Performing Fast Trend Analysis on Cell Key Design Parameters

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Plan of the Presentation

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- Cathode bottom heat loss sub-model
- Anode voltage drop sub-model
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Introduction

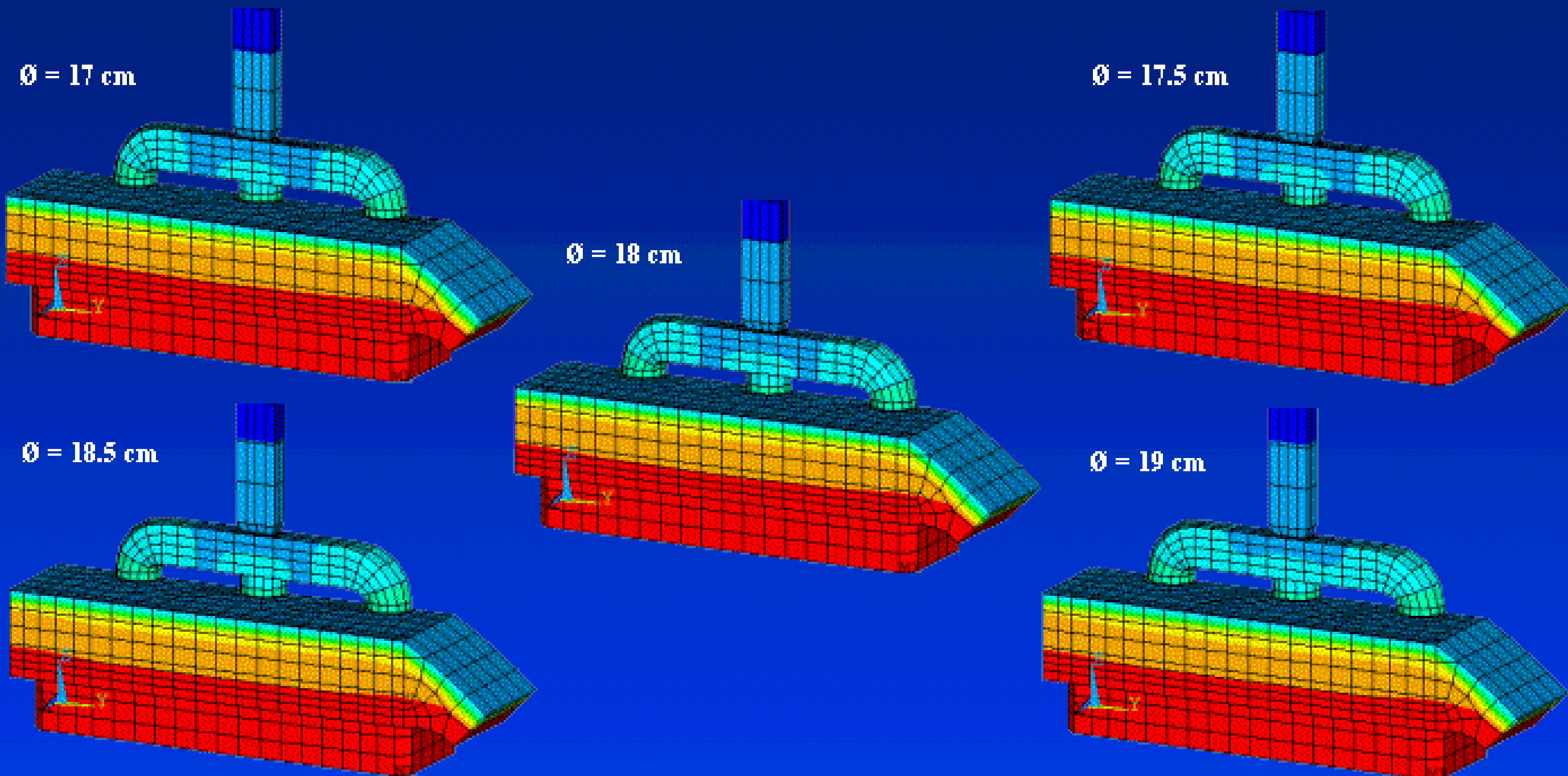
A lump parameters+ model has been expanded by adding to it four new algebraic sub-models that respectively calculate the anode panel heat loss, the cathode bottom heat loss, the anode voltage drop and the cathode voltage drop. Those new algebraic sub-models are based mainly on correlations developed in the late 1950's.

```
      HEAT BALANCE AND

      C.E. COMPUTATION

 7 0 FH=0.74+ 0.065*Z2
 8 0 QA=(0.025*(AH-3.)+0.034*ELI+0.
 8 1 15*Z1)*AN*FT*FH
 9 0 QAS=0.0535*AAS*FT*FH
10 0 QC=(0.70/B+0.25/(B*B*B))*(1.+0
10 1 .09*ELI)*AC*FT*FH
11 0 QCO=(0.04*TB-26.0)*TO*AO/1440.
12 0 QB=(TB-TR)/(1897.0*RB)
13 0 QCB=0.0425*ACB*FT
```

Anode panel heat loss sub-model



The initial work done in the 1950's was based on correlations with measurements while the recent development is rather based on correlations with 3D ANSYS® model results.

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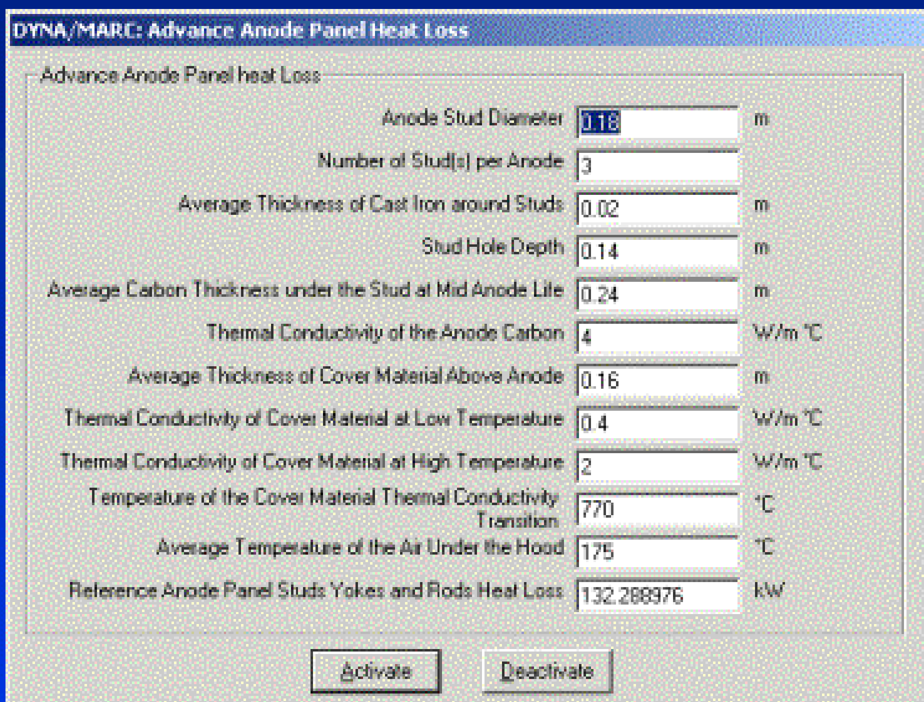
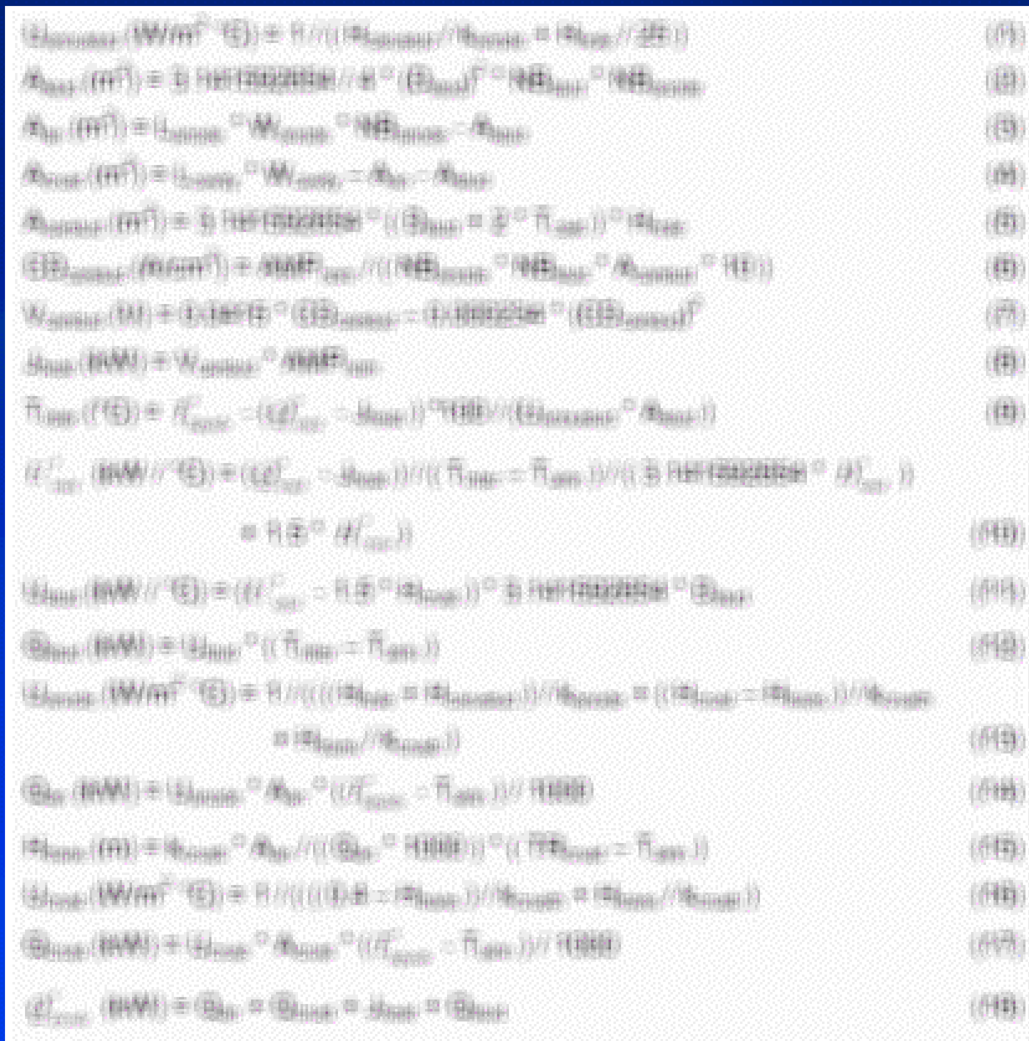
Anode panel heat loss sub-model



The total anode panel heat loss is assumed to be the sum of three independent parallel paths: one goes from the bath to the surface of the anode cover through the anode carbon, one goes directly through the crust in the different channels and one goes from the bath to the surface of the studs, yokes and rods exposed to the air through the anode carbon and the metallic components of the anode.

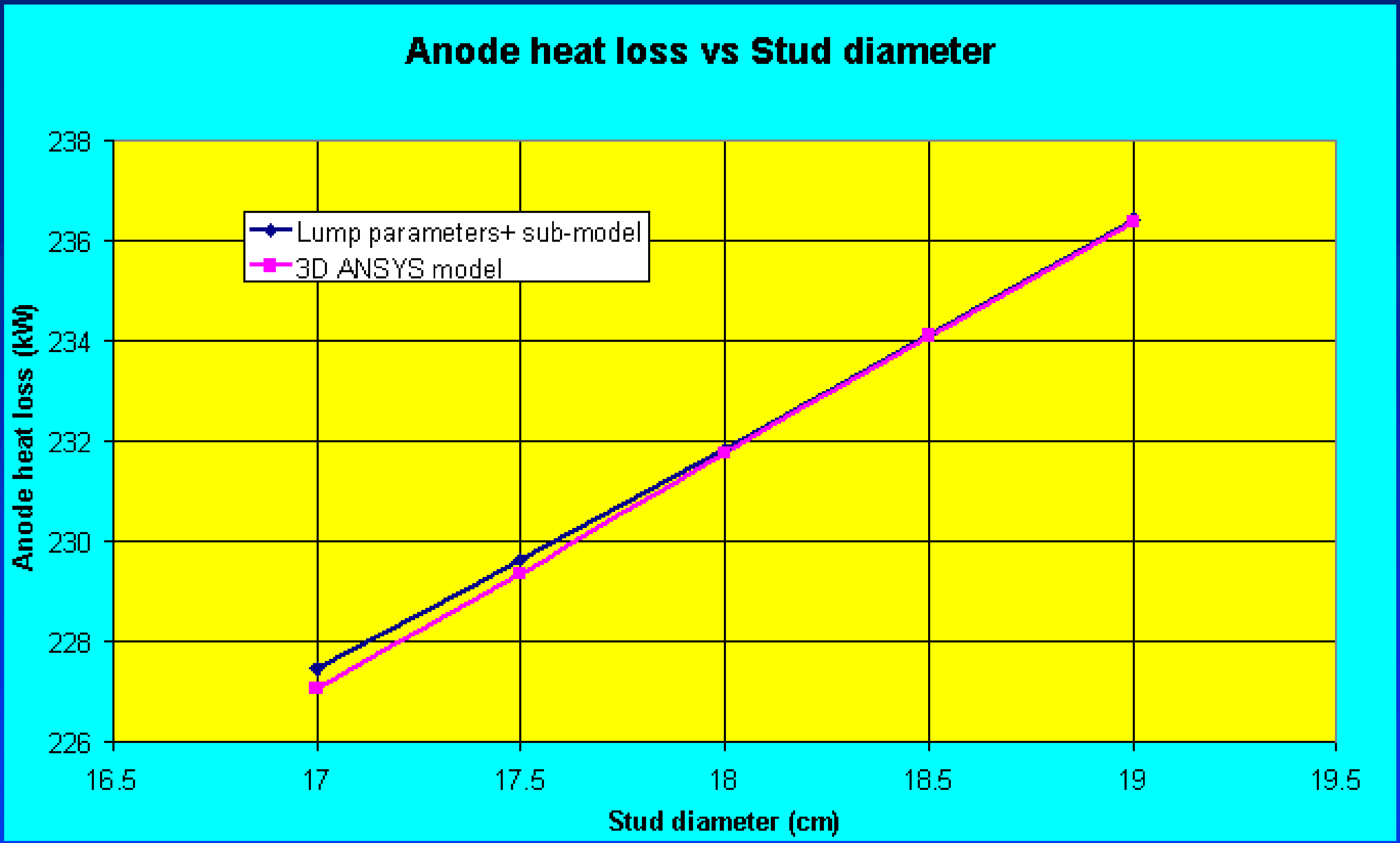
Anode panel heat loss sub-model



It is relatively straightforward to calibrate the new algebraic anode panel heat loss sub-model in order for it to reproduce the 3D ANSYS® model results for the base case configuration.

After calibration, the accuracy of the new algebraic sub-model was tested by comparing its trend analysis of such key design parameters as the stud diameter or the thickness of cover material with those produced by the 3D ANSYS® model studies.

Anode panel heat loss sub-model



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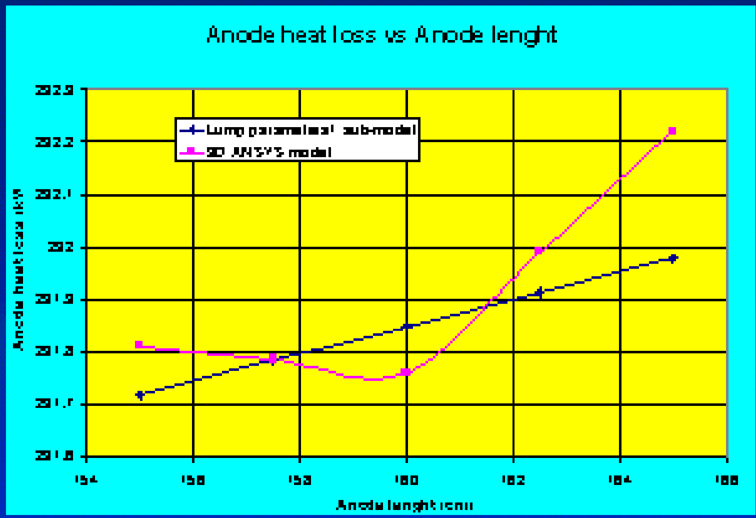
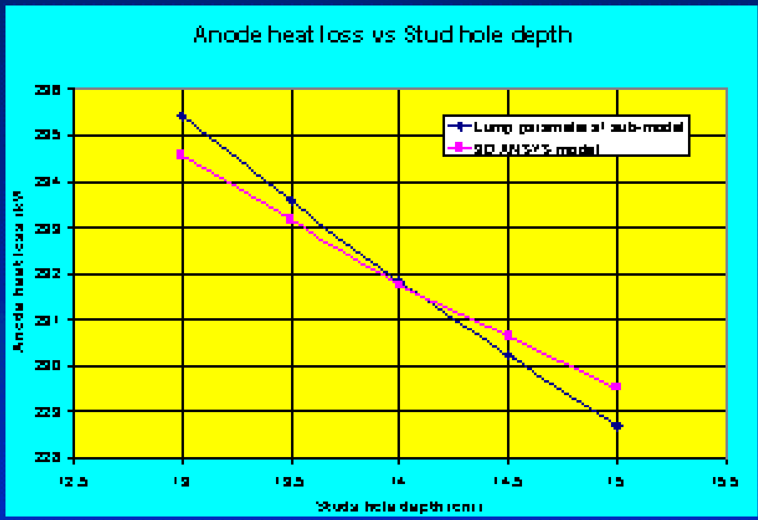
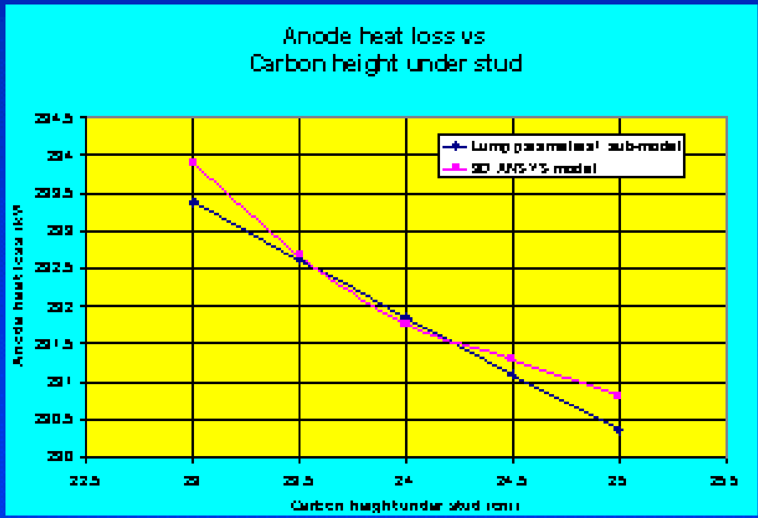
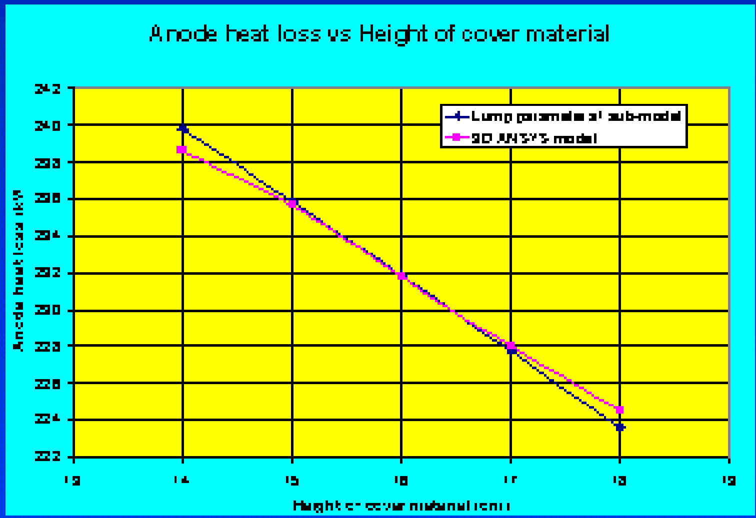
Anode panel heat loss sub-model









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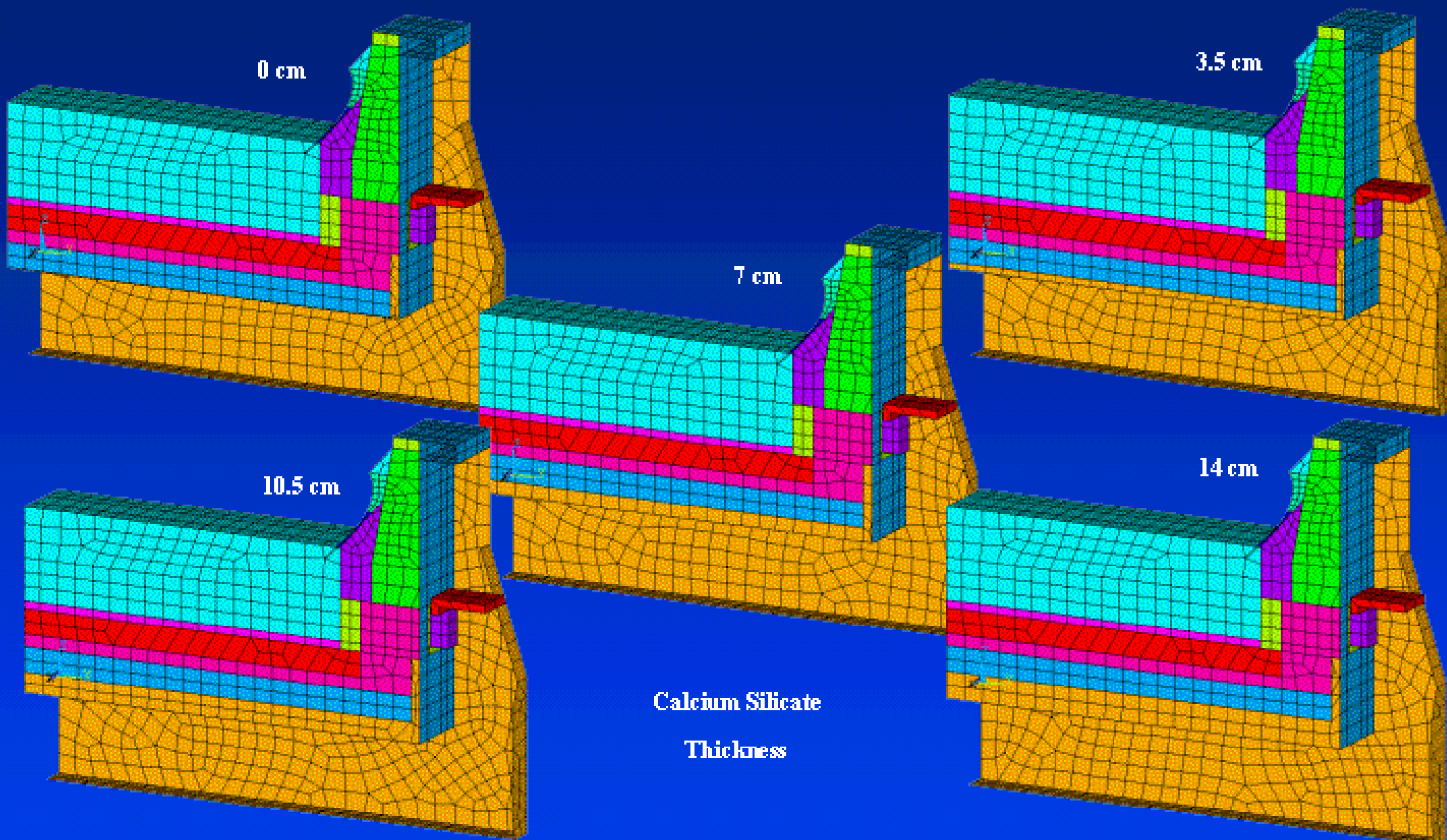
Cathode bottom heat loss sub-model



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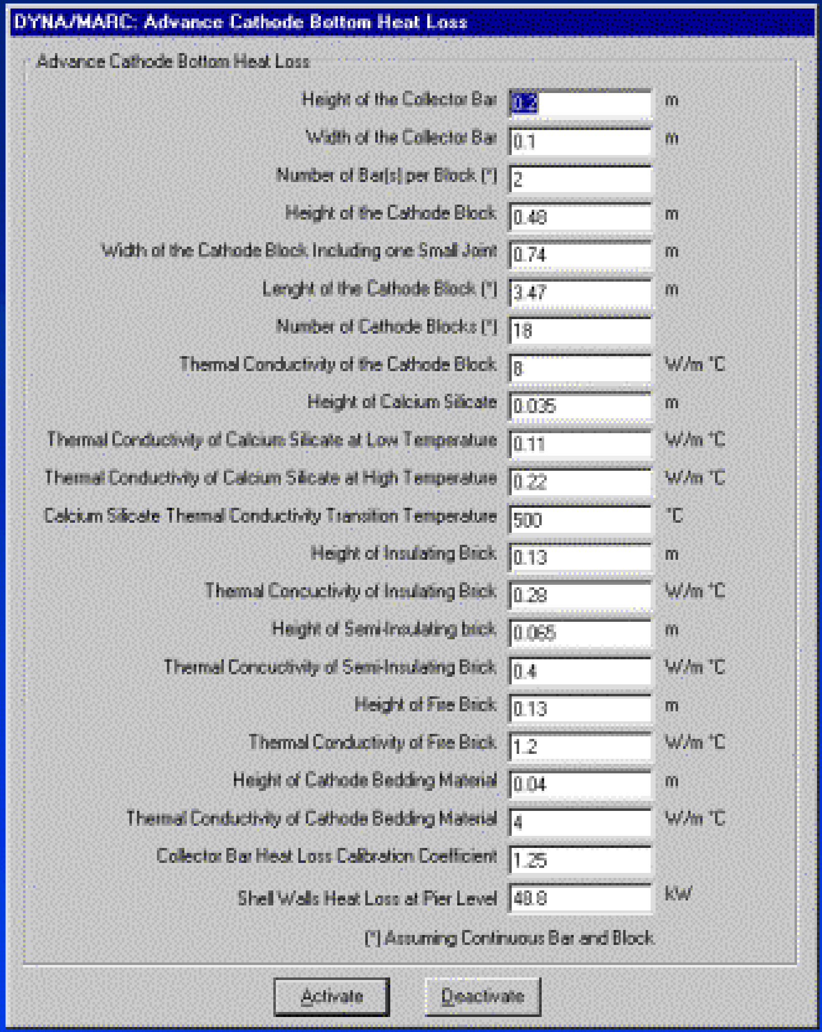
Cathode bottom heat loss sub-model



The cathode bottom heat loss is assumed to be the sum of three independent parallel paths: from the metal to the shell floor through the cathode blocks and the cell bottom lining, from the metal to the shell lower walls section through the cathode blocks and the cell side lining (pier) and finally from the metal to the collector bars through the blocks and the bars themselves.

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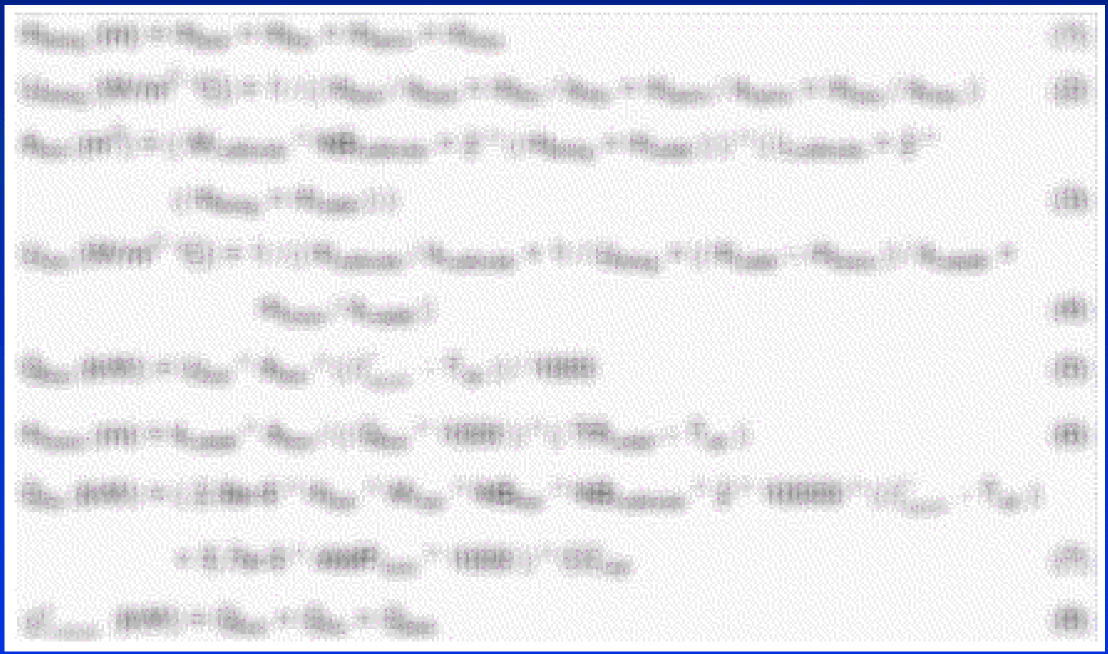
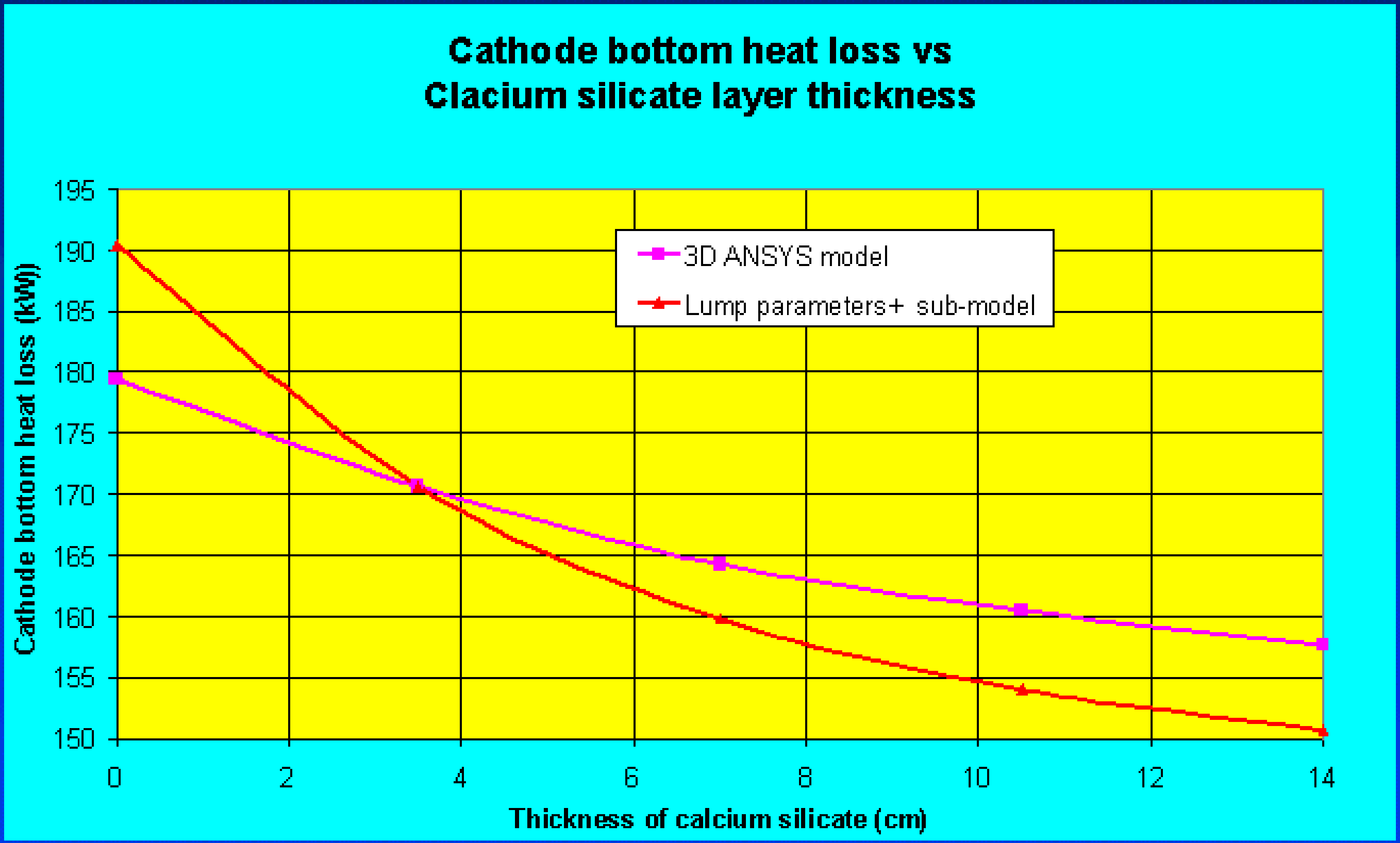
Cathode bottom heat loss sub-model



The thermal resistance of the path going from the metal pad to the shell floor is computed using a standard heat transfer equation. The calcium silicate layer, if it is present, is assumed to have two different thermal conductivities (initial and degraded) with a step transition occurring at a prescribed temperature. All the other layers (cathode block, bedding material, firebrick, semi-insulating brick and insulating brick) are considered having a uniform and invariable thermal conductivity.

Cathode bottom heat loss sub-model



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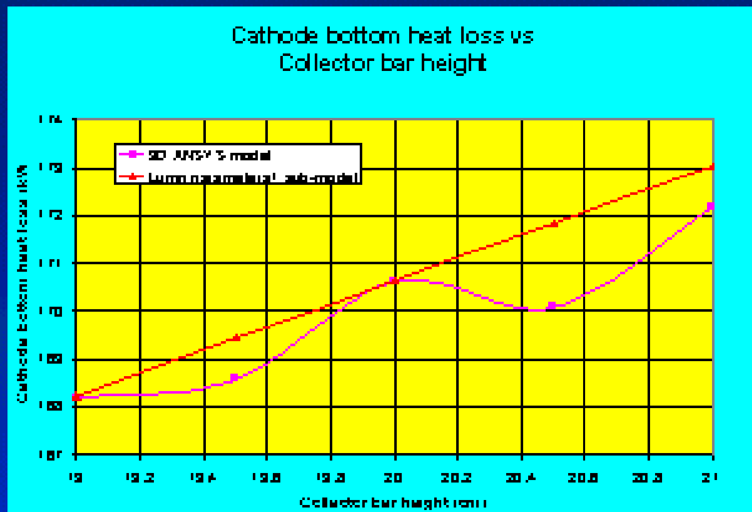
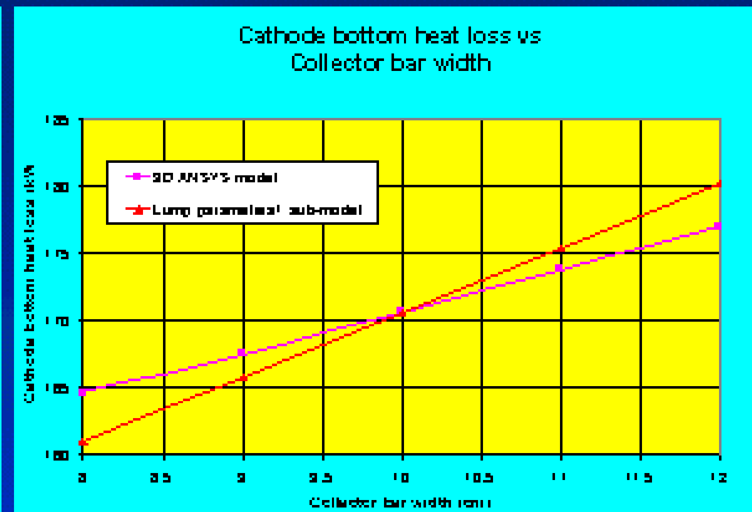
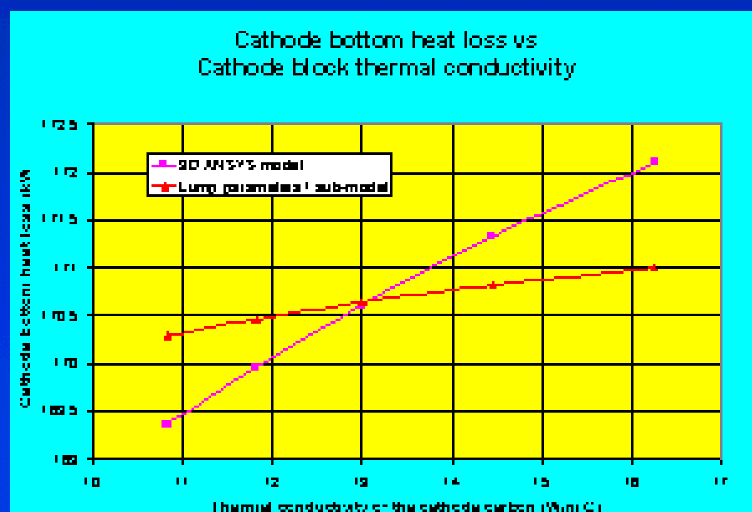
Cathode bottom heat loss sub-model







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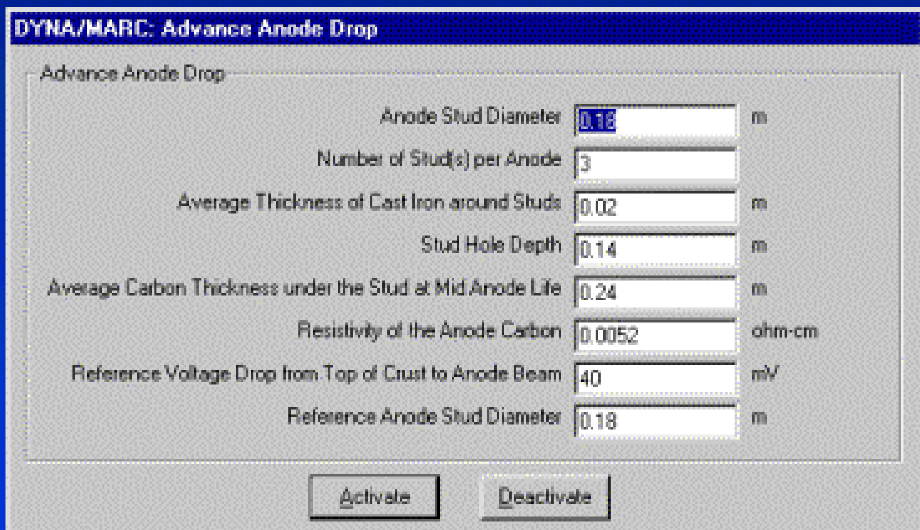
Anode voltage drop sub-model



The global anode electrical resistance is evaluated as the sum of four resistances in series: the resistance of the carbon under the stud(s) where the current is assumed to travel vertically at a uniform current density, the resistance of the carbon around the stud(s) where the current is assumed to travel radially in an horizontal plane, the carbon/cast iron contact resistance and the resistance of the metallic part of the anode up to the anode beam .

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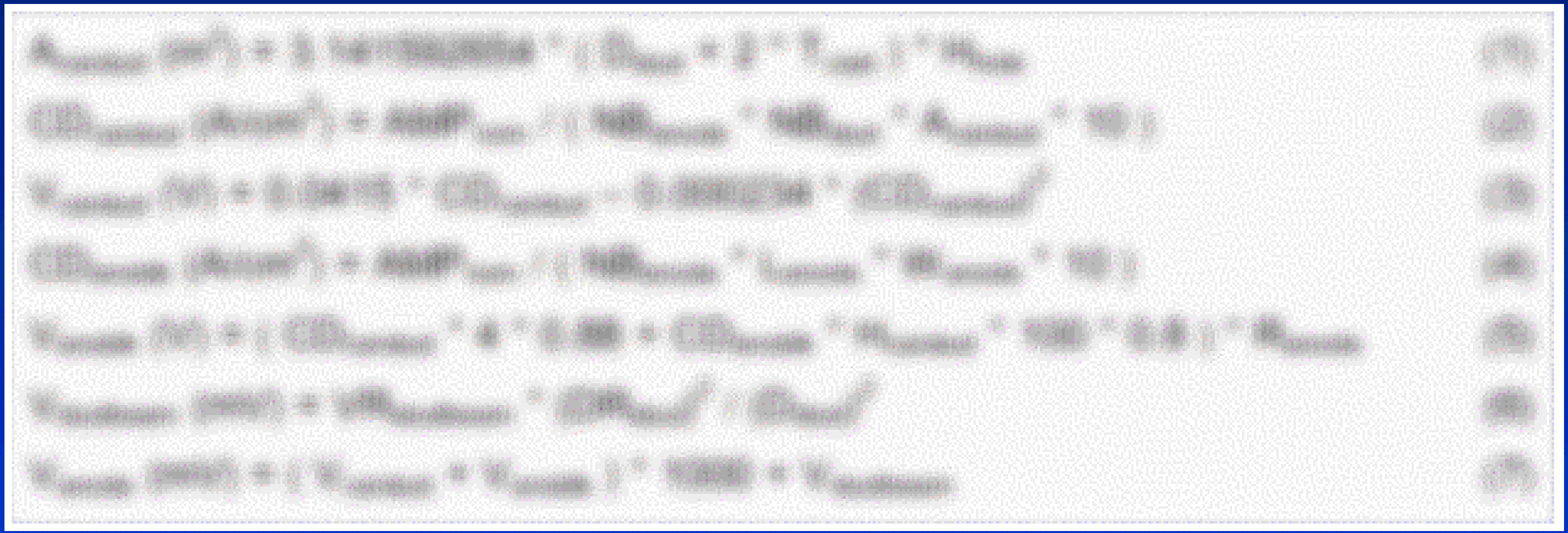
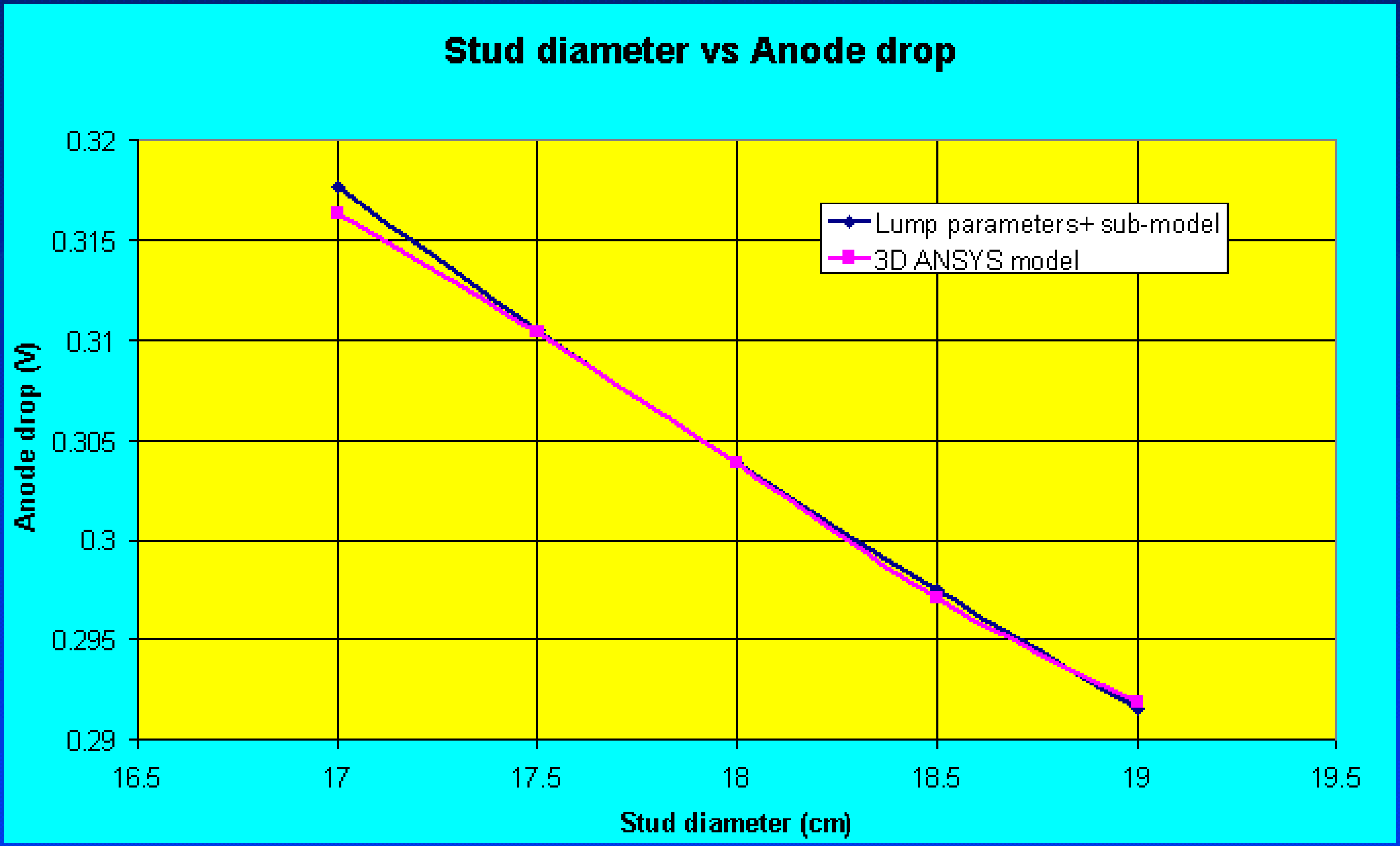
Anode voltage drop sub-model

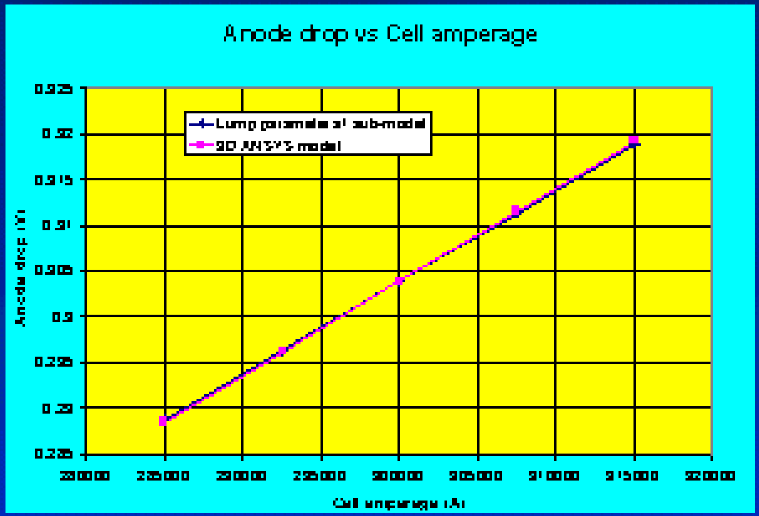


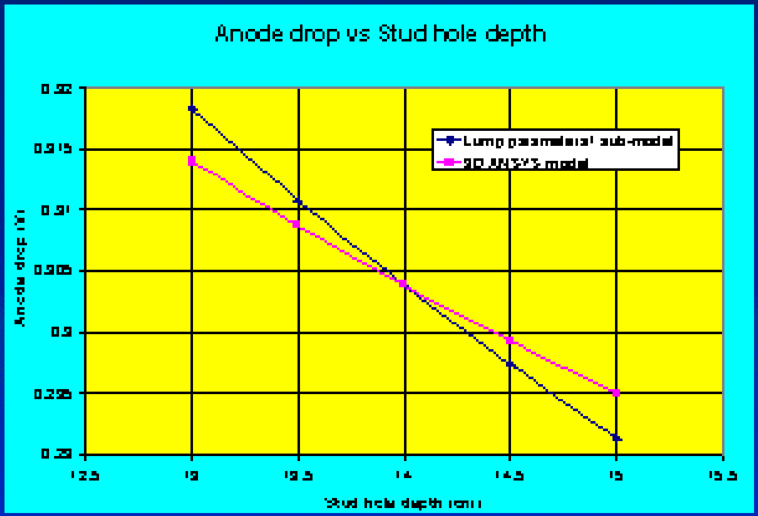
Despite the empirical nature of the formulation, the trend analyses of the new algebraic anode drop sub-model compare extremely well with those obtained using the 3D ANSYS® model

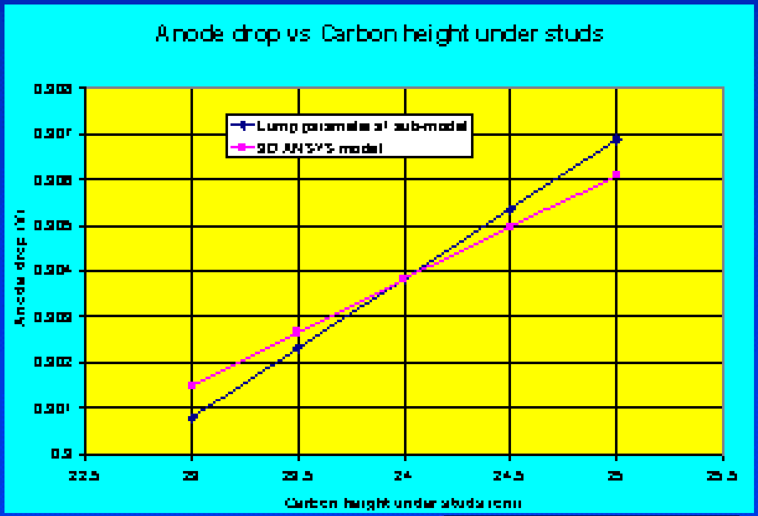
Anode voltage drop sub-model



Anode voltage drop sub-model







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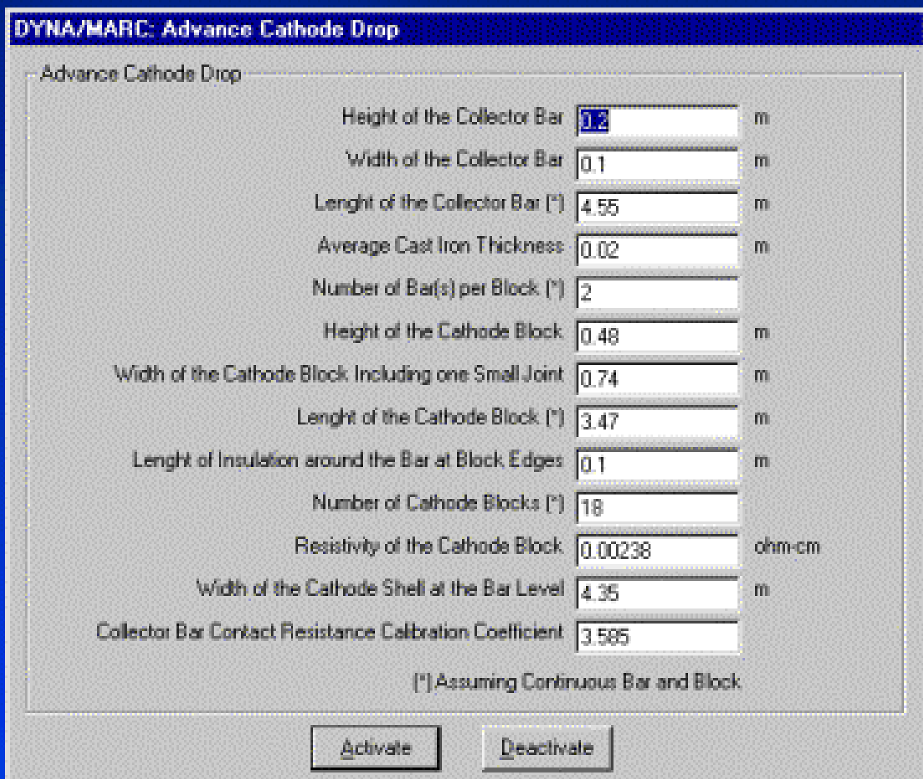
Cathode voltage drop sub-model



The global cathode electrical resistance is evaluated as the sum of three resistances in series: the resistance of the cathode blocks above the collector bar where the current is assumed to travel vertically at a uniform current density, the carbon/cast iron contact resistance and the resistance of the collector bars from the end of the cast iron connection up to the flexible.

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Cathode voltage drop sub-model

[illegible]

Again for the cathode drop, the trend analysis obtained using the new algebraic sub-model agreed very well with results obtained using the 3D ANSYS® model. This seems to indicate this it is somewhat easier to simplify the electrical behavior of the cell than its thermal behavior.

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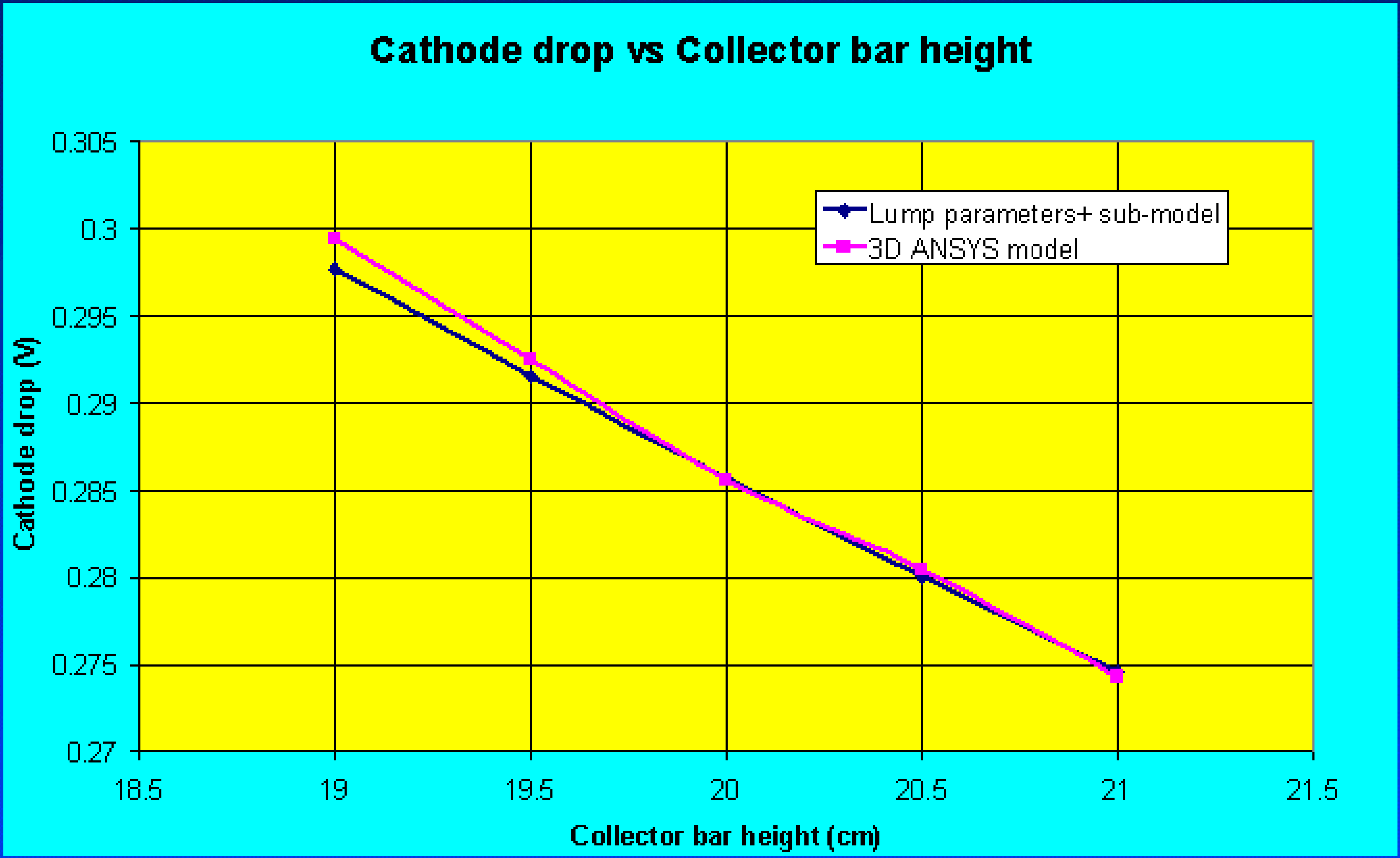
Cathode voltage drop sub-model



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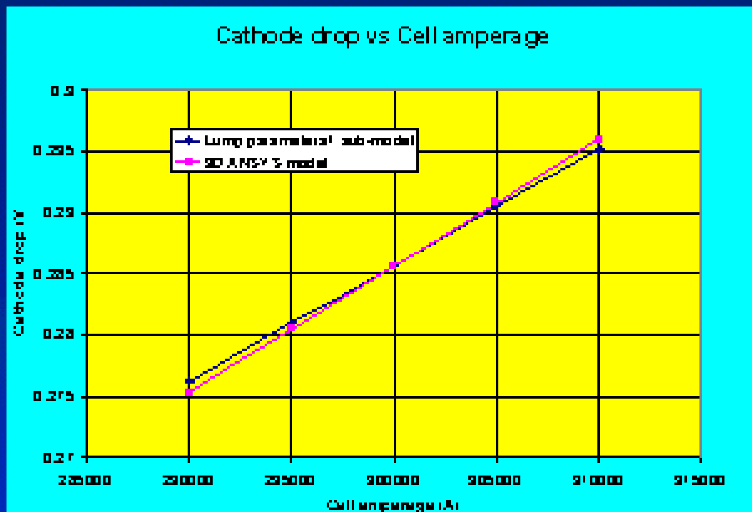
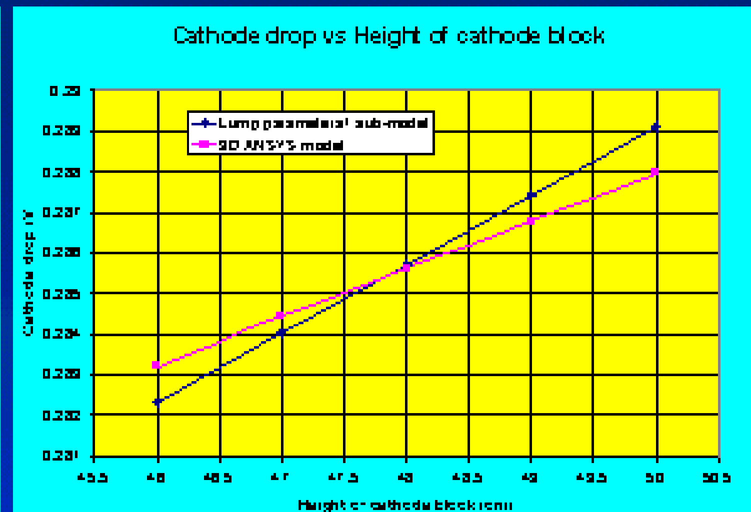
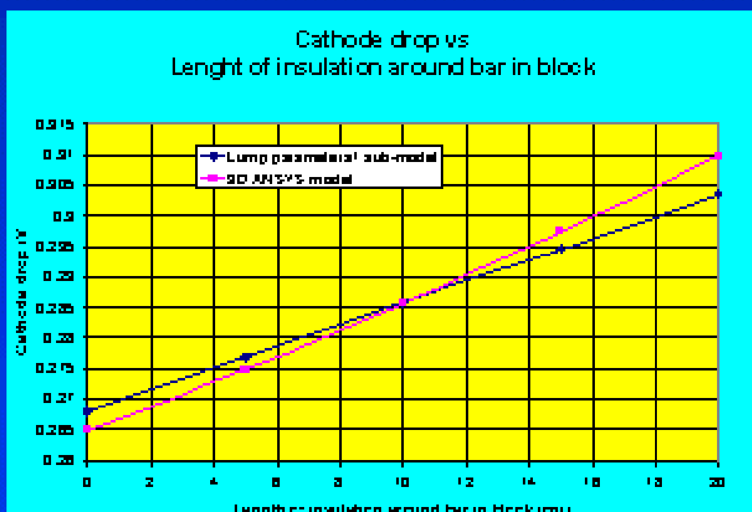
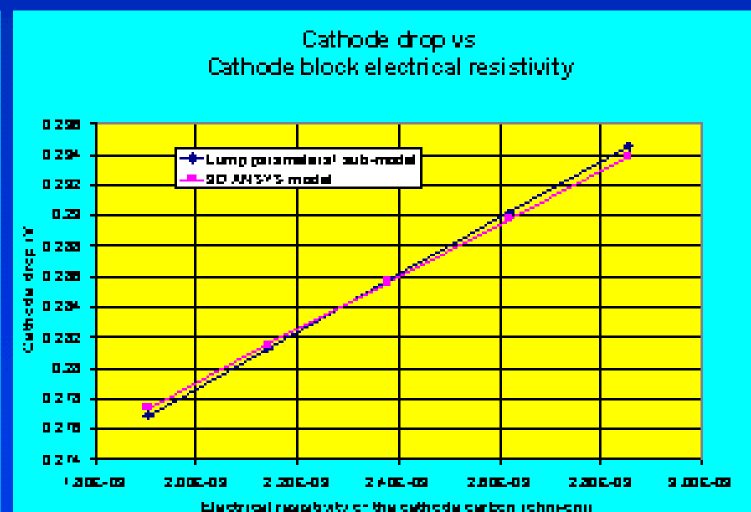
Cathode voltage drop sub-model









Retrofit of a 300 kA cell into a 350 kA cell

	Base case	Step 1	Step 2	Step 3	Step 4 to 7	Step 8	Step 9
Modeling tool	Dyna/Marc 1.4	Dyna/Marc 1.4	Dyna/Marc 1.4	Dyna/Marc 1.4	ANSYS 2D+	ANSYS 2D+	ANSYS 3D
Amperage	300 kA	320 kA	327 kA	327 kA	327 kA	335 kA	350 kA
Nb. of anodes	32	32	32	32	32	32	32
Anode size	1.6 m X 0.8 m	1.6 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m
Nb. of anode studs	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode
Anode stud diameter	18 cm	18 cm	18 cm	18 cm	18 cm	18 cm	19 cm
Anode cover thickness	16 cm	16 cm	16 cm	16 cm	16 cm	10 cm	10 cm
Nb. of cathode blocks	18	18	18	18	18	18	18
Cathode block length	3.47 m	3.47 m	3.47 m	3.47 m	3.67 m	3.67 m	3.67 m
Type of cathode block	HC3	HC3	HC3	HC3	HC10	HC10	HC10
Type of side block	HC3	HC3	HC3	HC3	SiC	SiC	SiC
Side block thickness	15 cm +	15 cm +	15 cm +	15 cm +	10 cm +	10 cm +	10 cm +
ASD	35 cm	35 cm	25 cm	25 cm	30 cm	30 cm	30 cm
Inside potshell size	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m
ACD	5 cm	4 cm	4 cm	4 cm	4 cm	4 cm	4 cm
Excess AlF_3	10.9 %	10.9 %	10.9 %	13.5 %	13.5 %	13.5 %	13.5 %
Operating temperature	973.3 °C	973.3 °C	973.3 °C	961.1 °C	958.9 °C	959.2 °C	960.4 °C
Liquidus superheat	6.8 °C	6.8 °C	6.8 °C	7.4 °C	5.2 °C	5.5 °C	6.7 °C
Current efficiency	94.0 %	94.3 %	94.2 %	95.8 %	96.0 %	96.0 %	96.1 %
Internal heat	628 kW	628 kW	628 kW	641 kW	624 kW	657 kW	713 kW
Energy consumption	13.75 kWh/kg	13.32 kWh/kg	13.20 kWh/kg	13.15 kWh/kg	12.95 kWh/kg	13.20 kWh/kg	13.40 kWh/kg

Retrofit of a 300 kA cell into a 350 kA cell

	Base case	Step 1	Step 2	Step 3	Step 4 to 7	Step 8	Step 9
Modeling tool	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7
Amperage	300 kA	**322 kA**	**330 kA**	330 kA	330 kA	**335 kA**	**350 kA**
Nb. of anodes	32	32	32	32	32	32	32
Anode size	1.6 m X 0.8 m	1.6 m X 0.8 m	**1.7 m X 0.8 m**	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m
Nb. of anode studs	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode
Anode stud diameter	18 cm	18 cm	18 cm	18 cm	18 cm	18 cm	**19 cm**
Anode cover thickness	16 cm	16 cm	16 cm	16 cm	16 cm	**10 cm**	10 cm
Nb. of cathode blocks	18	18	18	18	18	18	18
Cathode block length	3.47 m	3.47 m	3.47 m	3.47 m	**3.67 m**	3.67 m	3.67 m
Type of cathode block	HC3	HC3	HC3	HC3	**HC10**	HC10	HC10
Type of side block	HC3	HC3	HC3	HC3	**SiC**	SiC	SiC
Side block thickness	15 cm +	15 cm +	15 cm +	15 cm +	**10 cm +**	10 cm +	10 cm +
ASD	35 cm	35 cm	**25 cm**	25 cm	**30 cm**	30 cm	30 cm
Inside potshell size	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m
ACD	5 cm	**4 cm**	4 cm	4 cm	4 cm	4 cm	4 cm
Excess AlF_3	10.9 %	10.9 %	10.9 %	**13.5 %**	13.5 %	13.5 %	13.5 %
Operating temperature	973.3 °C	973.3 °C	973.3 °C	**960.8 °C**	**960.2 °C**	**960.0 °C**	**961.5 °C**
Liquidus superheat	6.8 °C	6.8 °C	6.8 °C	**7.2 °C**	**6.5 °C**	**6.3 °C**	**7.8 °C**
Current efficiency	94.0 %	**94.4 %**	**94.2 %**	**95.9 %**	**95.9 %**	**96.0 %**	96.0 %
Internal heat	628 kW	**633 kW**	**637 kW**	**647 kW**	**633 kW**	**652 kW**	**712 kW**
Energy consumption	13.75 kWh/kg	**13.32 kWh/kg**	**13.20 kWh/kg**	**13.14 kWh/kg**	**13.00 kWh/kg**	**13.10 kWh/kg**	**13.37 kWh/kg**

Extension to a Greenfield design at 400 kA

	Original results	New results
Modeling tool	ANSYS 3D	Dyna/Marc 1.7
Amperage	400 kA	400 kA
Nb. of anodes	36	36
Anode size	1.7 m X 0.8 m	1.7 m X 0.8 m
Nb. of anode studs	3 per anode	3 per anode
Anode stud diameter	19 cm	19 cm
Anode cover thickness	10 cm	10 cm
Nb. of cathode blocks	20	20
Cathode block length	3.67 m	3.67 m
Type of cathode block	HC10	HC10
Type of side block	SiC	SiC
Side block thickness	10 cm +	10 cm +
ASD	30 cm	30 cm
Inside potshell size	16.1 X 4.35 m	16.1 X 4.35 m
ACD	4 cm	4 cm
Excess AlF_3	13.5 %	13.5 %
Operating temperature	961.7 °C	962.7 °C
Liquidus superheat	8.0 °C	9.0 °C
Current efficiency	96.1 %	96.0 %
Internal heat	831 kW	829 kW
Energy consumption	13.57 kWh/kg	13.49 kWh/kg

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Extension to a Greenfield design at 500 kA

	Base case	Step 1	Step 2	Step 3	Step 4
Modeling tool	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7
Amperage	400 kA	440 kA	480 kA	490 kA	500 kA
Nb. of anodes	36	40	40	40	40
Anode size	1.7 m X 0.8 m	1.7 m X 0.8 m	1.95 m X 0.8 m	1.95 m X 0.8 m	1.95 m X 0.8 m
Nb. of anode studs	3 per anode	3 per anode	3 per anode	4 per anode	4 per anode
Anode stud diameter	19 cm	19 cm	19 cm	17.5 cm	17.5 cm
Anode cover thickness	10 cm	10 cm	10 cm	10 cm	10 cm
Nb. of cathode blocks	20	22	22	22	24
Cathode block length	3.67 m	3.67 m	4.17 m	4.17 m	4.17 m
Type of cathode block	HC10	HC10	HC10	HC10	HC10
Type of side block	SiC	SiC	SiC	SiC	SiC
Side block thickness	10 cm +	10 cm +	10 cm +	10 cm +	10 cm +
ASD	30 cm	30 cm	30 cm	30 cm	30 cm
Inside potshell size	16.1 X 4.35 m	17.8 X 4.35 m	17.8 X 4.85 m	17.8 X 4.85 m	17.8 X 4.85 m
ACD	4 cm	4 cm	4 cm	4 cm	4 cm
Excess AlF_3	13.5 %	13.5 %	13.5 %	13.5 %	13.5 %
Anode drop	335 mV	332 mV	347 mV	314 mV	320 mV
Cathode drop	301 mV	331 mV	324 mV	331 mV	312 mV
Anode panel heat loss	311 kW	335 kW	367 kW	391 kW	394 kW
Cathode bottom heat loss	193 kW	202 kW	231 kW	231 kW	238 kW
Operating temperature	962.7 C	963.4 C	962.8 C	962.8 C	963.4 C
Liquidus superheat	9.0 C	9.7 C	9.1 C	9.1 C	9.7 C
Bath ledge thickness	5.11 cm	4.43 cm	4.97 cm	4.99 cm	4.44 cm
Metal ledge thickness	0.83 cm	0.15 cm	0.70 cm	0.71 cm	0.17 cm
Current efficiency	96.0 %	95.9 %	95.8 %	95.9 %	95.9 %
Internal heat	825 kW	916 kW	964 kW	988 kW	1019 kW
Energy consumption	13.49 kWh/kg	13.53 kWh/kg	13.31 kWh/kg	13.33 kWh/kg	13.39 kWh/kg

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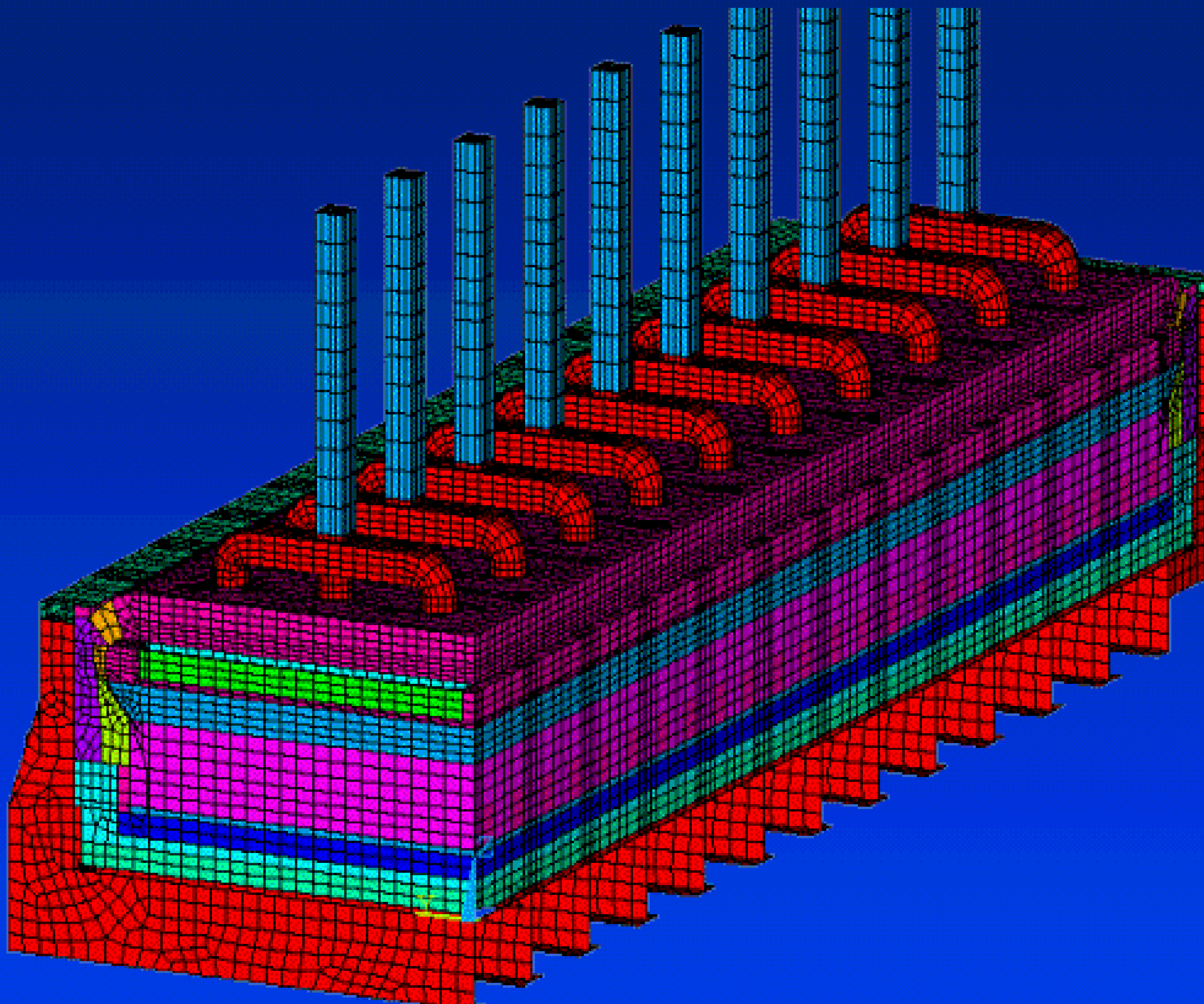
Extension to a Greenfield design at 500 kA



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Conclusions

- It was demonstrated that fairly simple semi-empirical algebraic equations can be used to calculate the anode panel heat loss, the cathode bottom heat loss, the anode voltage drop and the cathode voltage drop with a quite acceptable level of accuracy.
- It was also demonstrated that with the additions of the four new algebraic sub-models, the lump parameter+ model, also called Dyna/Marc 1.7 cell simulator, can be used as a stand-alone modeling tool to carry out a complete retrofit study without significant loss of accuracy in predicting operational results.
- This makes Dyna/Marc 1.7 an ideal tool to analyze "what if" scenarios raised during a brainstorming session at the beginning of a new retrofit project.

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