BALL'S FORMULA METHOD REVISITED ON COME-UP-TIME

A tribute to Dr. Ball monumental master piece

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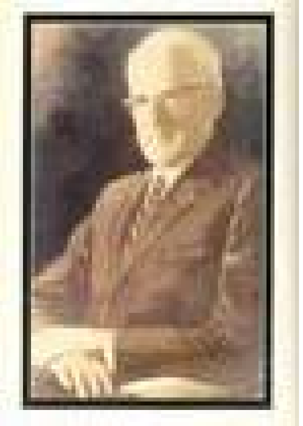
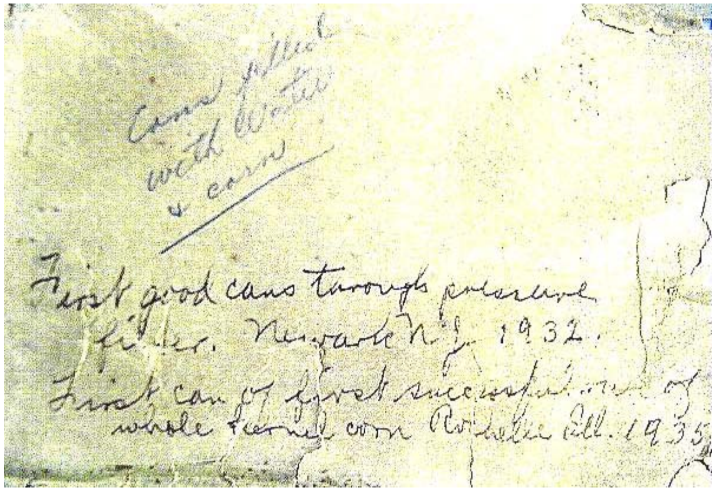
OUTLINE

- Introduction and objective.
- Formula method fundamentals.
- Formula method assumptions.
- Hypothesis
- Problem description.
- Results and Discussion
- Conclusions
- Corollary



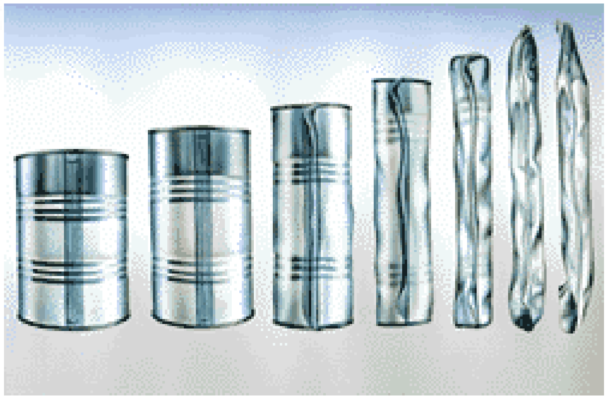


Cans filled with water & corn

First good cans through pressure filler. Newark N.J. 1932.
First can of first successful run of whole kernel corn Rochelle Ill. 1935

INTRODUCTION

Ball's formula method was first established in 1923. Although the original version of Formula Method has undergone some variations, it has conceptually remained unchanged.



OBJECTIVES

- Offer a critical analysis of the **correction factor** for come-up time (CUT) introduced by Dr. C. Olin Ball in his famous Formula Method, and

- Show that operator's process time (P_t) is always the same, regardless of how much come-up-time is taken into account.

FORMULA METHOD FUNDAMENTALS

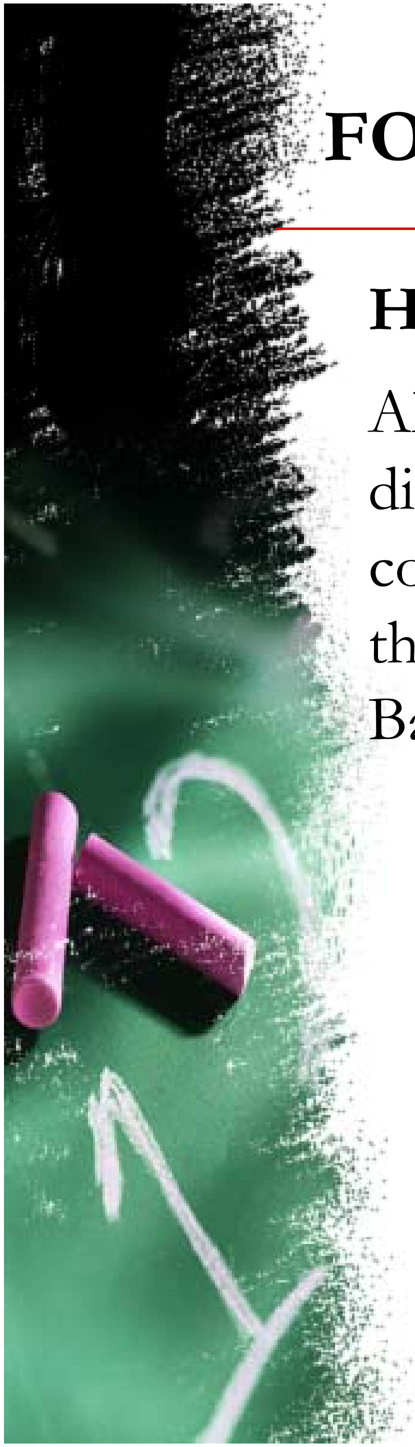
Ball referred to mathematical representations of heat transfer into bodies of cylindrical shape (both convection and conduction).

Heat Transfer Model for Perfect Mixing

$$\boxed{\frac{T_{RT}-T_{C.S.}}{T_{RT}-IT}=exp\left[-\frac{UA}{MC_p}t\right]}$$

Heat Transfer Model for Pure Conduction

$$\boxed{\frac{T_{RT}-T_{C.S.}}{T_{RT}-IT}=2.0396\,exp\left[-\left(\frac{\left(2.4048^2\right)}{R^2}+\frac{\pi^2}{l^2}\right)\cdot\frac{k}{\rho\,C_p}\cdot t\right]}$$

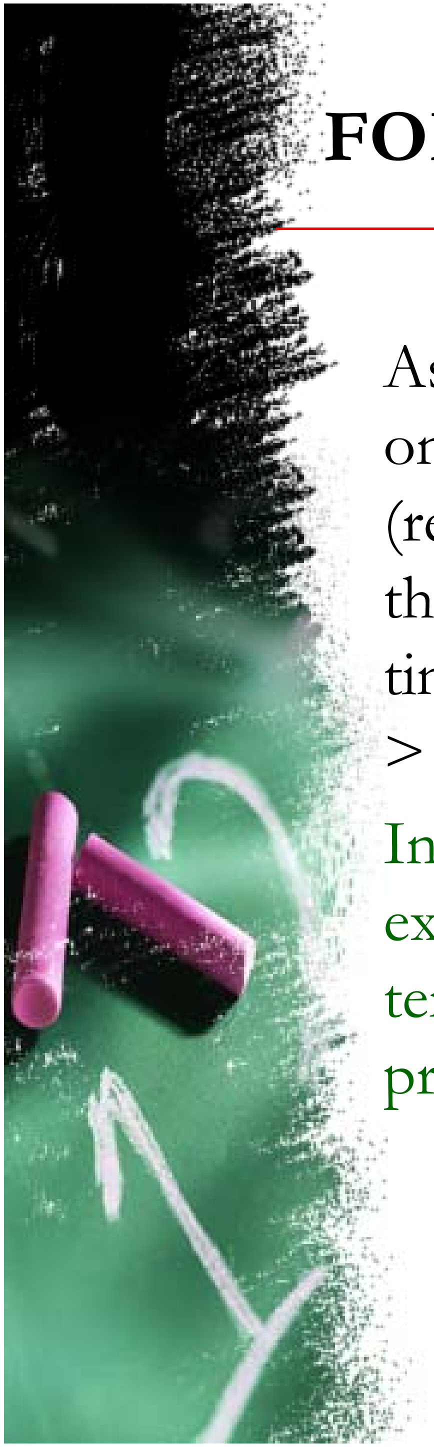


FORMULA METHOD FUNDAMENTALS

Heat Transfer Model: A general approach

Although the heat transfer mechanisms are rather dissimilar, both models (pure conduction and forced convection), within certain limitations, can be described by the same mathematical expression as was presented by Dr. Ball in 1923:

$$\boxed{t = f \cdot \log\left(j \frac{T_{RT} - IT}{T_{RT} - T} \right)}$$



FORMULA METHOD FUNDAMENTALS

As was shown by Datta (1990), the latter expression is not only valid for finite cylinders, but also for arbitrary shapes (rectangular, oval shape, etc.). The main limitations are that, for heat conduction foods, it is only valid for heating times beyond the initial lag period (when Fourier number > 0.6).

In addition, as noticed by Professor Ball the referred expression has the assumption of constant retort temperature (T_{RT}). However, everybody is aware that real processes have come-up time (CUT).

FORMULA METHOD ASSUMPTIONS

Correction factor for come-up time (CUT).

Ball (1923) determined a value of 42% for the contribution of CUT to the lethal effect, so that the effective process time, ***B*** was given by:

$$\boxed{B = P_t + 0.42 * CUT}$$

It has been stated that the figure of 42% is generally regarded as a conservative estimate and is really only applicable to batch retorts with linear come-up heating profile.

SCIENTIFIC LITERATURE

Normally, the lethal effects of CUT at the center or cold spot of a food are relatively small for containers of traditional size and shape. However, with thin profile plastic pouches and trays, the effect of CUT could be more significant.

Spinak & Wiley (1982) found that CUT effectiveness varied from 35-77% and Ramaswamy & Tung (1986) found that the effectiveness factor of 42% was very conservative for thin profile packages.

HYPOTHESIS

The hypothesis of this presentation is that Ball's formula method, just as the General method, also includes the effect of CUT in its calculations, regardless of where the zero time line is placed within the come-up time.

Then, there is no need for a correction factor!

FOCUS OF THE ANALYSIS

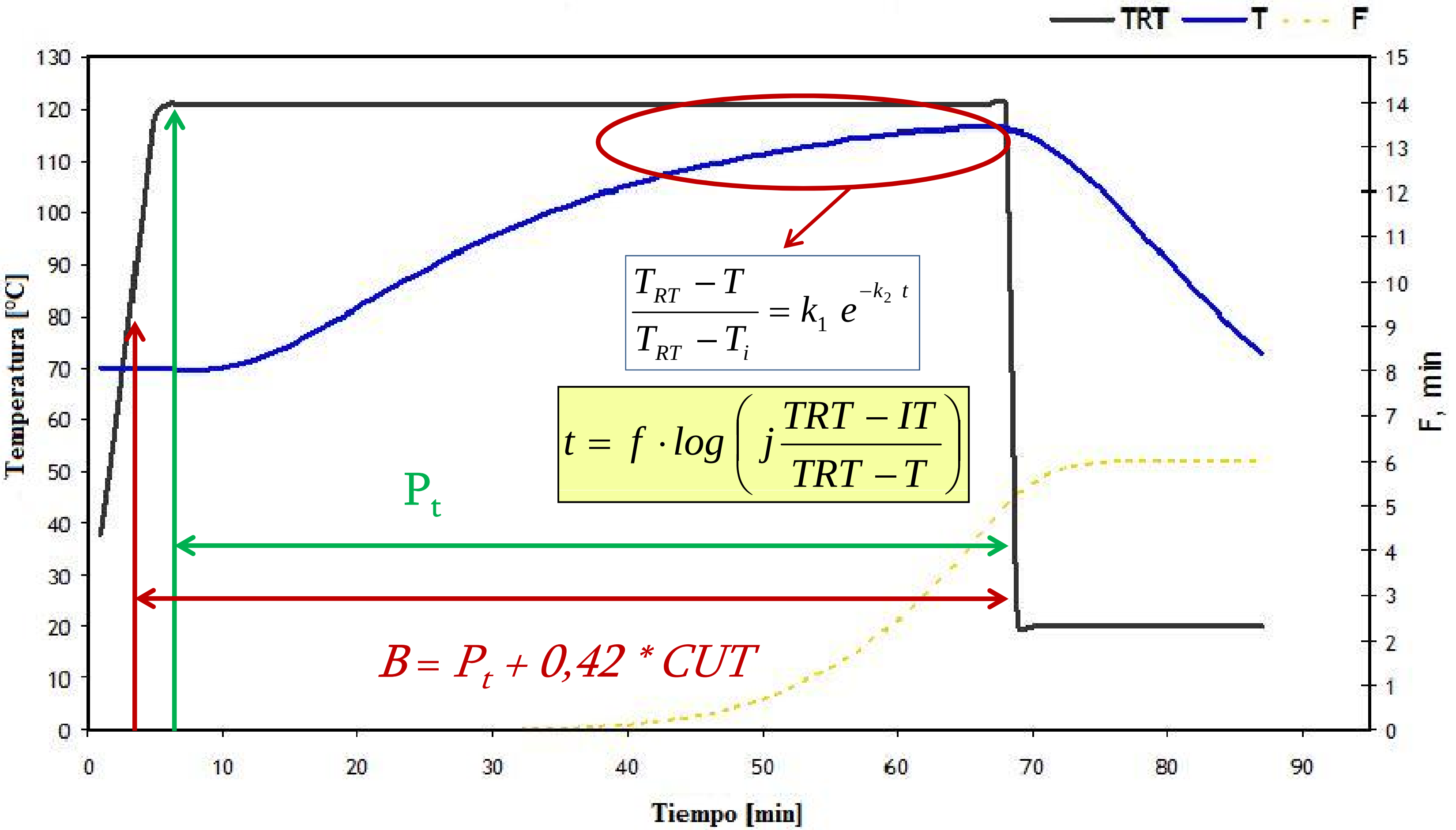
The ***F*** value of a given process can be expressed as follows:

$$\boxed{F_{PROCESS} = F_{HEATING} + F_{COOLING}}$$

$$\boxed{F_{PROCESS} = \int_0^{t_g} 10^{\frac{T-T_{ref}}{z}}\,dt + \int_{t_g}^{t} 10^{\frac{T-T_{ref}}{z}}\,dt}$$

The focus of our analysis will be to evaluate the accuracy of Ball's method in relation to $\boldsymbol{F_{HEATING}}$ calculation, and also its prediction on $\boldsymbol{T_g}$.

GRAPHICAL REPRESENTATION



$$\frac{T_{RT}-T}{T_{RT}-T_i}=k_1\,e^{-k_2\,t}$$

$$t = f\cdot \log\left(j\,\frac{TRT-IT}{TRT-T}\right)$$

P_t

$B = P_t + 0{,}42 * CUT$

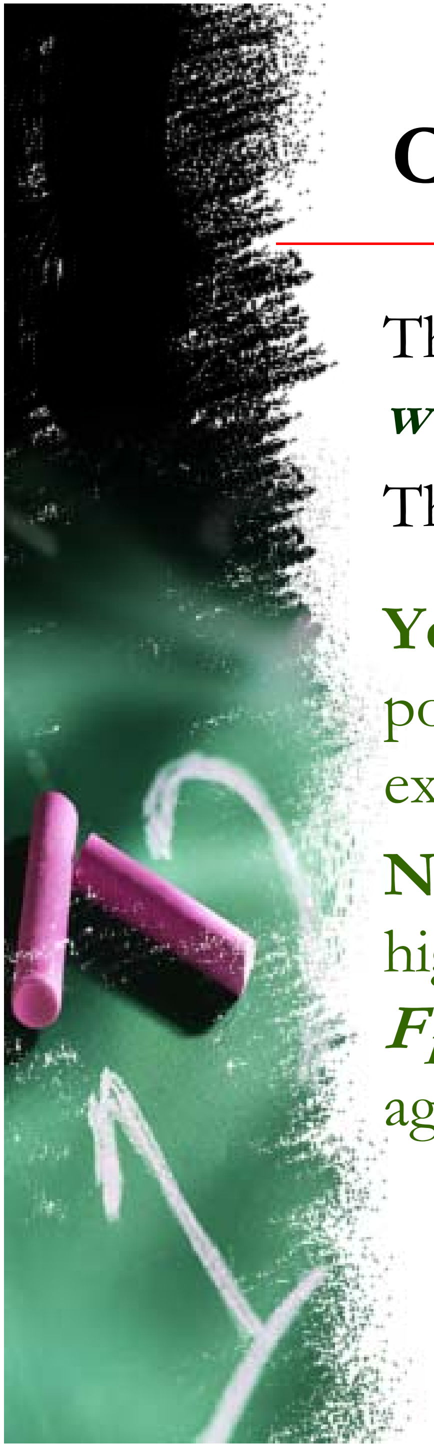
CONCEPTUAL ANALYSIS

Given that the formula method is solving the $\boldsymbol{F_{PROCESS}}$ equation analytically, it is necessary to express temperature versus time with an analytical expression .

Dr. C. Olin Ball proved with a strong and sound heat transfer background that the following equation could fit well the data during the heating period for any foods.

$$t = f \cdot log\left(j \frac{T_{RT} - IT}{T_{RT} - T} \right)$$

For $\boldsymbol{F_{HEATING}}$ his main concern was the fact that $\boldsymbol{T_{RT}}$ was not constant in a real processes because of the presence of come-up time..



CONCEPTUAL ANALYSIS

The question is, ***was Dr. C. Olin Ball right to be worried with the presence of come-up time?***

The answer is YES and NO, and then NO!, why?

Yes, because depending on CUT length and shape, possibly, the proposed equation will not fit well the experimental data.

No, because the proposed equation normally has very high correlation, meaning that the calculations of $F_{HEATING}$ and T_g -with the fitted data- are in close agreement with real data.

CONCEPTUAL ANALYSIS

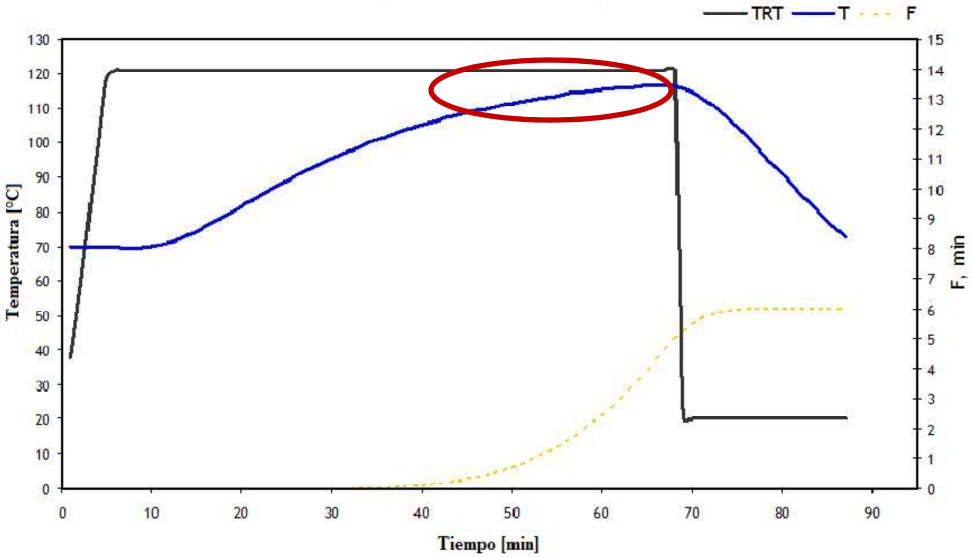
When using the referred mathematical expression coupled with experimental data to obtain ***f*** and ***j*** by regression analysis (curve fitting); normally results in extremely high correlation (R^2 in the order of 0.999)

In fact, as we will see in the next slides, in this presentation, independent of CUT shape and length the proposed equation normally has an extremely high correlation.

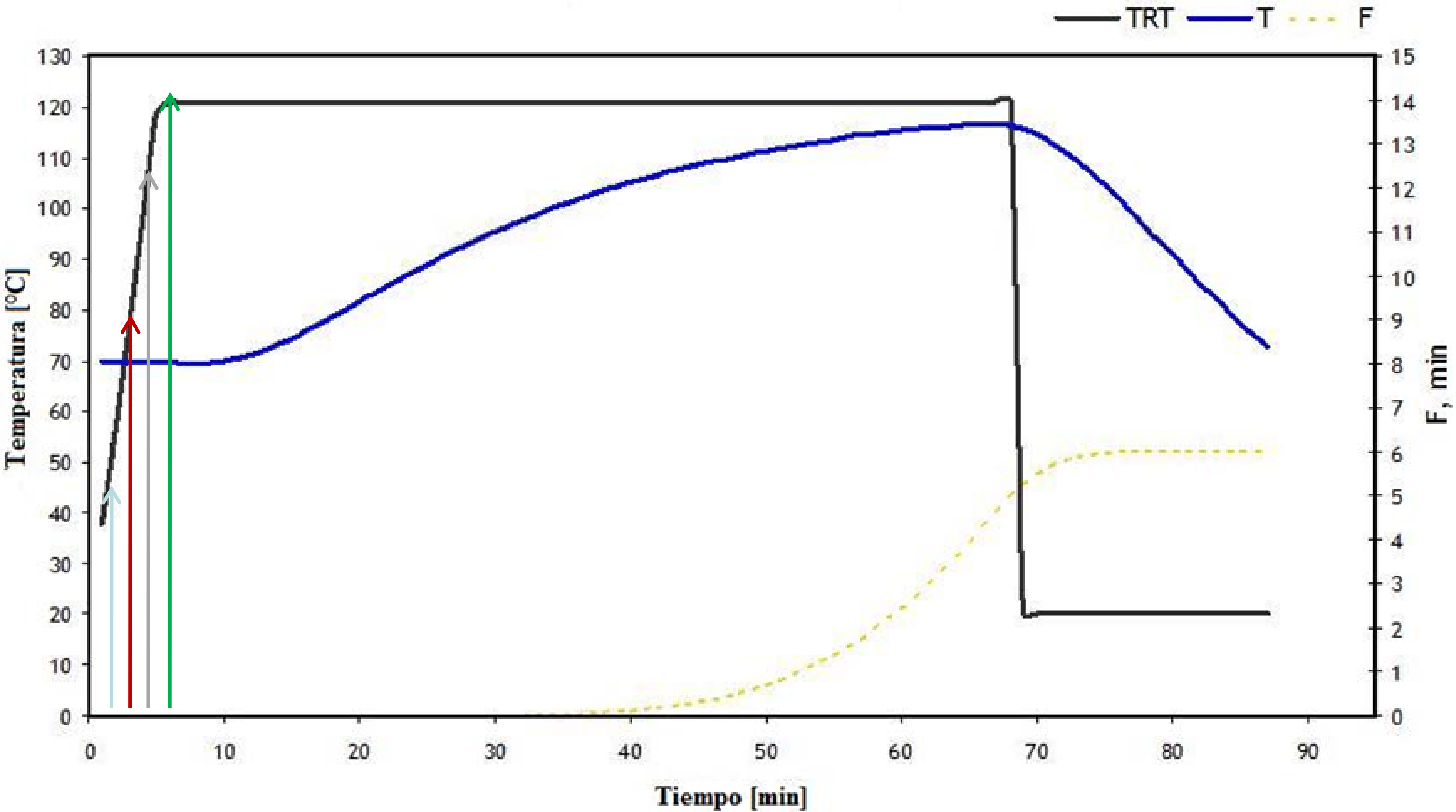
Finally, we will demonstrate that there is no need for such correction factor.

CONCEPTUAL ANALYSIS

What is really needed is an equation that independent of CUT shape and length will be able to fit well experimental data, why?, because the equation is not used for prediction, is just to have an expression able to have a good degree of fitness and, then, accurately calculate $F_{HEATING}$ and T_g.



RESULTS



TRT
T
F
Temperatura [°C]
130
120
110
100
90
80
70
60
50
40
30
20
10
0
F, min
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
10
20
30
40
50
60
70
80
90
Tiempo [min]

RESULTS

Linear heating profile

CUT (min)	*α*	*f (min)*	*j*	*B (min)*	P_t
10	1.0	55.4	2.250	98.85	**88.85**
	0.7	55.4	1.986	95.85	**88.85**
	0.42	55.4	1.768	93.05	**88.85**
	0.2	55.4	1.613	90.84	**88.84**
	0	55.4	1.484	88.84	**88.84**

$\boxed{B = P_t + \alpha * CUT}$ then $\boxed{P_t = B - \alpha * CUT}$

RESULTS

Linear heating profile, can size 81x106 for different come-up times.

CUT (min)	α	*f (min)*	*j*	*B (min)*	P_t
5	1.0	55.4	2.016	96.25	**91.25**
	0.7	55.4	1.894	94.75	**91.25**
	0.42	55.4	1.787	93.35	**91.25**
	0.2	55.4	1.707	92.25	**91.25**
	0	55.4	1.638	91.25	**91.25**

CUT (min)	α	*f (min)*	*j*	*B (min)*	P_t
15	1.0	55.4	2.519	101.6	**86.6**
	0.7	55.4	2.089	97.1	**86.6**
	0.42	55.4	1.754	92.9	**86.6**
	0.2	55.4	1.530	89.6	**86.6**
	0	55.4	1.350	86.6	**86.6**

RESULTS

Different can sizes: 74x141; 83x106 and 151x174

CUT (min)	*α*	*f (min)*	*j*	*B (min)*	P_t
10	1.0	51.5	2.184	92.35	**82.35**
	0.7	51.5	1.910	89.35	**82.35**
	0.42	51.5	1.680	86.45	**82.35**
	0.2	51.5	1.527	84.35	**82.35**
	0	51.5	1.396	82.35	**82.35**

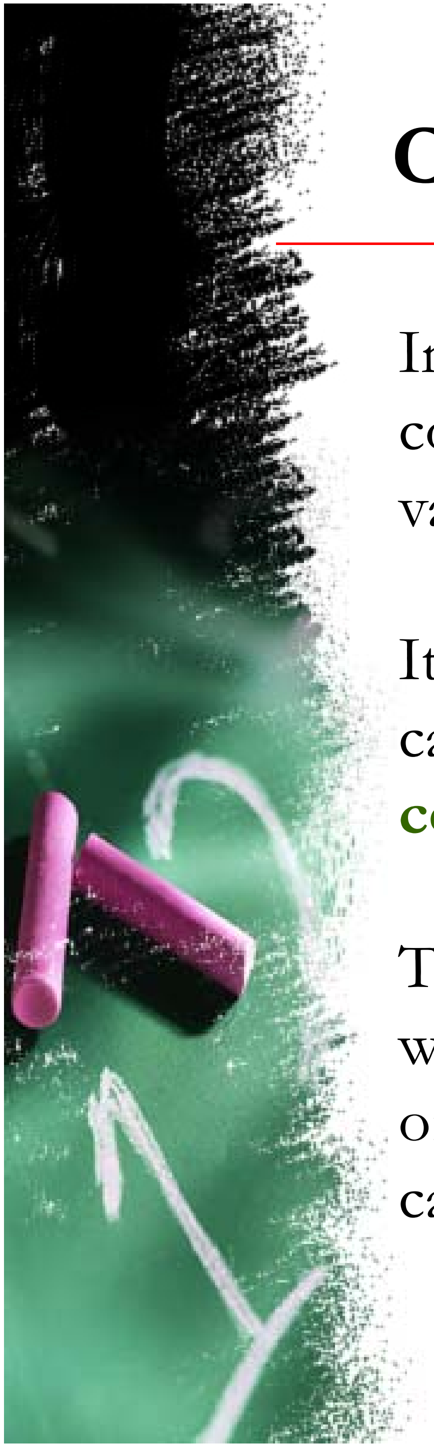
CUT (min)	*α*	*f (min)*	*j*	*B (min)*	P_t
10	1.0	55.4	2.250	98.85	**88.85**
	0.7	55.4	1.986	95.85	**88.85**
	0.42	55.4	1.768	93.05	**88.85**
	0.2	55.4	1.613	90.84	**88.84**
	0	55.4	1.484	88.84	**88.84**

CUT (min)	*α*	*f (min)*	*j*	*B (min)*	P_t
10	1.0	176.1	1.989	255.25	**245.25**
	0.7	176.1	1.912	252.25	**245.25**
	0.42	176.1	1.840	249.3	**245.25**
	0.2	176.1	1.791	247.25	**245.25**
	0	176.1	1.745	245.25	**245.25**

RESULTS

Accuracy of $F_{HEATING}$ calculation from Ball Formula method when compared with General Method

CASE	GENERAL METHOD		FORMULA METHOD			
	F	*B*	*f*	*j*	*F*	*B*
Linear CUT	2.991	91	55.4	1.768	2.994	90.8
Concave CUT	3.048	89	55.4	1.679	3.051	88.8
Convex CUT	3.059	92	55.4	1.897	3.059	92.7
TRT with oscillations	2.992	91	55.4	1.766	3.006	90.8



CONCLUSIONS

Independent of the time-shift associated with chosen contribution of come up time, always the obtained value for operators process time (P_t) is the same.

It is not recommended to shift the time because you can obtain directly P_t and **avoid conceptual confusions.**

Testing with different CUT shapes and length we were able to verify the high and consistent goodness of fit, then assuring the accuracy of Ball method in calculating $F_{HEATING}$ and T_g.

COROLLARY

Independent of the correction factor established by Dr. C. Olin Ball, his calculations are correct and always take into account <u>100%</u> of come-up time.

Muchas Gracias

EX UMBRA IN SOLEM

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