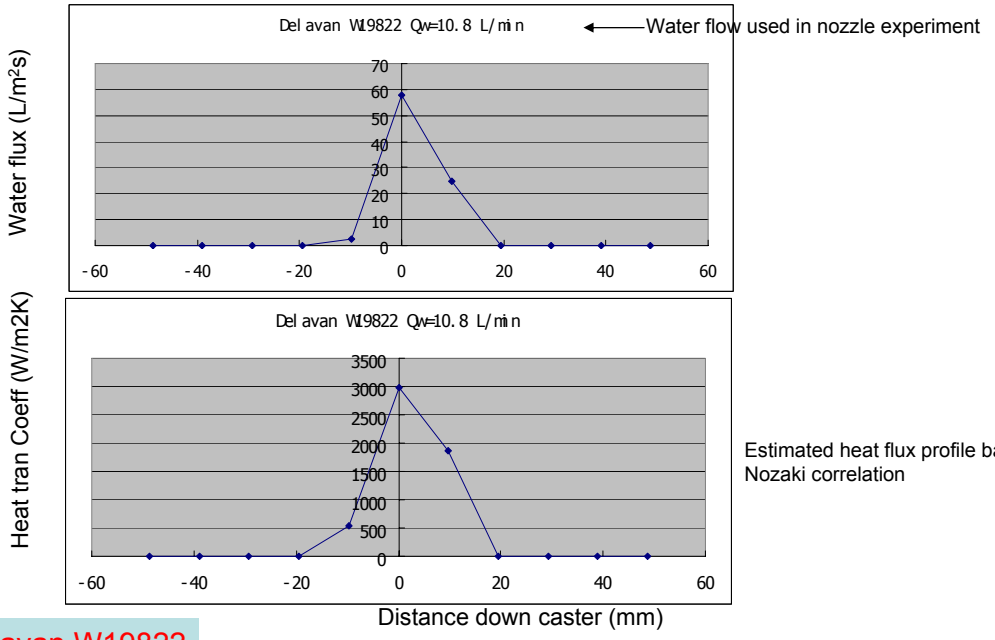
Estimated heat flux profile based on Nozaki correlation

Delavan 51468-1

Characterize using CON1D

--from Vapalahti's 2006 ccc meeting report:

"Delavan Nozzle Characterization at CINVESTAV"



Estimated heat flux profile based on Nozaki correlation

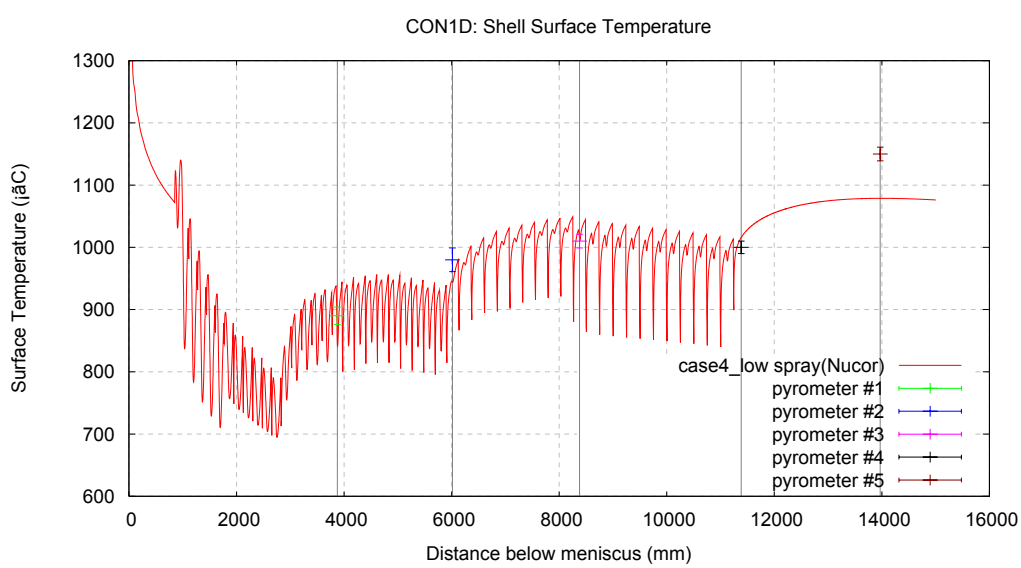
Delavan W19822

Con1d prediction of Nucor trails

Specific input variables:

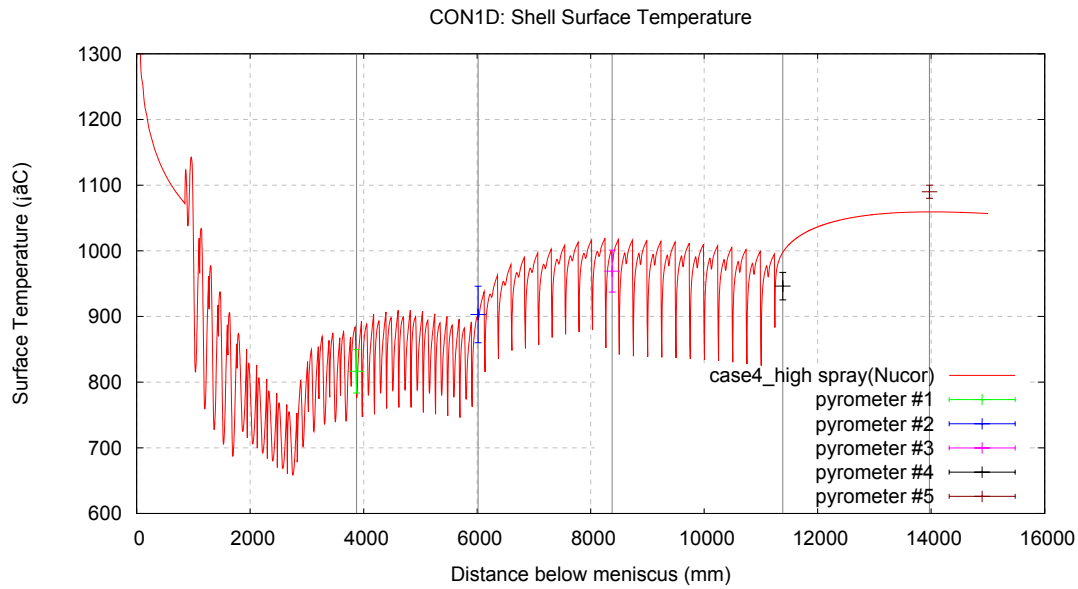
Model parameters	Casting speed	Spray length	Solid fraction	h profile						Water flow rates	
values	3.61 m/min	0.078 0.148 0.16 0.17 0.176 0.176 0.204 0.204 0.212 0.212 0.212	0.7	z1	z2	z3	h1	h2	h3	Low	High
				0.08	0.50	0.92	0.30	2.22	0.30	79.763	87.757
				0.19	0.50	0.81	0.50	3.97	0.50	187.967	162.603
				0.14	0.50	0.86	0.70	3.36	0.70	129.934	101.644
				0.30	0.50	0.70	0.30	5.36	0.30	50.642	29.012
				0.37	0.50	0.63	0.50	6.11	0.50	50.642	36.426
				0.37	0.50	0.63	0.50	6.11	0.50	50.642	36.426
				0.34	0.50	0.66	0.02	0.92	0.02	25.980	18.613
				0.34	0.50	0.66	0.02	0.92	0.02	25.980	18.613
				0.39	0.50	0.61	0.01	1.13	0.01	47.375	47.375
				0.39	0.50	0.61	0.01	1.13	0.01	47.375	47.375
				0.39	0.50	0.61	0.01	1.13	0.01	47.375	47.375

Con1d predictions-- case 4_low spray



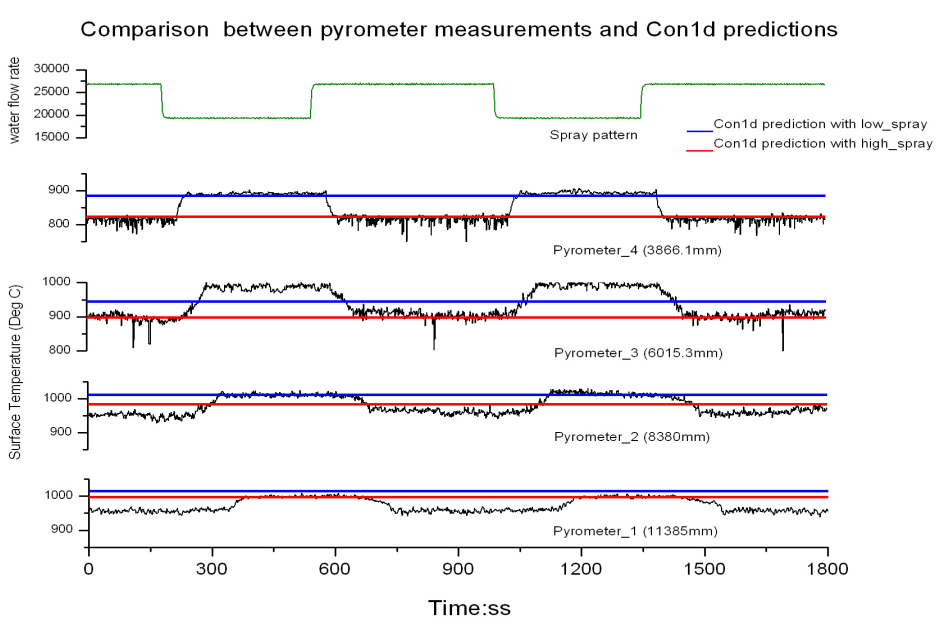
-Huan's Nucor trial ppt

Con1d predictions-- case 4_high spray

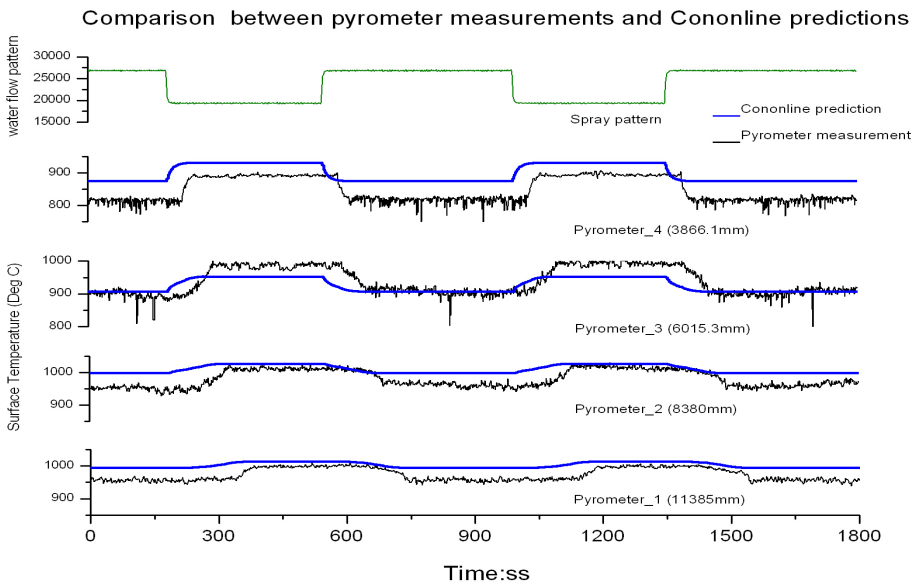


-Huan's Nucor trial ppt

Con1d predictions (steady state simulation)



Cononline Prediction (transient simulation)



Observations

- Compared to pyrometer measurements Con1d gives higher temperature prediction in the spray region except the pyrometer 2 in the case 4_low spray. In order to match pyrometer 2 measurement, the heat transfer coefficient should be increased appropriately around 6000 mm down the strand.
- Pyrometer focuses the thermal radiation onto the detector. However, there is much mist around strand which should decrease the power intensity collected by pyrometers. Then, it is the fact that pyrometer gives lower reading.
- Thus, Con1d temperature prediction matches reasonably pyrometer measurements in the spray region in these two cases.

whale formation cases
Casting conditions (Nucor Dec 9, 2003)

	Case 1	Case 2	Case 3
Casting Speed (ipm)	146	157	146
Spray Pattern	1	1	6
Observation at Plant	No Whale	No Whale	**Whale**

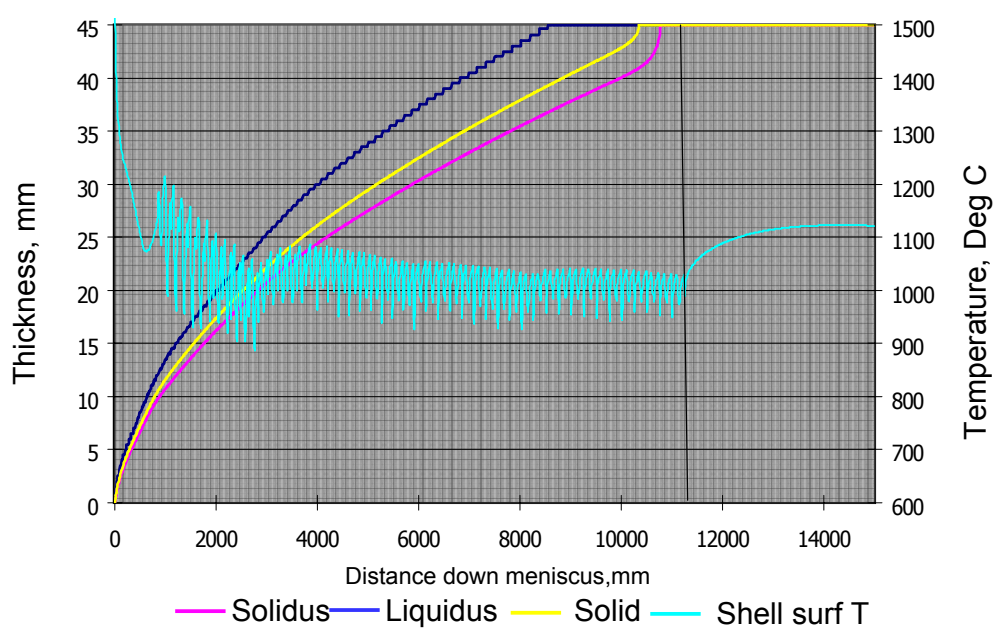
Containment limit = 11246.0mm

Specific input variables in con1d:

Model parameters	Spray length	Solid fraction	h profile
values	0.05 mm for all sprays	0.7	Flat-top for all sparys (z1 z2 z3 h1 h2 h3) (0 0.5 1.0 1.0 1. 0 1.0)

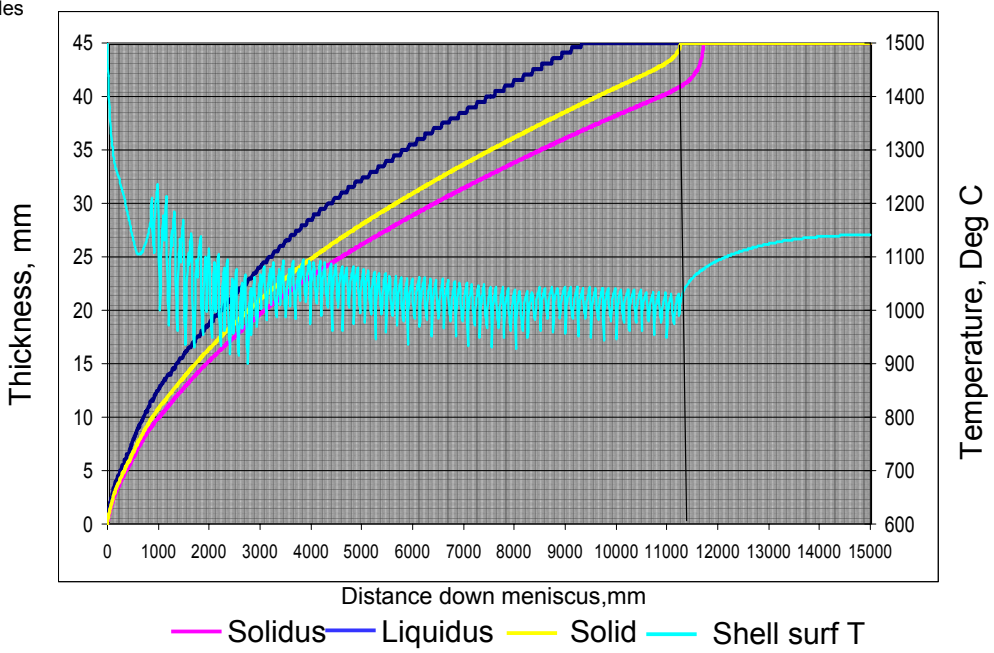
Con1d prediction of Case 1

Note: no whale, match the observation



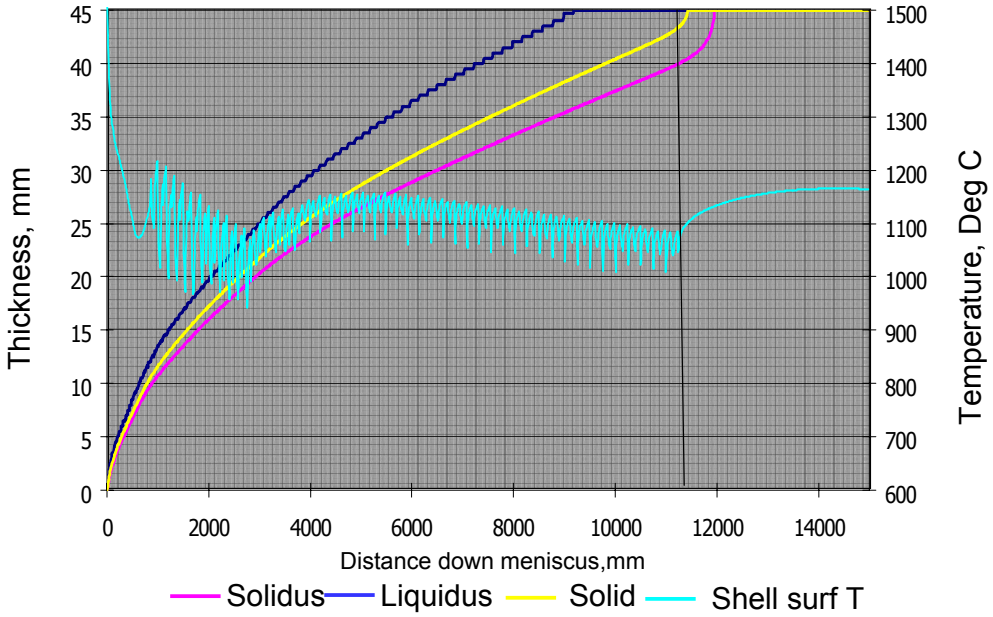
Con1d prediction of Case 2

Note: Solid coincides containment limit.



Con1d prediction of Case 3

Note: whale, match the observation



Con1d prediction of whale formation of case 3 using pointed h profile

Input variables:

Model parameters	Casting speed	Spray length	Solid fraction	h profile	Water flow rates
values	3.9878 m/min (157ipm)	0.078 0.148 0.16 0.17 0.176 0.176 0.204 0.204 0.212 0.212 0.212	0.7	z1 z2 z3 h1 h2 h3 0.08 0.50 0.92 0.30 2.22 0.30 0.19 0.50 0.81 0.50 3.97 0.50 0.14 0.50 0.86 0.70 3.36 0.70 0.30 0.50 0.70 0.30 5.36 0.30 0.37 0.50 0.63 0.50 6.11 0.50 0.37 0.50 0.63 0.50 6.11 0.50 0.34 0.50 0.66 0.02 0.92 0.02 0.34 0.50 0.66 0.02 0.92 0.02 0.39 0.50 0.61 0.01 1.13 0.01 0.39 0.50 0.61 0.01 1.13 0.01 0.39 0.50 0.61 0.01 1.13 0.01	98.600 216.600 146.100 57.100 57.300 57.300 51.100 51.100 30.300 30.300 30.300

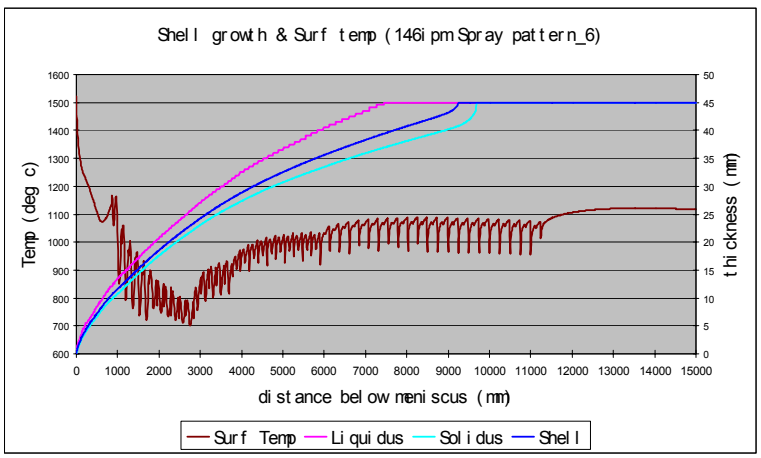
Whale formation Con1d9.6 prediction Case3

Whale observed in the plant for Case 3.

But prediction gives solid far away before containment limit.

Conclusions:
Heat transfer coefficients were too high

Pyrometer temperatures (which are matched by this run) were reading too low



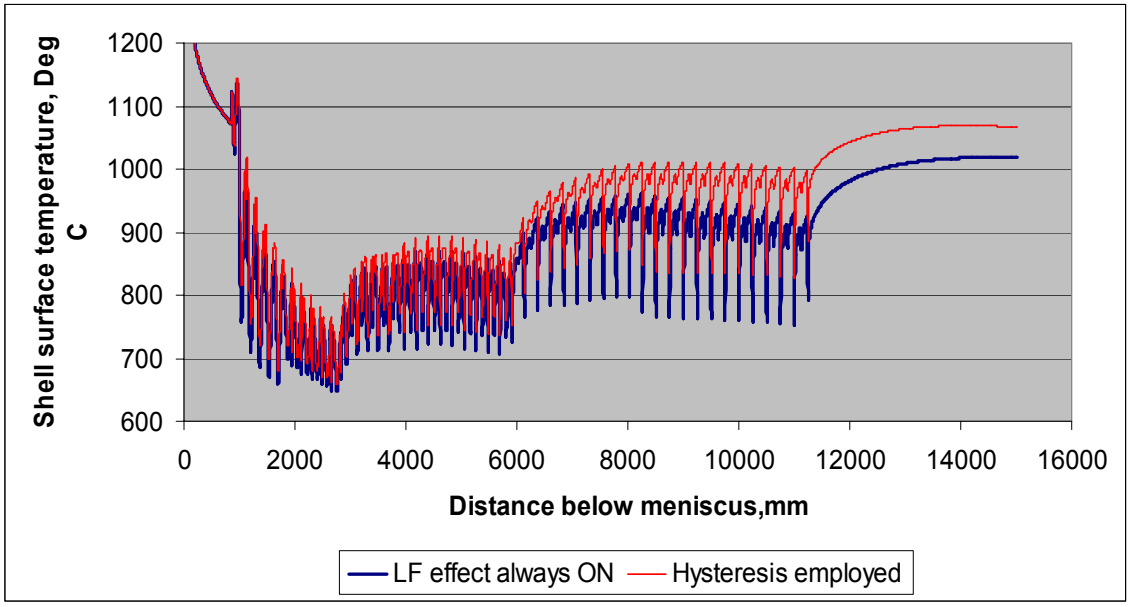
Leidenfrost effect with hysteresis

- Con1d 9.6 was modified to consider hysteresis in Liedenfrost effect:
  - If surface temperature $ts_{next} > ts$, meaning heating, LF effect is employed.
  - If surface temperature $ts_{next} < ts$, meaning cooling, LF effect is not employed.

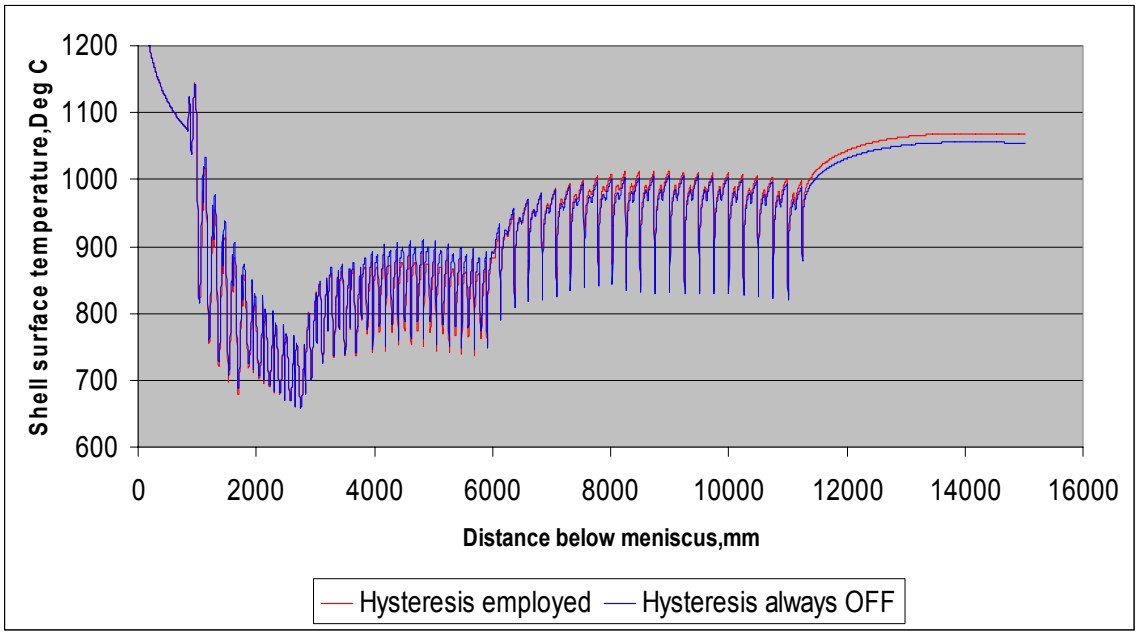
- Using the following set of h multipliers

h-multipliers	1.0	1.2	2.2	1.6	1.0
temperatures	700.	800	900.	1000	1050.

Hysteresis effect



Hysteresis effect



Conclusion and future work

- Several CON1D simulations have been combined to show that pyrometer measurements maybe not believable.
- Hysteresis based on heating / cooling is oversimplified, as fluctuations between rolls made the Leidenfrost effect with hysteresis negligible in test simulations.
- Parameters are needed to simultaneously match:
  - lab heat extraction measurements at Cinvestav
  - Pyrometer temperatures or TC traces measured at plant
  - Whale formation / shell thickness