# Calculating Temperatures Under Hood of a Prebake Anode Cell

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**ABSTRACT**

In computer modeling of a prebaked anode Hall Héroult cell, one needs to know the temperature of the mixture of air and cell gas (Tairin) that cools the top of the cell crust and the anode rods under the cell hoods. This temperature can be measured, of course, if a similar operating cell is available, but not if the model is of a distinctly new design. However, it is also possible to estimate the temperature. This is the aim of the present work.

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

## DEFINITION OF TERMS

% Air Burn – Part of the anode carbon which air burns, %
AirburnC – The amount of carbon that air burns, kg mol/min
CE – Current efficiency, %
Cp – Heat capacity, j °C $^{-1}$ gmol $^{-1}$
RH – Relative humidity of the potroom air, %
Tamb – Temperature of the potroom air drawn into the cell, °C
Telectrolyte – Temperature of the cell's electrolyte, °C
Tblend – Temperature of the blend of air plus cell gas just above the crust before picking up heats of combustion and heat from the crust and anode stubs , °C
Tmix – Temperature of the mix of air and cell gas a few centimeters above the crust after picking up heat of combustion and heat from the crust and anode stubs, °C
Texh – Temperature of the mix of air plus cell gas as it enters the exhaust duct, °C
Tairin – Log mean temperature of Tmix and Texh, °C
Tan top – Temperature at the top of the anode under the ore cover, °C
T – Mean temperature at which heat capacities are evaluated, °C
Qcombust – Heat generated by the burning of CO as it contacts the air drawn into the cell, kj min $^{-1}$
Qairburn – Heat generated by the air burning of the upper part of the carbon anode, kj min$^{-1}$
Qtop – Sum of heat loss from ore covered crust plus heat loss from ore cover over anodes plus the heat loss from anode stubs, kW
Qrods – Heat loss from anode rods, kW

## ASSUMPTIONS

It is assumed the cell is so designed that the air is drawn in uniformly around the periphery of the cell, that it mixes uniformly with the cell gas producing a gas mixture at an initial temperature, Tblend. The CO of this gas mixture burns to $CO_2$ at temperature, Tblend, consuming some of the oxygen and generating heat, Qcombust. Also some of the oxygen of this mixture air burns the tops of the anodes generating $CO_2$ at temperature Tblend and generates heat, Qairburn. The combination of Qcombust, Qairburn and Qtop heats this gas mixture raising its temperature to Tmix. As this gas rises, it extracts heat from the anode rods raising the gas temperature to Texh. This gas mixture then exits uniformly into a slotted gas collection duct extending the length of the cell at the top of the superstructure. Tairin is taken as the log mean of Tmix and Texh.

## CALCULATIONS

Heat capacities are needed for the various gases. They were obtained from the JANAF tables[1] and fitted to the equations below in j °C$^{-1}$ gmol$^{-1}$.

$$Cp\ CO_2 = 36.216 + 0.038894\ T - 1.8743e\text{-}5\ T^2 \quad (1)$$

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

$$Cp\ H_2O(g) = 33.467 + 0.004365\ T + 1.49e\text{-}5\ T^2 \quad (3)$$

$$Cp\ Air = 29.066 + 0.0011449\ T + 1.214e\text{-}5\ T^2 \quad (4)$$

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

$$Cp\ N_2 = 29.006 + 6.1987e\text{-}5\ T + 1.2e\text{-}5\ T^2 \quad (6)$$

$$Cp\ Ar = 20.786 \quad (7)$$

**Calculation of heat contents of gases**

The moisture content of the air drawn in has a significant effect on the heat capacity of the air. To get the percent moisture in the ambient air first we calculate the mass % water in water saturated air[2] based on the temperature of the air in the potroom.

$$Sat.\ \%H_2O = 0.5544 + 0.024237 * Tamb + 0.00012594 * Tamb^2 + 2.4237e\text{-}5 * Tamb^3 + 6.25e\text{-}7 * Tamb^4 \quad (8)$$

If Tamb is less than 12°C, then:

$$Sat.\ \%H_2O = 0.3125 * e^{(0.08759 * Tamb)} \quad (9)$$

Next using data from a psychometric chart[2] we calculate a factor to correct the saturated moisture content to the actual wt % $H_2O$ in the air.

$$Humid\ Factor = ( 0.009096 + 0.0002196 * Tamb ) * RH + ( 9.0377e\text{-}6 - 2.1963e\text{-}6 * Tamb ) * RH^2 \quad (10)$$

$$\%H_2O\ in\ ambient\ air = (Sat.\ \%H_2O) * (Humid\ Factor) \quad (11)$$

**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)

$$Cp(blend) = ( 0.78112 * (kg\ mol\ air / min) / (kg\ mol\ exh / min) * Cp\ N_2 +$$
$$( 0.00934 * (kg\ mol\ air / min) / (kg\ mol\ exh / min) * Cp\ Ar +$$
$$[kg\ mol\ H_2O(g)] / (kg\ mol\ exh / min) * Cp\ H_2O(g) +$$
$$[ (kg\ mol\ CO_2 / min) + (kg\ mol\ CO/ min) + AirburnC ] /$$
$$(kg\ mol\ exh / min) * Cp\ CO_2 +$$
$$[ 0.20954 * (kg\ mol\ air / min) - 0.5 * (kg\ mol\ CO/ min) – AirburnC ] /$$
$$(kg\ mol\ exh / min) * Cp\ O_2 \qquad (12)$$

**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.

$$Cp(mix) = ( 0.78112 * (kg\ mol\ air / min) / (kg\ mol\ exh / min) * Cp\ N_2 +$$
$$( 0.00934 * (kg\ mol\ air / min) / (kg\ mol\ exh / min) * Cp\ Ar +$$
$$[kg\ mol\ H_2O(g)] / (kg\ mol\ exh / min) * Cp\ H_2O(g) +$$
$$[ (kg\ mol\ CO_2 / min) + (kg\ mol\ CO/ min) + AirburnC ] /$$
$$(kg\ mol\ exh / min) * Cp\ CO_2 +$$
$$[ 0.20954 * (kg\ mol\ air / min) - 0.5 * (kg\ mol\ CO/ min) – AirburnC ] /$$
$$(kg\ mol\ exh / min) * Cp\ O_2 \qquad (13)$$

**Calculating the cell's evolution of CO and $CO_2$**

$$kg\ mol\ O_2 /min = ( \%CE / 100 ) * ( Cell\ kA / 6432.3 ) \qquad (14)$$

A normalizing factor is used to account for only one oxygen being used per mol of CO.

$$NF = 100 / ( \%CO_2 + \%CO / 2 ) \qquad (15)$$

%CO and %$CO_2$ come from calculations of current efficiency by the model.

$$kg\ mol\ CO_2 / min = NF * (kg\ mol\ O_2 /min ) * ( \%CO_2 / 100) \qquad (16)$$

$$kg\ mol\ CO / min = NF * (kg\ mol\ O_2 /min ) * ( \%CO / 100) \qquad (17)$$

**Calculating air drawn into cell**

$$kg\ mol\ exh / min = (Std.\ m^3 / min\ exhaust) / 22.41 \qquad (18)$$

$$kg\ mol\ air / min = ( (kg\ mol\ exh / min) – (kg\ mol\ CO_2 / min) –$$
$$0.5 * (kg\ mol\ CO / min) ) * ( 1 - \%H_2O / 100 ) \qquad (19)$$

$$kg\ mol\ H_2O / min = ( (kg\ mol\ exh / min) – (kg\ mol\ CO_2 / min) –$$
$$0.5 * (kg\ mol\ CO / min) ) * \%H_2O / 100 \qquad (20)$$

**Calculating Tblend**

Let:

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)

Equation 21 equates the heat transferred, kJ/min, from the cell gas to the air drawn in:

AIR * (Tmix –Tamb) + H2O * (Tblend– Tamb) =
CO2 * (Telectrolyte - Tblend) + CO * (Telectrolyte - Tblend) (21)

Solving the above equation for Tblend:

Tblend = [ Telectrolyte * CO2 + Telectrolyte * CO + Tamb * AIR +
Tamb * H2O ] / [ CO2 + CO + AIR + H2O ] (22)

**Calculating Tmix**

Calculating Qcombust

Qcombust, the quantity of heat generated by the combustion of CO as it exits the electrolyte is needed to calculate Tmix. Qcombust is obtained by calculating the enthalpy of the reaction:

$$CO(g, Tblend) + O_2(g, Tblend) \rightarrow CO_2(g, Tblend) \quad (23)$$

The data from this calculation was fitted to the following equation:

Qcombust (kj/min) = (kgmol CO / min) *
[ 283033 + 3.98* Tblend – 7.493e-3 * $(Tblend)^2$ ] (24)

Calculating Qairburn

We take the total carbon consumption by electrolysis and multiply it by a fraction representing the amount that air burns to get the airburn carbon. Net carbon consumption will be the sum of electrolytically consumed Carbon plus AirburnC plus Dusting.

Carbon = kg mol CO/min + kg mol $CO_2$/min (25)

AirburnC (kg mol/min) = Carbon * % Air Burn / 100 (26)

This carbon burns:

$O_2$(Tblend) + C(Tan top) $\rightarrow$ $CO_2$(Tblend) (27)

Generating Qairburn kj $min^{-1}$ of heat:

$$Qairburn = AirburnC * [\ 391996 - 9.876 * Tblend - 7.936e\text{-}5 * Tblend^2 + 16.265 * Tan\ top + 3.55e\text{-}3 * (Tan\ top)^2\ ] \quad (28)$$

Calculating Tmix

$$Tmix = Tblend + [\ (\ Qtop * 60\ ) + Qcombust + Qairburn\ ] / [\ (kg\ mol\ exh/min) * Cp(blend)\ ] \quad (29)$$

**Calculating Texh and Tairin**

$$\Delta Trise = (\ Qrods * 60\ ) / [\ (kg\ mol\ exh/min) * Cp(mix)\ ] \quad (30)$$

$$Texh = Tmix + \Delta Trise \quad (31)$$

$$Tairin = (Texh - Tmix) / \ln (Texh / Tmix) \quad (32)$$

Because the calculation of many of the values depend upon Tblend, Tmix and Tairin, not yet calculated, the solution has to be an iterative process. The suggested value for first iteration is Tblend = 50° C, Tmix = 160° C and Tairin = 170° C.

## ANALYSIS OF RESULTS

Figure 1 shows, as expected that the temperature under the hood will drop as more air is drawn in.

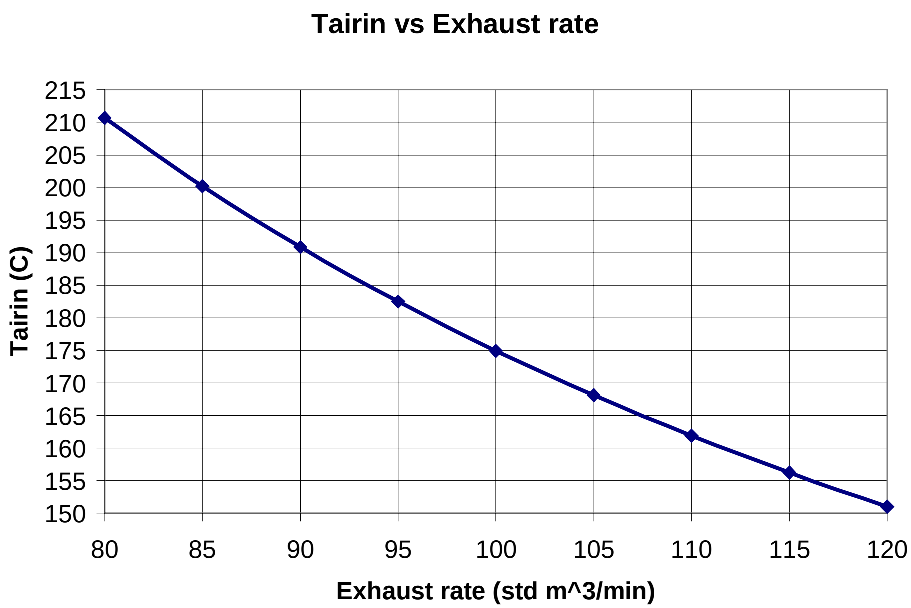


Figure 1 – Tairin vs Exhaust rate

Figure 2 indicates that as current efficiency increases, the temperature under the hood should drop. This is an idealized curve and may not be seen in practice. It is true that more energy goes into making aluminum and less into heat at higher current efficiencies. Changes in crust cover and anode changing will often obscure the effect of current efficiency.

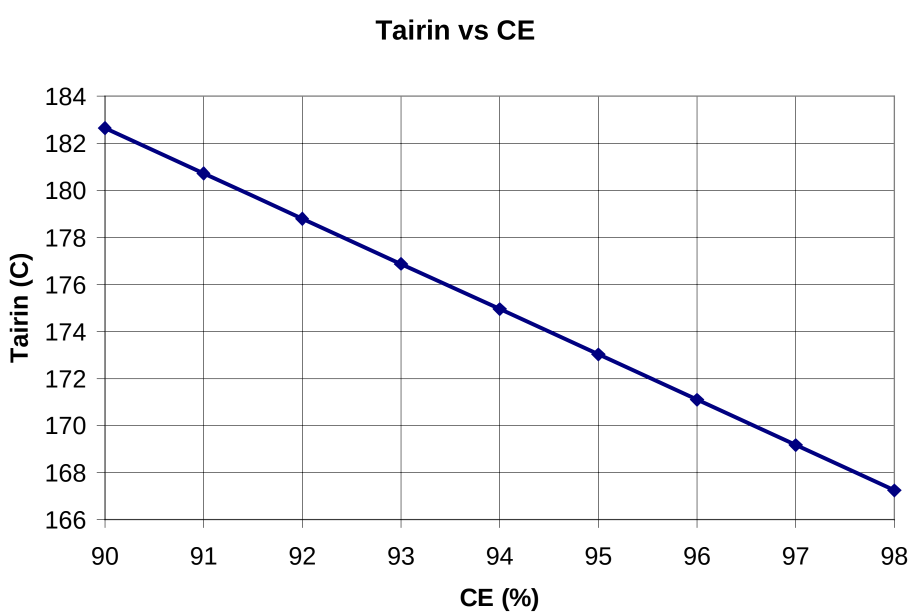


Figure 2 – Tairin vs Current efficiency

Figure 3 shows, as expected that the temperature under the hood will increase with increasing heat off the top of the cell.

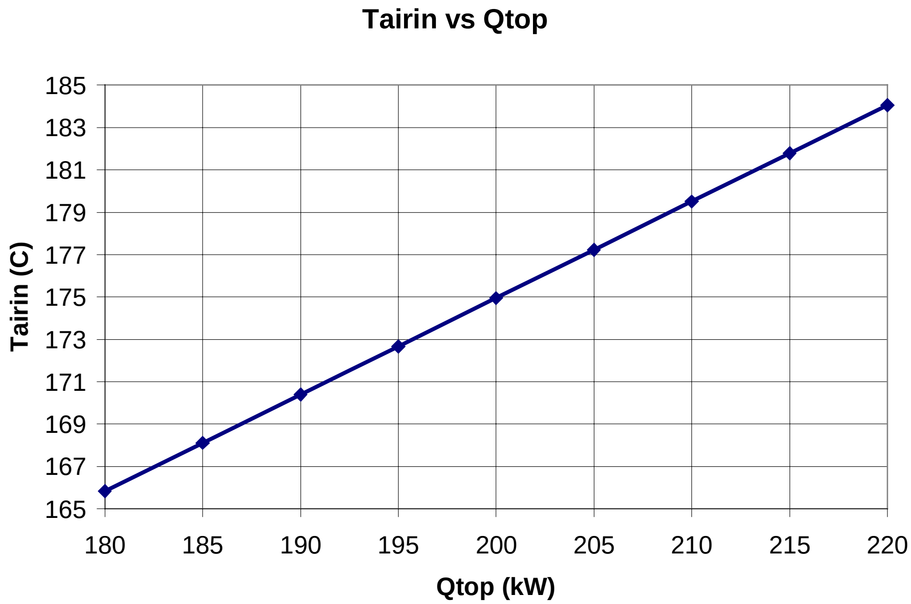


Figure 3 – Tairin vs Sum of heat loss from ore covered and anode stubs

Figure 4 shows that similarly to the current efficiency, the amount of anode carbon that air burns has a non-negligible impact on the temperature under the hood.

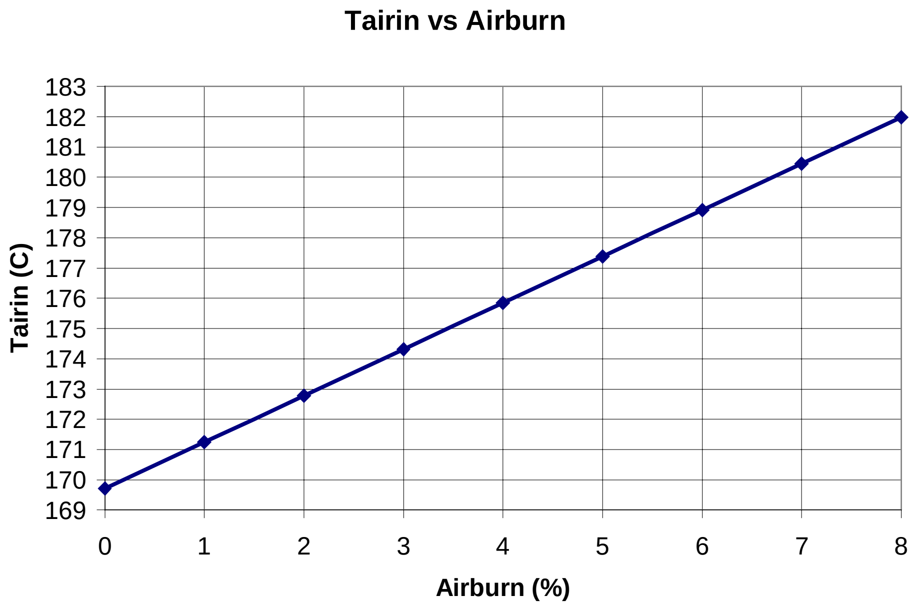


Figure 4 – Tairin vs Anode carbon air burn

## 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 have been programmed into a computer program that will let you estimate the gas temperature distribution under the hood. You can download a free copy of this program from the GeniSim Web site at www.genisim.com/download/tairin.exe.

## REFERENCES

(1) W.N. Chase Jr, C.A. Davies, J.R. Downey, Jr, D.F. Frurip, R.A. McDonald, and A.N. Syverud, JANAF Thermochemical Tables, 3rd Edition, Publised by thre American Chemical Society and the American Institute of Physics for the National Bureau of Standards (1985).

(2) Perry and Chilton, Chemical Engineers' Handbook, Fifth Edition, McGraw-Hill, New York, Pages 12-5, 12-7 and 12-8 (1973).