Background Report Reference

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Title: Notes and Calculations of an Emission Factor Relationship

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Calculation of Emission Factors and Correction factors for section 6.5.2 Wine Making.

Note: H.W. Zimmermann, E.A. Rossi, Jr., and E. Wick conducted laboratory experiments to determine the ethanol emissions from wine fermentation (Ref. 2 of section 6.5.2). From the data in Table I of this report, I have plotted a graph of alcohol losses (as percentage of that made) vs. temperature and for two different sugar contents. From this graph, a relationship of ethanol losses to temperature and °Brix is determined.

Recently, the Ca. ARB conducted measurements on a large wine fermentation vat. I have carefully compared the ARB data to the Zimmermann et al data, and found that they are in essential agreement.* Therefore, the two were used together the determine the EF's and correction factors for section 6.5.2. The calculations are shown on the following pages.

I. Known Relationships:

- 1°Brix ≡ 1g sugar / 100 g juice

- Every 1°Brix initial sugar will add

* Proven later

.55 % alcohol by volume to the final alcohol content.

Therefore, an initial 20 °Brix will produce a wine of 11 % alcohol(v), and an initial 23 °Brix will produce a wine of 12.6 % alcohol by volume.

II. Calculation of EF's for juice fermentation:

A. From Zimmerman et al. data:

.155 %. From graph I, @ 52°F (11°C) C_2H_5OH lost is .14 % of that produced. Initial °Brix is 20.4 therefore an expected 11.22 % C_2H_5OH(v) wine produced, and therefore, if 1000 gallons of wine is produced, 112.2 gallons of C_2H_5OH are in it.

$$EF = \left(\frac{112.2 \text{ gal } C_2H_5OH \text{ made}}{1000 \text{ gal wine made}}\right)\left(\frac{.00155 \text{ gal } C_2H_5OH \text{ lost}}{1 \text{ gal made}}\right)\left(\frac{6.610 \text{ lb } C_2H_5OH}{1 \text{ gal } C_2H_5OH}\right) = \boxed{\frac{\overset{0.125}{\cancel{1.15}} \text{ lb lost}}{10^3 \text{ gal wine m.}}}$$

ethanol

* For 20.4 °Brix and 52°F (11°C)

• Now calculated for 52°F (11°C) from ARB measured data*:

$$\left(\frac{*44.9 \text{ lb } C_2H_5OH \text{ lost}}{*3761 \text{ lb made}}\right) = .12\,\% \text{ lost}$$

source

$$\therefore EF = \left(\frac{.0012 \cancel{\text{ gal } C_2H_5OH \text{ lost}}}{1 \cancel{\text{ gal made } C_2H_5OH}}\right)\left(\frac{104 \cancel{\text{ gal } C_2H_5OH \text{ made}}}{10^3 \text{ gal wine made}}\right)\left(\frac{6.61 \text{ lb}}{1 \cancel{\text{ gal } C_2H_5OH}}\right)$$

$$= \boxed{.82 \text{ lb} / 10^3 \text{ gal wine made}}$$

* this is for 18.95 °Brix and 52°F (11.1°C)

[Notice that the only factor different is the initial °Brix.]

III. Establisment of correction factor for different °Brix;

I chose three points from Graph I. to establish correction factors for Δ °Brix: these are 10°C, 20°C and 26.5 °C.

Factors used in the following calculations are:

- 20.4 °Brix → Wine of 11.22 % alcohol (volume)
- 25 ° Brix → Wine of 13.75 % alcohol (volume)

III (cont)

1) 20°C $\qquad 0.78934 \frac{g}{ml}$

ⓐ 20.4 °Brix

$$\left(\frac{112.2 \cancel{\text{gal } C_2H_5OH \text{ made}}}{10^3 \text{gal wine made}}\right)\left(\frac{6.61 \cancel{\text{lb } C_2H_5OH}}{\cancel{\text{gal } C_2H_5OH}}\right)\left(\frac{.0045 \text{ lb lost } C_2H_5OH}{1 \cancel{\text{lb made}} C_2H_5OH}\right)$$

$$= \frac{3.34 \text{ lb } C_2H_5OH \text{ lost}}{10^3 \text{ gal wine made}}$$

ⓑ 25° Brix

$$\left(\frac{137.5 \cancel{\text{gal } C_2H_5OH \text{ made}}}{10^3 \text{gal wine made}}\right)\left(\frac{6.61 \text{ lb } C_2H_5OH}{\cancel{1 \text{ gal } C_2H_5OH}}\right)\left(\frac{.0055 \text{ lb } C_2H_5OH \text{ lost}}{1 \text{ lb made}}\right)$$

$$= \frac{5.0 \text{ lb } C_2H_5OH \text{ lost}}{10^3 \text{ gal wine made}}$$

$$\therefore \frac{(5.0 \text{ lb}/10^3\text{gal}) - (3.34 \text{ lb}/10^3\text{gal})}{4.6 \ \Delta °\text{Brix}} = \boxed{\frac{.36 \text{ lb}/10^3\text{gal}}{\Delta 1 °\text{Brix}}}$$

This is now plotted on graph

III. (cont.)

2) 10 °C $\rho = 0.79784 \frac{g}{mL}$

15°C 0.79360

@ 20.4 ° Brix

$$\left(\frac{112.2 \cancel{\text{ gal } C_2H_5OH \text{ made}}}{10^3 \text{ gal wine made}}\right)\left(\frac{6.61 \cancel{\text{ lb } C_2H_5OH}}{\cancel{\text{gal } C_2H_5OH}}\right)\left(\frac{.0011 \text{ lb } C_2H_5OH \text{ lost}}{\cancel{\text{lb made } C_2H_5OH}}\right)$$

$$= .82 \text{ lb } C_2H_5OH \text{ lost} / 10^3 \text{ gal wine made}$$

ⓑ 25 ° Brix

$$\left(\frac{137.5 \cancel{\text{ gal } C_2H_5OH \text{ made}}}{10^3 \text{ gal wine made}}\right)\left(\frac{6.61 \cancel{\text{ lb } C_2H_5OH}}{\text{gal } \cancel{C_2H_5OH}}\right)\left(\frac{.0021 \text{ lb } C_2H_5OH \text{ lost}}{\text{lb. } \cancel{C_2H_5OH \text{ made}}}\right)$$

$$= 1.91 \text{ lb } C_2H_5OH \text{ lost} / 10^3 \text{ gal wine made}$$

$$\therefore \frac{(1.91 \text{ lb}/10^3 \text{gal}) - (.82 \text{ lb}/10^3 \text{gal})}{4.6 \ \Delta ° \text{Brix}}$$

$$= \boxed{\frac{.24 \text{ lb}/10^3 \text{ gal}}{\Delta 1 ° \text{Brix}}} \rightarrow \text{plotted on graph II}$$

III (cont)

3) 26.5 °C @ 20.4 °Brix

25° - 0.78506 g/ml
30° - 0.78075 g/ml
40° - 0.77203

$$\left(\frac{112.2 \text{ gal } C_2H_5OH \text{ made}}{10^3 \text{ gal wine made}}\right)\left(\frac{6.61 \text{ lb } C_2H_5OH}{\text{gal } C_2H_5OH}\right)\left(\frac{.0066 \text{ lb } C_2H_5OH \text{ lost}}{\text{lb } C_2H_5OH \text{ made}}\right)$$

$= 4.89 \text{ lb} / 10^3 \text{ gal}$

(b) 25 °Brix

$$\left(\frac{137.5 \text{ gal } C_2H_5OH \text{ made}}{10^3 \text{ gal wine made}}\right)\left(\frac{6.61 \text{ lb } C_2H_5OH}{\text{gal } C_2H_5OH}\right)\left(\frac{.0076 \text{ lb } C_2H_5OH \text{ lost}}{\text{lb } C_2H_5OH \text{ made}}\right)$$

$= 6.91 \text{ lb} / 10^3 \text{ gal}$

$$\therefore \frac{(6.91 \text{ lb}/10^3 \text{gal}) - (4.89 \text{ lb}/10^3 \text{gal})}{4.6 \ \Delta \ °\text{Brix}}$$

$$= \boxed{\frac{.44 \text{ lb}/10^3 \text{gal}}{\Delta 1 °\text{Brix}}} \rightarrow \text{plotted on graph II}$$

III (cont)

Now, the formula for the °Brix correction factor, as a function of temperature and ΔEF, is simply the equation of the graph:

$$\left(\begin{array}{c}\text{correction for } 1\,°\text{Brix} \\ \text{deviation from } 20.4\,°\text{Brix}\end{array}\right) = \left[.01233\,(T_{°C}) + .115\right]$$

$$\therefore \Delta EF = (°Brix - 20.4)(.01233(T_c) + .115)$$

It is desirable to report T as °F why not °C, therefore the conversion is worked into the formula:

$$\Delta EF = (B - 20.4)\left[(.01233)\underbrace{(T_{°F} - 32)(5/9)}_{T°C} + (.115)\right]$$

$$= (B - 20.4)\left[(T - 32)(.00685) + (.115)\right]$$

$$= (B - 20.4)\left[(T_{°F})(.00685) - .2192 + .115\right]$$

$$= (B - 20.4)\left[(T_{°F})(.00685) - .1042\right]$$

$$= (B - 20.4)(T_{°F} - 15.21)(.00685)$$

IV. Establishing EF as a function of Temperature.

From the data in graph III, the equation of the line for 20.4 ° Brix will give the formula for EF as a function of temperature. It is:

$$\boxed{EF^{*} = .136\,(T_{°F}) - 5.91}$$

* for 20.4 °Brix.

V. EF for ANY Juice Fermentation:

The two preceeding equations can be combined to give the EF for ANY JUICE fermentation:

$$\boxed{EF = [.136\,(T_{°F}) - 5.91] + [(B - 20.4)(T_{°F} - 15.21)(.00685}$$

The accuracy of this formula can be checked by plugging in data and seeing if the results fall on graph III.

VI. Red Wine

All of the above equations are for juice fermentation, which is for making white wine.

It is known that when a red wine is being made (must fermentation), the EF is higher.

There is NOT enough data to establish an exact correction factor.

From what data is available, I approximate* the correction factor to be:

$\boxed{2.4 \quad lb / 10^3 gal}$ at around 80° F

This should be added to the juice emission factor determined for the given temp. and Brix.

* based on comparison of 1 red & white fermentation at 80°F.

VII. Check:

The ARB tested only one fermentation temperature and one °Brix. All of the equations above are based on Zimmermann, et al., data.

If, by plugging the ARB test information into the formula derived from Zimmermann, et. al. data, we arrive at the same EF calculated directly from ARB test measurements, this would validate both of the studies and therefore my formulas also.

ARB Test data:

- 44.9 lb C_2H_5OH lost
- 37611 lb C_2H_5OH produced
- Initial Brix = 18.95° Brix
- Fermentation temp = 52°F (11.1°C)

∴ EF By Calculation:

$$EF = \left(\frac{44.9 \text{ lb } C_2H_5OH \text{ lost}}{37611 \text{ lb } C_2H_5OH \text{ made}}\right)\left(\frac{6.61 \text{ lb made } C_2H_5OH}{1 \text{ gal made } C_2H_5OH}\right)\left(\frac{104 \text{ gal } C_2H_5OH}{10^3 \text{ gal Wine made}}\right)$$

$$\boxed{EF = 0.82 \text{ lb}/10^3 \text{ gal } (18.95°\text{Brix}/52°F)}$$

and By derived Formula:

$$EF = (1.16) - (.35)$$

$$= \boxed{0.81 \text{ lb}/10^3 \text{gal}}$$

VIII. Check of All of Table 1 (Zimmermann) by my formula:

	Temp.	Initial °Brix	% Alcohol lost	by formula EF ($lb/10^3 gal$)	by formula % lost
①	10°C (50°F)	20.4	.11	.89	.12
②	21°C (69.8°F)	20.4	.47	3.58	.48
③	21°C (69.8°F)	25	.58	5.30	.58
④	32°C (89.6°F)	20.4	.90	6.28	.85
⑤	34°C (93.2°F)	25	1.02	9.23	1.02

EF by formula:

① $(.89) + (0) = .89 \ lb/10^3 gal$

② $(3.58) + (0) = 3.58$

③ $(3.58) + (1.72) = 5.30$

④ $(6.28) + (0) = 6.28$

⑤ $(6.77) + (2.46) = 9.23$

EF's converted to %:

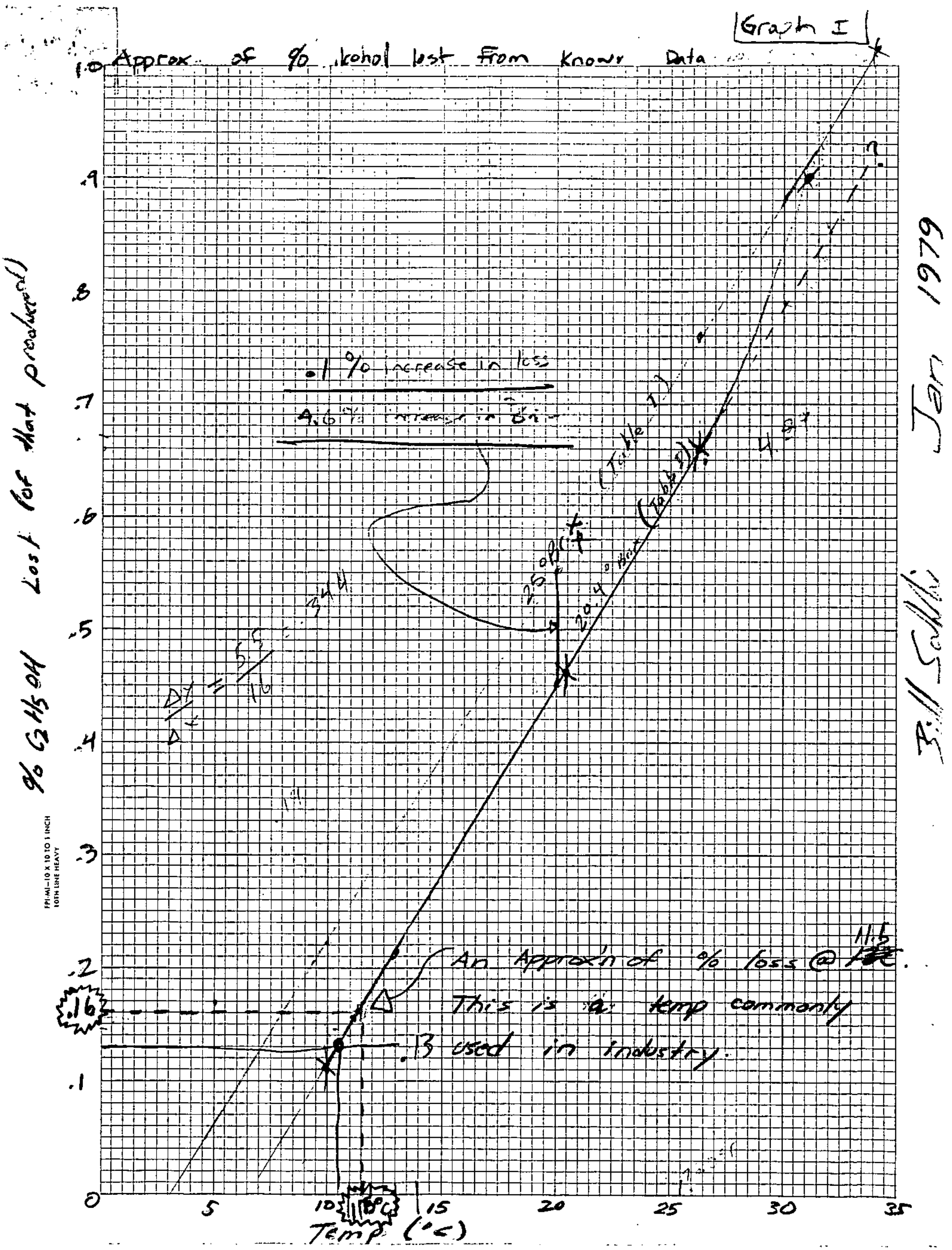
① $\left(\frac{.89 \ C_2H_5OH \ lb \ lost}{10^3 gal \ wine \ made}\right)\left(\frac{10^3 gal \ wine \ made}{112.2 \ gal. \ C_2H_5OH \ made}\right)\left(\frac{1 \ gal \ made}{6.61 \ lb \ made}\right)(100\%) = .12$

② $\left(\frac{3.58}{1}\right)\left(\frac{1}{112.2}\right)\left(\frac{1}{6.61}\right)(100\%) = .48$

③ $\left(\frac{5.30}{1}\right)\left(\frac{1}{137.5}\right)\left(\frac{1}{6.61}\right)(100\%) = .58$

④ $\left(\frac{6.28}{1}\right)\left(\frac{1}{112.2}\right)\left(\frac{1}{6.61}\right)(100\%) = .85$

⑤ $\left(\frac{9.23}{1}\right)\left(\frac{1}{137.5}\right)\left(\frac{1}{6.61}\right)(100\%) = 1.02$


Graph I
Approx of % alcohol lost from Known Data
% C2H5OH Lost for that produced
Temp (°C)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
5
10
15
20
25
30
35
.1 % increase in loss
4.6 % increase in temp
ΔY/ΔX = .55/16
(Table 1)
(Table 2)
25.0
20.4
An Approx'n of % loss @ 11.5
This is a temp commonly
used in industry.
.16
.13
11.5°C
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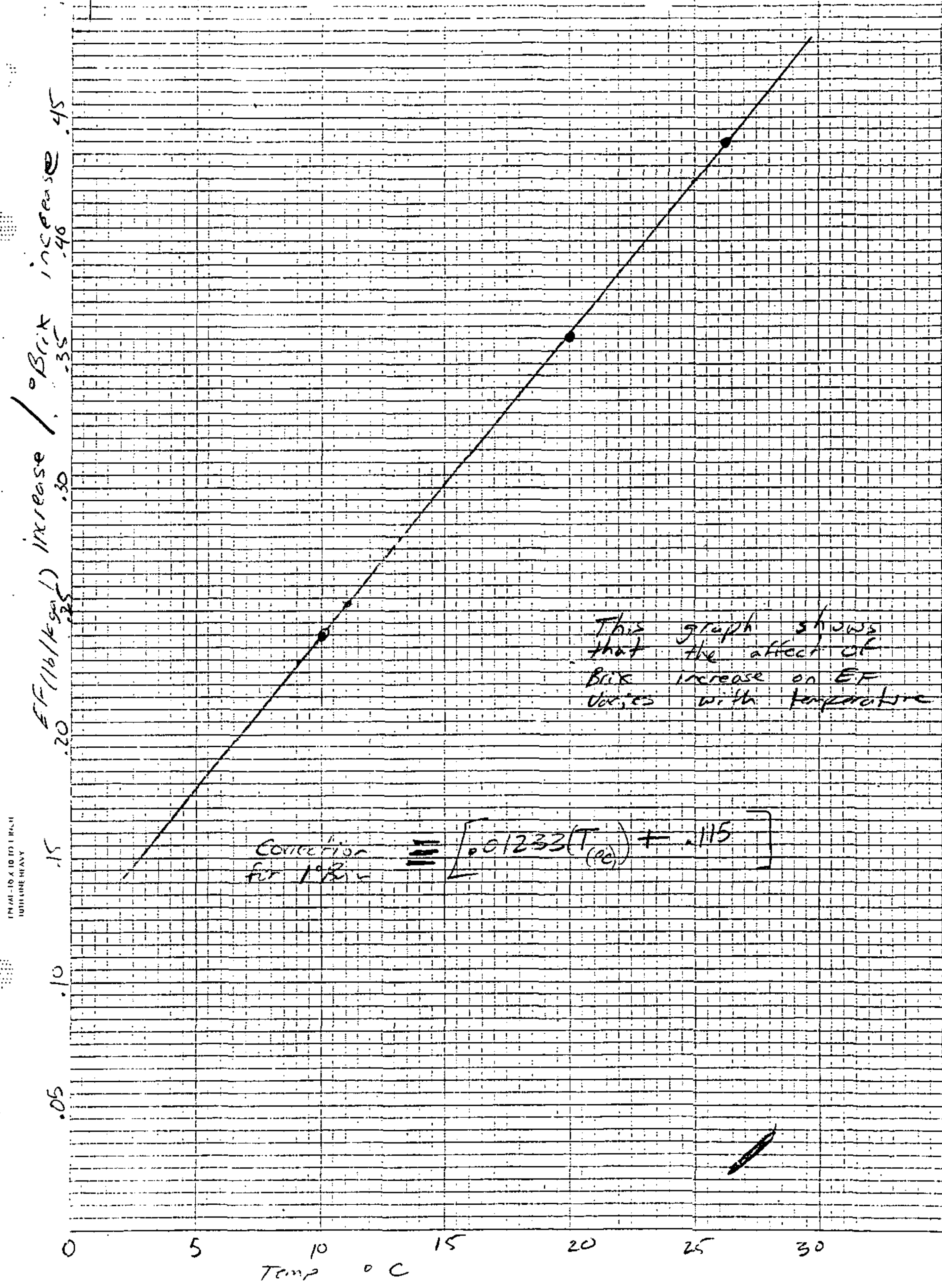
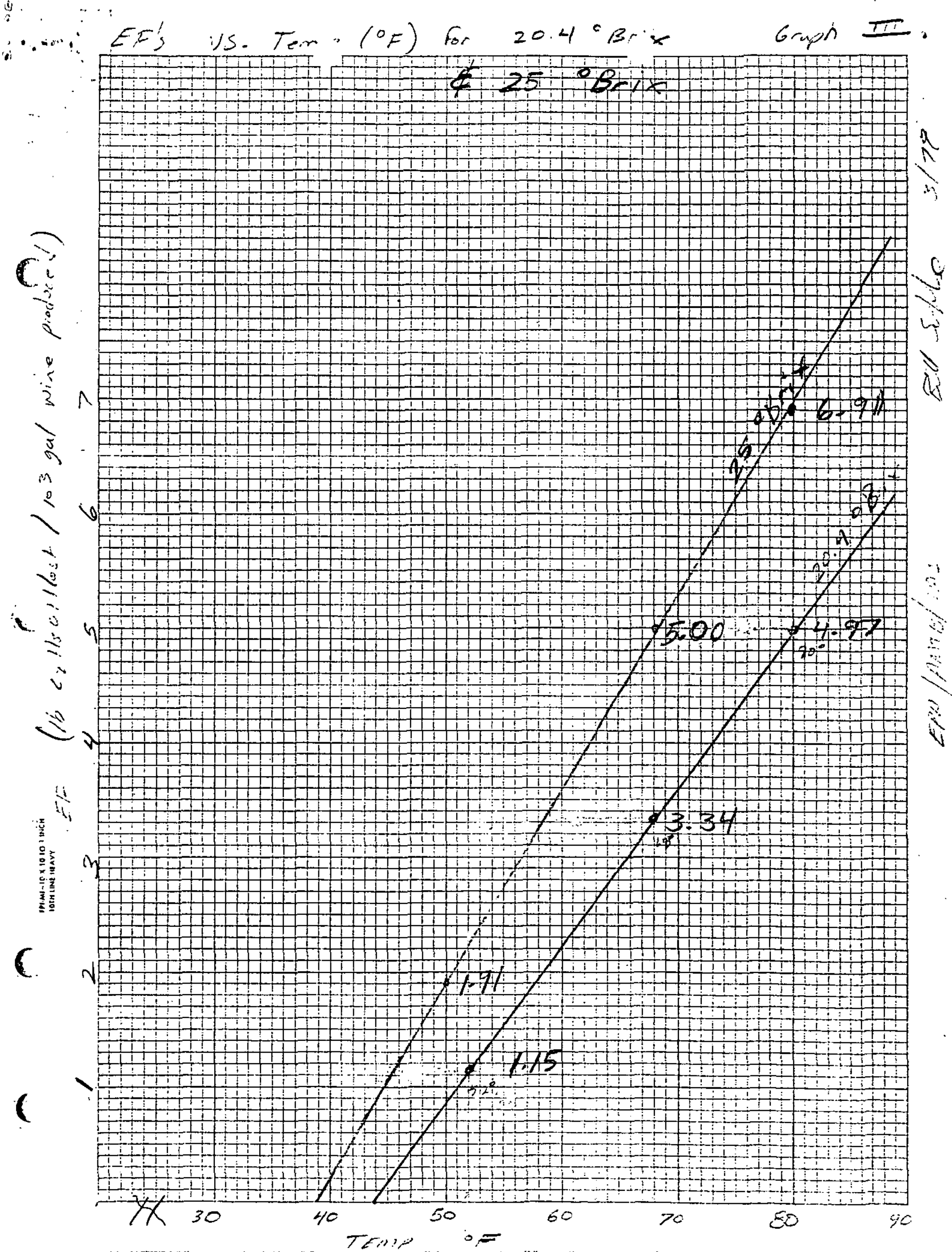
FPI-MI-10 X 10 TO 1 INCH 10TH LINE HEAVY

Graph II


EF (lb/ksgal) increase / °Brix increase
.05
.10
.15
.20
.25
.30
.35
.40
.45
0
5
10
15
20
25
30
Temp °C
This graph shows that the affect of Brix increase on EF varies with temperature
Correction for 1°Brix = [.01233(T(°C)) + .115]



EF's vs. Temp (°F) for 20.4 °Brix & 25 °Brix
Graph III
EF (lb C_2H_5OH lost / 10^3 gal wine produced)
TEMP °F
30
40
50
60
70
80
90
1
2
3
4
5
6
7
25 °Brix
20.4 °Brix
6.91
5.00
4.97
3.34
1.91
1.15