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Accuracy of the Different Calculation Methods of Specific Edge Load

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ABSTRACT

The specific edge load (SEL) is the commonly used intensity for measuring the low consistency refining process, while the cutting edge length (*CEL*) is the core parameter of it and the accuracy of its calculation is important for the process characterization. There are two main types of calculation methods of *CEL* for isometric straight bar plates, direct measurement methods and mathematical calculations based on the bar parameters. The *CEL* of isometric straight bar plates with different bar angles, field angles and bar width, calculated by different methods, were explored in order to verify the calculation accuracy of different methods. It was found that CEL_4 and CEL_5 could not be used for the *CEL* calculation of isometric straight bar plates due to the large errors, and CEL_1 was the most accurate direct measurement method. While the recommended mathematical calculation method was CEL_3 which could effectively and simply calculate the *CEL* of the straight bar plates with smaller errors.

Keywords: *Low consistency refining, isometric straight bar plate, specific edge load, cutting edge length, accuracy*

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1. Introduction

Low consistency pulp refining is an important operating unit to modify the properties of pulp and fibers, and it is usually measured by the refining intensity. Specific edge load (SEL)[1] is a widely used indicator to measure the strength of low consistency (LC) refining process conducted by straight bar plates, and many other intensities were proposed based on it, such as specific surface load (SSL),[2] modified edge load (MEL)[3] and modified specific surface load (MSSL)[4] *etc*. Meanwhile, the SEL is the basis of the structure design of straight bar plates and controlling of the LC refining processes.[5-10] Therefore, the accurate calculation of the SEL is important for the optimal design of the straight bar plates and the control of the LC refining process.

Specific edge load, proposed by Brecht *et al.*,[1] is one of the earliest established refining intensities. Compared with other refining intensities that con-sidering more bar parameters, SEL has the char-acteristics of simple and easy calculation. It can be directly used to the design of the straight bar plates due to the value of it can be converted into the arrangement of bars or the calculation of cutting edge length. The SEL could be expressed by *Eq*.1.

$$SEL=\frac{P_{net}}{n\cdot CEL} \quad [1]$$

In which the P_{net} is the net power of the refining process (kW), n is the rotation speed of the refining plate (r/min), and the CEL is the cutting edge length of the refining plate (m/r).

A reasonable value of SEL can be determined through comprehensive consideration of pulp type and refining process,[11,12] and then the range of CEL can be obtained to guide the design of straight bar refining plates. It was noted that the CEL is the characterization parameter and core parameter of SEL,[13] which can also be called the characterization parameter of refining plates.

Through the analysis of previous studies, many kinds of calculation methods of CEL existed. When Wultsch *et al.*,[14] proposed the prototype of SEL, they defined a new parameter, cumulative edge length, L, that is the bar edge length or the cutting edge length during refining mentioned above, and the expression of it is,

$$L=n_R\cdot n_S\cdot l_a \quad [2]$$

In which, n_R and n_S is the bar number of rotor and stator, and l_a is the average bar length (mm).

If the CEL of the isometric straight bar plates was calculated according to the definition of *Eq*.2, it could be obtained[15]

$$CEL=\sum_{k=1}^{P}n_{Rk}\cdot n_{Sk}\cdot\Delta R_k \quad [3]$$

Where k is the number of ring partition, n_{Rk} and n_{Sk} are the bar number of rotor and stator in the ring partition k, and the ΔR_k is the radial length of the ring k.

The bar angle of the isometric straight bar plate was not considered in the CEL calculated by *Eq*.3. And the TAPPI Preparation Committee[16] considers the bar angle of the refining plate and the calcula-tion method, expressed by *Eq*.3, was modified, which could be expressed by *Eq*.4.

$$CEL=\sqrt{\frac{\sum_{k=1}^{P}n_{Rk}^2\Delta R_k}{\cos\alpha_{AR}}}\cdot\sqrt{\frac{\sum_{k=1}^{P}n_{Rk}^2\Delta R_k}{\cos\alpha_{AS}}} \quad [4]$$

In which, α_{AR} and α_{AS} are the average bar angle of the rotor and stator (°), and it could be calculated by the following equation.

$$\cos\alpha_{AR}=\alpha_{AR}+\beta/2 \text{ and } \cos\alpha_{AS}=\alpha_{AS}+\beta/2 \quad [5]$$

Where β is the field angle (°).

Roux *et al.*[15] considered the bar angle of the refiner plate and recalculated the bar number of rotor and stator. The *CEL* of the refining plate could be obtained by integration from the internal radius, R_i, to the outer radius, R_o, and it could be expressed by *Eq*.6.

$$CEL = \int_{R_i}^{R_o} \frac{n_R(R) \cdot n_S(R) \cdot dR}{\cos\alpha_S \cdot \cos\alpha_R} = \frac{4\pi^2 (R_0^3 - R_i^3)}{3(b_R + g_R)(b_S + g_S)} \quad [6]$$

In which, α_S and α_R are the bar angle of the stator and rotor (°), b_R and b_S are the bar width of the stator and rotor (mm), and the g_R and g_S are the groove width of the stator and rotor (mm).

If the calculation method of the bar number used in *Eq*.6 was introduced, the *Eq*.4 could be written as

$$CEL = \frac{4\pi^2 (R_0^3 - R_i^3)}{3(b_R + g_R)(b_S + g_S)} \times \sqrt{\cos\alpha_{AR} \cos\alpha_{AS}} \quad [7]$$

Except the bar width, groove width, there are three important angular parameters of refining plate, field angle, bar angle of the rotor and stator, which must be concerned when charactering the refining process. However, the filed angle of the refining plate is not considered in Eqs.3, 4, 6 and 7.

Roux *et al.*[17] comprehensively considered the field angle β, bar angles of rotor and stator, α_S, α_R, and defined an angular parameter factor. Therefore, the *CEL* becomes,

$$CEL = \frac{4\pi^2 (R_0^3 - R_i^3)}{3(b_R + g_R)(b_S + g_S)} \cdot \frac{[\sin(\alpha_S + \beta) - \sin\alpha_S][\sin(\alpha_R + \beta) - \sin\alpha_R]}{\beta^2} \quad [8]$$

Through the analysis of the above calculation methods of the *CEL*, it can be concluded that two types of calculation methods existed, direct measurement methods, represented by *Eqs*.3 and 4, and mathematical calculation methods proposed by considering different bar parameters, mainly represented by *Eqs*.6, 7 and 8. Theoretically, the direct calculation method is relatively accurate, while the mathematical calculation methods are relatively simple and convenient compared to the previous one. However, its accuracy should be further studied.

The objective of this study was to explore the accuracy of different methods for calculating the SEL based on the analysis of the *CEL* of isometric straight bar plates with different bar widths, field angles and bar angles, which is benefit for the selection of the calculation method and the optimal controlling of the LC refining process.

2. Methodology

2.1 Isometric straight bar plates with different bar parameters

The bar parameters of the isometric straight bar plates mainly include the inner and outer radius of the refining plates, R_i, R_o, the bar angle α, the field angle β, the bar width b, the groove width g, *etc*., as shown in Fig. 1. To explore the accuracy of the above methods for calculating the *CEL* of refining plates, three types of isometric straight bar plates with different bar angle, field angle, and bar width were designed in this paper.[6,18] The inner radius, outer radius and bar height of them are the same, they are 41.25 mm, 101.5 mm, and 4 mm. Other parameters will be described in the following section.

2.1.1 Bar angle

Seven isometric straight bar plates with different bar angles were designed to clarify the accuracy of different calculation methods for the *CEL* calculation of straight bar plates with different bar angles, as shown in Table 1. The bar width, groove width and field angle of them are 2 mm, 3 mm and 40°.

2.1.2 Field angle

The field angle is one of the important bar parameters of the straight bar refining plates.

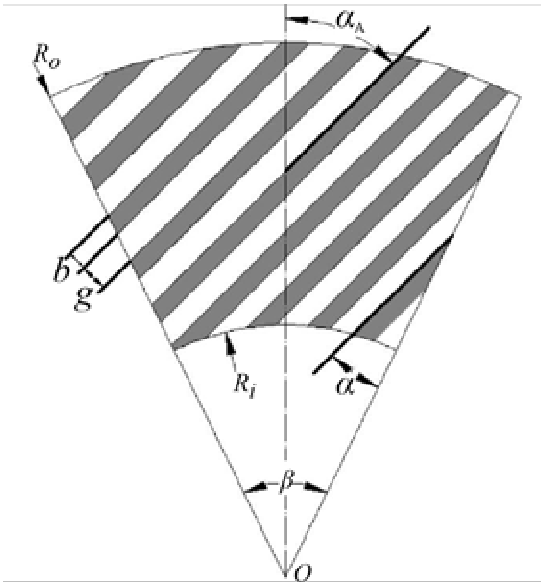


Fig. 1. Main parameters of the straight bar plates.

Through considering the calculation method of β in previous study[6] and the convenience design of the refiner plate, nine isometric straight bar plates with different filed angles were designed, which can be shown in Table 2. The bar width, groove width and bar angle of them are 2 mm, 3 mm, and 10°.

2.1.3 Bar and groove width

The bar and groove width are the two key parameters of straight bar plates. Under the constant refining conditions, the intensity of the refining process can be changed by adjusting both. Therefore, it is very important to investigate the *CEL* calculation of straight bar plates with different bar and groove widths. The code of straight bar plates is usually expressed by "bar width–groove width–bar height", and it can be referred to "bar width–groove width" when the bar height was kept constant. In this paper, nine straight bar plates with different bar width were designed with the constant ratio of bar width and groove width, 2/3, as shown in Table 3, in which the field angle and bar angle are 40° and 10°.

Table 1. The structure of the isometric straight bar plates with different bar angles

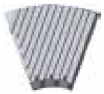
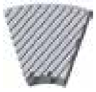
α	0°	5°	10°	15°	22°	39°	50°
Plate structure							

Table 2. The structure of the isometric straight bar plates with different field angles

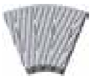
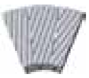
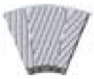
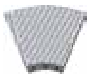
β	12°	18°	22.5°	24°	30°	36°	40°	45°	60°
Plate structure									

Table 3. The structure of the isometric straight bar plates with different bar and groove width

Code	1.5–2.25	2–3	2.5–3.75	3–4.5	3.5–5.25	4–6	4.5–6.75	5–7.5	6–9
Plate structure									

2.2 *CEL* calculation

The calculation methods mentioned above, such as *Eqs*.3, 4, 6, 7 and 8, were proposed based on the fact the bar parameters of rotor and stator are different. While the rotor and stator with the same bar parameters were concerned to simplify the calculation and clarify the accuracy of different methods. The simplified calculation formulas were shown in Table 4, in which the α_A is the average bar angle of the rotor and stator.

Elahimehr[19] thought that the integral form of the *CEL* defined by the TAPPI standard TIP could be expressed by

$$CEL = \int_{R_i}^{R_o} \frac{n_R(R)n_s(R)}{\cos\alpha_A} dR \qquad [9]$$

For the rotor and stator plates with the same bar parameters, *Eq*.9 could be simplified and it was shown in Table 4.

Among all the calculation methods in Table 4, the corresponding formulas of *Eqs*.3 and 4 are the two closest methods to the definition, *Eq*.2. However, the radial length of the single ring zone was considered in *Eq*.3 which is not the true bar length, and the bar length of the single ring zone was concerned by *Eq*.4. Therefore, the *CEL* calculated by *Eq*.4 would be more accurate. It was found the bar length of a right-handed plate in the single ring zone will gradually decrease from left to right, which means the bar length in the middle of the ring can better measure the average bar length. The controlled *CEL* was calculated which can be described by *Eq*.10.

$$CEL_c = \sum_{k=1}^{p} n_k^2 \cdot \Delta l_{mk} \qquad [10]$$

In which, the Δl_{mk} is the bar length of the bar in the middle of the zone *k*.

3. Results and discussion

3.1 Theoretical analysis

The calculation methods of *Eqs*.3, 4, and 10 were the direct measurement method and their principle was similar to the definition expressed by *Eq*.2. However, their understanding of the bar length was different, and the radial length of the single ring zone was considered in the calculation of CEL_0, which could not characterize the *CEL* accu-

Table 4. CEL calculation methods for the rotor and stator plates with same bar parameters

NO	Original formula	Simplified calculation formula
1	*Eq*.3	$CEL_0 = \sum_{k=1}^{p} n_k^2 \cdot \Delta R_k$
2	*Eq*.4	$CEL_1 = \sum_{k=1}^{p} n_k^2 \cdot \Delta R_k \Big/ \cos\alpha_A$
3	*Eq*.6	$CEL_2 = 4\pi^2 (R_0^3 - R_i^3) \Big/ \left[3(b+g)^2\right]$
4	*Eq*.7	$CEL_3 = 4\pi^2 (R_0^3 - R_i^3)\cos\alpha_A / 3(b+g)^2$
5	*Eq*.8	$CEL_4 = 4\pi^2 (R_0^3 - R_i^3)\left[\sin(\alpha+\beta) - \sin\alpha\right]^2 \Big/ \left[3(b+g)^2 \beta^2\right]$
6	*Eq*.9	$CEL_5 = 4\pi^2 (R_0^3 - R_i^3) \Big/ \left[3\cos\alpha (b+g)^2\right]$

rately. *Eqs*. 6 to 9 are the mathematical calculation formulas that relating n_k and bar length to other bar parameters of the refining plates. While the bar angle and field angle were not included in the calculation of CEL_2, which means that CEL_2 cannot be affected by them and CEL_2 cannot better measure the refining intensity of the straight bar plates with different bar angles and field angles. Although the *Eqs*.7 ,8 and 9 are the modified version compared to the *Eq*.6, the accuracy of them should be further explored compared to the actual value calculated by *Eq*.10.

3.2 Bar angle

Bar angle is one of the important parameters that greatly affects the *CEL* of the isometric straight bar plates. And the accuracy of different calculation methods for the *CEL* of straight bar plates with different bar angles was explored in this paper, as shown in Fig.2. Except for the CEL_2 and CEL_5, all the value of *CEL* calculated by other methods gradually decreases with the increasing of plate bar angle which is consistent with the results obtained by Liu *et al*.[18,20] However, the degree of reduction of them is different and it depends on the accuracy of the calculation method. The CEL_1 and CEL_C are basically the same due to the similar calculation of the bar length in the single ring zone. While the calculation of the CEL_1 and CEL_C are troublesome for that all the bar lengths in different ring zones should be measured separately. In addition, there is no obvious relationship between CEL_2 and plate bar angle, which is consistent with the conclusion obtained from the section of theoretical analysis, and the value of it is bigger than that of CEL_C. The CEL_5 of plates gradually increases with the increasing of plate bar angle which is not in line with the facts. Although the value of CEL_4 gradually increase with the bar angle, both the value of CEL_4 and CEL_5 are much larger than that of actual *CEL* value. Therefore, the calculation methods of CEL_2, CEL_4 and CEL_5 are not suitable for accurate calculation of *CEL* for isometric straight bar plates with different bar angles. The change of CEL_0, CEL_1 and CEL_3 over the bar angle is consistent with that of CEL_C, while the value of CEL_1 is closer to the actual value, CEL_C, as shown in Fig.3. Meanwhile, the CEL_0 is smaller than the CEL_C due to the radius increment in a single ring zone was considered as the bar length. Therefore, it is recommended to use CEL_1 and CEL_3 when the *CEL* of isometric straight bar plates with different bar angles were calculated, while the value of CEL_1 is the closest one to the actual value and CEL_3 is the easiest method.

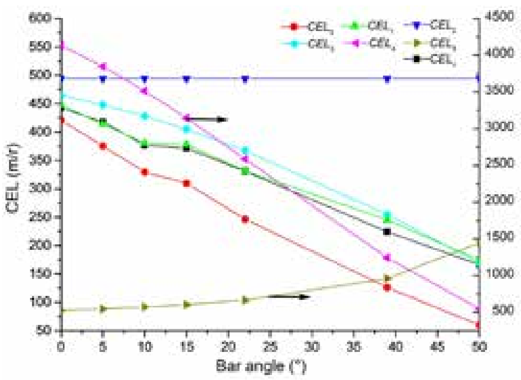


Fig. 2. The relationship between the *CEL* calculated by different methods and the bar angle of isometric straight bar plate.

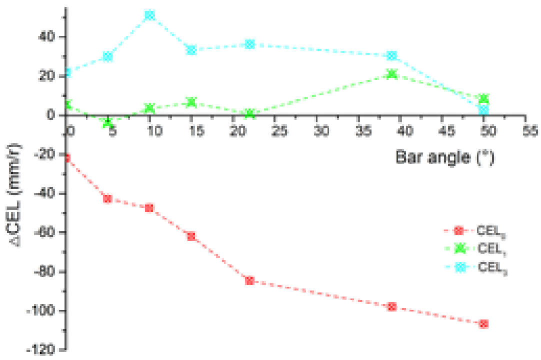


Fig. 3. The deviation of CEL_0, CEL_1, CEL_3 and CEL_C over bar angle of the straight bar plates.

3.3 Field angle

The field angle is another angular parameter of isometric straight bar plates, and there is a direct relationship between the field angle and *CEL*, meanwhile, the accuracy of *CEL* calculated by different methods is different, as shown in Figs. 4 and 5. Similar to the results obtained from theoretical analysis, CEL_2 remains constant as the increasing of the field angle of straight bar plate due to that it does not take into account the important angular parameters. Actually the *CEL* of straight bar plate has a tendency to decrease as the increase of the field angle, which means that it is difficult for CEL_2 and CEL_5 to accurately calculate the *CEL* of straight bar plates with different field angles. In addition, CEL_4 cannot be used to accurately calculate it due to its large volatility. Therefore, the effective method to calculate the *CEL* of straight bar plates with different field angles are the direct measurement methods, CEL_0 and CEL_1, and the mathematical calculation method, CEL_3, as shown in Fig. 5. And the accuracy of the above three is different, and the recommended order would be CEL_1, CEL_3 and CEL_0 according to the magnitude of the deviation value. Therefore, the most effective *CEL* calculation method of straight bar plates with different field angles is CEL_3, except the direct measurement method, CEL_1.

3.4 Bar and groove width

The change of the bar and groove width of straight bar plates is one of the main ways to adjust the refining intensity of the LC refining process, and both the value of them will directly affect the *CEL* of the plates. The effect of the bar width on the *CEL* calculated by different methods were explored under the constant ratio of the bar width and groove width, as shown in Fig. 6. It was found that the value of *CEL* gradually decreases with the increasing of bar width no matter which method was used, while the value of CEL_4 is much larger than the actual value, CEL_C, and the *CEL* calculated by other methods, therefore, the CEL_4 cannot be used to the *CEL* calculation of the straight bar plates with different bar width. The difference between the value obtained by other calculation methods and the CEL_C gradually decreases as the bar width of the straight bar plates increases, as shown in Fig. 7. Among them, the value of CEL_1, CEL_2, CEL_3 and CEL_5 is greater than the CEL_C, and CEL_0 is less than it, and the reason for it was explained in the section of bar angle. It can also be seen that CEL_1 is almost the same as the actual value, CEL_C, which means that the average bar length can be represented by the bar length of the intermediate bar in the ring. And

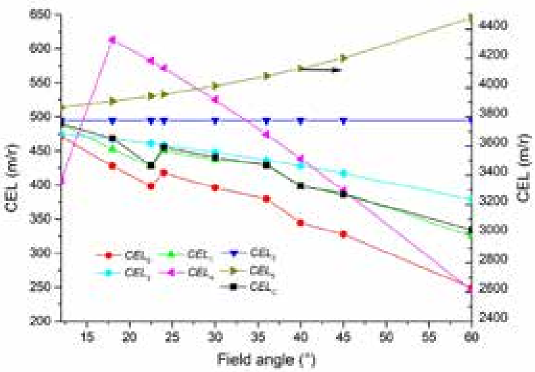


Fig. 4. The relationship between the *CEL* calculated by different methods and the field angle of isometric straight bar plate.

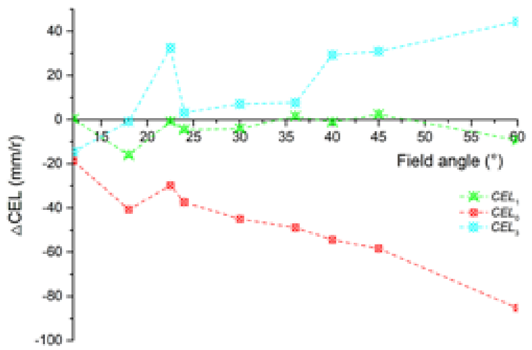


Fig. 5. The deviation of CEL_0, CEL_1, CEL_3 and CEL_C over field angle of the straight bar plates.

the deviation of CEL_3 from the CEL_C is the smallest among all mathematical calculation methods. Therefore, the recommended *CEL* calculation methods of isometric straight bar plates with different bar width are the CEL_1 and CEL_3, while the latter is the simple one.

4.Conclusions

As the characteristic parameter of SEL, *CEL* is the core calculation part of it. Different *CEL* calculation methods of isometric straight bar plates

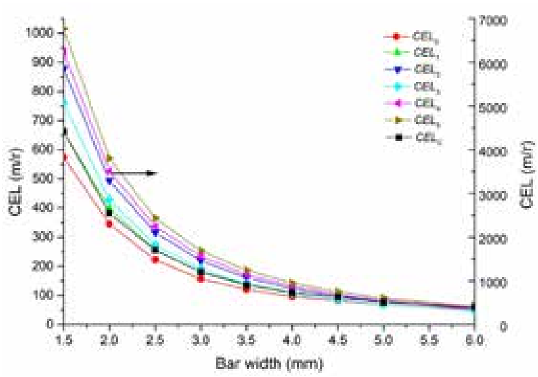


Fig. 6. The relationship between the *CEL* calculated by different methods and the bar width of isometric straight bar plate.

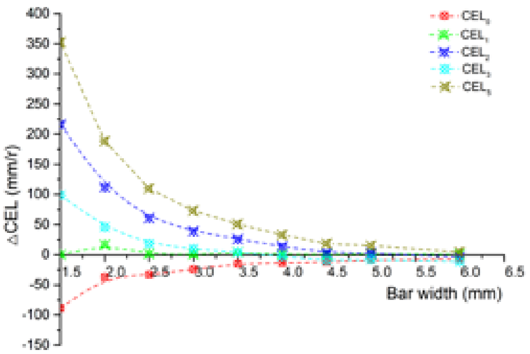


Fig. 7. The deviation of CEL_0, CEL_1, CEL_3 , CEL_5 and CEL_C over bar width of the straight bar plates.

were summarized, and the accuracy of them were explored in this paper.

The direct measurement methods and mathematical calculation methods based on bar parameters are the two main types methods of *CEL* calculation for straight bar plates. The core of the direct measurement method is the calculation of the bar length in the single ring zone, while the mathematical calculation methods are relatively simple compared to direct one. However, the most accurate methods are the direct measurement methods based on the bar average length, and there are large errors of the mathematical methods for the *CEL* calculation.

The bar angle and field angle of isometric straight bar plates will greatly affect the *CEL* of the plates, and the change trend of the *CEL* obtained by the different calculation methods over the bar angle and field angle are different. The actual value of *CEL*, CEL_C, gradually decrease with the increase of bar angle and field angle of the plates, while its change rate over the bar angle is more obvious compared to that of the field angle. In addition to the direct measurement method, CEL_1, which can accurately calculate the *CEL* of straight bar plates with different angular parameters, CEL_3 can replace the direct measurement method to a certain extent and simplify the *CEL* calculation.

The value of *CEL* of the isometric straight bar plates, calculated by all methods, gradually decrease with the increasing of the bar width under the constant ratio of bar and groove width. And the CEL_1 and CEL_3 are the two effective methods for the calculating of the *CEL* of isometric straight bar plate with different bar width.

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