THE BASE PHILOSOPHY OF AN AVAILABLE WORKING SERVICE REGARDING THE PETROCHEMICAL TECHNOLOGICAL EQUIPMENTS

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Abstract: There are grounded the security factor in comparison with destruction/damage time by creep and comparison with creep resistance limit. The association of those two security factors and corresponding numerical analysis are standing out the residual availability of running time under circumstances related to technicaland technological industrial reliability/security.

Key board: creep, lenght, equipement, thermomechanics, petrochemistrie.

1. THE ISSUE WORDING

The appropriate recent studies [3,4] pointed out new percepts which may promote the non-equivocal formulation and practically applicable one of the grounds necessary to compile criteria regarding the quantization of available and durable working service, including the limits constraint of this availability, with implementation for petrochemical technological equipments made of steels 0.5 …. 1,0% Mo, 2.25% / 1.00% Cr/Mo, etc, for which the period of service/designing/calculation − equal with 100 000 hr. – was already or is almost exhausted.

The standard tests for steels used in constructional structure of the nominated equipments, at creep resistance limit (standing/time) is usually effected under (static) load and constant temperature, similar with proper creep resistance standard tests , but until the "breaking /destructive " of the proof – sample, measuring and/or recording the time up to the moment of loosen → 'breaking" → destruction. The corresponding time is called destructive duration/time and is noted by τ_d . Obviously, it stands to reason that destructive duration/time is a characteristic which defines in a way – a steel creep resistance (time/standing) σ_d^t , this steel supported the long-time action of a certain static load (or quasi-static), for a *t* temperature.

2. THE SAFETY FACTOR TOWARDS THE DESTRUCTIVE DURATION/TIME

For the general case, from a practical alternative to another one, the destructive duration/time τ_d can be directly numerical estimated on analytically side, either using one of the formulas from [5] or by using any of the well-known and recognized parametric method including [1] Larson-Miller one. The working service/time – real τ_s , exhausted as such or available in strict sense – thus, is obviously that must be restricted :

$$\tau_s << \tau_d \text{ [h]} \tag{1}$$

the simplex

$$C_\tau = \frac{\tau_d}{\tau_s} >> 1{,}000 \tag{2}$$

which is named the safety factor towards the destructive duration/time.

In order to ensure the safety conditions corresponding to a technical and technological processing under load (for the mechanical strength of σ = constant and for a temperature t = constant), regarding the petrochemical equipment constructive structured from a certain basic material (steel), is necessary that C_τ factor to be restricted so that, in extremis, not to be in steel destructive creep stage (III, respectively IV), but to remain in the creep strain stage (II) , the stages being found in the typical flow curve [3 – 5]. Therefore:

$$\tau_d = C_\tau \ \tau_s >> \tau_s \tag{3}$$

and after the substitution in the classical equation [5] :

$$\tau_d \left(\sigma_d^t\right)^N = C \rightarrow \tau_d = C\left(\sigma_d^t\right)^{-N}, \tag{4}$$

followed by the looking up the logarithm, is obtaining :

$$\lg \tau_s = \lg \frac{C}{C_\tau} - N \lg \sigma_d^t, \tag{5}$$

respectively,

$$\lg \sigma_d^t = \frac{1}{N} \lg \frac{C}{C_\tau} - \frac{1}{N} \lg \tau_s, \tag{6}$$

where C and N are the numerical coefficients of which values are resulting after the corresponding mathematical–statistics processing of experimental correlation data. In consequence the LOG – LOG coordinates , (5) and (6) represents the equations of some lines for angular coefficient → slope – N and N^{-1} – respectively the y-coordinate originally $\lg(C/C_\tau)$ and $N^{-1}\lg(C/C_\tau)$.

The dependent $\sigma_d^t = \sigma_d^t(\tau_{s,d})$ corresponding to the equations (4) and respectively (5,6) are graphical illustrated in figure 1, for only one value C_τ = const, directly representing :

$$(\tau_{d1} - \tau_{s1}) > (\tau_{d2} - \tau_{s2}) > (\tau_{d3} - \tau_{s3}), \tag{7}$$

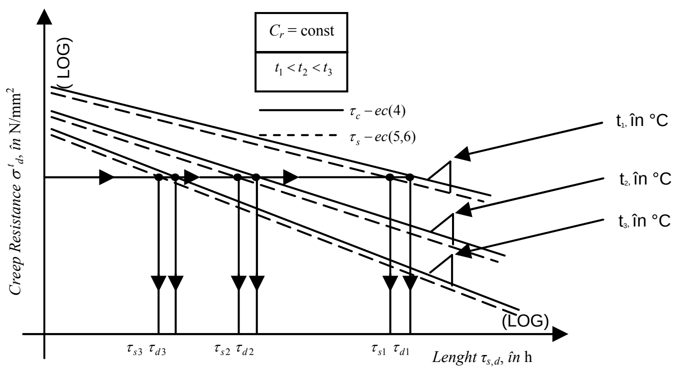

Fig. 1. The dependent $\sigma_d^t = \sigma_d^t(\tau_{s,d})$ for a certain basis material (steel) and different t temperatures.

which certifies that numerical factor value C_τ >> 1.000 must be differentiate established – – at least from one range/interval of temperature to another – to ensure the following general constraint:

$$\tau_d - \tau_s = \text{const}\,. \tag{8}$$

The safety factor C_τ can be numerically estimated, on analytical side, if we are knowing the following sizes (figure 2):

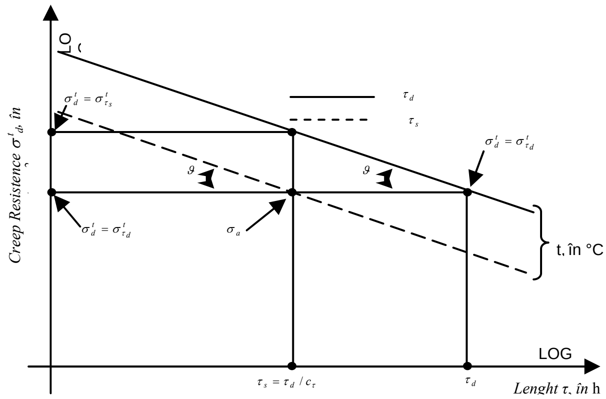

Fig. 2. Diagram for calculation of C_τ security factor.

$\sigma_{\max}$ – max. (mechanical) stress the so-called effective or real designing /calculation ;

$\sigma_a = \sigma^t_d / C_d, \sigma_{as} = \varphi\,\sigma_a \le \sigma_a$ – strength admitted /administrated for the basic material (steel) σ_a and for the welds σ_{as}, respectively $C_d \ge 1.000$, mostly $C_d \ge 1.500$ – safety factor towards the creep resistance limit σ^t_d and $\varphi \le 1.00$ − strength coefficient of welds ;

τ_s − working service/designing /calculation;

$\sigma^t_{\tau_s}$ − creeping strength for the nominated period of time τ_s ;

ϑ − angle of fall/gradient , respectively N^{-1} = tg. ϑ counter-slope, in addition must be reiterated the following evident constraints :

$$\sigma^t_d = \sigma^t_{\tau_s} = C_d\,\sigma_{as} = C_d\,\varphi\sigma_a \ge C_d\,\sigma_{\max}\,;$$

$$C_d = \frac{\sigma^t_{\tau_s}}{\sigma_{as}} = \frac{\sigma^t_{\tau_s}}{\varphi\,\sigma_a} \ge 1{,}000;\ \tau_s = \frac{\tau_d}{c_\tau} \le \tau_d\,.$$

From figure 2, obviously is resulting :

$$tg\,\vartheta = \frac{1}{N} = \frac{\lg\sigma^t_{\tau_s} - \lg\sigma_a}{\lg\tau_d - \lg\tau_s}, \tag{9}$$

from which is obtaining :

$$N = \frac{\lg C_\tau}{\lg C_d} = \frac{\ln C_\tau}{\ln C_d}\,, \tag{10}$$

respectively :

$$C_\tau = C_d^N = \left(\varphi \frac{\sigma_d^t}{\sigma_{\max}}\right)^N = \left(\varphi \frac{\sigma_d^t}{\sigma_{as}}\right)^N = \left(\frac{\sigma_d^t}{\sigma_a}\right)^N , \tag{11}$$

this last expression can be obtained directly from the classical equation (4).

The formulas (9) – (11) are conclusively proving that minimum value C_τ = 1.000 is corresponding to some alternatives which cannot be found in the practical and technological , for which (N lg C_d) = 0, (N In C_d) = 0 or C_d^N = 1.000, the respective alternatives being achievable if in one this cases with

- C_d = 1.000 , any N and accordingly any ϑ ; any;
- C_d , N = 0 and therefore ϑ = 90° ;
- C_d > 1.000 , $N \rightarrow$ and , therefore, $\vartheta \rightarrow$ 90°.

Due to the fact that in practical activity specific to constructive structure and processing of technological and petrochemical equipments, commune and representative are meanwhile only the alternatives for which $C_d \geq$ 1.50, 0° < $\vartheta \leq$ 45° and therefore N >> 1.000, invariable is resulted :

$$C_\tau \gg 1{,}000. \tag{12}$$

3. THE SAFETY FACTOR TOWARDS THE CREEPING STRENGTH

According to its general philosophical meaning, the technical-technological safety defines and means the state of relative ratio/interval between the different technical-technological systems, equipments, facility /machinery, structures, elements, components, etc. or from a specific technical-technological system, equipment, facility/machinery , structure, component, element, etc. on one hand and environment or human being (community !) on the other hand, the respective state being created as a result of observance, compliance and application of some reliability levels restricted by projects (technical, technological, execution, assembling/mounting, processing, etc.) and by the regulations of authorities , in order to prevent and to fight against occurrences on matters like damages, accident, etc. [3,4].

Strictly from technical-technological point of view, the safety (including security !) of a certain technical-technological system, equipment, facility /machinery, structure, component, element, etc. is defined – according to Holzhauer [2] – as being that values interval of a certain parameter (load, force or force couple, strain, mechanical stress, pressure, temperature, period (of time), etc.) which separates the technical-technological system, equipment, facility/machinery structure, component, element, etc. from a non-deliberated and unexpected occurrence – for instance its take out of service due to the exceeding of its bearing /supporting power or due to some residual strain (plastic flow or creep strain) through breakage, or stability loss, through mechanical relaxation /creeping, through resonance, etc.

Therefore, the important problem to be solved during the technical-technological activity in general and mainly about the extension of lump continuous service time of the technological and petrochemical equipments beyond their service time /designing/calculation, is that of extension as much as possible of its service time → processing, without modifying the range of guard time which ensures the processing of equipments under security conditions, thus, without any compromise concerning the general security of the technological processing units.

The general problems concerning the technical-technological security of the industrial units and the technical limited security of the petrochemical units for technological processing in the course of time, the problems concerning the effective operating time and creeping strength of the equipments, facility/machinery, structures, components, elements, etc. processed under creeping conditions came in again of present interest in the last 10-15 years, the studies involved being decisivel stimulated, on one side by the remarkable technical improvements during elaboration, conceiving, design, materials implementation (especially steels and special refractory alloys) etc. regarding the equipments and on the other side stimulated by some alternatives and practical necessities, with high managerial implications (as the opportunity to extend the effective operating time beyond the designing /calculation, respectively the corresponding rehabilitation, or the replacement of equipments structural elements immediately after the exceeding of conventional operating time /designing/calculation, equals by example with 100 000 hr.).

Because the implementation of similar technical materials (steels, alloys) was and yet remains conditioned by the values of own creeping strength $\sigma_d^t = \sigma_{B/\tau_d}^t = \sigma_{r/\tau_d}^t$ during the past, about 40 years ago in Germany was put into practice a technical program in order to determine through mechanical testing of the respective values for temperatures of about 400 … 1000°C, for different steel grades and steels brand. The experimental results obtained and first published in 1996 pointed out the designing/calculation values $\sigma_d^t = \sigma_{B/\tau_d}^t = \sigma_{r/\tau_d}^t$, restricted by the German standard 17175 and Romanian standard 8184-68, which were a little bit higher than real standards, the corresponding operating time and designing/calculation being at their turn much smaller than the compliance standards.

These findings being validated, which obviously has as a ground a huge volume of experimental data, the/builders, building contractors and the authorities for technical – – technological monitoring and control from Germany considered as normal and optimum that all the technological equipments and thermo mechanical ones from the system of industrial processing units, which previously have been designed/calculated for a conventional operating time the so-called $\tau_{calc} = \tau_s$ = 100 000 hr and for C_d = 1.500, to be re-calculated → redesigned for an operating "calculated" time of $\tau_{calc} = \tau_s$ = 200 000 hr and (according to Ruttman [6]) C_d = 1.000. Ruttman estimated that using this way the sizing calculus and the checking ones, regarding the equipment elements and components, should be closer to the real situation, hence, an existing situation and practical one in countries like USA, former-USSR and Russia, UK, France, Germany, Romania, etc.

In such context, the condition regarding the mechanical strength/resistance, according to Ruttman expression, should be re-formulated as follows :

$$\sigma_{\max} \le \sigma_{as} = \varphi\,\sigma_a = \varphi \frac{\sigma_{r/200\,000}^t}{1{,}000} = \varphi\,\sigma_{r/200\,000}^t , \tag{13}$$

which reminds us about admitting that designing and /or rational checking of equipment elements and components from petrochemical units for industrial processing and similar units must be done when first has to take into consideration the τ_{calc} operating "calculated" time directly mentioned on the basis of σ_d^t values and therefore totally maintaining the determining values of the (global) security factor $C_d \ge 1.500$.

Meanwhile, this last point of view cannot be totally accepted. It seems that was not accepted in Germany, too. On the basis of experimental results (data), generally known or unknown (see the specialty standards STAS, SR, EN, DIN, GOST, ASTM, ISO, etc) is admitted as a range of values dispersion σ_d^t which is delimitated by a deviation of +/- 20 % in comparison with σ_{dmed}^t (fig.3). Obviously, as far as during the time will get some conclusive and additional results (data), the respective range of values dispersion σ_d^t should be reduced, having as a result the amplification /strengthening of the values $\sigma_{d\min}^t$. This alternative allows to estimate in a predictable future that from the practical numerical estimations /evaluations shall be currently used only the values $\sigma_{d\min}^t$ to which are corresponding the maximum values $\tau_s = \tau_{calc}$.

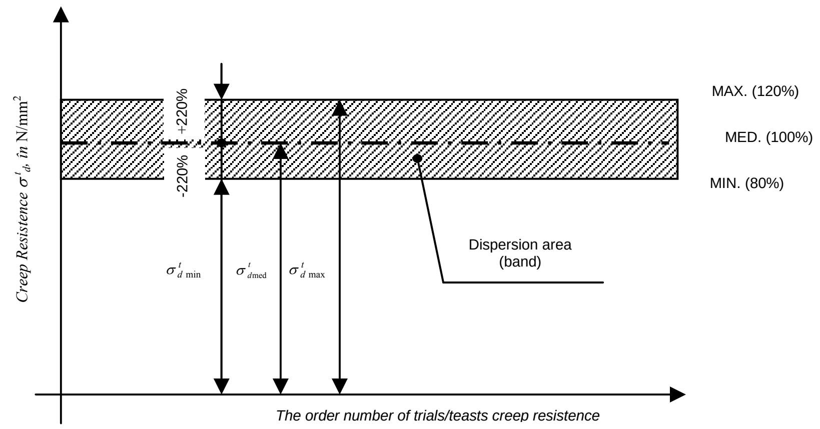

Fig. 3. The schematic range (band) of dispersion for the creep resistance values j σ^t_d .

For the present stage when are accumulated the experimental (data) results, admitting (in the alternative having a pessimist deviation/ minus tolerance of - 20 %, figure 3) :

$$\sigma^t_{d\,\min} = 0{,}8\ \sigma^t_{d\,\mathrm{med}} \tag{14}$$

and taking into consideration that $C_{d\ \mathrm{med}}$ = 1.500, if we are considering the realistic quantitative appraisal/evaluation of allowable mechanical stress/tension (strength) σ_a and general condition (13), is obtaining:

$$\sigma_a = \frac{\sigma^t_{d\,\mathrm{med}}}{C_{d\,\mathrm{med}}} = \frac{\sigma^t_{d\,\min}}{C_{d\,\min}} = \frac{\sigma^t_{d\,\max}}{C_{d\,\max}},$$

from which immediately resulting that:

$$C_{d\ \min} = 0{,}8\ C_{d\ \mathrm{med}} = 0{,}8 \cdot 1{,}500 = 1{,}200 > 1{,}000\ . \tag{15}$$

When $C_{d\,\mathrm{med}}$ = 1.650 , is obtained :

$$C_{d\ \min} = 0{,}8\ C_{d\ \mathrm{med}} = 0{,}8 \cdot 1{,}650 = 1{,}320 > 1{,}200\ .$$

Therefore, the (global) security factor Cd min , in comparison with the minimum values (lower/ inferior) of creeping strength $\sigma^t_{d\,\min}$, is supra unitary and in any practical case and cannot be unitary (see condition 13), as Ruttmann estimated.

4. THE CORRELATION OF SECURITY FACTORS C_d AND C_τ

From (11) results the following expression of numerical evaluation for C_d security factor:

$$C_d = C_\tau^{1/N} = \sqrt[N]{C_\tau}\ . \tag{16}$$

In the table no. 1 are mentioned the values of security factor C_τ for some representative stages $C_d \in$ [1.000 ; 1.650] , and in table no. 2 are found the values of security factor C_τ for some representative stages C_d $C_\tau \in$ [1.000;10.000], all these values being numerically evaluated /estimated for the actual /real counter-slope $N \in [4.4 ; 8.8]$ as well as for the hypothetical counter-slope $N \in [1.04 ; 4.0]$.

Tabel 1. The security factor C_τ value (11)

Calculation temperature			N \ C_d	$C_{d\,\min}$ = 1,00	$C_{d\,\min}$ = **1,20**	$C_{d\,\min}$ = 1,32	$C_{d\,\min}$ = **1,50**	$C_{d\,\min}$ = 1,65
t, în ºC	*T*, în K	*T*, în ºF						
538	811	1 000	8,8	1,000	4,975	11,509	35,448	82,008
566	839	1 050	7,5	1,000	3,925	8,022	20,925	42,769
593	866	1 100	7,2	1,000	3,716	7,381	18,529	36,803
621	894	1 150	6,3	1,000	3,153	5,749	12,863	23,450
649	922	1 200	5,9	1,000	2,932	5,145	10,938	19,193
677	950	1 250	5,2	1,000	2,580	4,236	8,235	13,518
704	**977**	**1 300**	**4,4**	1,000	**2,230**	3,392	**5,953**	9,055
Peste 704	Peste 977	Peste 1 300	4,0	1,000	2,073	3,035	5,062	7,412
			3,0	1,000	1,728	2,299	3,375	4,492
			2,0	1,000	1,440	1,742	2,250	2,722
			1,0	1,000	1,200	1,320	1,500	1,650

Tabel 2. The security factor C_d value (16)

Calculation temperature			N \ C_τ	1,0	**2,0**	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0
t, în ºC	*T*, în K	*T*, în ºF											
538	**811**	**1 000**	**8,8**	1,000	**1,081**	1,132	1,170	1,200	1,225	1,247	1,266	1,283	1,299
566	839	1 050	7,5	1,000	1,096	1,157	1,203	1,239	1,269	1,296	1,319	1,340	1,359
593	866	1 100	7,2	1,000	1,101	1,164	1,212	1,250	1,282	1,310	1,334	1,356	1,376
621	894	1 150	6,3	1,000	1,116	1,190	1,246	1,291	1,328	1,361	1,391	1,417	1,441
649	922	1 200	5,9	1,000	1,124	1,204	1,264	1,313	1,354	1,390	1,422	1,451	1,477
677	950	1 250	5,2	1,000	1,142	1,235	1,305	1,362	1,411	1,453	1,491	1,525	1,557
704	977	1 300	4,4	1,000	1,170	1,283	1,370	1,441	1,502	1,556	1,604	1,647	1,687
Peste 704	Peste 977	Peste 1 300	4,0	1,000	1,189	1,316	1,414	1,495	1,565	1,626	1,681	1,732	1,778
			3,0	1,000	1,259	1,442	1,587	1,709	1,817	1,912	2,000	2,080	2,154
			2,0	1,000	1,414	1,732	2,000	2,236	2,449	2,645	2,828	3,000	3,162
			1,0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000

Analyzing and explaining the data included in tables no. 1 and 2 , data which are graphically illustrated in figure no. 4, has to be remembered the followings :

● the minimum value $C_{d\,\min}$ = 1.200 which ensures a C_τ level ≥ 2.230 for any counter-slope $N \geq 4.4$, but to the last is corresponding the maximum temperatures − for Cr/Mo steels of 2.25/1.00 grade/type – maximum temperatures which meets the constraint /restriction t max ≤ 704°C = 1300 °F and breakage /damage time which are complying with $\tau_d = c_\tau \tau_{calc} \geq 2.230\,\tau_{calc}$ restriction , for τ_{calc} = 100 000 hr and is resulting τ_d = 223 000 hr and for a known τ_d is obtained $\tau_{calc} \leq 0.4484$, thus, in circumstances with $C_d = C_{d\,\min}$ =1.200 even for the equipments made by Cr/Mo steels of 2.25/1.00 grade/type can be capitalized less than half (below 50%) from τ_d time , and resulting a considerable and available working service $\Delta\tau_s = \tau_d - \tau_{calc} \leq 223\ 000 - 100\ 000 = 123\ 000$ hr for 1.000 < C_d < $C_{d\,\min}$ = 1.200;

● the usual medium value C_d med = 1.500 ensures a security factor C_τ ≥ 5.953 for any level $N \geq$ 4.4, then $\tau_d = c_\tau \tau_{calc} \geq 5.953\tau_{calc}$ in the case with τ_{calc} = 100 000 hr is resulting τ_d ≥ 595 300 hr, but in the case with τ_d known $\tau_{calc} \leq 0.1680\,\tau_d < 0.200\,\tau_d$ is obtained; thus, in circumstances with $C_d = C_{d\,\mathrm{med}}$ = 1.500, even for the same equipments can be capitalized not than less 20% from τ_d time, and resulting a considerable and available working service $\Delta\tau_s = \tau_d - \tau_{calc} = 595\ 300 - 100\ 000 = 495\ 300$ hr for 1.000 < C_d < $C_{d\,\mathrm{med}}$ = 1.500 ;

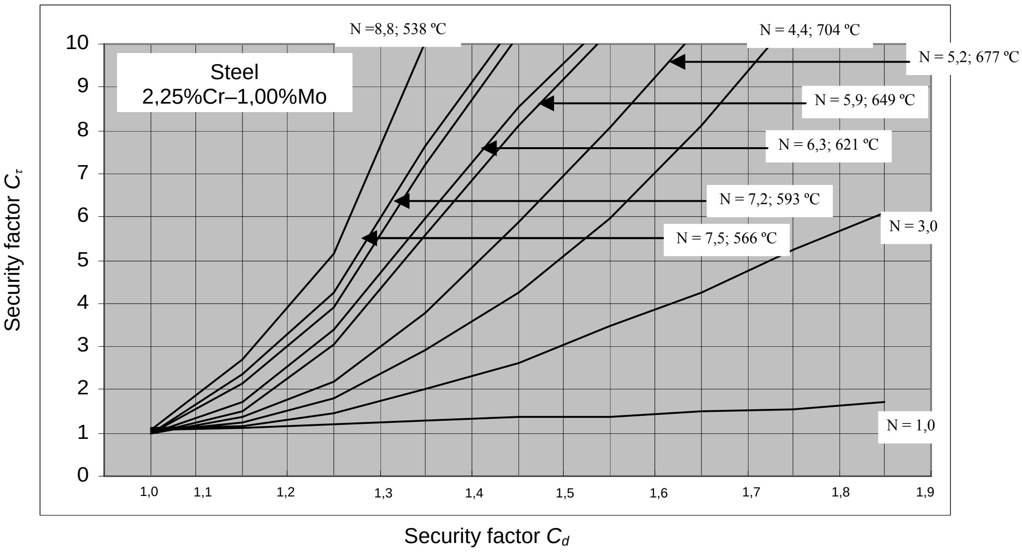

Fig. 4. The security factor correlation C_d and C_τ diagram.

● for C_d > 1.081 is corresponding C_τ ≥ 2.000 in any case characterized for the level $N \in$ [1,0;8,8], therefore, $\tau_d = c_\tau \tau_{calc} \geq 2.000 \tau_{calc}$, for τ_{calc} = 100 000 hr is resulting τ_d ≥ 200 000 hr and for τ_d known is obtaining τ_{calc} ≤ 0.5000 τ_d ; thus in such circumstances with C_d = 1.081 even for the above-mentioned equipments can be capitalized only half (50%) from τ_d time and resulting a pretty higher available working service $\Delta\tau_s = \tau_d - \tau_{calc} = 200\,000 - 100\,000 = 100\,000$ hr for 1.000 < C_d < 1.081.

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