ANNUAL REPORT 2006

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Temperature evolution in the spray zones: Plant measurements and CON1D predictions

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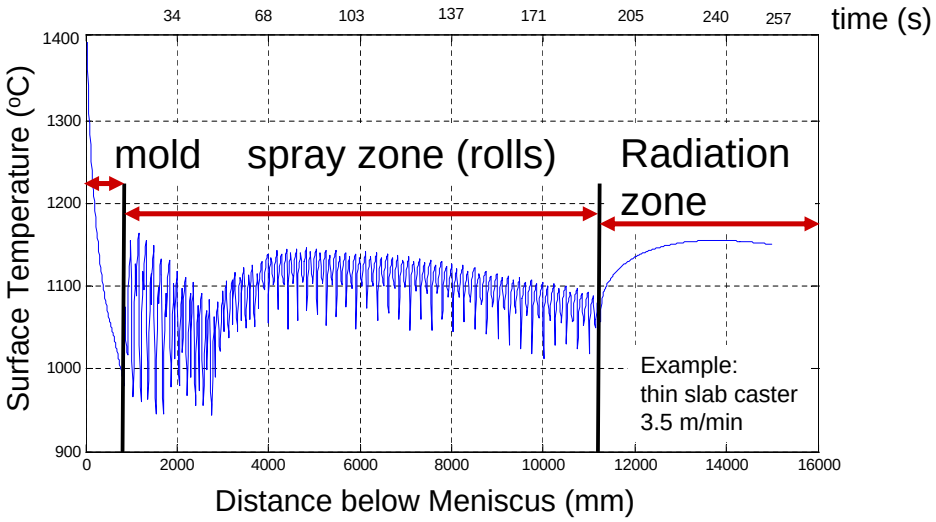
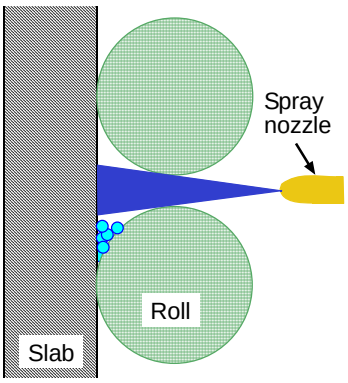
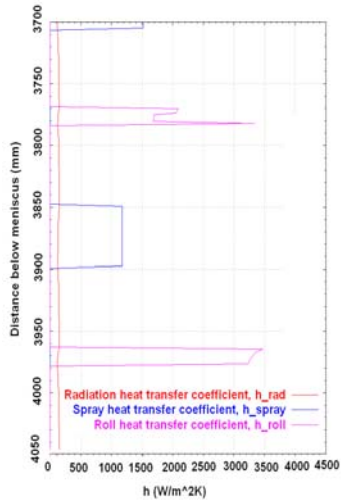
Surface Temperature down strand

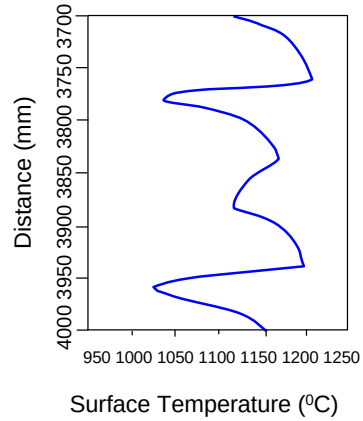


Note: reheating below mold; and after sprays
variations caused by rolls (slab caster)

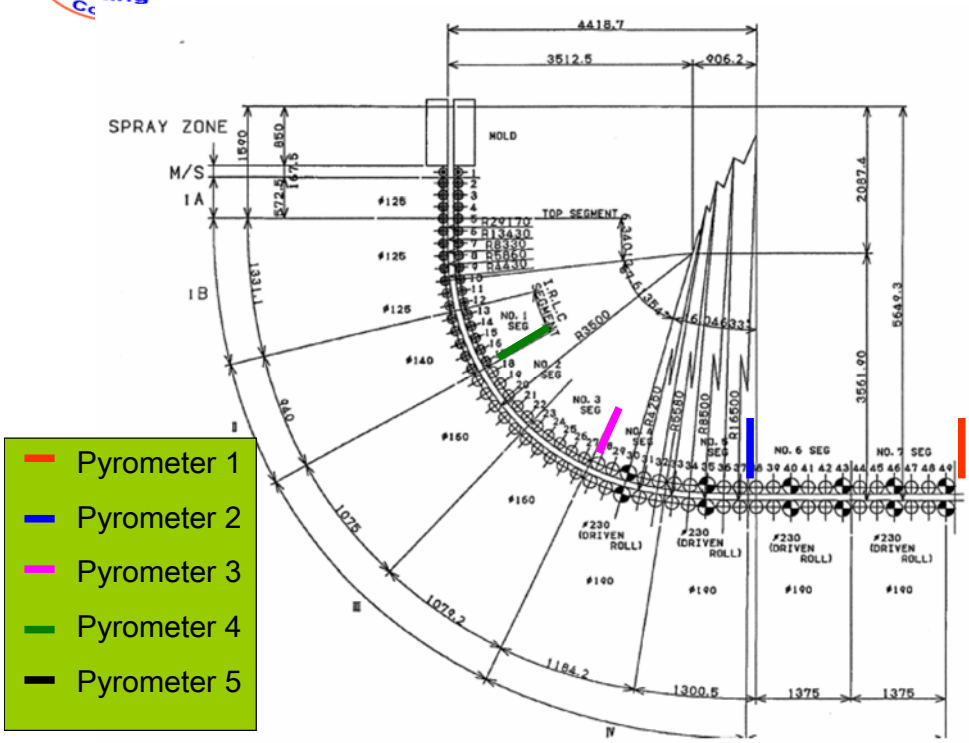
Heat transfer between rolls







Pyrometer Locations



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	3875 mm
Location of Pyrometer 5 from meniscus	13970 mm

Zones in CON1D File

Zone No.		Zone Starts	# of Rolls	Roll Radius (m)
M/S	(1)	850	1	0.062
M/S, IA, IB	(2)	940	5	0.062
IB	(3)	1767	6	0.062
IB, II	(4)	2823.3	5	0.070
II, III	(5)	3773.6	1	0.080
III	(6)	3968.6	9	0.080
III, IV	(7)	5903.6	1	0.095
IV	(8)	6130.3	9	0.095
IV	(9)	8260.0	1	0.095
V	(10)	8495.8	10	0.095
V	(11)	10995.8	1	0.115

( ) – CON1D Zone No. 11246.0 End of last spray zone (mm)

Experiments at Nucor Steel

Case Number	Time	Steady/ Transient
1	01/13/06- 0950-1010	Steady
2	01/13/06- 1535-1610	Steady
3	01/16/06- 0945-1012	Steady
4	01/13/06 1610-1640	Transient

Case 1 13 Jan Steady State

Parameter	Value
Time of Experiment	0950-1010 hrs.
Casting Speed	135.4 ipm (3.44 m/min) (0.057 m/s)
Spray Pattern Number	2
Composition (%)	C 0.247% Mn 1.09 S 0.0019 Al 0.039 Ca .0018 Si .175 P .014 Cu .087 N (leco).0076
Caster	North
Pouring Temperature	1542.222 ^{o}C

Simulation – CON1D

Mold Heat Flux

$$Q_G = 4.63 \cdot 10^6 \mu^{-0.09} T_{flow}^{-1.19} V_C^{0.47} \left\{ 1 - 0.152 \exp\left[-\left(\frac{0.107 - \%C}{0.027} \right)^2 \right] \right\}$$

Q_G Mean heat flux (MW/m^2)

μ Powder Viscosity at 1300°C (Pa-s)

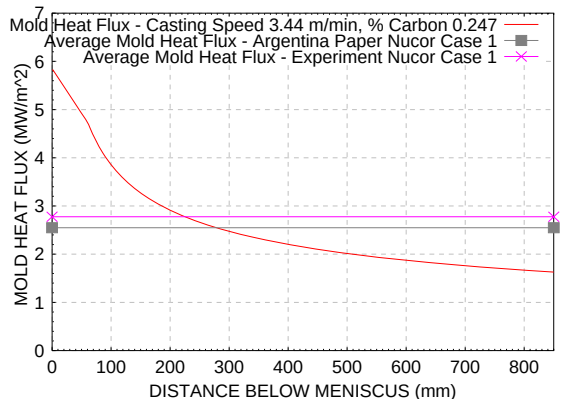
T_{flow} Melting Temperature of Mold Flux (^{o}C)

$\%C$ Carbon Content

V_c Casting Speed (m/min)

$\mu = 0.025$ Pa-s

$T_{flow} = 1180^0 C$



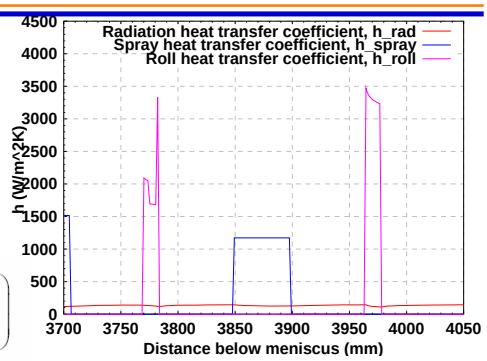
Simulation – CON1D

Spray Zones

$$h_{spray} = A \cdot Q_{water}^c \cdot \left(1 - b \cdot T_{spray}\right)$$

$$h_{rad\_spray} = \sigma \cdot \varepsilon_{steel} \left(T_{sK} + T_{ambK}\right)\left(T_{sK}^2 + T_{ambK}{}^2\right)$$

$$h_{roll} = \frac{f_{roll}}{L_{roll\ contact} \cdot (1 - f_{roll})} \left(\begin{array}{l} \left(h_{rad\_spray} + h_{conv} + h_{spray}\right) \cdot L_{spray} + \\ \left(h_{rad\_spray} + h_{conv}\right) \cdot \left(L_{spray\ pitch} - L_{spray} - L_{roll\ contact}\right) \end{array} \right)$$

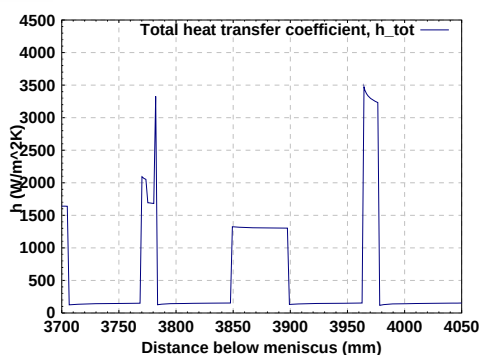


Q_{water} Water Flux

T_{spray} Temperature of spray cooling water

T_{amb} Ambient Temperature

f_{roll} Fraction of heat extraction to rolls

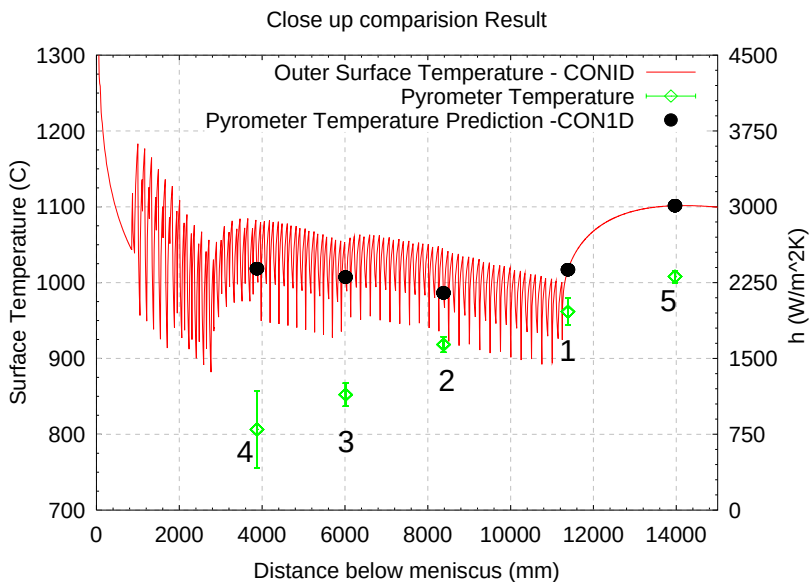


Nozaki - A=0.3925 c=0.55 b=0.0075

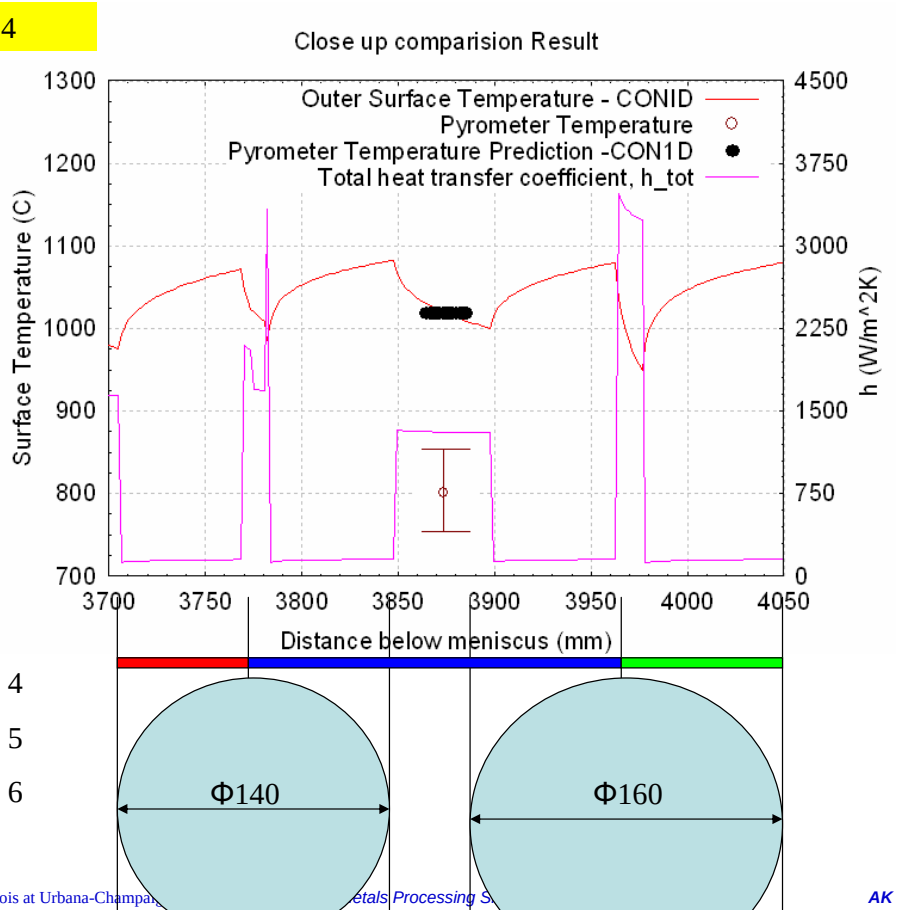
$T_{spray} = T_{amb} = 25^0 C$ $\quad \varepsilon_{steel} = 0.8$

$\sigma = 5.67 * 10^{-8} W K^{-4} m^{-2}$

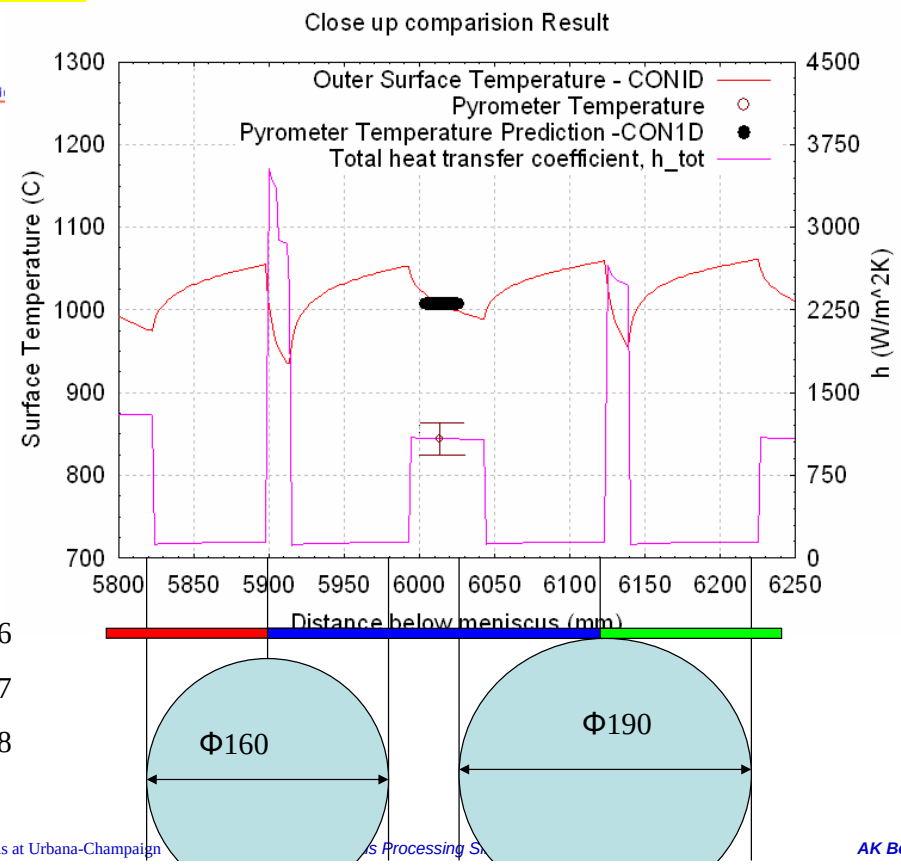
Case 1 Results



Pyrometer 4



Pyrometer 3

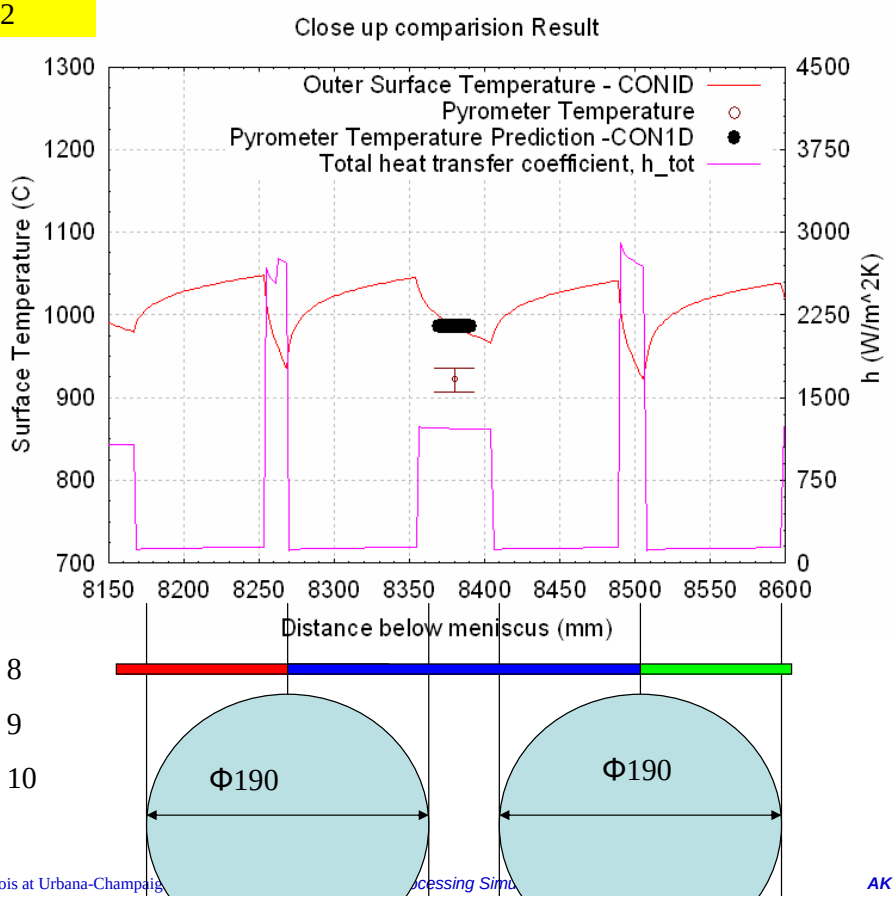


Zone 6

Zone 7

Zone 8

Pyrometer 2

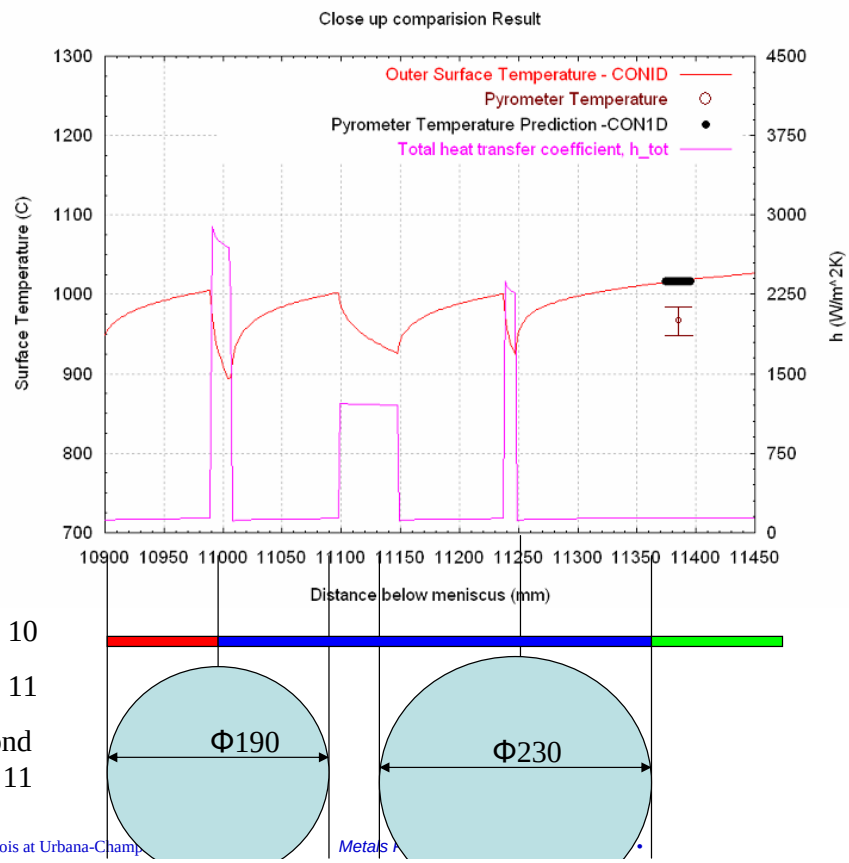


Zone 8

Zone 9

Zone 10

Pyrometer 1

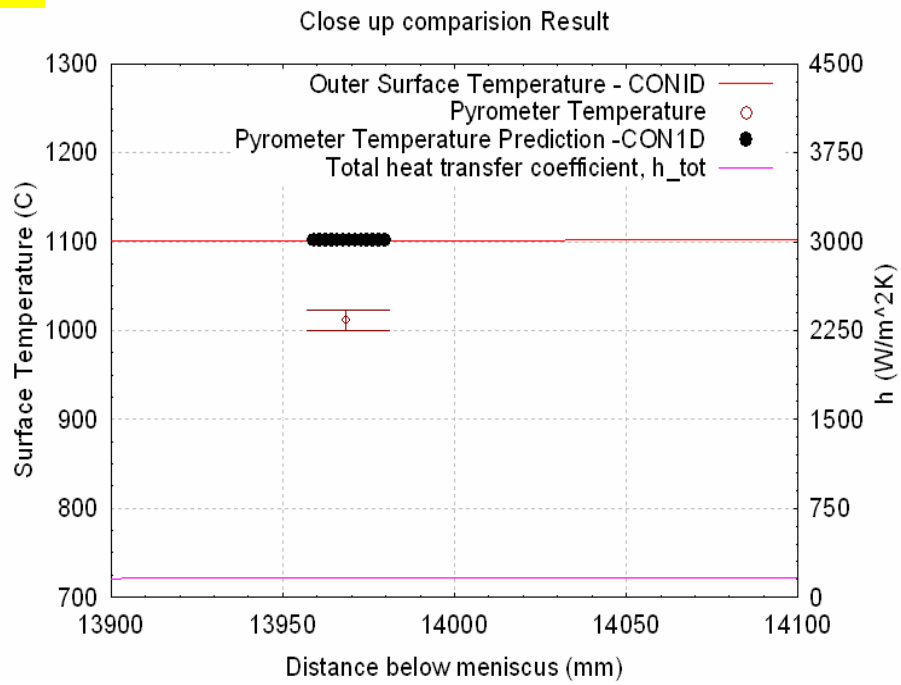


Zone 10

Zone 11

Beyond zone 11

Pyrometer 5

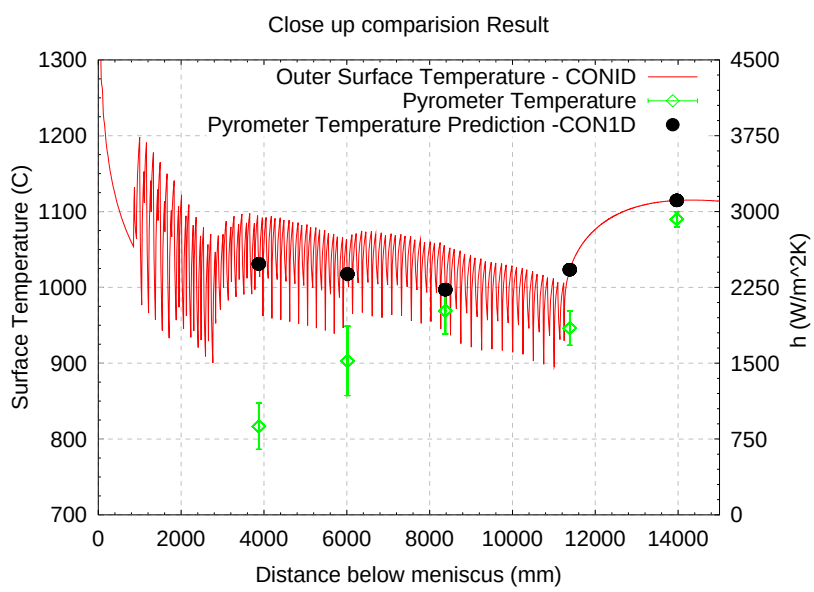


Beyond zone 11

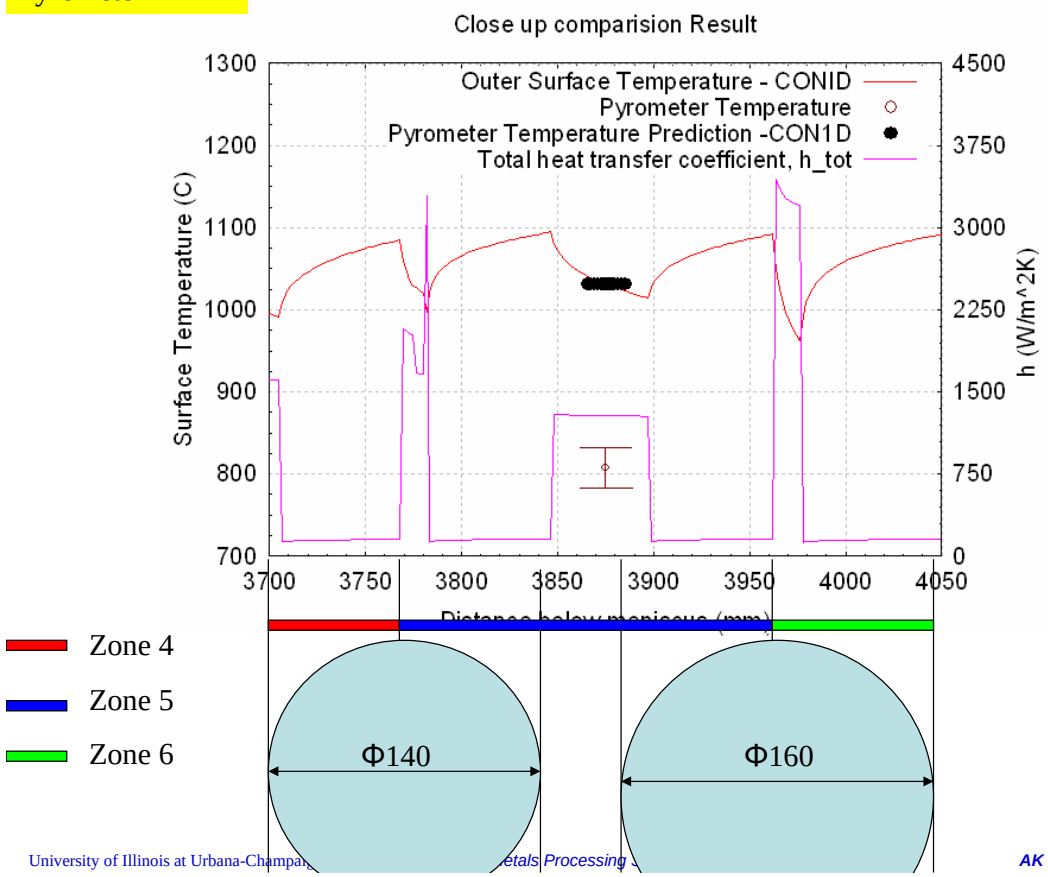
Case 2 - 13 Jan Steady State

Parameter	Value
Time of Experiment	1535-1610 hrs.
Casting Speed	142.1 ipm (3.61 m/min) (0.06 m/s)
Spray Pattern Number	4
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 ^{o}C

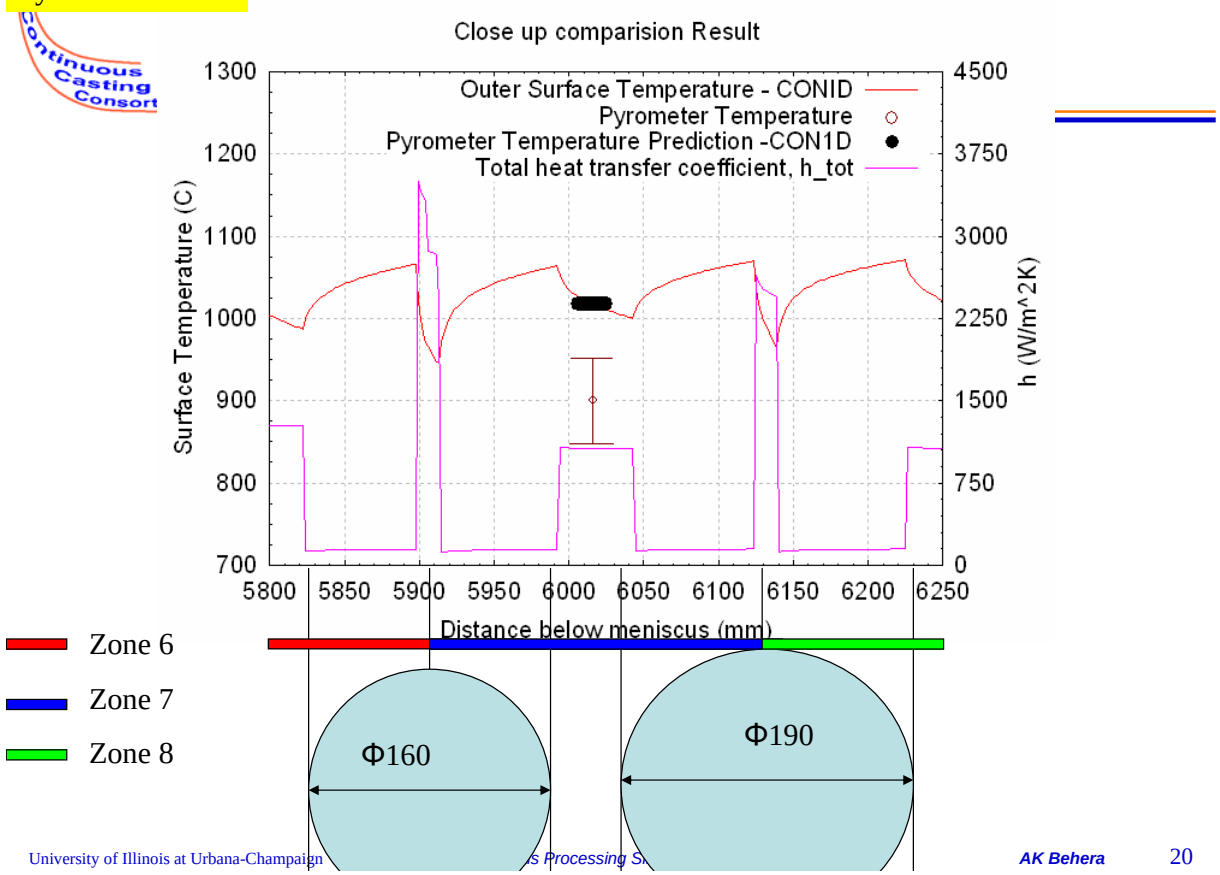
Case 2 Results



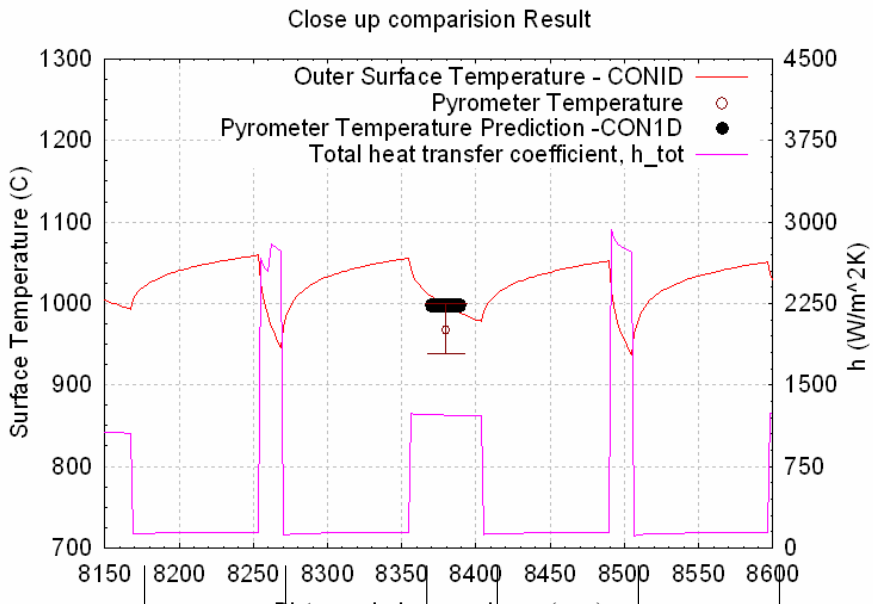
Pyrometer 4



Pyrometer 3



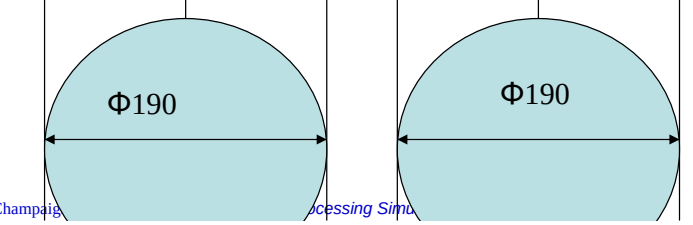
Pyrometer 2



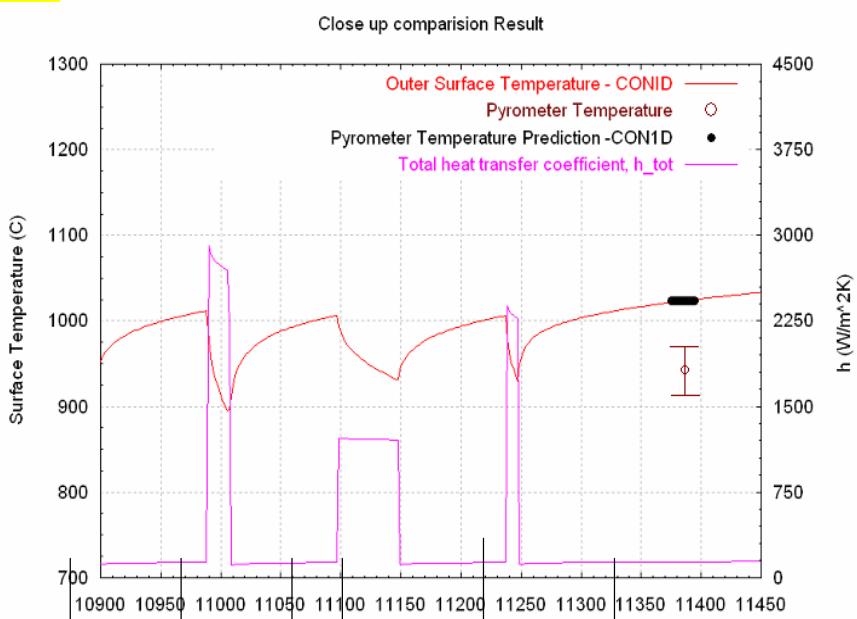
Zone 8

Zone 9

Zone 10



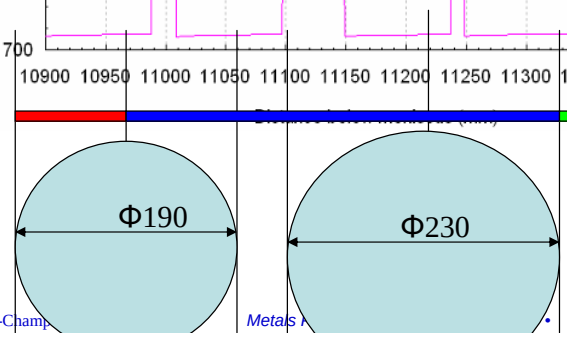
Pyrometer 1



Zone 10

Zone 11

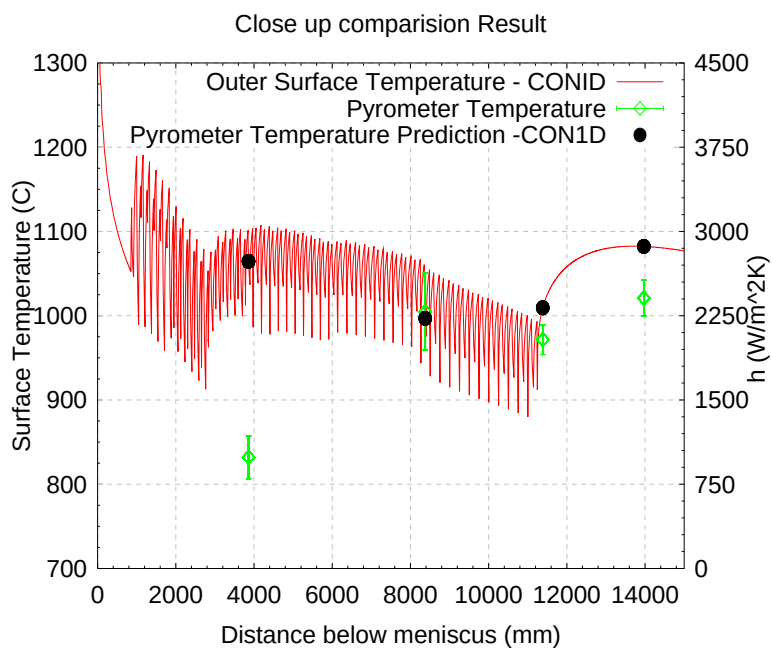
Beyond zone 11



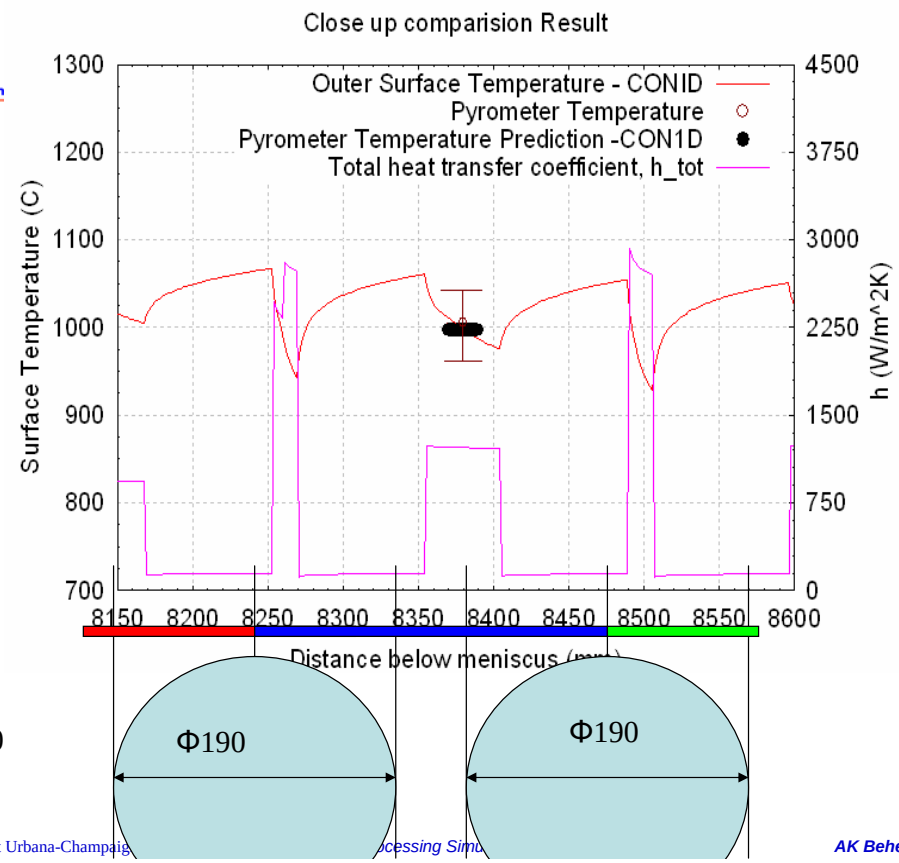
Case 3 16 Jan Steady State

Parameter	Value
Time of Experiment	0945-1012 hrs.
Casting Speed	118.1 ipm (3.03 m/min) (0.051 m/s)
Spray Pattern Number	1
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
Pouring Temperature	1556.944 ^{o}C

Case 3 Results



Pyrometer 2

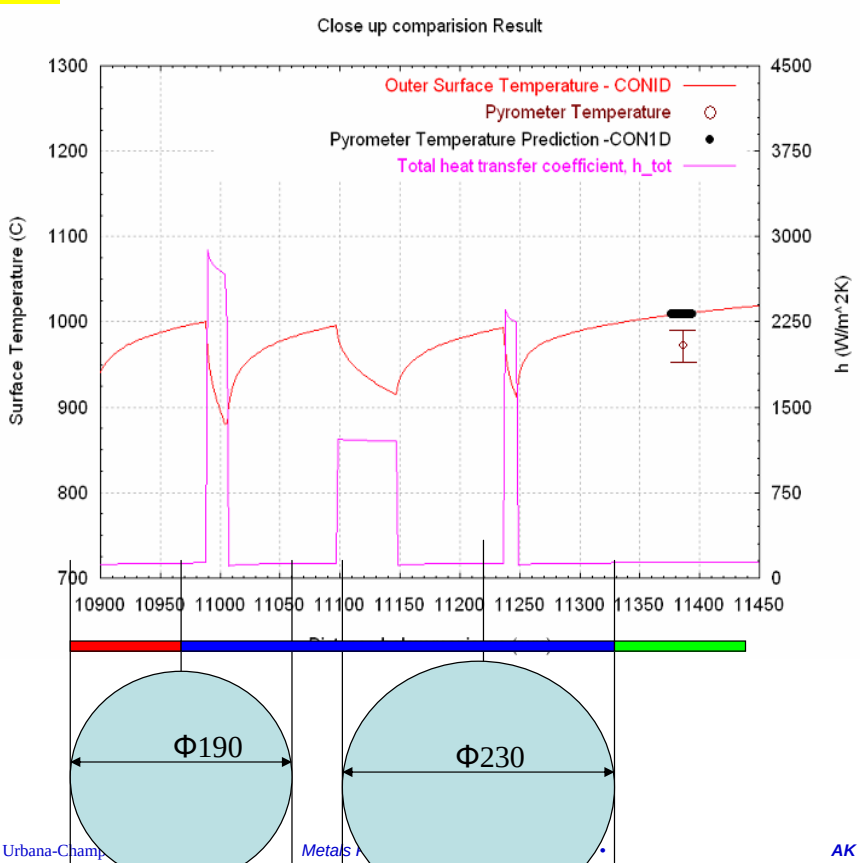


Zone 8

Zone 9

Zone 10

Pyrometer 1



Zone 10

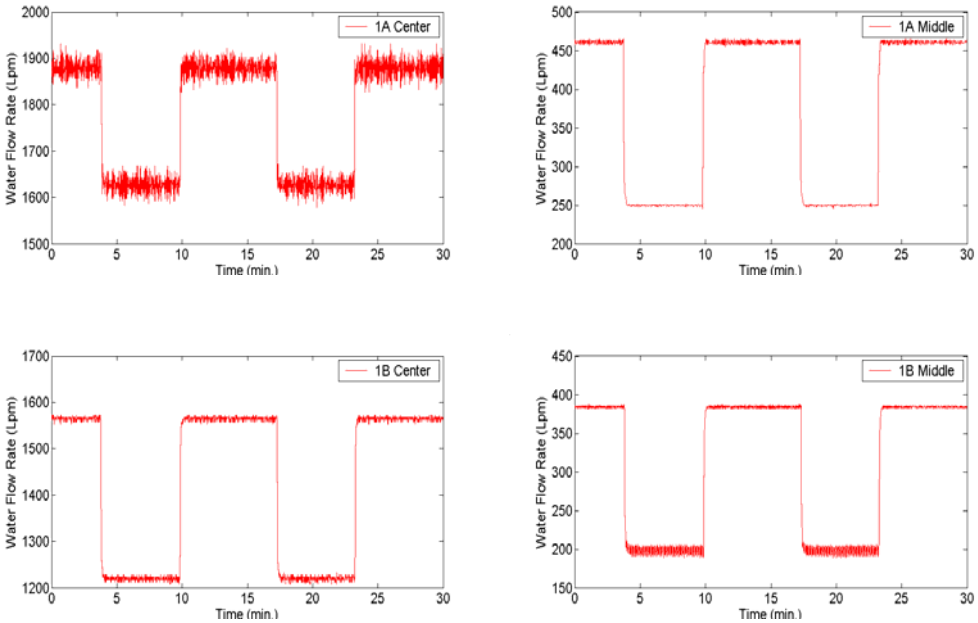
Zone 11

Beyond zone 11

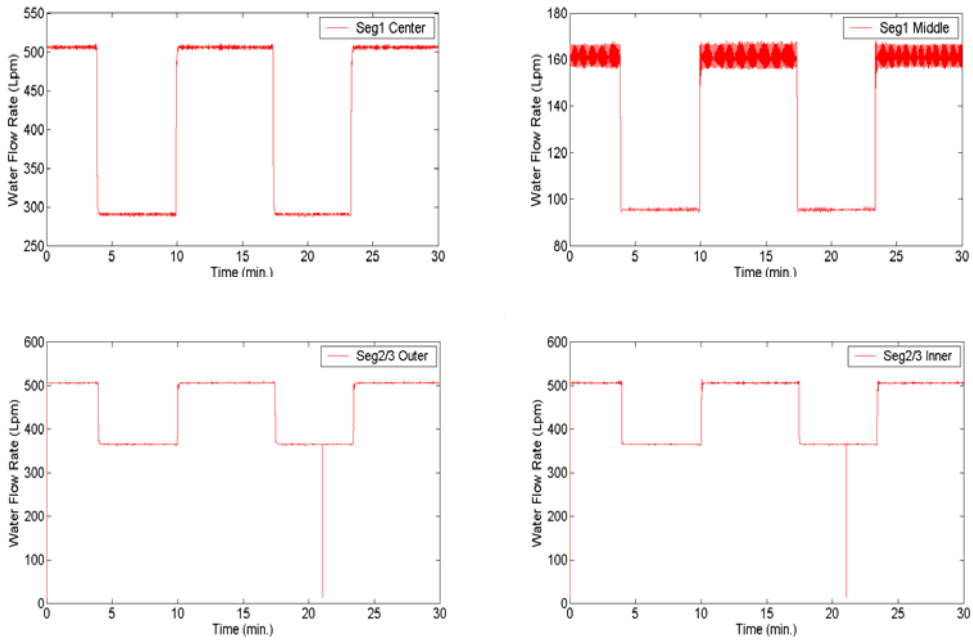
Case 4 13 Jan Transient

Parameter	Value
Time of Experiment	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 ^{o}C

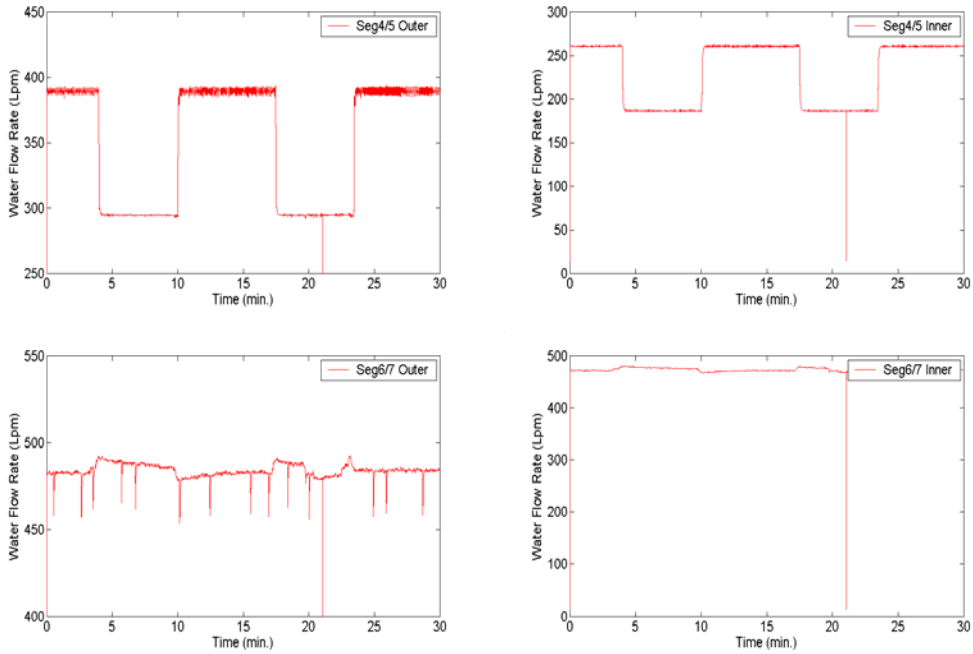
Spray Pattern Change



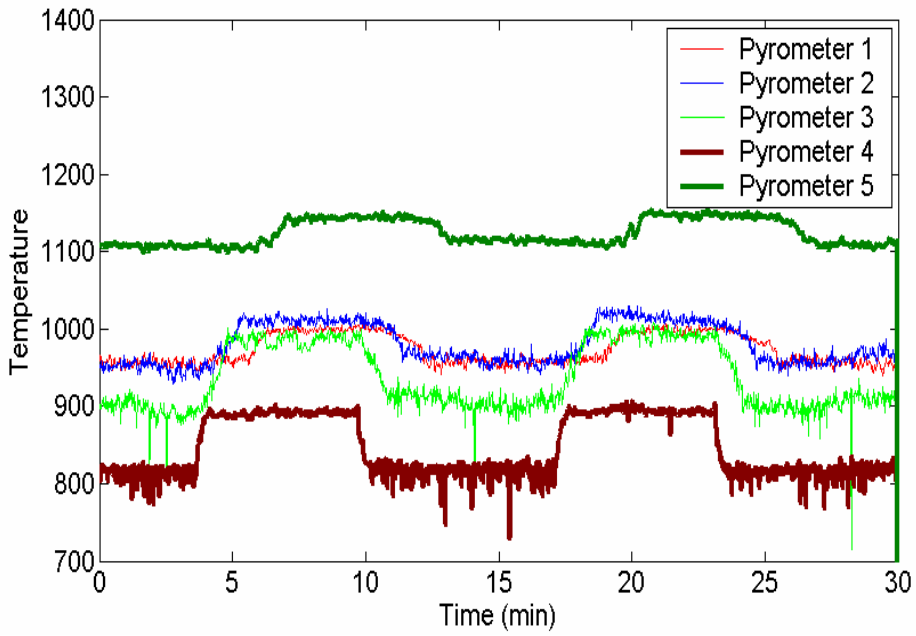
Spray Pattern Change



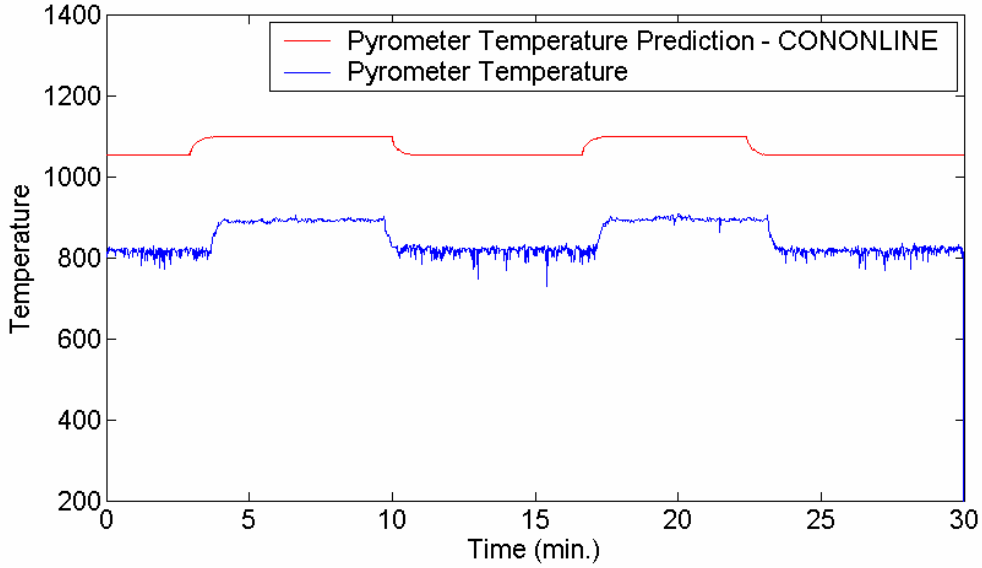
Spray Pattern Change



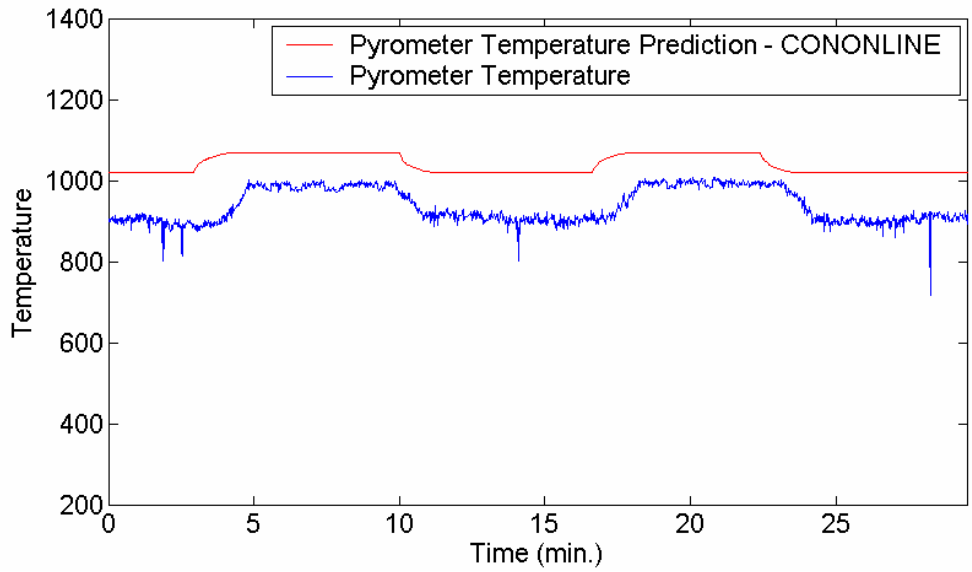
Experimental Temperature Profile



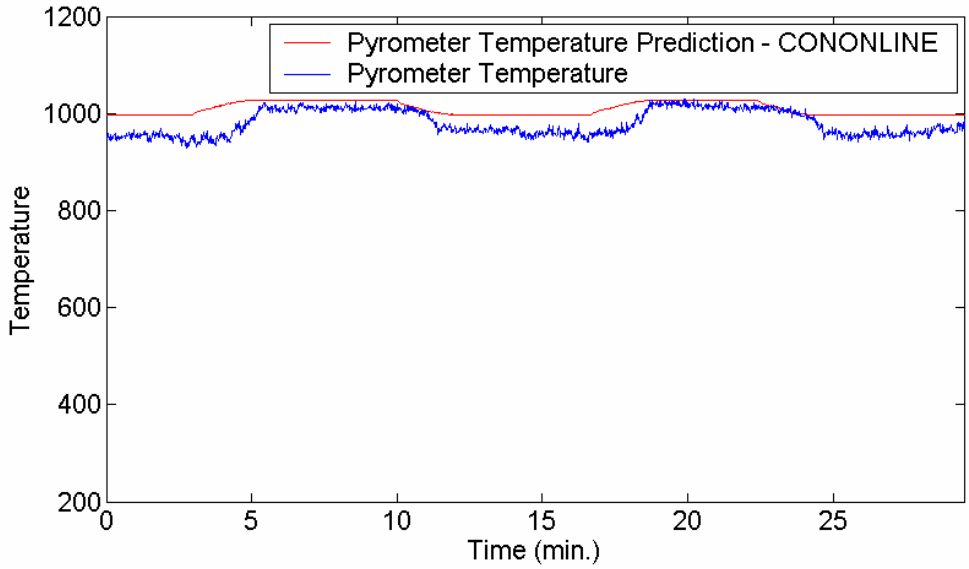
Case 4 Pyrometer 4 3875 mm



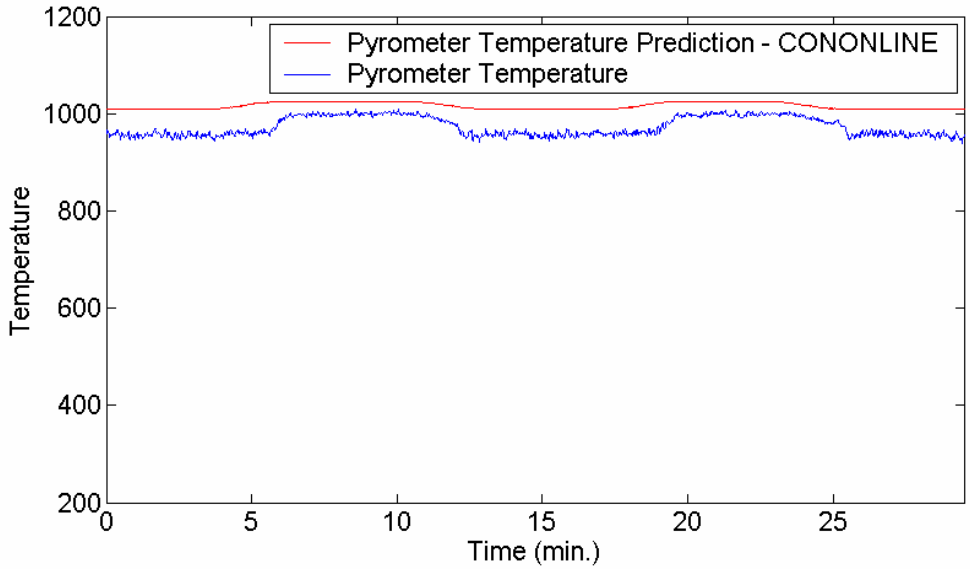
Case 4 Pyrometer 3 6015.3 mm



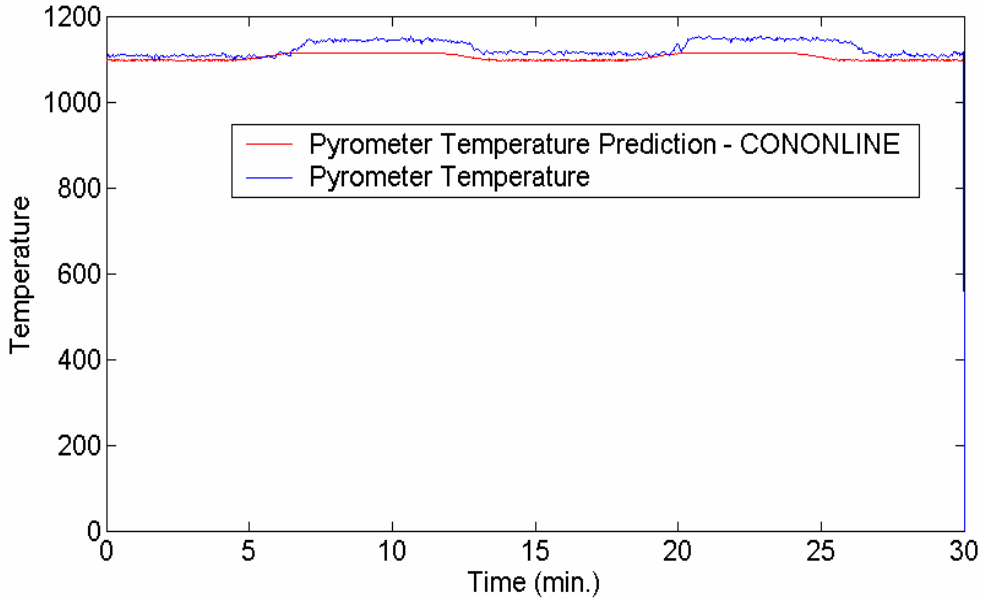
Case 4 Pyrometer 2 8380 mm



Case 4 Pyrometer 1 11385 mm



Case 4 Results Pyrometer 5 13970 mm



Sources of Error

- Steam surrounding the slab
- Scale formation
- Pyrometer positioning
- Random Noise in PDA system

Conclusions

- Comparison of Temperature Profile from CON1D with Pyrometer Measurements shows good results for pyrometers 5,1 and 2
- Pyrometers at top of caster (3 and 4) are consistently over-predicted
- Transient behavior seems to be modeled reasonably

Future Work

- Further calibration of CON1D
  - S. Vapalahti experiments in Mexico
  - Top hat Heat transfer profile to be put in place of Flat top
- Transient case with casting speed variation to be studied