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Thermal analysis of CC mold and Calibration of CON1D

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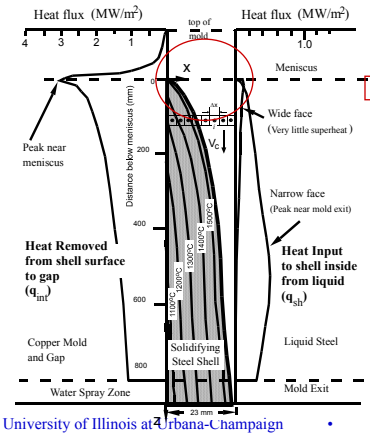
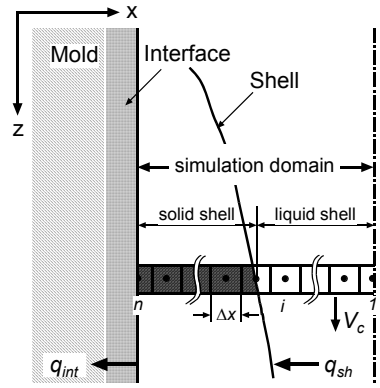
- Fluent, Inc., CFX, UIFLOW (P. Vanka)
- Other Graduate students, especially B. Zhao

Introduction to CON1D

- 2-D steady heat conduction in mold
- 1D transient conduction and solidification in shell:

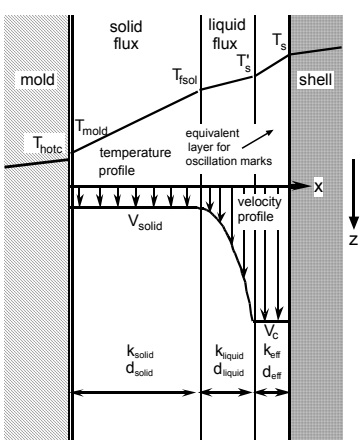
$$\rho_{steel} Cp^*_{steel} \frac{\partial T}{\partial t} = k_{steel} \frac{\partial^2 T}{\partial x^2} + \frac{\partial k_{steel}}{\partial T} \left(\frac{\partial T}{\partial x} \right)^2$$





CON1D – features special analysis of interface phenomena

- Mass balance and heat transfer in the interfacial gap:

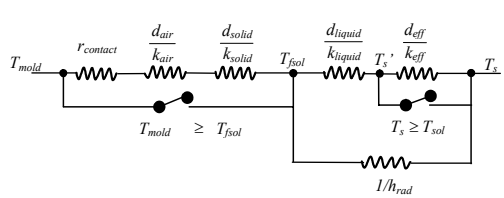


Mass balance:

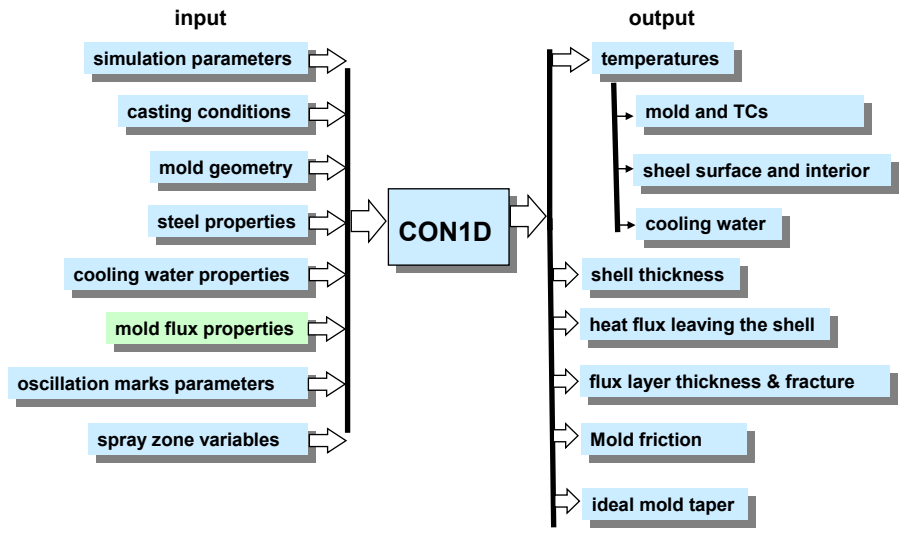
$$\frac{Q_{slag} \times V_c}{\rho_{slag}} = V_{solid} d_{solid} + \int_0^{d_{liquid}} V_{liquid} dx + V_c \bar{d}_{osc}$$

Heat transfer:

$$q_{int} = h_{gap} \left(T_s - T_{mold} \right)$$

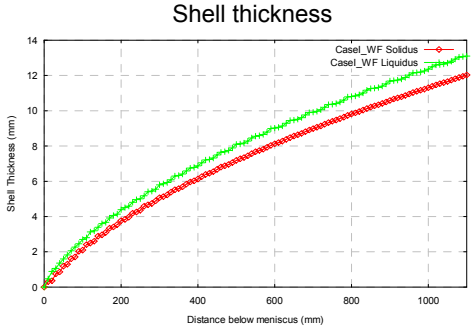


CON1D - Applications

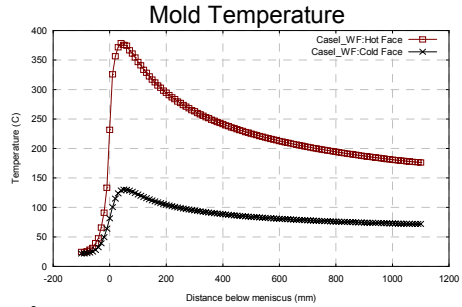


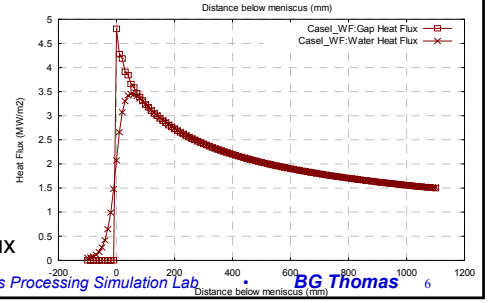
CON1D – example output (Algoma Steel WF-I case)

Shell thickness



Mold Temperature

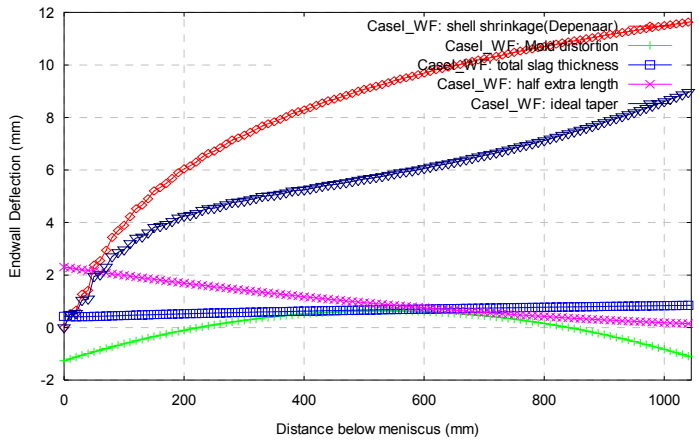




Mold Heat flux

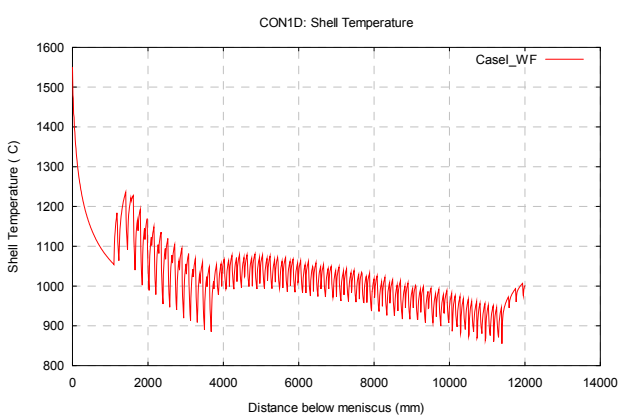
CON1D – example output (Algoma Steel WF-I case)

Ideal Mold Taper



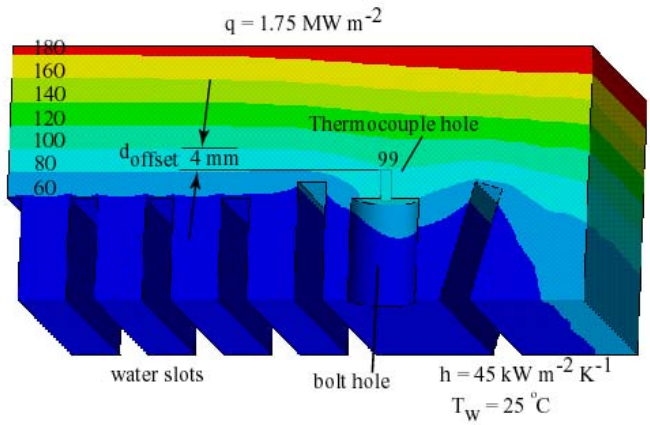
CON1D – example output (Algoma Steel WF-I case)

Surface temperature in mold and spray zones



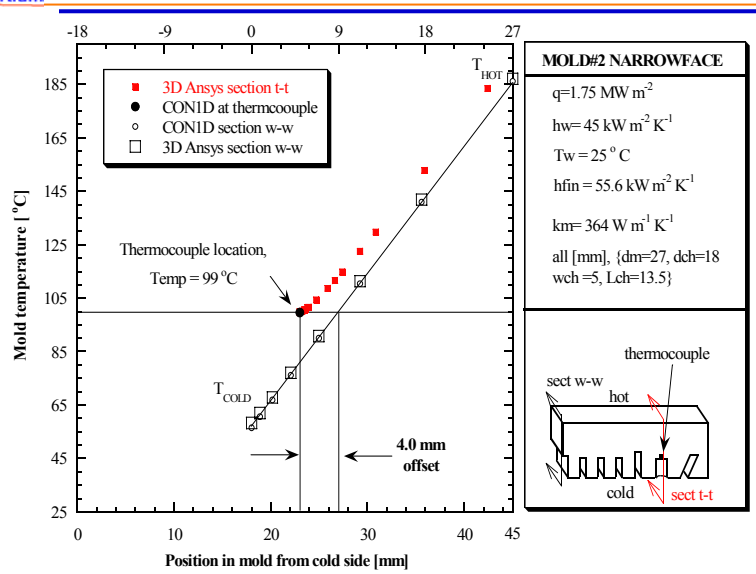
TC prediction (useful for validation) needs calibration with 3-D model

- Example 3-D mold section analysis for offset



M. Langeneckert, MS Thesis, 2001

Offset Calculation

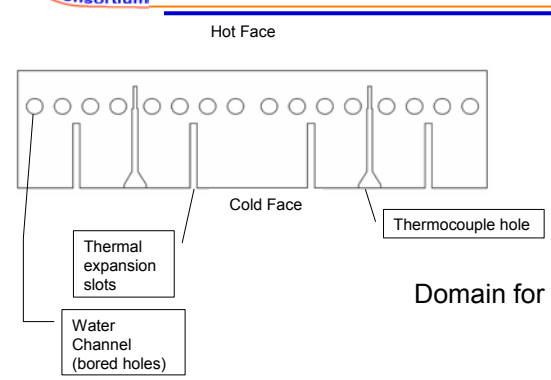


Case Study: Algoma funnel mold

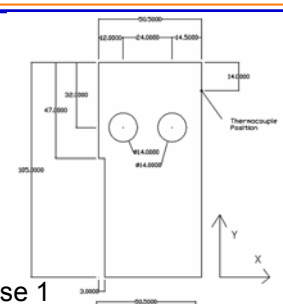
- CON1D calculation for more accurate boundary conditions for hot and cold faces
- ANSYS calculations to investigate different cases:
  - Case 1: No thermocouple hole present in domain.
  - Case 2: Thermocouple hole included in domain.
  - Case 3: Thermocouple hole and the cooling effect of the TC wire are both modelled in the domain.
  - Other cases: show that mold thickness variations due to funnel have negligible effect on hotface and TC temps.

- Offset calculations with CON1D considering ANSYS case 2

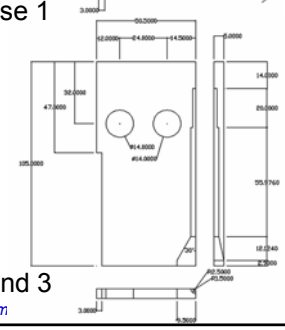
Algoma: model domains



Cross section of the mold

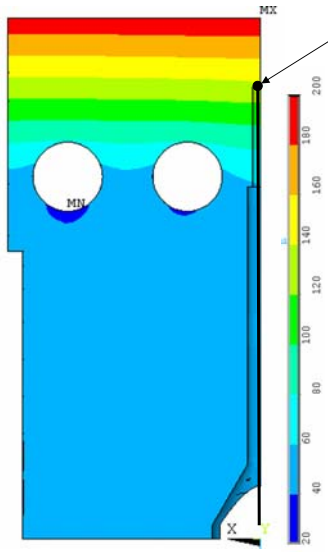


Domain for case 1



Domain for cases 2 and 3

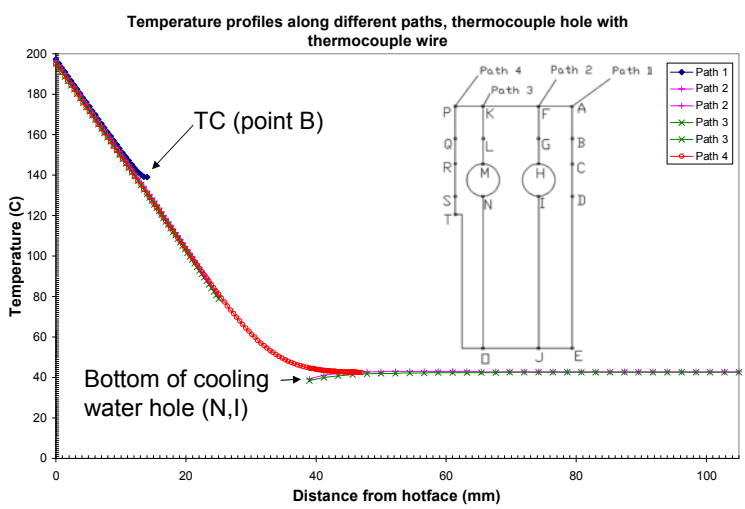
Algoma: 3-D mold temperatures



TC Temperature
(base of TC hole):
132.7°C (case 1)
138.95°C (case 2 & 3)

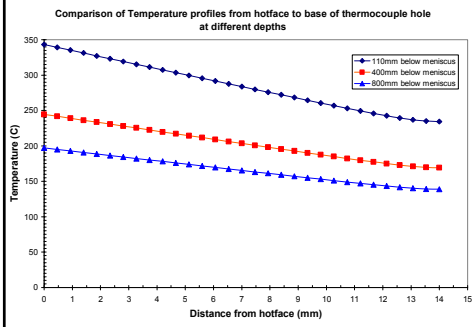
Simulation Conditions (Case 3)	
Thermal conductivity of copper	372 W $m^{-1}K^{-1}$
Distance of thermocouple from hot face	14mm
Remaining faces of model	Perfectly insulated
Water Velocity in bored holes	8.7 m/s
Depth below meniscus (mm)	800
Heat Flux (MW m^{-2})	1.704
Water tube heat transfer coefficient (kW $m^{-2}K^{-2}$)	35.7748
Water temperature (°C)	28.31

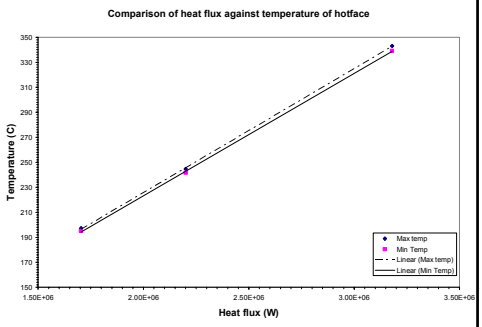
Algoma Mold Temp.: Case 3



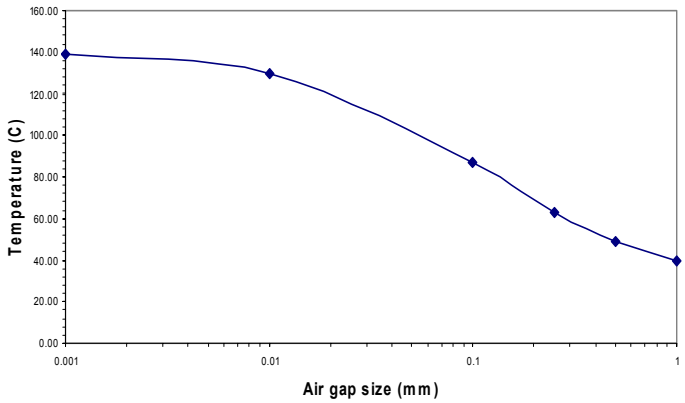
Case Studies: Algoma

- The difference in temperature profiles at 110, 400 and 800mm below meniscus
- Correlation between hotface temperature and heat flux





Small air gap between TC bead and mold greatly lowers TC temperature

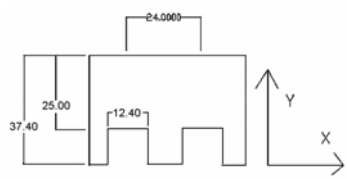


Maintaing close contact between TC and mold wall is important

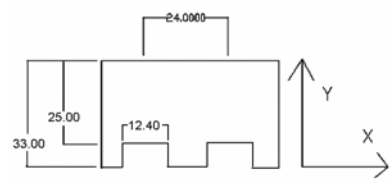
Case Studies: Algoma

- CON1D assumes rectangular cooling channels -> find way to match temperature with a round cooling channel (for same heat flux)
- Method found:
  - match the area of the cooling channels:
    Acircle (14mm diameter) = Arectangle (12.4x12.4mm)
  - Keep same distance from hotface
  - Decrease mold thickness to 33mm

CaseI_WF



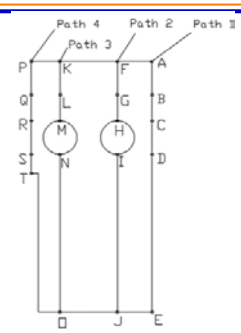
CaseIV_WF



Case Studies: Algoma

Thermocouple hole no conduction ANSYS							
Path 4	Temp	P 3	Temp	P 2	Temp	P 1	Temp
P	194.95	K	195.11	F	196.45	A	197.21
Q	130.67	L	130.68	G	132.17	B	138.95
R	81.093	M	78.787	H	79.974	C	N/A
S	44.589	N	38.345	I	39.299	D	N/A
T	42.46	O	42.638	J	42.697	E	N/A

CON1D CaseI_WF		CaseIV_WF
Hot Face	190.5	195.4
Cold Face	75.7	80.6



Heat Flux	ANSYS	CaseIV_WF 14 mm	CaseIV_WF 12.10 mm
1.704 MW/m^2	139.95	131.10	139.82

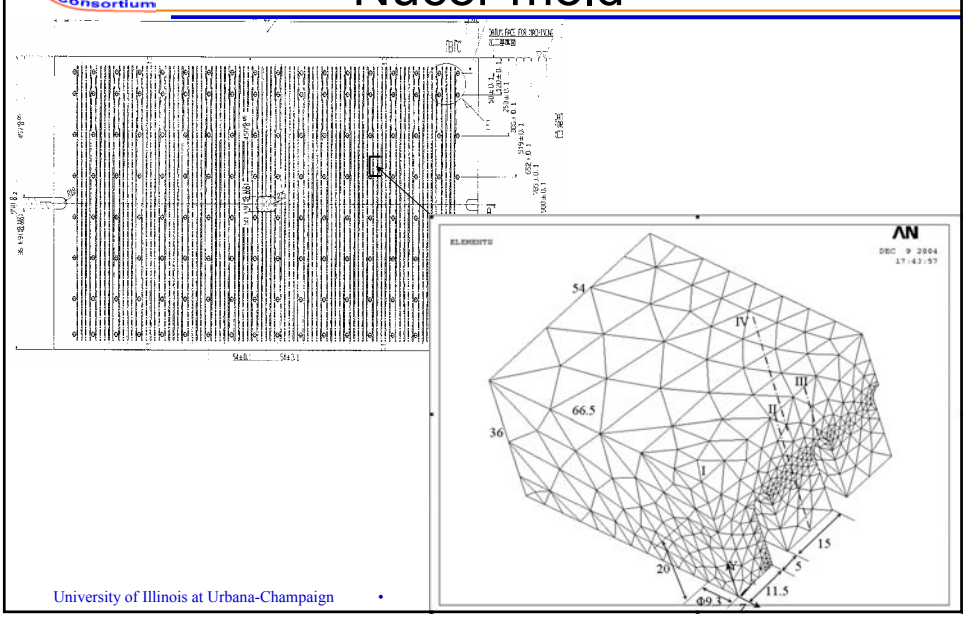
CON1D matches ANSYS for 3-D mold temperature calculations, so long as the mold thickness is decreased to 33.0 mm (from a range of thicknesses around funnel up to 105mm).

Offset = **1.9mm** (meaning that TCs in CON1D should positioned at 12.1 mm below the hotface, which is 1.9mm closer to the hotface than actually occurs in the caster).

Case Studies: Nucor

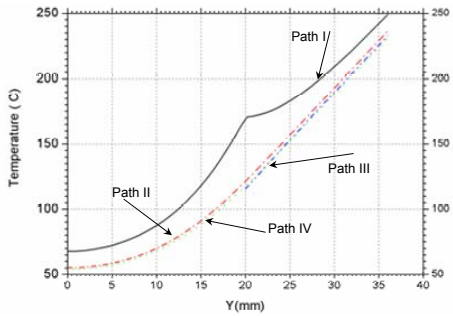
- ANSYS calculations to investigate different cases:
  - Constant Q_{hot} and copper conductivity
    - Q = 2500 and 4000 kW/m^2 :
  - Temperature dependent conductivity of copper
  - Q_{hot} a function of distance below meniscus
- Offset calculations with CON1D considering ANSYS cases 1 and 3

Case Studies: 3-D analysis of Nucor mold

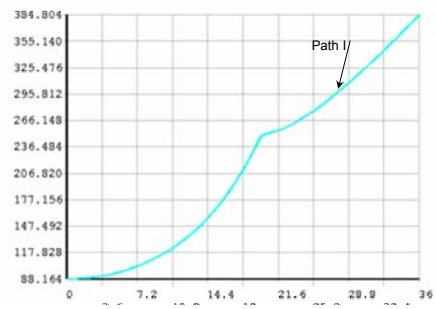


Case Studies: Nucor

Temperature profiles along different paths



Q = 2500 kW/m^2



Q = 4000 kW/m^2

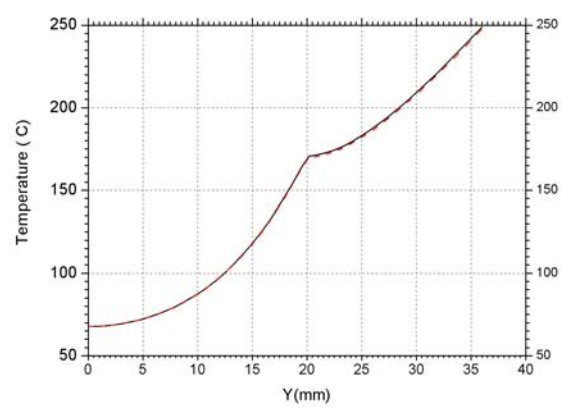
Case Studies: Nucor

Difference between constant and temperature dependent K_{copper}

$$K_{copper} = 355 - \frac{1}{60}(T - 50)$$

- Difference in thermocouple temperatures:

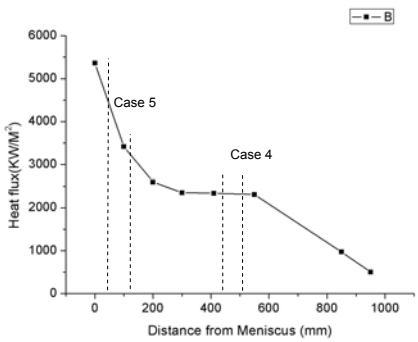
$$\frac{123.81 - 124.37}{124.37} * 100\% = 0.45\%$$

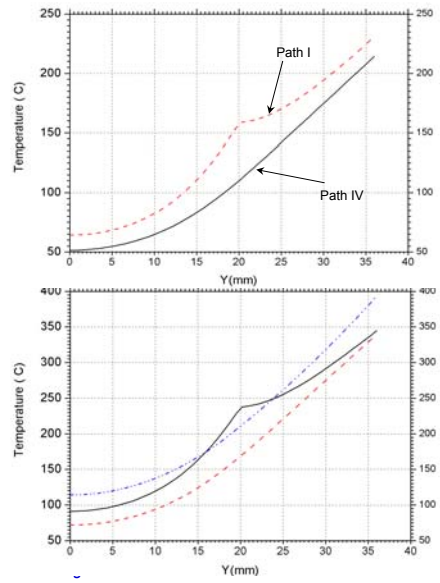


Case 1 and 3 temperatures along path 1

Case Studies: Nucor

Q as a function of Z coordinate





Case Studies: Nucor

- Using the same boundary conditions as in case 3
- The effect of changing K taken into account in ANSYS
- Thermocouple hole was not taken into account in ANSYS calculation

Case (distance from hotface)	ANSYS (15mm)	CON1D (15mm)	CON1D (15.3mm)
Temperature	123.81	125.97	123.85

CON1D: offset is **-0.3mm**

Conclusions

- CON1D can be used to optimize and design a casting machine and to inspect possible problems in production
- Calibration of CON1D needs 3D thermal analysis to define the offset, which was performed for 2 production casting molds
- When defining the offsets:
  - It is reasonable to neglet temperature dependence of thermal conductivity of copper
  - The thermocouple hole should be included in the 3D simulation model
  - Copper near to the mold coldface far from the cooling channels has little effect on the temperature profile between the hotface and cooling channel, so may be neglected in 3-D calculations
  - With offsets, the simple CON1D model predictions of mold and thermocouple temperatures are quite close to the 3-D model