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EMBr Effect on Mold Level Fluctuations

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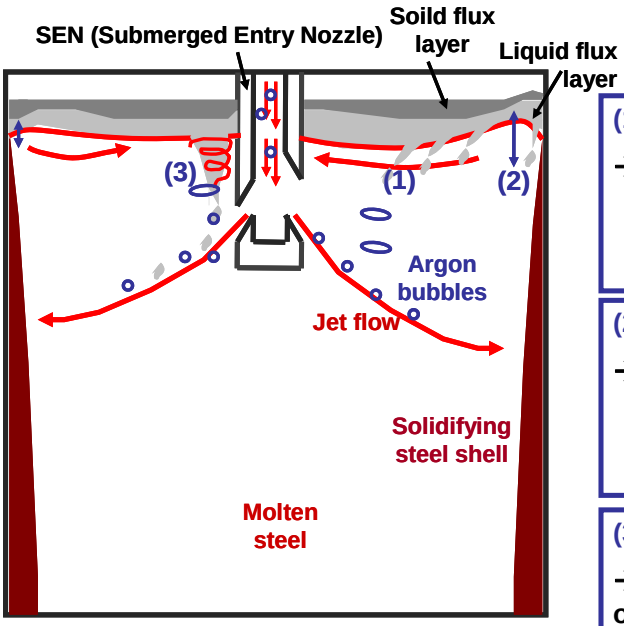
Research Background: Transient Surface Flow Problems



< Flow phenomena in the mold of steel continuous caster >

"Transient surface flow problems"

(1) High surface flow velocity

→ Mold flux entrainment by increasing the instability between mold flux layer and molten steel layer

(2) Level fluctuation

→ Mold flux entrapment by time-variations in the interface level between mold flux layer and molten steel layer

(3) Vortex formation

→ Mold flux entrainment by pulling a funnel of mold flux into the mold

→ Slab surface defects

Research Background: Electromagnetic Systems

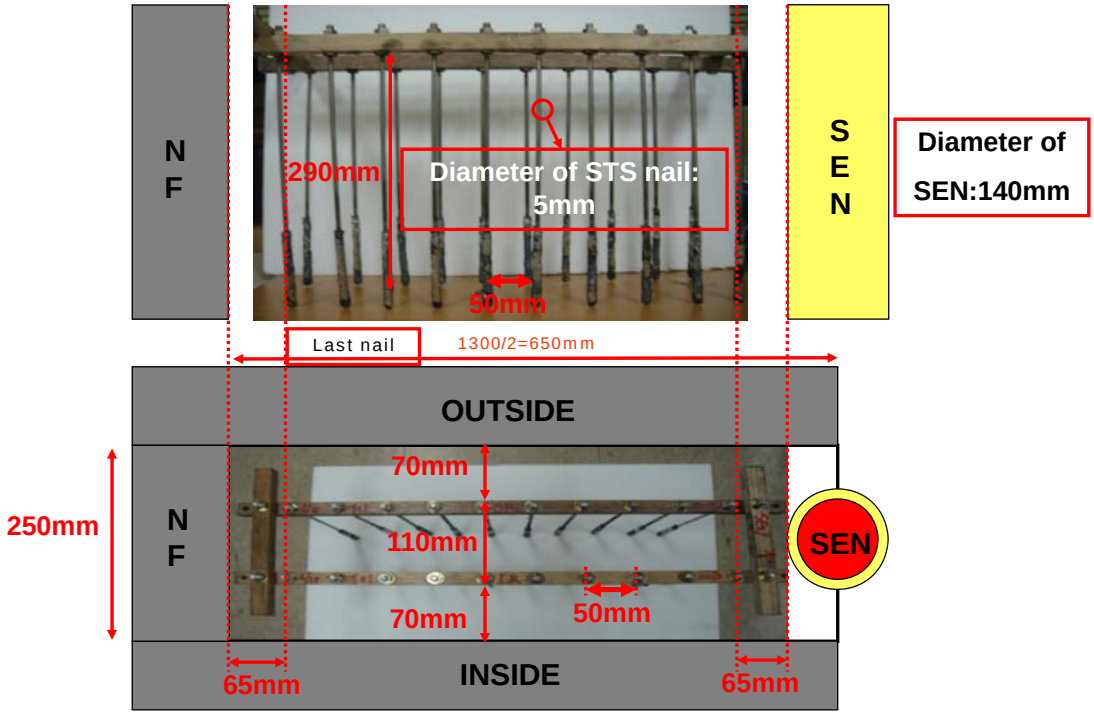
- Braking
  - Local EMBR (Electro-Magnetic Brake):
    Locally braking using Direct Current (DC)
  - FC (Flow Control):
    Double-ruler braking using DC
  - EMLS (Electro-Magnetic Level Stabilizer):
    Moving braking using Alternating Current (AC)

- Accelerating
  - EMLA (Electro-Magnetic Level Accelerater):
    Moving accelerating using AC
- Rotating
  - EMRS (Electro-Magnetic Rotate Stirrier):
    Moving rolating using AC

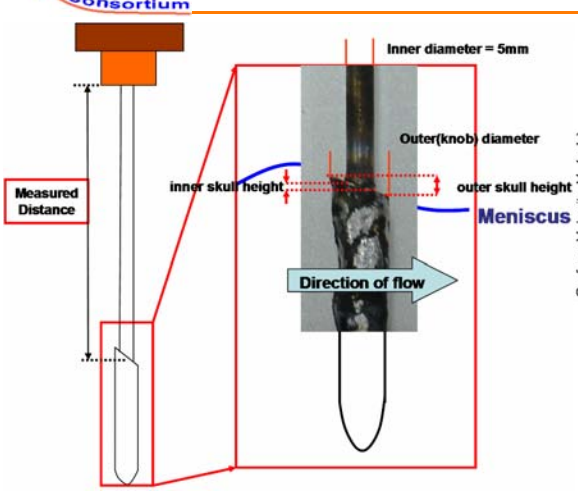
Research Scope

- Objectives:
  - To gain insight into EMBr (FC: double ruler) effect on transient surface flow pattern and surface level fluctuation
  - (Improve / Confirm Trials conducted in 2008 and reported at CCC Annual in 2009)
- Methodologies:
  - Nail board dipping test for visualizing surface flow pattern, level and quantifying surface velocity, level fluctuation

Schematic of Nail Board Set



Information from Nail Board Test



< Sample nail with solidified skull >

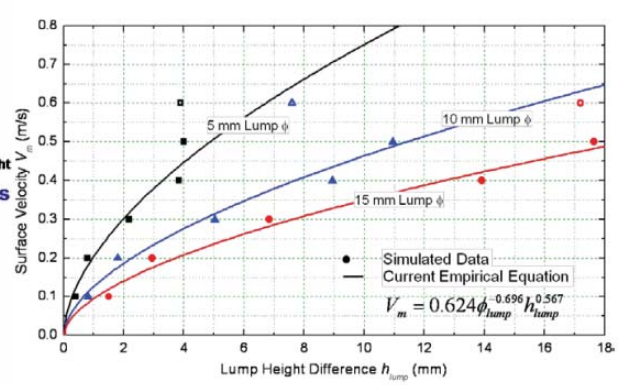


Fig. 4 Curves to convert nail lump height difference into velocity magnitude

< Relation between surface velocity and skull height difference [1] >

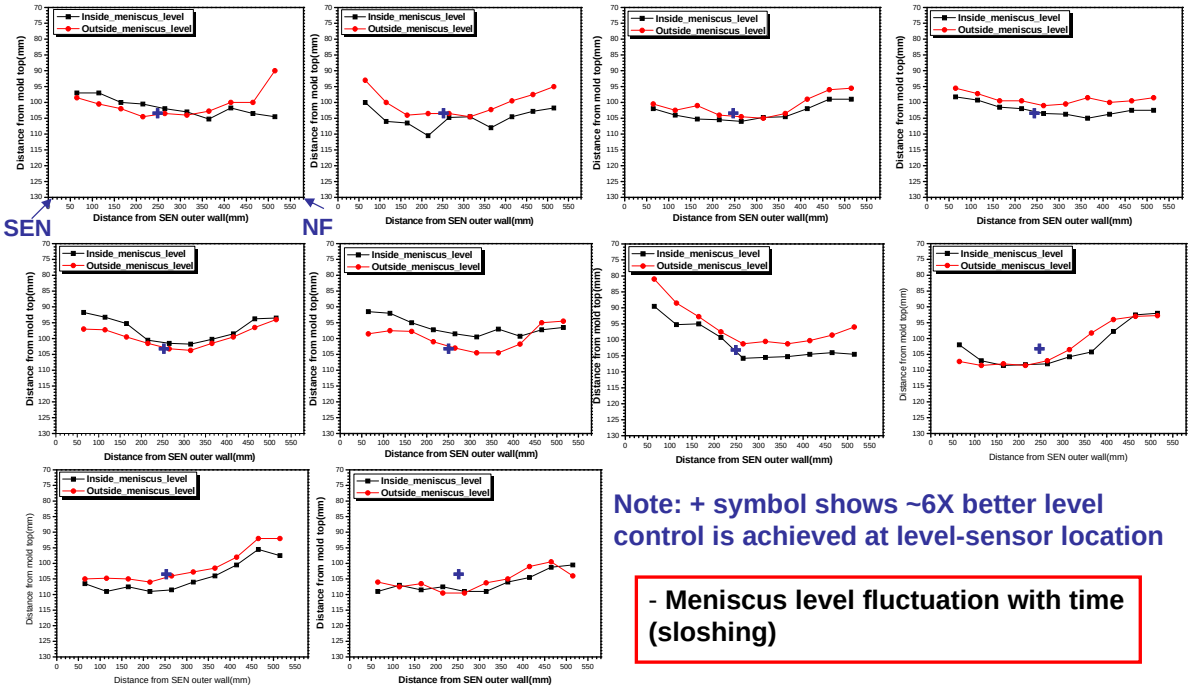
Surface level, surface flow direction, surface flow velocity

[1] Rui Liu et al., TMS Proceedings 2011

Process Conditions

Steel flow rate		552.5 LPM (3.9 ton/min)
Casting speed		1.70 m/min
Argon gas injection rate		9.2 SLPM (1atm and 273K)
Flow control system		Slide-gate
Nozzle	Bottom type	Well bottom
	Port angle	35 degree angle at both top and bottom
	Port area	80mm (width) x 85mm (height)
	Bore diameter (inner/outer)	90 (at UTN top) to 80 (at bottom well) mm / 140 mm
Mold	Width	1300 mm
	Thickness	250 mm
EMBr Current	FC off	Upper: 0A, Lower: 0A
	FC on	Upper: 300A, Lower: 300A

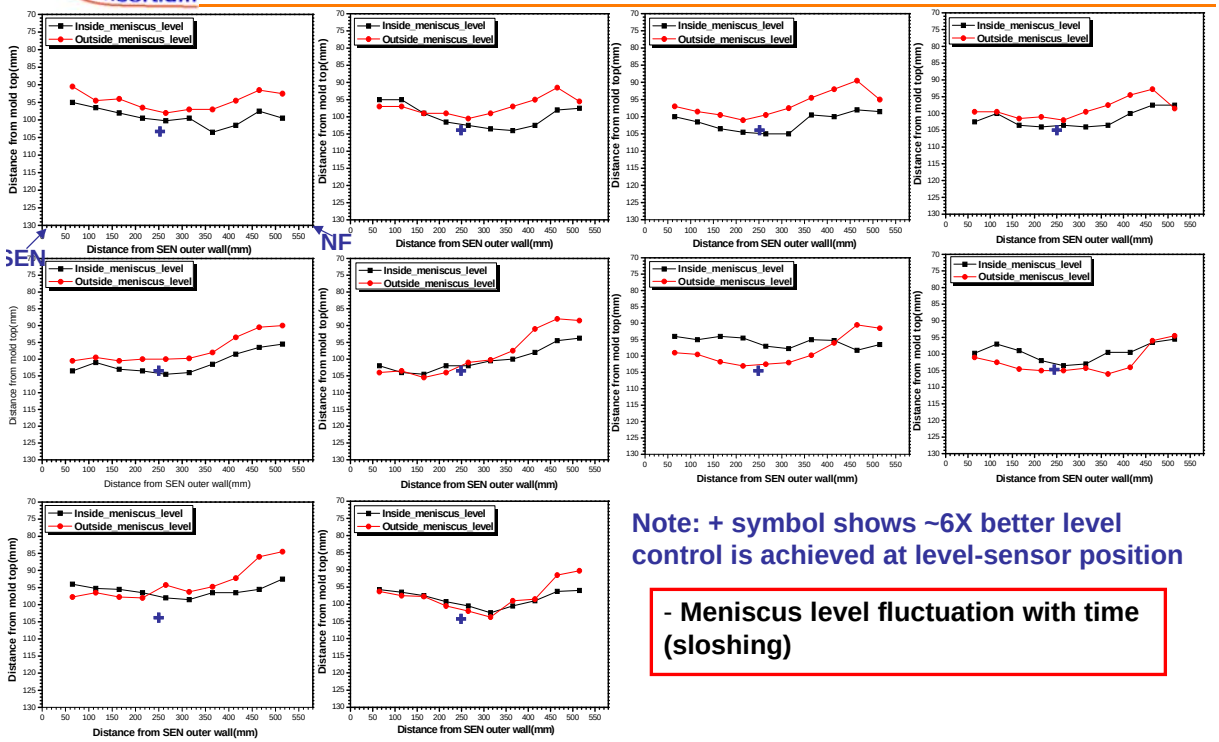
Level Variation with FC off



Note: + symbol shows ~6X better level control is achieved at level-sensor location

- Meniscus level fluctuation with time (sloshing)

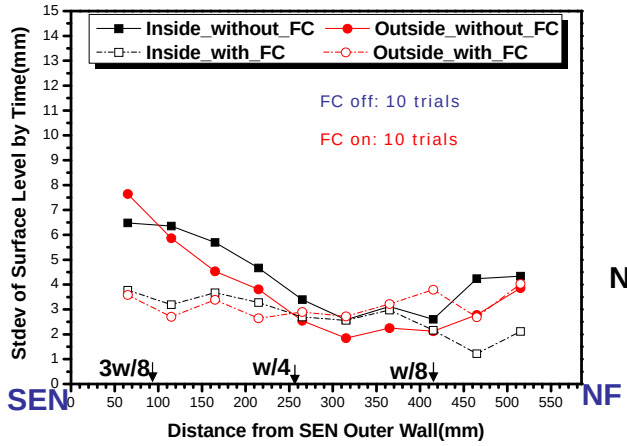
Level Variation with FC on

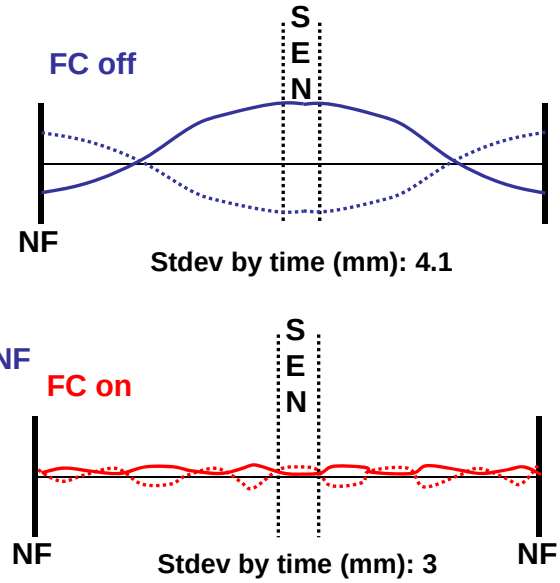


Note: + symbol shows ~6X better level control is achieved at level-sensor position

- Meniscus level fluctuation with time (sloshing)

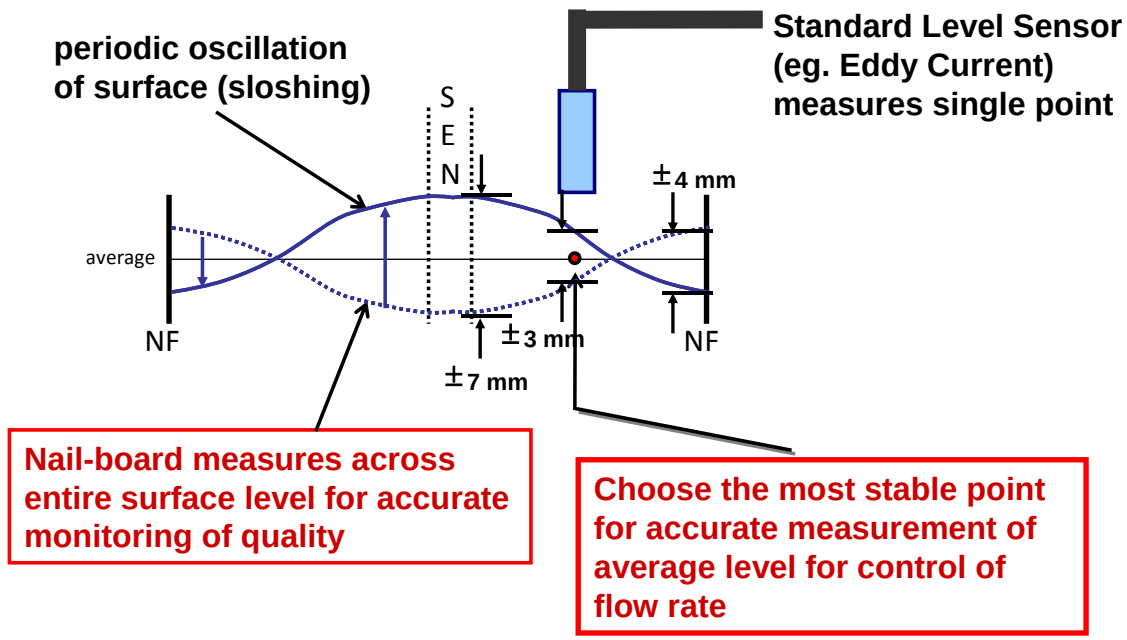
Comparison of Level Variation between FC off and FC on





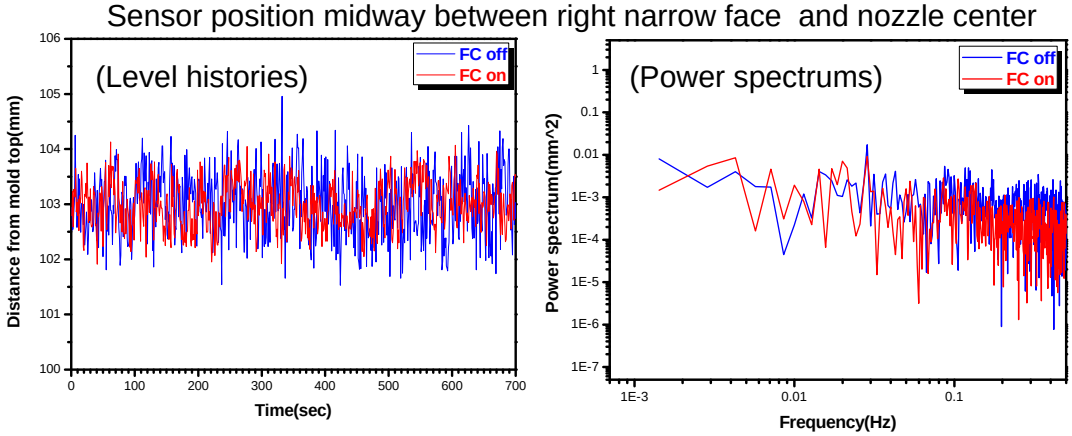
	Stdev of surface level by time (mm)		
	IR	OR	Avg
FC off	4.4	3.7	4.1
FC on	2.8	3.2	3

Comparison of Surface Level Variation Monitoring between Nail Board and Standard Level Sensor (Example: FC off)



Level variation with FC off and on (eddy current sensor)

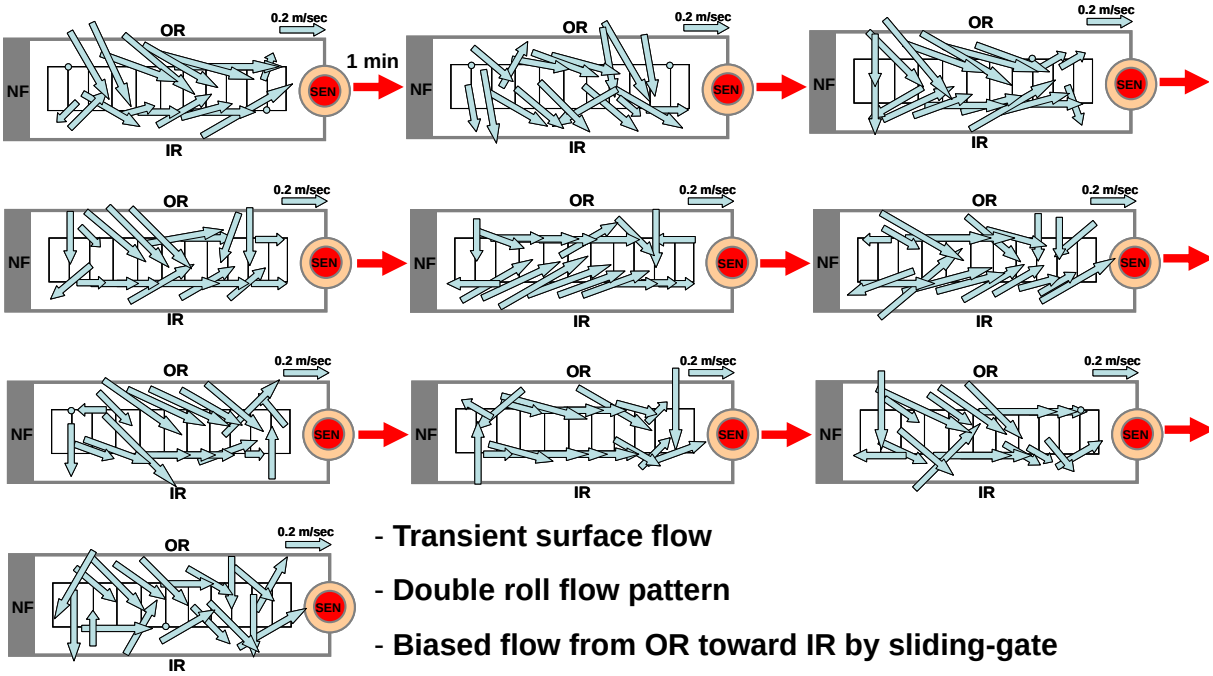
Sensor position midway between right narrow face and nozzle center



	Avg_level (mm)	Stdev_level (mm)
FC off	103.01	0.6
FC on	102.99	0.4

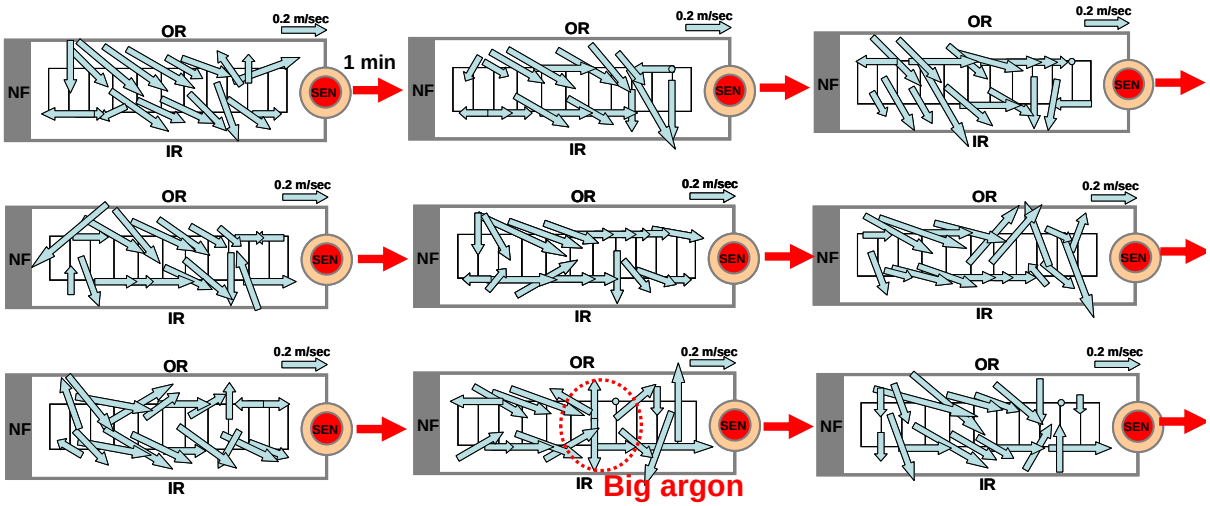
- FC induces more stable level at the ½ region between NFs and nozzle center

Surface Flow Pattern with FC off



- Transient surface flow
- Double roll flow pattern
- Biased flow from OR toward IR by sliding-gate
- Chaotic flow near SEN and NF

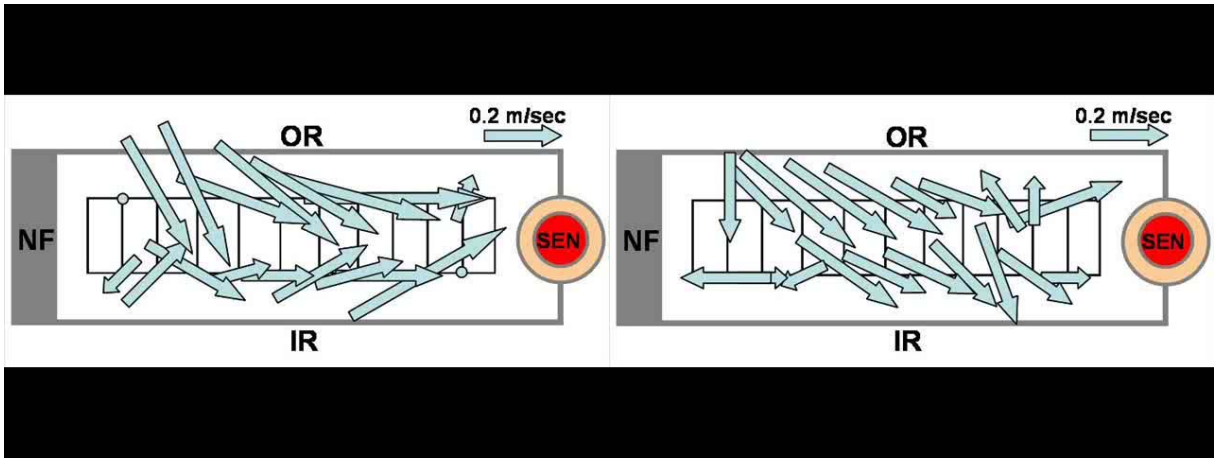
Surface Flow Pattern with FC on



Big argon bubble floating?

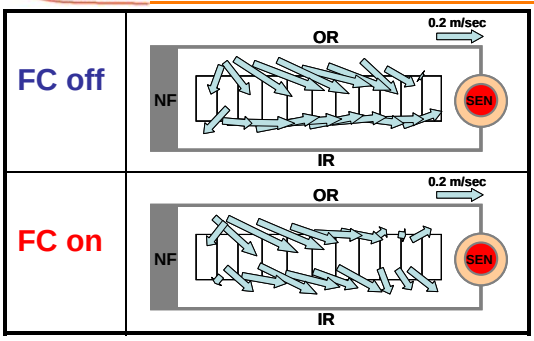
- Transient surface flow
- Double roll flow pattern
- Biased flow from OR toward IR by sliding-gate
- Chaotic flow near SEN and NF

Comparison of Transient Surface Flow Pattern between FC Off and On

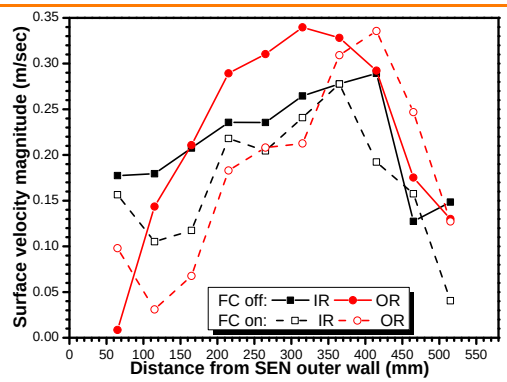


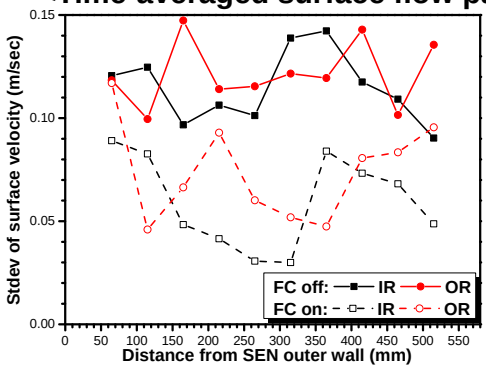
<FC off> <FC on>

FC Effect on Surface Flow Velocity & Fluctuation



<Time-averaged surface flow pattern>

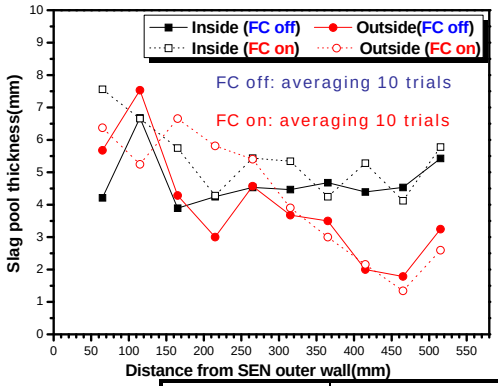


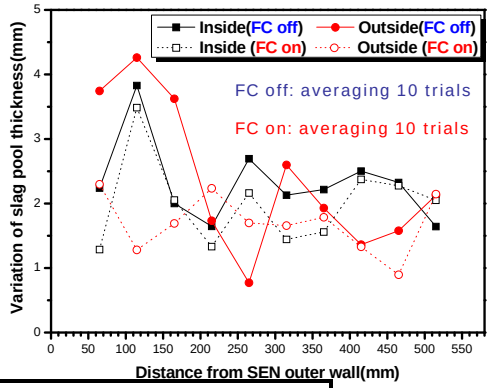


	Surface velocity (m/sec): Avg +/- Stdev		
	IR	OR	Avg
FC off	0.21 +/- 0.11	0.22 +/- 0.12	0.215 +/- 0.115
FC on	0.17 +/- 0.06	0.18 +/- 0.07	0.175 +/- 0.065

- FC induces slower and more stable surface flow
- Biased flow between IR / OR still exits with FC

Comparison of Slag Pool Thickness between FC off and FC on





	Slag Pool Thickness (mm): Avg (Stdev)		
	IR	OR	Avg
FC off	4.7 +/- 2.3	3.9 +/- 2.4	4.3 +/- 2.4
FC on	5.4 +/- 2.0	4.3 +/- 1.7	4.9 +/- 1.9

- Slag pool thickness of inside region near NF is thicker than outside
- Slag pool thickness is more uniform in inside than outside
- With FC on, slag pool thickness is thicker and more stable than FC off

Summary

- ❑ FC-EMBr effect on surface level
  - Surface level is transient by time (sloshing)
  - Level control is much better at level-sensor position than elsewhere
  - FC reduces level fluctuations near SEN with higher-frequency, lower-amplitude sloshing pattern
- ❑ FC effect on surface flow velocity
  - Flow pattern is generally double-roll with transient fluctuations
  - FC induces slower and more stable surface flow
  - Biased flow between IR / OR still exits with FC
- ❑ FC effect on slag pool
  - slag pool thickness is thicker and more stable with FC on than with FC off

Acknowledgements

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