# *Relationship between the kappa number and the permanganate number of the western hemlock kraft pulp*

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**ABSTRACT:** The semi-logarithmic, logarithmic, and power form equations were developed to calculate the kappa number of western hemlock kraft pulp from its permanganate number and vice versa. The relationship between these numbers was expressed by a straight line equation. The kappa and permanganate numbers calculated fit well with the experimental values determined by proper standards. The kappa number of western hemlock kraft pulp can be calculated from its permanganate number and vice versa.

***Application:*** The kappa number of western hemlock kraft pulp can be calculated from its permanganate number and vice versa.

For practical reasons, bleachable-grade pulps are not characterized by an estimation of lignin content but by the value of the kappa number or permanganate number. It is faster to determine the kappa or permanganate number [1, 2] than to analyze the lignin content. Moreover, the determination of either the kappa or permanganate number is more precise and has a higher reproducibility.

We have studied the relationship between the kappa and permanganate numbers of the kraft pulp prepared from western hemlock wood. We based our study on results reported by Hatton *et al.* [3], who studied kraft delignification of western hemlock wood (*Tsuga heterophylla*, *Raf. Sarg.*). They used maximum pulping temperatures of 160°C, 170°C, and 180°C, an effective alkali charge (EA) of 12%, 17%, and 22% (as $Na_2O$), a sulfidity of 25%, and a liquor-to-wood ratio of 4.3/1 L/kg. The inputs of active alkali (AA) under these conditions amounted to 13.7%, 19.4%, and 25.1% (as $Na_2O$) on o.d. wood, respectively.

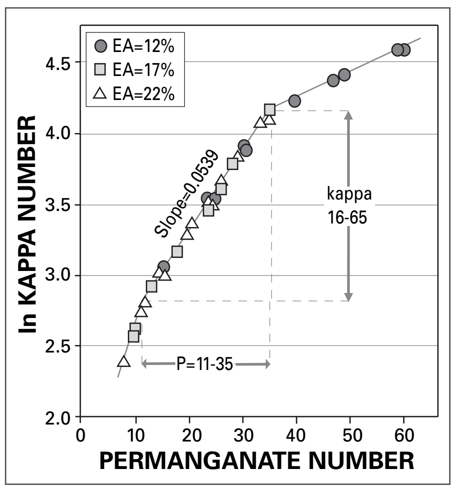
### *Semi-logarithmic relationship*

Hatton *et al.* found the relationship between kappa number (*K-No.*) and permanganate numbers (*P-No.*) for western hemlock kraft pulps to be expressed by the semi-logarithmic equation, as follows:

$$K\text{-}No. = \log^{-1}(0.980 + 0.0232\ P\text{-}No.) \tag{1}$$

where $R^2$ = 0.988. This relationship is applicable only to a specific range of permanganate and kappa numbers.

From Eq. 1, it is easy to calculate *P-No.* from log *K-No.*:




***1. Semi-logarithmic relationship between the kappa number and the permanganate number of the western hemlock kraft pulps. Kappa numbers are expressed in the natural logarithm.***

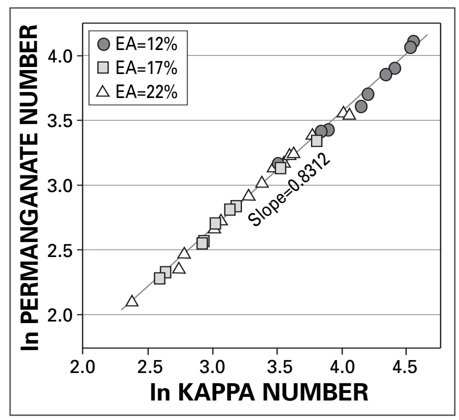
$$P\text{-}No. = 43.10345 \log K\text{-}No. - 42.24138 \tag{2}$$

From the results published by Hatton *et al.*, we have found a semi-logarithmic relationship between kappa number and permanganate number. This relationship is expressed in **Fig. 1** as the straight lines. The relationship rests on the basis of a semi-natural logarithm. The relationship in the permanganate number range of 11–35 and the kappa number range of 16–65 is expressed by the Eq. 3:

$$K\text{-}No. = \ln^{-1}(2.2421 + 0.0539\ P\text{-}No.) \tag{3}$$

where $R^2$ = 0.9928.

From Eq. 3, it is easy to calculate *P-No.* from ln *K-No.*:




***2. Logarithmic relationship between the kappa number and the permanganate number of the western hemlock kraft pulps, both of which are expressed in the natural logarithm.***

$$P\text{-}No. = 18.552876 \ln K\text{-}No. - 41.5974 \tag{4}$$

We have used the least squares method of calculating, with calculations performed by an appropriate computer program. Equation 3 has a higher correlation coefficient than Eq. 1 has. As shown in Fig. 1, the higher and lower values of kappa and permanganate numbers have different values for the slope and intercept constants.

### *Logarithmic and power relationship*

By expressing the experimental results of the kappa and permanganate numbers in a ln–ln relationship, a straight line can be drawn. Such a relationship is shown in **Fig. 2**. Thus, the relationship of the kappa

| Temp.,°C | EA, % | Kappa No. | Calculated Kappa No. Eq. 1 | Eq. 3 | Eq. 6 |
|---|---|---|---|---|---|
| 160 | 17 | 44.6 | 44.0 | 44.0 | 44.4 |
| | 17 | 33.5 | 33.9 | 33.7 | 35.4 |
| | 22 | 59.4 | 59.0 | 59.1 | 54.9 |
| | 22 | 29.5 | 28.2 | 28.1 | 29.4 |
| | 22 | 26.6 | 26.8 | 26.6 | 27.7 |
| 170 | 12 | 56.3 | 61.9 | 62.0 | 56.6 |
| | 12 | 49.0 | 48.4 | 48.5 | 47.8 |
| | 17 | 34.4 | 35.0 | 34.8 | 36.5 |
| | 17 | 20.6 | 21.1 | 21.1 | 20.3 |
| | 22 | 32.7 | 32.8 | 32.7 | 34.3 |
| | 22 | 21.5 | 21.6 | 21.5 | 20.9 |
| | 22 | 16.6 | 17.8 | 17.6 | 15.2 |
| 180 | 12 | 45.7 | 46.1 | 46.1 | 46.1 |
| | 12 | 32.5 | 33.8 | 33.7 | 35.4 |
| | 17 | 24.3 | 24.4 | 24.3 | 24.7 |
| | 17 | 14.1 | 16.4 | 16.2 | 12.7 |
| | 22 | 20.7 | 20.2 | 20.0 | 18.8 |
| | 22 | 11.0 | 14.6 | 14.4 | 9.6 |

***I. Comparison of the analytical and computational kappa numbers.***

number to the permanganate number can be expressed by the natural logarithmic straight line equation or its power form, as follows:

$$\begin{aligned} P\text{-}No. &= \ln^{-1}(0.8312 \ln K\text{-}No. + 0.1994) \\ &= 1.22067\,(K\text{-}No.)\,(\exp 0.8312) \end{aligned} \tag{5}$$

where $R^2 = 0.9776$.

This equation can be recalculated to fit the relationship for finding the kappa number based on the permanganate number:

$$\begin{aligned} K\text{-}No. &= \ln^{-1}(1.20308 \ln P\text{-}No. - 0.239894) \\ &= 0.786711(P\text{-}No.)\,(\exp 1.20308) \end{aligned} \tag{6}$$

Equations 5 and 6 can express the relationship between the kappa and permanganate numbers in a broader range. From the results expressed in Fig. 2, it follows that the ln–ln relationship expressed by Eqs. 5 and 6 can be applied also to pulps with kappa numbers in the range of 11–90 and permanganate numbers in the range of 8–60. For calculations of Eq. 5, we employed the least squares method using a computer program.

| Temp.,°C | EA, % | Permanganate No. | Calculated Permanganate No. Eq. 2 | Eq. 4 | Eq. 5 |
|---|---|---|---|---|---|
| 160 | 17 | 28.6 | 28.8 | 28.8 | 28.6 |
| | 17 | 23.7 | 23.5 | 23.5 | 22.6 |
| | 22 | 34.1 | 34.2 | 34.2 | 36.4 |
| | 22 | 20.3 | 21.1 | 21.2 | 20.3 |
| | 22 | 19.3 | 19.2 | 19.3 | 18.7 |
| 170 | 12 | 35.0 | 33.2 | 33.2 | 34.8 |
| | 12 | 30.4 | 30.6 | 30.6 | 31.0 |
| | 17 | 24.3 | 24.0 | 24.0 | 23.1 |
| | 17 | 14.9 | 14.4 | 14.5 | 15.0 |
| | 22 | 23.1 | 23.0 | 23.1 | 22.1 |
| | 22 | 15.3 | 15.2 | 15.3 | 15.6 |
| | 22 | 11.7 | 10.3 | 10.5 | 12.6 |
| 180 | 12 | 29.5 | 29.3 | 29.3 | 29.3 |
| | 12 | 23.7 | 22.9 | 23.0 | 22.0 |
| | 17 | 17.6 | 17.5 | 17.6 | 17.3 |
| | 17 | 10.1 | 7.3 | 7.5 | 11.0 |
| | 22 | 14.0 | 14.5 | 14.6 | 15.1 |
| | 22 | 8.0 | 2.6 | 2.9 | 8.8 |

***II. Comparison of the analytical and computational permanganate numbers.***

Kappa and permanganate numbers were calculated using Eqs. 1–6. The results are compared in **Tables I and II**. The results confirm a good agreement between the experimental values and the values calculated by both the semi-logarithmic and the ln–ln expressions. **TJ**

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### INSIGHTS FROM THE AUTHOR

For some time I have studied the mathematical expression of the non-linear relationship of chemical reactions. In this field of research I have published many papers, relating to the kraft pulping process, the acid sulphite pulping process, and neutral sulfite semi-chemical (NSSC) pulping. The relationship between kappa number and permanganate number of the western hemlock kraft pulp supports my previous findings on the non-linear relationship of the pulping reactions.

The most interesting finding of my paper was the discovery that my method of solving non-linear relationship of the pulping reaction is universal, and can be applied for any non-linear relationship including the relationship between kappa number and permanganate number. Pulping mill workers can calculate the kappa number from the determined permanganate number, and vice versa.

As a next step, I'm interested in researching the application of my method to solve the kinetics of the non-linear delignification reaction of some wood species.

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