Calculating Temperatures Under Hood of a Prebake Anode Cell

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Introduction

A lump parameters+ model has been expanded by adding to it a new algebraic sub-model that calculates the temperature under the anode hood (Tairin). The new sub-model adds to the four algebraic sub-models presented at the TMS 2003. Again, this work is a follow up on the early cell modeling efforts started 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
```

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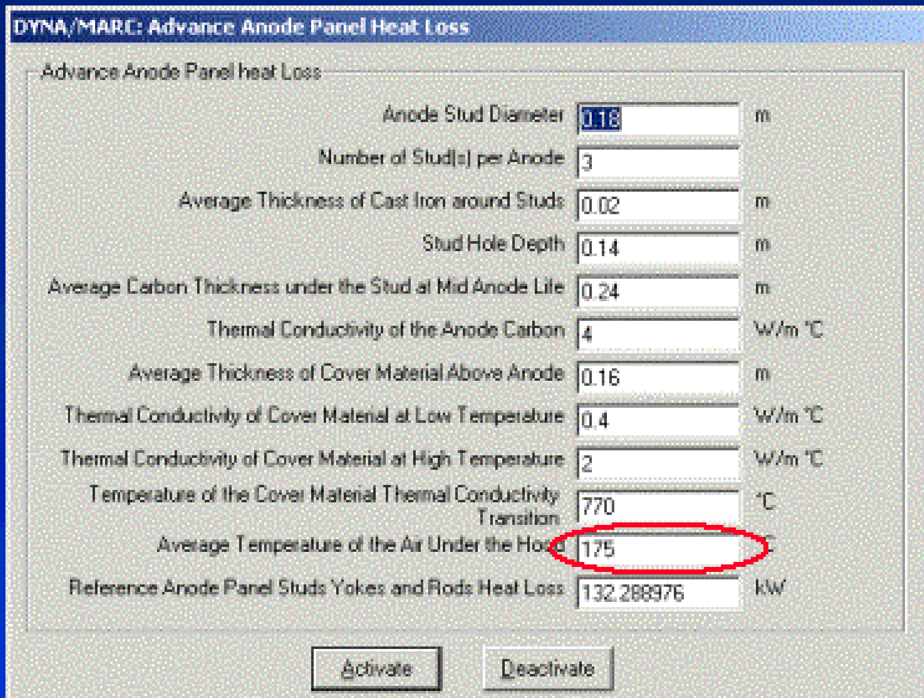
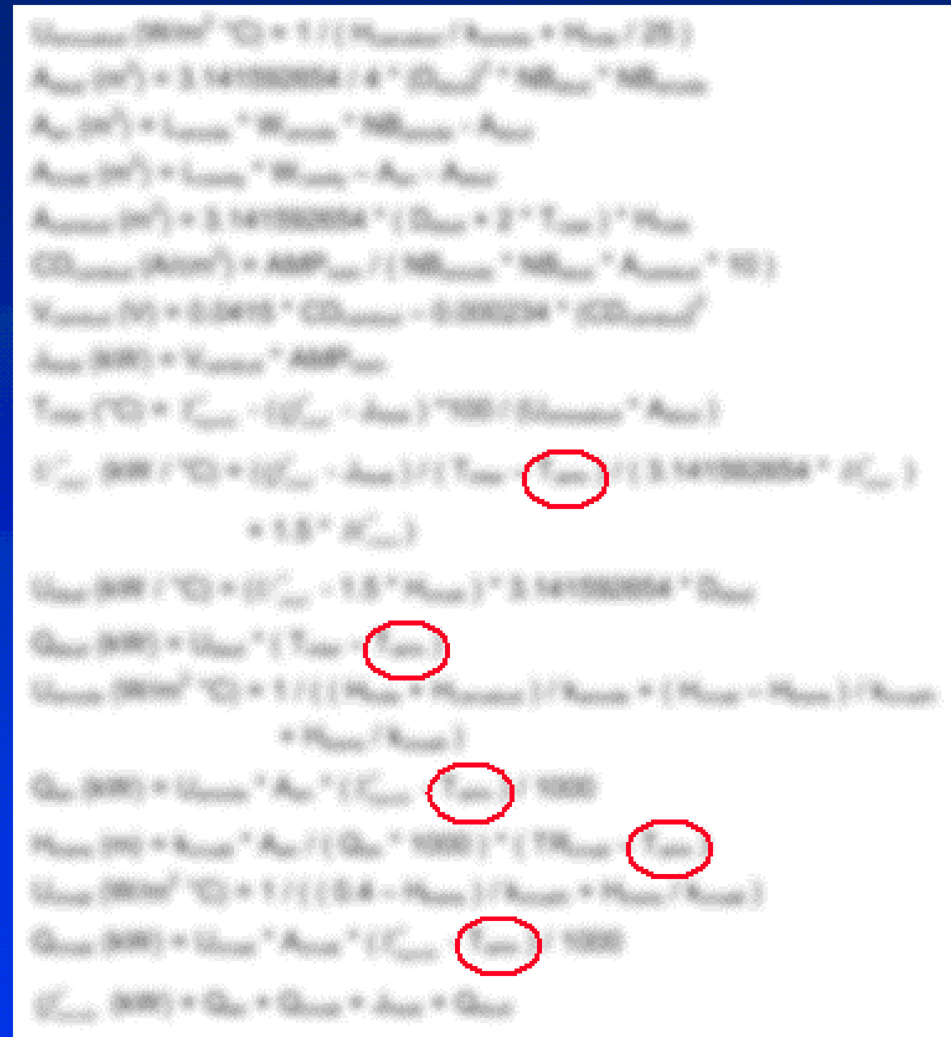
Anode panel heat loss sub-model



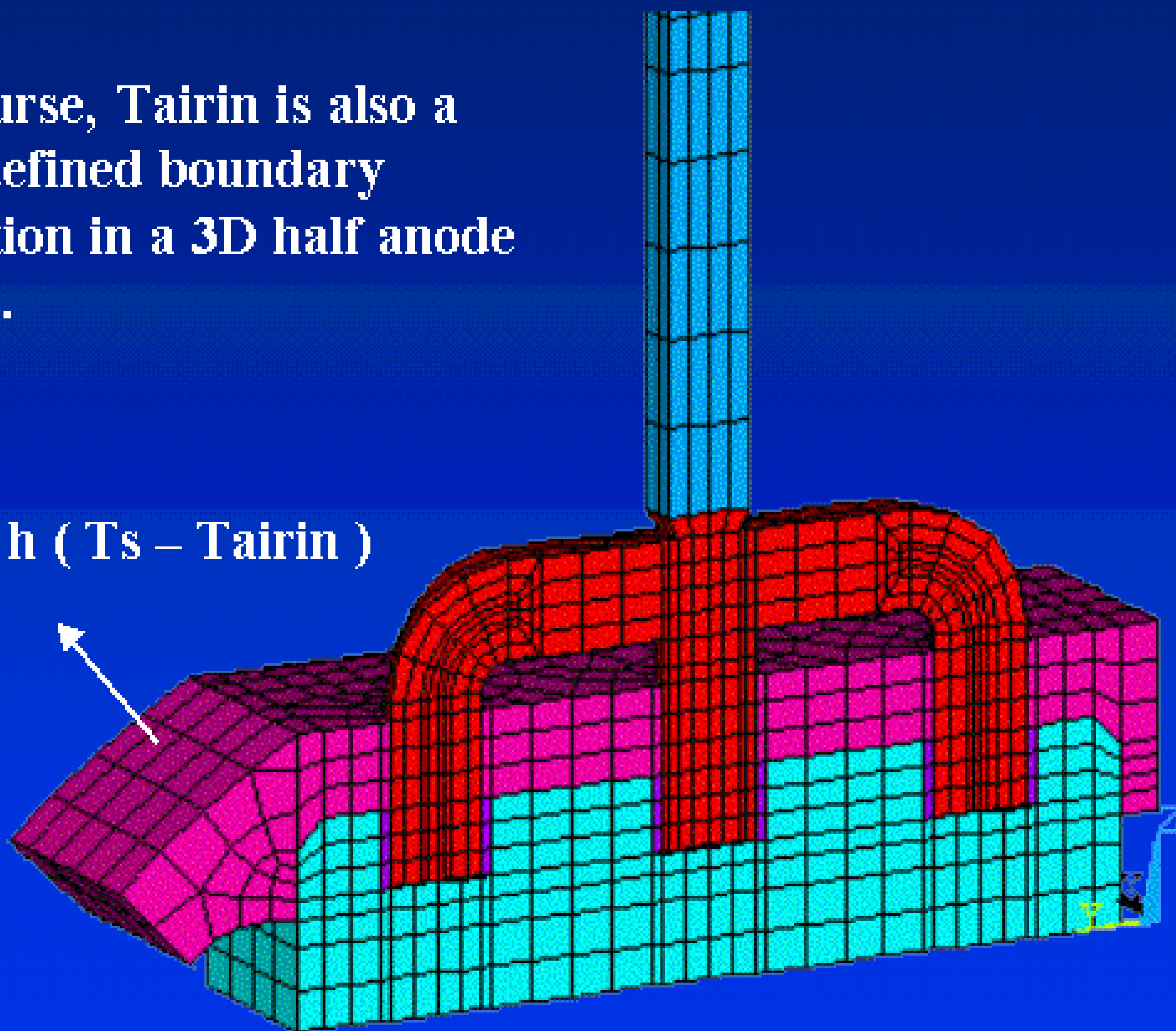


As seen before, the anode panel heat loss sub-model requires the user to specify the average air temperature under the hood (Tairin).

3D half anode model

Of course, Tairin is also a user defined boundary condition in a 3D half anode model.

$q = h\ (\ Ts - Tairin\ )$



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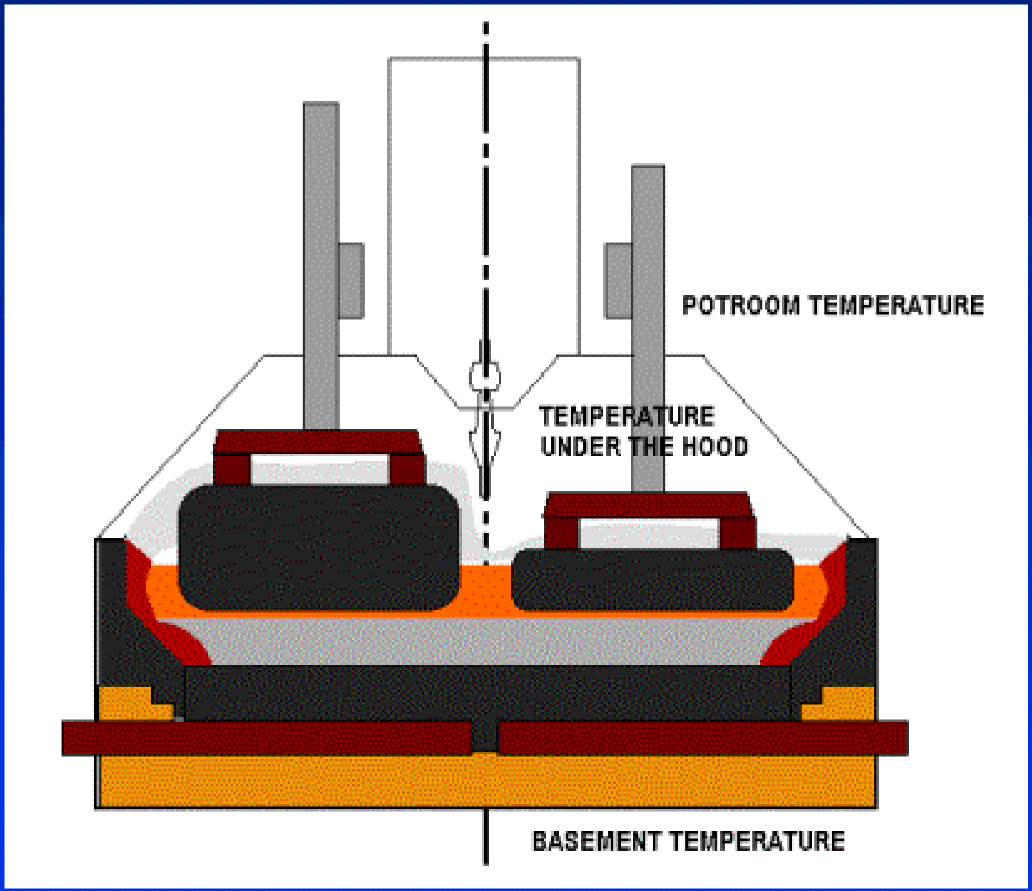
Temperature under the hood sub-model

Obviously, the temperature under the hood (Tairin) can be measured, but we expect that temperature to be function of many paratemers like:

- -the hood exhaust air rate
- -the anode panel heat loss
- -etc etc

Hence, it would be nice to develop a model in order to be able to predict its value.



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Temperature under the hood sub-model

- First we must calculate the air drawn in under the hoods at potroom temperature, and combine it with the CO_2 and CO escaping at electrolyte temperature to produce a gas blend at temperature: Tblend.
- The CO of the mixture burns, generates heat, forms more CO_2, and consumes O_2 from the air drawn in. Also, heat is generated by air burning of the anode forming additional CO_2 and consuming O_2. The heats of combustion of CO and air burning of anode carbon plus the heat from the cover and anode stubs raise the temperature of the mixture of gases to temperature: Tmix.
- This gas mixture then extracts heat from the anode rods and rises to the exhaust temperature: Texh.
- Tairin is calculated as the log mean of Tmix and Texh, just as the log mean of inlet and outlet temperatures are used to calculate heat transfer in heat exchangers.

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Heat capacities from fitted JANAF tables

$$Cp\ CO_2 = 36.216 + 0.038894\ T - 1.8743e\text{-}5\ T^2$$

$$Cp\ CO = 28.973 + 0.0050973\ T + 6.0436e\text{-}7\ T^2$$

$$Cp\ H_2O(g) = 33.467 + 0.004365\ T + 1.49e\text{-}5\ T^2$$

$$Cp\ Air = 29.066 + 0.0011449\ T + 1.214e\text{-}5\ T^2$$

$$Cp\ O_2 = 29.236 + 0.00525\ T + 1.32e\text{-}5\ T^2$$

$$Cp\ N_2 = 29.006 + 6.1987e\text{-}5\ T + 1.2e\text{-}5\ T^2$$

$$Cp\ Ar = 20.786$$

In order to compute Tblend, Tmix and Texh, the heat capacities of the gas mixtures is needed .

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Calculating the wt % H_2O in the air

$$\text{Sat. }\%H_2O = 0.5544 + 0.024237 * Tamb + 0.00012594 * Tamb^2 + 2.4237e\text{-}5 * Tamb^3 + 6.25e\text{-}7 * Tamb^4$$

If Tamb is less than 12°C, then:

$$\text{Sat. }\%H_2O = 0.3125 * e^{(0.08759 * Tamb)}$$

$$\text{Humid Factor} = (0.009096 + 0.0002196 * Tamb) * RH + (9.0377e\text{-}6 - 2.1963e\text{-}6 * Tamb) * RH^2$$

$$\%H_2O \text{ in ambient air} = (\text{Sat. }\%H_2O) * (\text{Humid Factor})$$

The moisture content of the air drawn in has a significant effect on the heat capacity of the air.

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Calculating the cell's evolution of CO and CO_2 and the air drawn into cell

kg mol O_2 /min = (%CE / 100) * (Cell kA / 6432.3)

NF = 100 / (%CO_2 + %CO / 2)

kg mol CO_2 / min = NF * (kg mol O_2 /min) * (%CO_2 / 100)

kg mol CO / min = NF * (kg mol O_2 /min) * (%CO / 100)

kg mol exh / min = (Std. m^3 / min exhaust) / 22.41

kg mol air / min = ((kg mol exh / min) – (kg mol CO_2 / min) – 0.5 * (kg mol CO / min)) * (1 - %H_2O / 100)

kg mol H_2O / min = ((kg mol exh / min) – (kg mol CO_2 / min) – 0.5 * (kg mol CO / min)) * %H_2O / 100

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Calculating Tblend

AIR = (kg mol air / min) * Cp air

H2O = (kg mol H_2O / min) * Cp H_2O

CO2 = (kg mol CO_2 / min) * Cp CO_2

CO = (kg mol CO / min) * Cp CO

Cp of CO_2 and CO are evaluated at:
T°C = (Telectrolyte – Tblend) / ln(Telectrolyte / Tblend)

Cp of Air and H_2O(g) are evaluated at:
T°C = (Tamb – Tblend) / ln(Tamb / Tblend)

Tblend = [Telectrolyte * CO2 + Telectrolyte * CO + Tamb * AIR + Tamb * H2O] / [CO2 + CO + AIR + H2O]

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Calculating Qcombust and Qairburn

Qcombust (kj/min) = (kgmol CO / min) * [283033 + 3.98* Tblend – 7.493e-3 * $(Tblend)^2$]

Carbon = kg mol CO/min + kg mol CO_2/min

AirburnC (kg mol/min) = Carbon * % Air Burn / 100

Qairburn = AirburnC * [391996 – 9.876 * Tblend – 7.936e-5 * $Tblend^2$ + 16.265 * Tan top + 3.55e-3 * $(Tan\ top)^2$]

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Calculating Cp(blend) used to calculate the temperature rise of Qtop, Qcombust and Qairburn

To compute Cp(blend), the Cp of CO_2, N_2, Ar, O_2 and H_2O (g) are evaluated at:
T°C = (Tmix – Tblend) / ln(Tmix / Tblend)

Cp(blend) = (0.78112 * (kg mol air / min) / (kg mol exh / min) * Cp N_2 +
(0.00934 * (kg mol air / min) / (kg mol exh / min) * Cp Ar +
[kg mol H_2O(g)] / (kg mol exh / min) * Cp H_2O(g) +
[(kg mol CO_2 / min) + (kg mol CO/ min) + AirburnC] /
(kg mol exh / min) * Cp CO_2 +
[0.20954 * (kg mol air / min) - 0.5 * (kg mol CO/ min) – AirburnC] /
(kg mol exh / min) * Cp O_2

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Calculating Cp(mix) used to calculate ΔT rise caused by removing heat from the anode rods

To compute Cp(mix), the Cp of CO_2, N_2, Ar, O_2 and H_2O (g) are evaluated at the temperature Tairin.

Cp(mix) = (0.78112 * (kg mol air / min) / (kg mol exh / min) * Cp N_2 +
(0.00934 * (kg mol air / min) / (kg mol exh / min) * Cp Ar +
[kg mol H_2O(g)] / (kg mol exh / min) * Cp H_2O(g) +
[(kg mol CO_2 / min) + (kg mol CO/ min) + AirburnC] /
(kg mol exh / min) * Cp CO_2 +
[0.20954 * (kg mol air / min) - 0.5 * (kg mol CO/ min) – AirburnC] /
(kg mol exh / min) * Cp O_2

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Calculating Tmix, Texh and Tairin

Tmix = Tblend + [(Qtop * 60) + Qcombust + Qairburn] /
[(kg mol exh/min) * Cp(blend)]

ΔTrise = (Qrods * 60) / [(kg mol exh/min) * Cp(mix)]

Texh = Tmix + ΔTrise

Tairin = (Texh – Tmix) / ln (Texh / Tmix)

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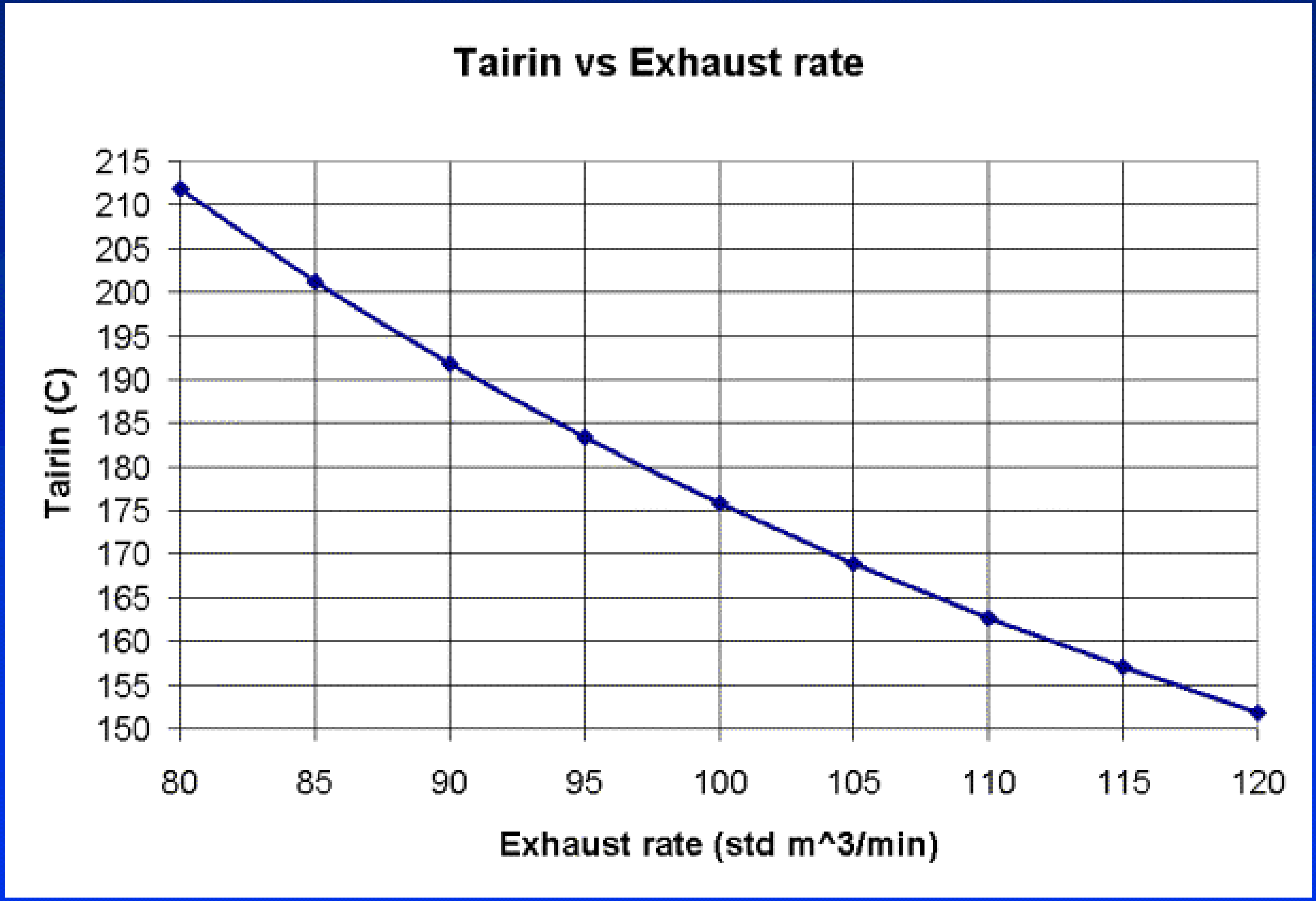
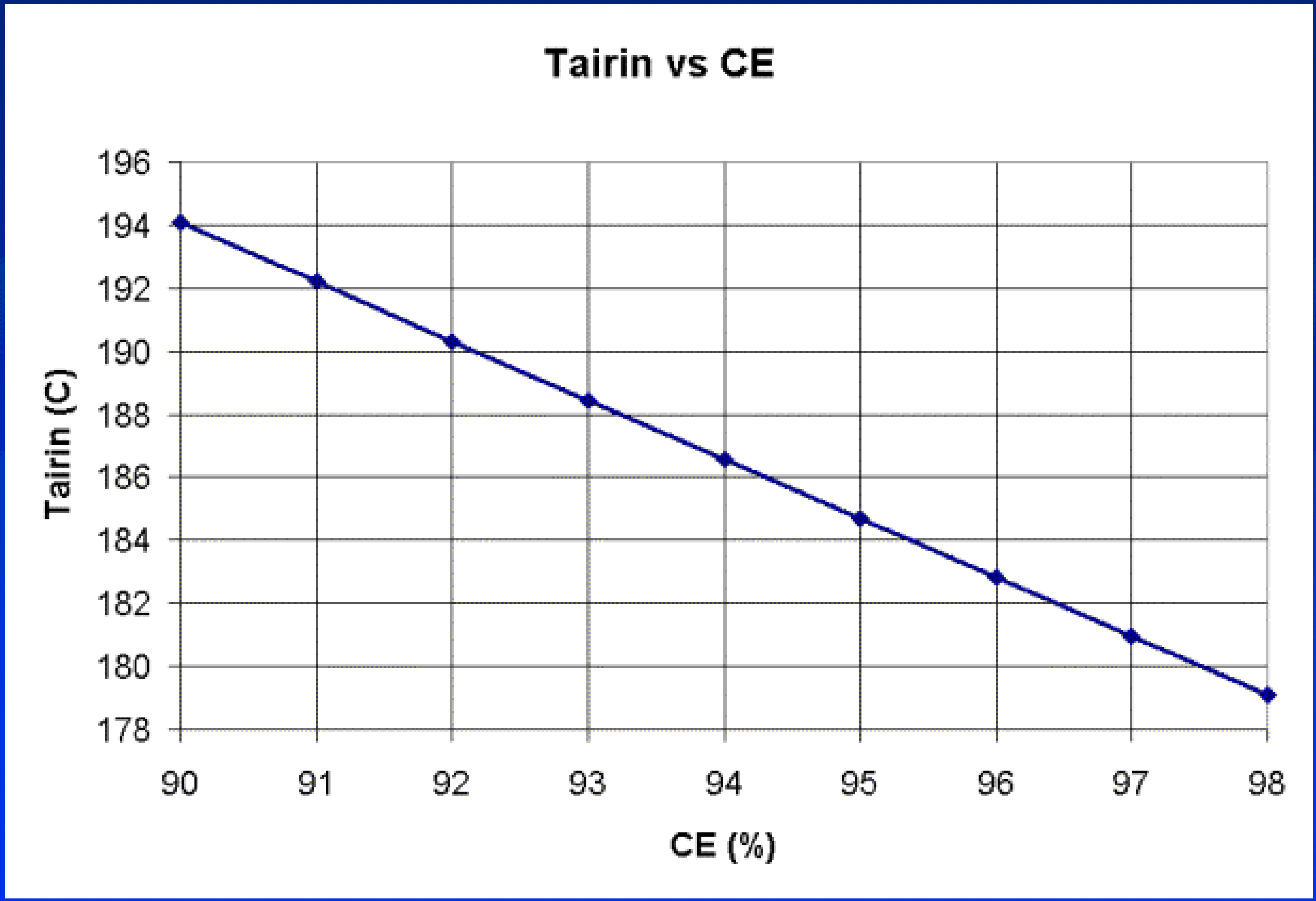
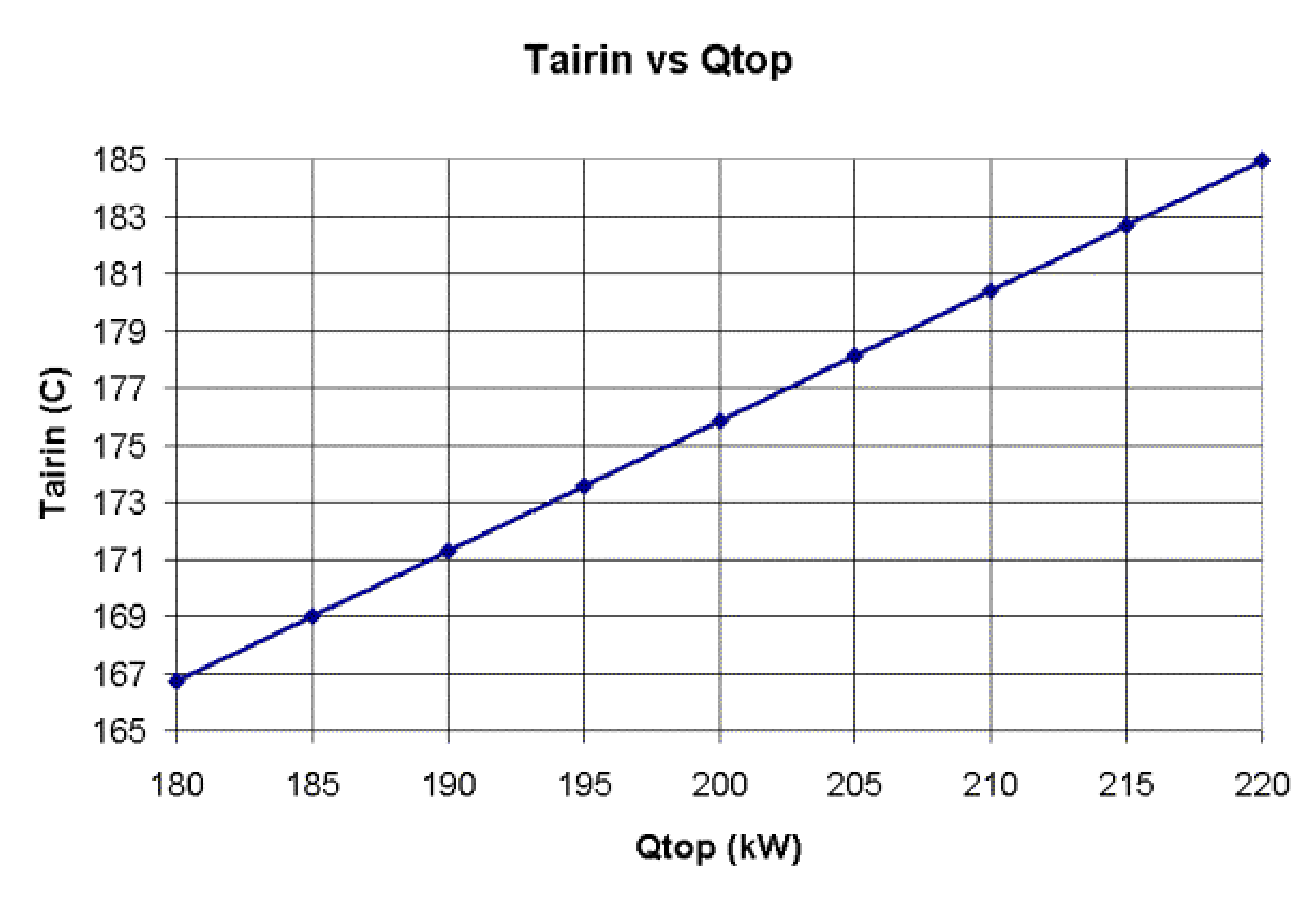
Analysis of results



Analysis of results



Analysis of results



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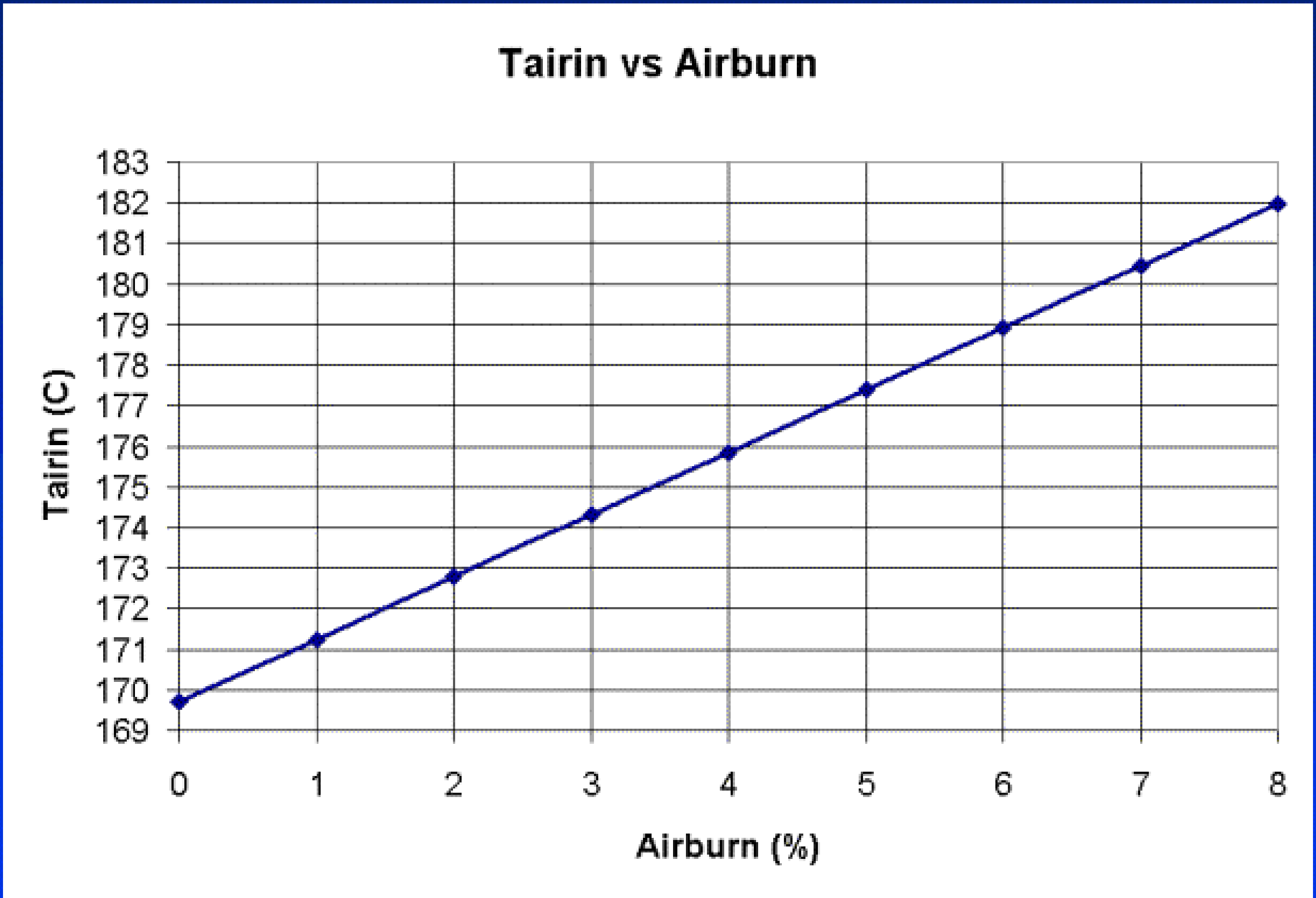
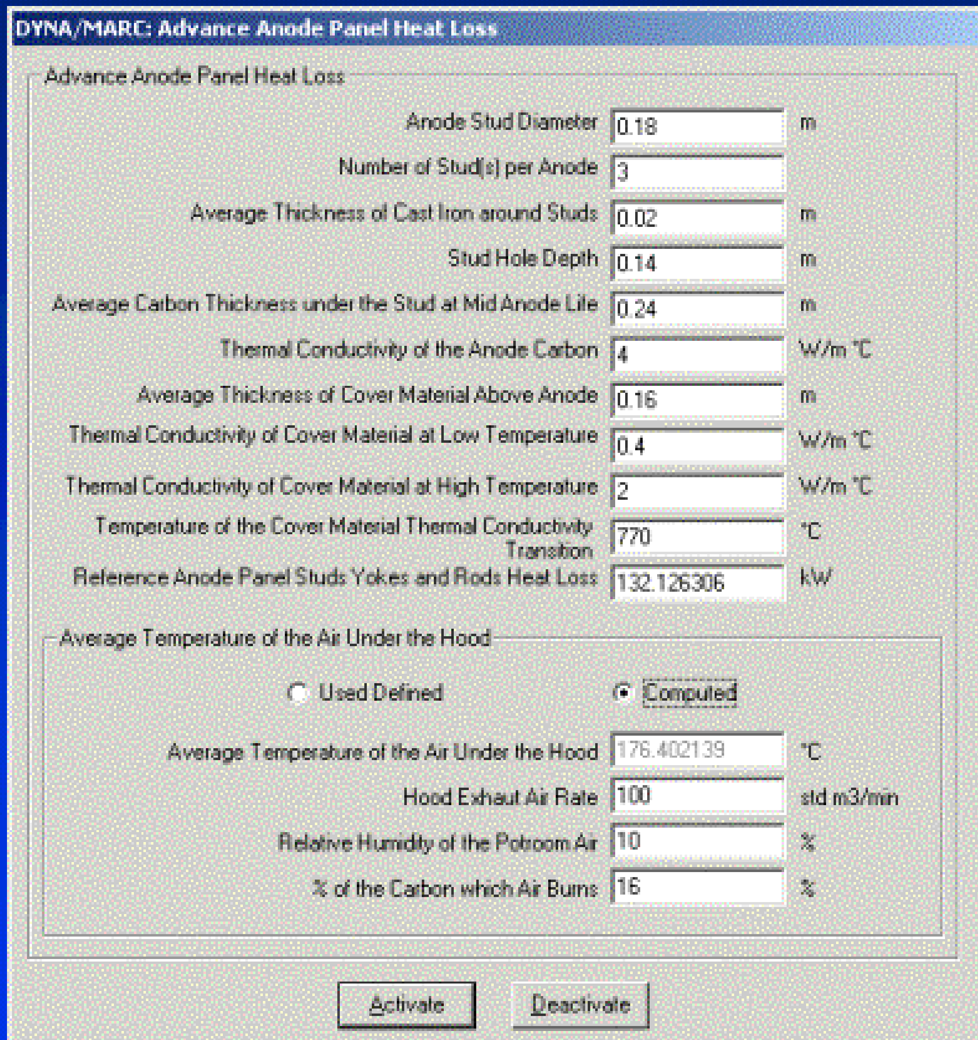
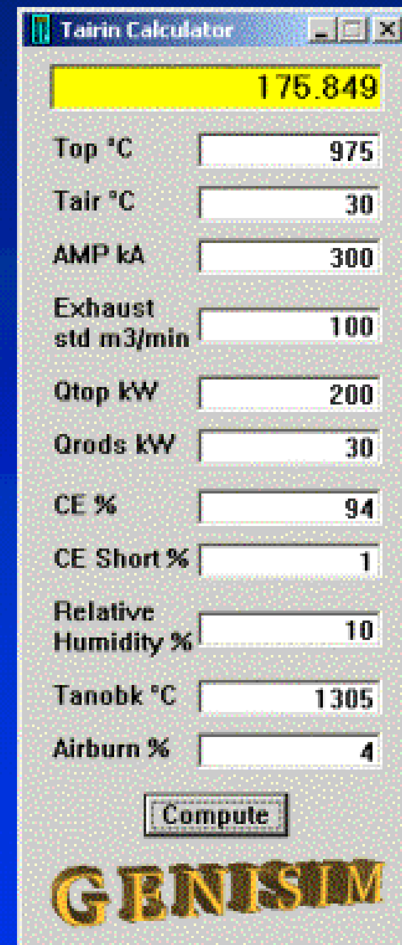
Analysis of results



Applications





Conclusions

- A method has been presented to estimate the temperatures found under the hood of a prebaked anode cell.
- The equations presented in this paper now form a new sub-model in the lump parameters+ dynamic cell simulator called Dyna/Marc version 1.8.
- The equations presented in this paper have also been coded into a little freeware program that you can download from the GeniSim Web site at www.genisim.com/download/tairin.exe.
- Both applications will let you easily estimate the gas temperature distribution under the hood.

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