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A QUANTITATIVE MEASURE OF MIXING BY NEUTRON TRANSMISSION

Introduction

The quality of the glass product and the magnitude of foaming during melting are related to the degree of mixing that exists in the calcine and frit feed. Visual criteria for a well mixed feed or a "good" glass can be subjective judgements. A need exists to quantitatively measure the ratio of calcine to frit in the feed and in the glass. A proposal is made to accomplish this by a thermal neutron transmission measurement technique. The method proposed is similar to one developed for assay of  $^6\text{Li}$  and Cd.

Summary

Thermal neutron transmission through samples of mixed calcine (or TDS oxides) and frit can provide a quantitative measure of the calcine to frit weight ratio and establish the uniformity of the feed or glass product. Calculations indicate the capability to measure the nominal calcine to frit weight ratio of 0.35 within  $\pm 2\%$ . The measurement can be done in the shielded SE room of Bldg. 777-M using equipment that has been retained from earlier neutron transmission studies.

Discussion

A simple thermal neutron transmission measurement in beam geometry can be used to quantitatively establish the calcine to frit weight ratio in small size samples of calcine and frit mixture. A number of small size samples from random locations provide information concerning the uniformity (degree of mixing) within the mixture. The same measurement techniques also can be applied to establish the uniformity of the glass product from pulverized samples.

A typical equipment arrangement for the transmission measurement is shown in Figure 1. Counting rates are determined for the open beam and for a powder sample in the beam both with and without a Cd. filter imposed. The measured thermal neutron transmission,  $T_m$ , is the ratio of the sub Cd. counting rate with the sample to the sub Cd. counting rate without the sample. Since the measured result is a simple ratio, the measurement is quite insensitive to instrument drift and does not depend upon periodic calibration with standards. The measurement is based on expressing  $T_m$  for the calcine + frit sample as the product of several transmission probabilities given by:

$$T_m = T_{({}^6\text{Li} + {}^{10}\text{B})}^f \cdot T_t^f \cdot T_t^c \quad (1)$$

where,

- $T_{({}^6\text{Li} + {}^{10}\text{B})}^f$  - transmission associated with the  $1/v$  absorption in  ${}^6\text{Li} + {}^{10}\text{B}$  in the frit.
- $T_t^f$  - transmission associated with the nearly constant total cross section of the remaining constituents in the frit.
- $T_t^c$  - transmission associated with the nearly constant total cross section of the calcine.

Thermal neutron cross sections for frit and calcine are given in Tables I and II. The thermal neutron absorption in B and Li of the frit are the dominate neutron removal mechanism in the frit and calcine transmission measurement.

In beam geometry with a Maxwellian incident spectrum and a  $1/v$  detector (Nancy Wood  $\text{BF}_3$ ), the neutron transmission for absorption in  ${}^{10}\text{B}$  or  ${}^6\text{Li}$  with a  $1/v$  cross section dependence can be expressed as

$$T_{({}^6\text{Li} + {}^{10}\text{B})}^f = e^{-K(Y_0, Z_0)Y_0} \quad (2)$$

where,

1.  $Y_0 = \Sigma t$  is the absorber thickness in mean free path lengths.
2.  $K(Y_0, Z_0)$  is a correction factor to convert the true thickness ( $Y_0$ ) of the absorber into an effective thickness ( $KY_0$ ) that accounts for spectrum hardening and preserves the simple exponential form for the transmission.
3.  $Z_0$  is the absorber thickness of the  $1/v$  ( $\text{BF}_3$ ) detector in mean free path lengths ( $Z_0 = 0.45$  for the 1-inch diam. Nancy Wood  $\text{BF}_3$ )

The dependence of  $K$  on  $Y_0$  for various  $Z_0$  is given in Figure 2. The transmission for a material with a constant cross section is given by

$$T = e^{-Y_0} \quad (3)$$

From Eqs. 1-3, the measured transmission,  $T_m$ , of a frit + calcine sample can be approximated by

$$T_m = e^{-[(1-w_c)(K_{\text{B} + \text{Li}}^f + \Sigma_t^f) + w_c \Sigma_t^c]t}$$

where,

$w_C$  - weight fraction of calcine

$$\Sigma_{B + Li}^f = 2.5232 \text{ cm}^{-1} \text{ (1/v absorption in Li + B from Table I)}$$

$$\Sigma_t^f = 0.1872 \text{ cm}^{-1} \text{ (constant absorption + scatter in frit from Table I)}$$

$$\Sigma_t^C = 0.1718 \text{ cm}^{-1} \text{ (constant absorption + scatter in calcine from Table II)}$$

$K$  = correction factor from Figure II.

$t$  = sample thickness, cm

Calculated values of  $T_m$  vs  $t$  for various calcine weight fractions are given in Figure 3. These curves provide a measure of the sensitivity of the transmission measurement to detect mixture variations. At a sample thickness of 0.6 cm, a  $\pm 14\%$  change in  $w_C$  from the nominal value of  $w_C = 0.35$  corresponds to a  $\pm 6.7\%$  change in  $T_m$ . The accuracy of a transmission measurement is limited mainly by counting statistics. An accuracy of  $\pm 1\%$  can be achieved with reasonable counting times - corresponding to a detection capability of about 2% in  $w_C$ .

In practice the calculated curves of Figure 3 would be replaced by measured curves of  $T_m$  vs sample "thickness" in units of grams/cm<sup>2</sup> of frit. The measured curves would be obtained from transmission measurements with known (well mixed) mixtures of the actual calcine and frit to be used in the melter. The calibration measurements would be made in slab geometry with the calcine + frit mixture placed in various height 1-1/2" diameter aluminum cups of known volume. The "thickness" of frit would be established from the measured weight, the known volume and the composition of the mixture. Measurements at low "thickness" values will be made with the calcine + frit mixture diluted (uniformly mixed) with "transmission inert" aluminum powder.

The procedure to establish the wt% of calcine in an unknown sample is outlined below:

1. Obtain  $\sim 3 \text{ cm}^3$  sample.
2. Fill a 0.6 cm high cylindrical aluminum cup of known circular area.
3. Obtain tare weight of sample.
4. Calculate "thickness" of the frit in units of grams/cm<sup>2</sup> from weight and known area. (assume nominal value of  $w_f = 0.65$ )
5. Determine  $T_m$  from a transmission measurement.
6. Enter calibration curves with measured value of  $T_m$  and assumed value of  $w_f$  and determine preliminary value of  $w_C$ .
7. Recalculate frit "thickness" based on value of  $w_C$  determined in step 6. ( $w_f = 1 - w_C$ )
8. Repeat steps 6 & 7 until convergence is obtained.

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Most of the major hardware items required to accomplish this measurement have been retained in Bldg 777-M from an earlier  ${}^6\text{Li}$  assay study. The 200-300 ug of  ${}^{252}\text{Cf}$  required for the experiment are available on loan from SRL-LSD.

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TABLE I: COMPOSITION & CROSS SECTIONS FOR FRIT 211\*

Compound	Wt%	M.W.		
SiO <sub>2</sub>	58.3	60.09	27.25% Si	31.05% O
Na <sub>2</sub> O	20.6	61.98	15.28% Na	5.32% O
B <sub>2</sub> O <sub>3</sub>	11.1	69.62	3.45% B	7.65% O
Li <sub>2</sub> O	4.4	29.88	2.04% Li	2.36% O
CaO	5.6	56.08	4.00% Ca	1.60% O

Element	Wt%	$\sigma_{a,b}$	$\sigma_{s,b}$	$\sigma_{t,b}$	$\Sigma_t^f$	$(\Sigma_B^f + Li)_a$
O	47.98	$20 \times 10^{-5}$	4.2	4.2	.1215	
Si	27.25	.13	1.7	1.83	.0171	
Na	15.28	.52	4.0	4.52	.0290	
B	3.45	755	4		.0123	2.322
Li	2.04	71	1.4		.0040	.2012
Ca	4.00	.43	3.0	3.43	.0033	

$$\text{TOTAL } \Sigma_t^f = .1872$$

$$(\Sigma_B + Li)_a = 2.5232$$

\* Assume  $\rho = 1.60 \text{ g/cm}^3$

TABLE II: COMPOSITION & CROSS SECTIONS FOR TYPICAL CALCINE\*

Compound	Wt%	M.W.				
Fe <sub>2</sub> O <sub>3</sub>	49.74	159.69	34.79% Fe	14.95% O		
Al <sub>2</sub> O <sub>3</sub>	10.84	101.96	5.74% Al	5.10% O		
MnO <sub>2</sub>	13.15	86.94	8.31% Mn	4.84% O		
CaCO <sub>3</sub>	6.19	100.09	2.48% Ca	2.97% O	.74% C	
NiO	5.78	74.71	4.54% Ni	1.24% O		
NaNO <sub>3</sub>	3.20	85.00	.87% Na	1.81% O	.53% N	
Na <sub>2</sub> SO <sub>4</sub>	1.34	126.04	.49% Na	.68% O	.34% S	
NaH <sub>6</sub> AlSiO <sub>7</sub>	9.78	196.10	.115% Na	5.59% O	.30% H	1.35% Al 1.40% Si

	Wt%	$\sigma_{a,b}$	$\sigma_{s,b}$	$\sigma_{t,b}$	$\Sigma_t$
O	37.18	$20 \times 10^{-5}$	4.2	4.2	.0471
Fe	34.79	2.53	11	13.5	.0406
Al	7.09	.23	1.4	1.63	.0021
Mn	8.31	13.2	2.3	15.5	.0113
Ca	2.48	.43	3.0	3.43	.0010
C	.74	.003	4.8	4.8	.0014
Ni	4.54	4.6	17.5	22.1	.0082
Na	2.51	.52	4.0	4.52	.0024
N	.53	1.88	10	11.9	.0022
S	.34	.49	1.1	1.59	.0001
H	.30	.33	38	38.3	.0550
Si	1.40	.13	1.7	1.83	.0004

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Total  $\Sigma_t^C = .1718$

\* Assume  $\rho = .801 \text{ gm/cm}^3$

FIG. 1: EXPERIMENTAL ARRANGEMENT FOR TRANSMISSION MEASUREMENTS

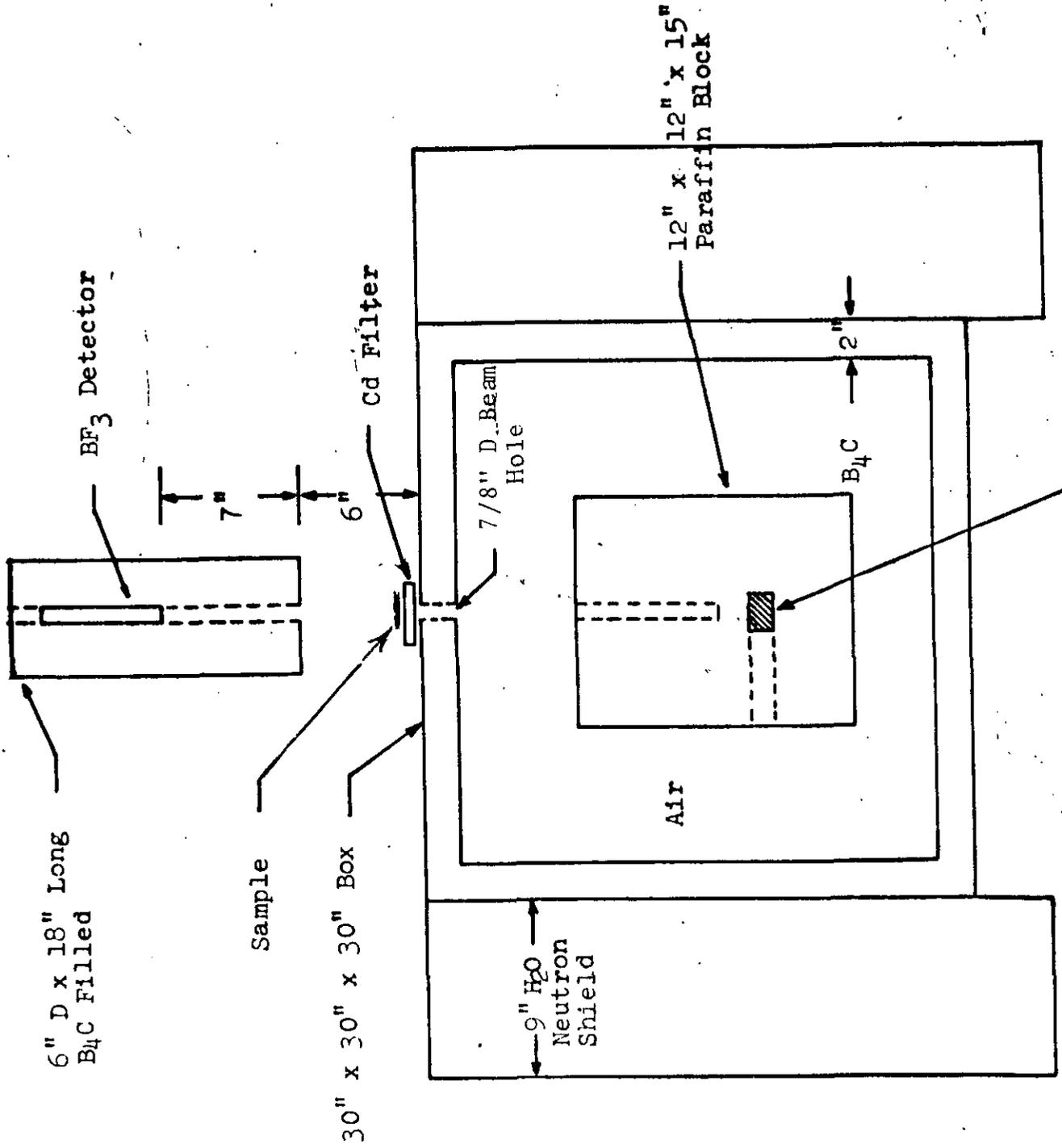
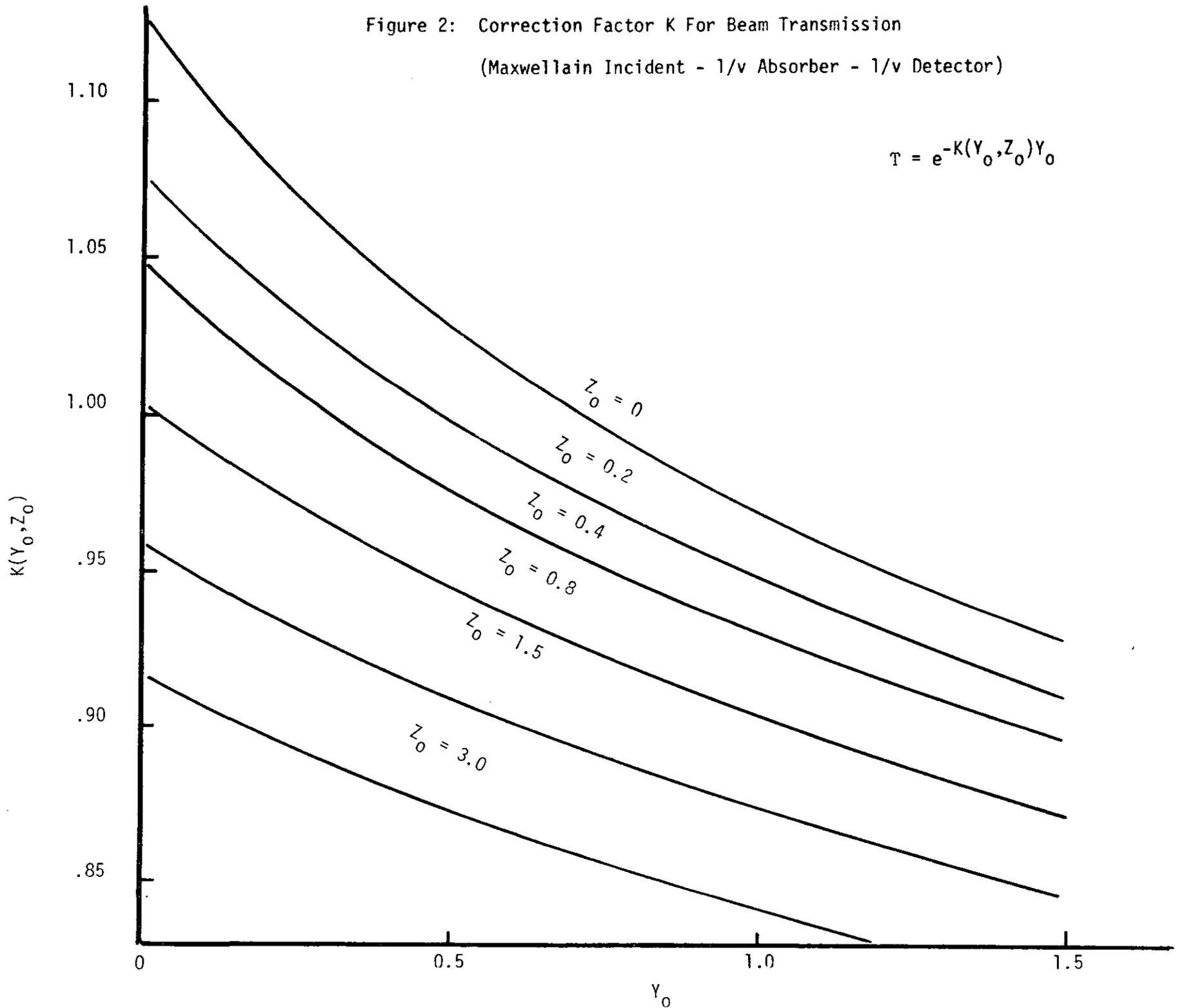


Figure 2: Correction Factor K For Beam Transmission

(Maxwellian Incident - 1/v Absorber - 1/v Detector)

$$T = e^{-K(Y_0, Z_0)Y_0}$$



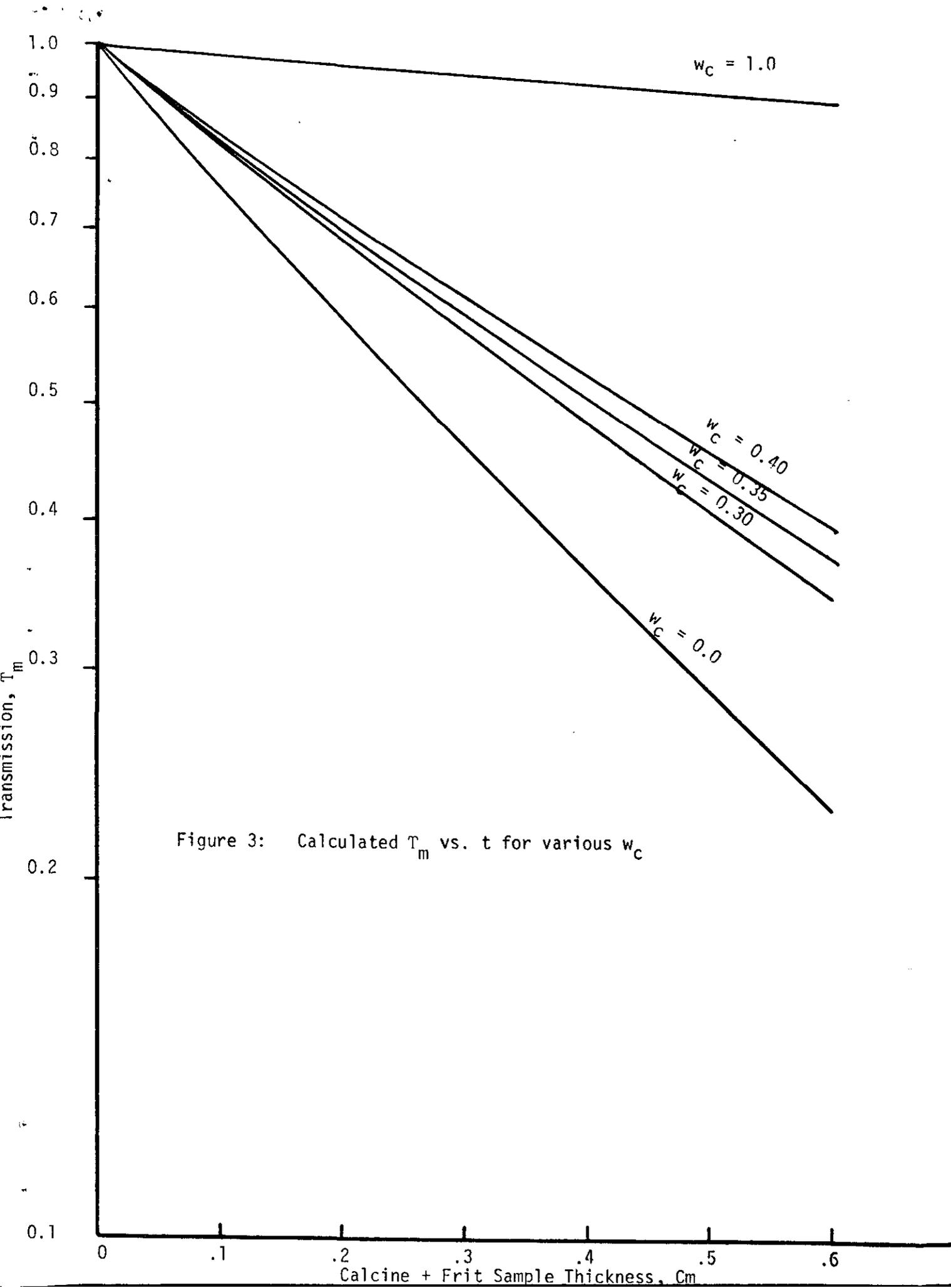


Figure 3: Calculated  $T_m$  vs.  $t$  for various  $w_c$