Excel programme for calculation of FAC (Flow Assisted Corrosion = Erosion Corrosion) on the basis of the publication of Kastner and Riedle (1986).

In 1982, Heitmann and Kastner[1] published the results of erosion corrosion experiments of KWU Siemens. Some years after this publication KWU-Siemens has processed these experimental results in a model and made the software programme WATCHEC which is applied in many power stations over the world.

We used the basic facts of the WATCHEC model, published in 1986 by Kastner and Riedle[2], to make our own programme in Excel.
The FAC-Calculation programm is available nearly for free. I will send you the program when you make a donation to the Dutch Reumafonds. Send me an E-mail for terms of delivery.

In particularly in case of erosion corrosion failures a model for calculating erosion corrosion rates is very useful.

Erosion corrosion experimental work of Kastner and Riedle

In 1982, published Heitman and Kastner [1] the results of the erosion corrosion experiments of KWU Siemens. Examples of the results have been given in the Figures 1, 2 and 3.

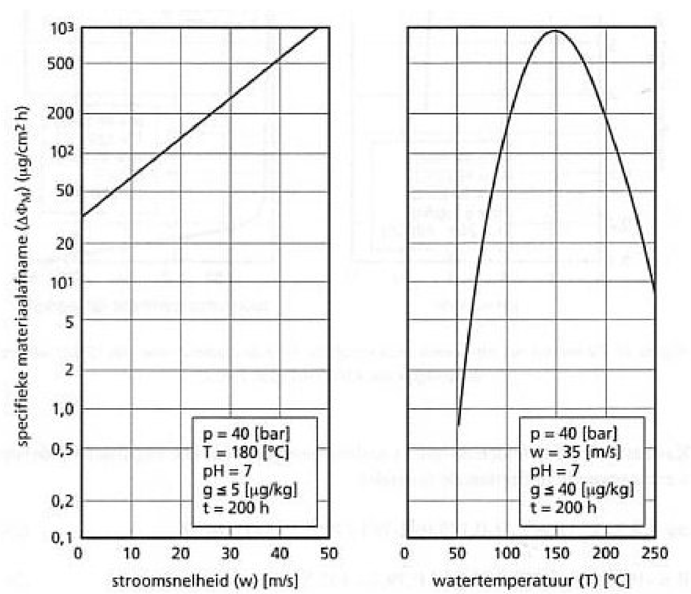


Figure 1. Influence of flow speed and temperature on erosion corrosion of 15Mo3 according to the experiments of KWU. (Heitmann, 1982).

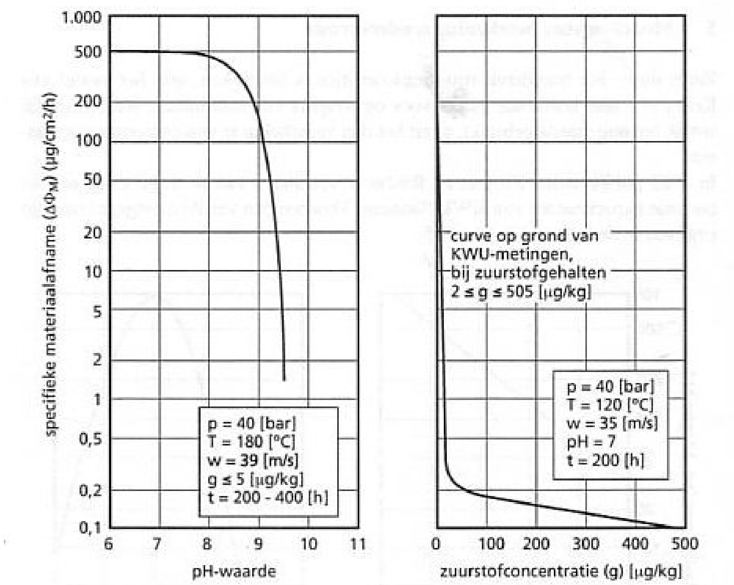


Figure 2. Influence of pH value and oxygen concentration on erosion corrosion of 15Mo3 according to the experiments of KWU. (Heitmann [1], 1982).

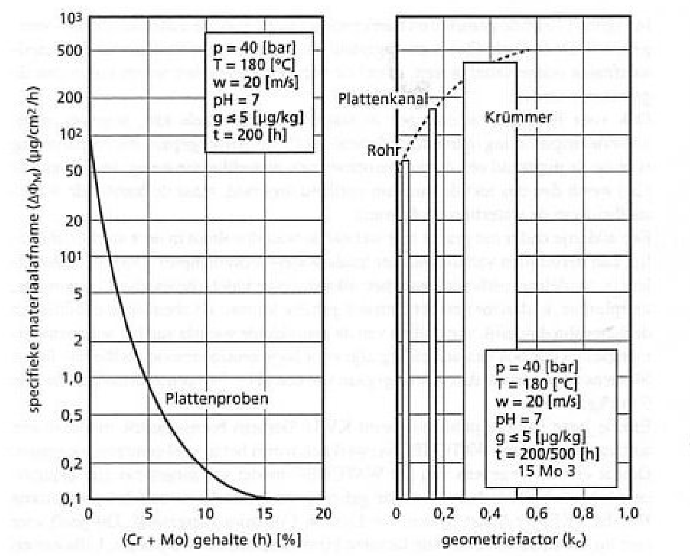


Figure 3. Influence of Cr+Mo content and the geometry on erosion corrosion according to the experiments of KWU (Heitmann [1], 1982).

Model of Kastner and Riedle for one phase flow

Kastner and Riedle [2] made reflected on the basis of the earlier erosion corrosion results an empirical model, in formulas mentioned below:

$$\Delta\varphi = 6{,}25.k_c.\{B.e^{Nw}.[1-0{,}175.(pH-7)^2].1{,}8.e^{-0{,}118.g}+1).\ [f(t)] \qquad (1)$$

The values B, N and f(t) are given as :

$$B = -10{,}5.\sqrt{h} - 9{,}375.10^{-4}.T^2 + 0{,}79.T - 132{,}5 \qquad (2)$$

$$N = -0{,}0875.h - 1{,}275.10^{-5}.T^2 + 0{,}01078.\ T - 2{,}15 \qquad \text{in which } 0 < h < 0{,}5\ \% \qquad (3)$$

$N = (-1{,}29.10^{-4}.T^2 + 0{,}109.T - 22{,}07).0{,}154.e^{-1.2.h}$ in which $0{,}5 < h < 5$ % (4)

$f(t) = C_1 + C_2.t + C_3.t^2 + C_4.t^3$ (5)

The values C_1, C_2, C_3, and C_4 are constants.

$C_1 = 0{,}9999934$ $C_2 = -0{,}3356901.10^{-6}$ (6)

$C_3 = -0{,}5624812.10^{-10}$ $C_4 = 0{,}3849972.10^{-15}$ (7)

In above comparisons notations mentioned below have been used

Description	Dimension	Notation	Comments
Material loss	$\mu g/cm^2/h$	$\Delta\varphi$	De omrekeningsfactor van gr/cm2h naar mm/jaar is 0,011)
Flow velocity	m/s	w	
Water temperature	°K	T	T<_ 613
pH	$-\log(H^+)$	pH	7.0 <_ pH _< 9.39
Oxygen concentration	µg/kg		0_< g < 30
Geometry factor (Keller[4])	No dimension *	k_c	
Expositietijd	hour	T	t>200 uur
Material factor (Cr+Mo)	%	H	0<h<5

* Kastner used a dimensionless Keller-factor.

The measured and calculated material losses have been given in Figure 4. Formula 1 is a conservative equation (calculated values will be higher than the measured values)

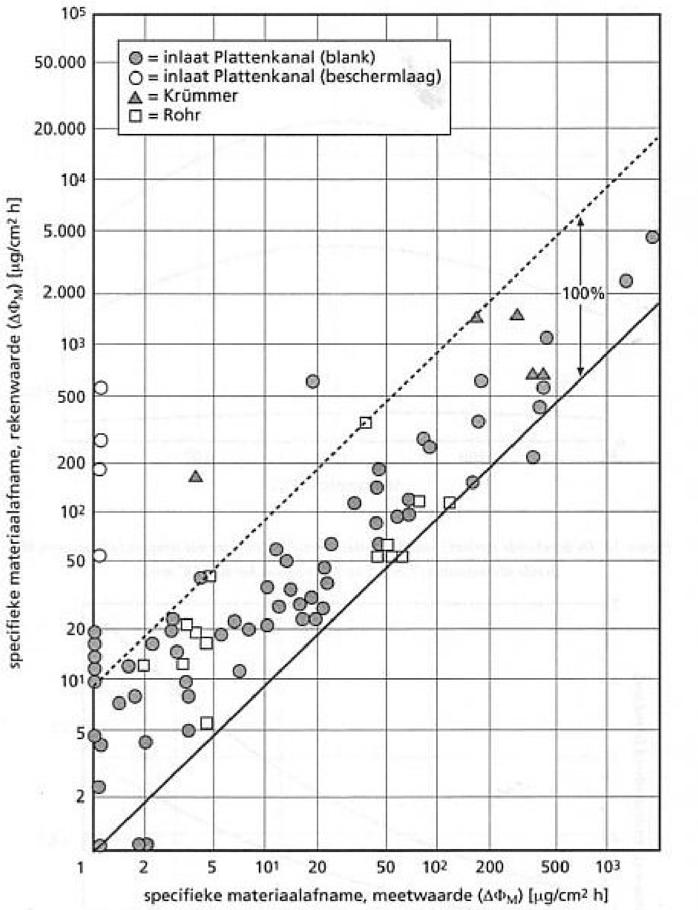


Figure 4. Measured and calculated erosion corrosion rates (Kastner [2], 1986).

Model of Kastner and Riedle for two phase flow

Also for two phase flow in water steam mixtures the formula (1) can be applied. Under annular flow conditions a thin water film is flowing over the metal surface and the steam flows in the core of the pipe. In formula (1) therefore the calculated flow velocity of the water film should be used.

Kastner and Riedle calculated these using the equations of Rouhani [5].

The flow velocity of the water film is calculated with the formula:

$W_F=(m'/ \rho_W)*(1-x)/1- \alpha)$ (8)

The volume fraction of steam is calculated with the equations 9, 10 and 11:

$\alpha =(x/ \rho_D)/(C*((x/ \rho_D)+(1-x)/ \rho_W)+ w_{rel} /m')$ (9)

$C= 1+0.12*(1-x)$ (10)

To the relative water speed the formula applies:

$w_{rel} =((1,18/ \rho_W{}^{0,5})*(g' * \sigma *(\rho_W - \rho_D))^{0,25})*(1-x)$ (11)

From dimension analysis of comparison 11 appears that the value 0.25 is a print failure. This number must be corrected in 0.5. This was confirmed by the author Dr. Riedle.

Description	Notation	Dimension	Value	Reference
Steam density at saturation	ρ_D	kg/m^3		steam table
Water density	ρ_W	kg/m^3		steam table
Mass flow	m'	$kg/m^2/s$		
Steam fraction (mass)	x			
Diameter	D	mm		
Surface tension (strength)	σ	kg/m	7.30E-03	Prins pg 18
Gravitation constant	g*	$m.^3/s^2/kg$	6.67E-11	Prins pg 173

The values for steam density at saturation and water density at a certain temperature are read from the steam table.

FAC-Calculation file: instructions for use.

The complex formulas of Kastner and Riedle can be handled quite easy with the contemporary Excel programme.

On the basis of their publication of 1986 we made the FAC-Calculation file. It appeared that in the Kastner and Riedle paper one small print failure was present. In our calculations this failure is corrected.

The instructions for use are simple.

1. In the sheet “Start” the red values are the input values. There is choice from “Main Choice”, “Choice 1” and “Choice 2”. This way the EC values of various conditions can be compared easy.

2. For two phase flow the velocity of the water film must be read from the graph “2 Phase Flow”.

3. Graphs are generated with the “Main Choice” data in the “Start” sheet.
   The following graphs can be made:
   - Erosion corrosion rate against Cr+Mo content of steel
   - Erosion corrosion rate against oxygen content
   - Erosion corrosion rate against the flow velocity
   - Erosion corrosion rate against pH value
   - Erosion corrosion rate against Keller number
   - Erosion corrosion rate against temperature

4. The sheets with calculations and formulas have been hidden and can not be modified. They have been protected with a pass word.

References

1. Heitmann und Kastner (1982), VGB Kraftwerkstechnik 62, H. 3, pg. 211-219.

2. Kastner W. , Riedle K. Empirycal model for the Calculation or Material Losses due to Corrosion Erosion, VGB Kraftwerkstechnik 66, no. 12, dec 1986, pg 1023-1029

3. Huijbregts W.M.M., Uilhoorn F., Wels H.C. (1997), "Erosion-corrosion in heat exchangers, the value of material specification", Euromat , Maastricht

4. Keller H. (1974), Erosionskorrosion in Nassdampfturbinen VGB Kraftwerkstechnik 54, 5, pg 292-295

5. Rouhani Z. , Modified Correlations for Void and Two-Phase Pressure drop off. AE-RTV-841 (1969).

Some erosion-corrosion failures.

With the help of the calculation model influence of various factors can be estimated rather well. Cr en Mo were incorporated in the correlation formula of KWU Siemens. Other elements as Cu and C were neglected.

From the extensive erosion-corrosion experiments of KEMA it was proven that Cu had a 40% more erosion-corrosion resistant effect than Cr.

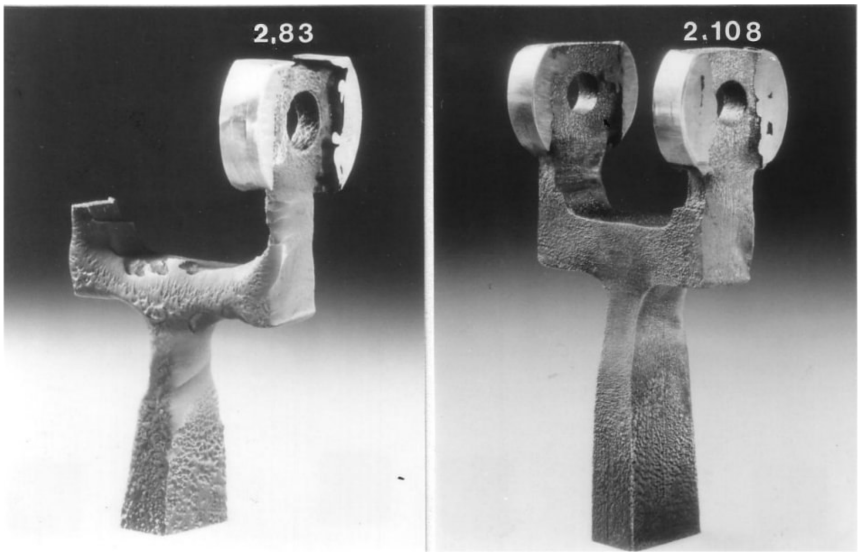
The relative erosion-corrosion resistance of C-steels and 15Mo3 was expressed in the Cr-equivalence formula below:

Cr-equivalent = Cr +1.4 Cu + 0.3 Mo - 0.3 C > 0.09

By comparing the Cr equivalence of steels from failures and non-failures it appeared that steels from failures generally had a Cr-equivalence less than 0.09.

Only under very exceptional erosive-corrosive conditions (p.a. very hig flow velocities) erosion corrosion can take place in steels with high Cr-equivalence. See examples on page 10.

Some examples of erosion corrosion failures are given below. For more erosion corrosion information see published papers nr: 21, 22, 27, 28, 46, 47, 58 en 60 on my website www.hbscc.nl .



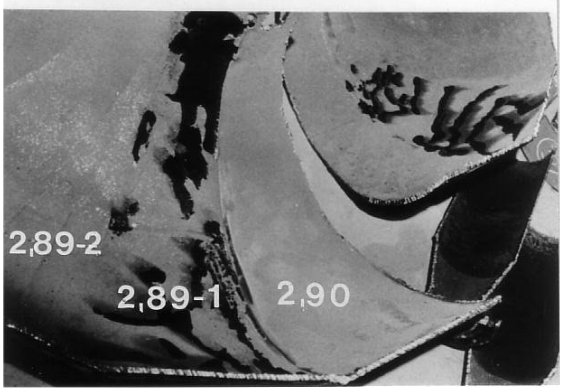
Two eroded corroded switch levers of feed water pumps. (photo KEMA).

On the left: Switch lever after 10.000 hr operation (2.83)

Cr	Cu	Mo	C	Cr-eq.
0.01	0.01	0.005	0.09	-0.0015

On the right: Switch lever after 40.000 hr operation (2.108).

Cr	Cu	Mo	C	Cr-eq.
0.025	0.03	0.02	0.06	0.055



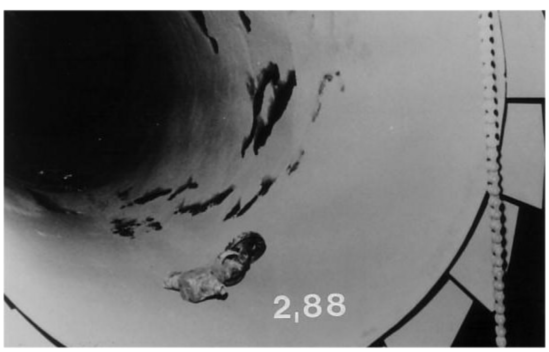
Wet steam pipes. (photo KEMA)

Eroded corroded plate (2.89-1)

Cr	Cu	Mo	C	Cr-eq.
0.01	0.02	0.003	0.17	-0.0121

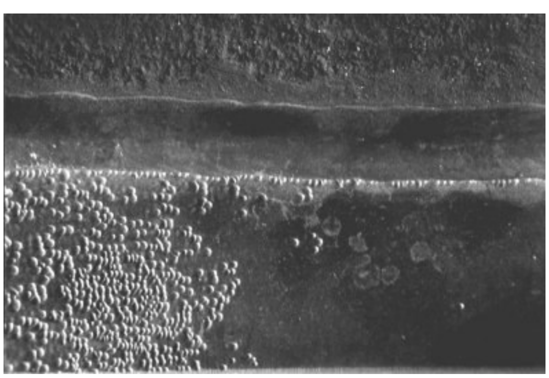
Non eroded corroded plates (2.90 en 2.89-2)

Cr	Cu	Mo	C	Cr-eq.
0.04	0.11	0.01	0.14	0.155



High pressure water separator, tiger skin erosion corrosion pattern. (photo KEMA) (2.88).

Cr	Cu	Mo	C	Cr-eq.
0.01	0.04	0.003	0.15	0.0219



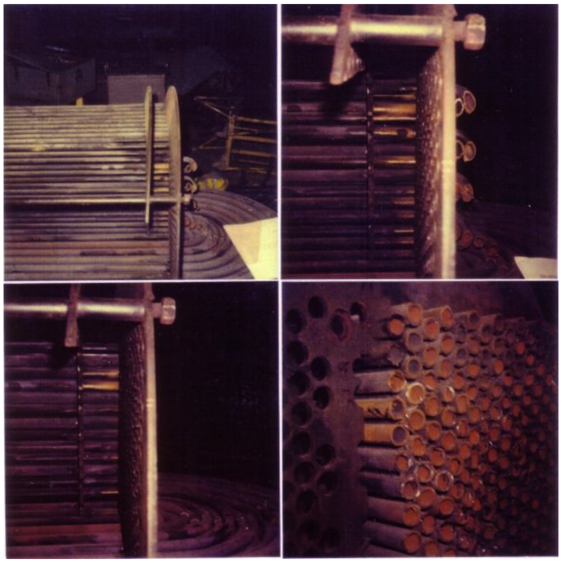
Welded plates in a water separator. (photo KEMA)

Non eroded corroded plate (2.120-2)

Cr	Cu	Mo	C	Cr-eq.
0.1	0.21	0.02	0.12	0.364

Eroded corroded plate (2.120-1)

0.01	0.006	0.01	0.12	-0.0146



Dismantled preheater. Two different heats were used. (photo KEMA)

Eroded corroded tubes (2.69-1A)

Cr	Cu	Mo	C	Cr-eq.
0.03	0.03	0.01	0.12	0.039

Non eroded corroded tubes (2.69-2B)

Cr	Cu	Mo	C	Cr-eq.
0.07	0.04	0.02	0.12	0.096

Steam blanketing at the inner side and erosion corrosion at the outer side of the bellow. (photo KEMA) (2.131-2)

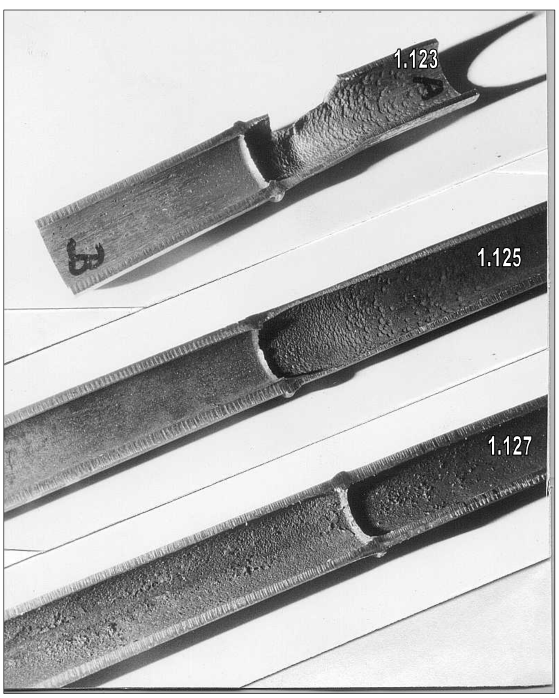
Cr	Cu	Mo	C	Cr-eq.
0.005	0.02	0.005	0.12	-0.0015

Spindle under high flow condition. Top was not coated. (photo KEMA). (2.114)

Cr	Cu	Mo	C	Cr-eq.
0.02	0.05	0.02	0.01	0.093

Buffle plate for wet steam in experimental boiler of KEMA.(photo KEMA). (2.133)

Cr	Cu	Mo	C	Cr-eq.
0.07	0.07	0.02	0.12	0.138



Erosion corrosion just after butt welds. (photo KEMA).

Severe attack (1.123)

Cr	Cu	Mo	C	Cr-eq.
0.02	0.04	0.3	0.14	0.124

Attack (1.125)

Cr	Cu	Mo	C	Cr-eq.
0.03	0.03	0.36	0.14	0.138

No attack (1.127).

Cr	Cu	Mo	C	Cr-eq.
0.06	0.09	0.36	0.14	0.252