Risk Quantification Methodologies

Background Information

	Langelier Saturation Index (LSI)
Adverse Effect	Corrosion and scaling
Dependent Parameters	pH, Temperature, TDS, Hardness and Alkalinity
Definition	The Langelier Saturation Index is an equilibrium model derived from the concept of saturation. It is purely an equilibrium index and deals only with the thermodynamic driving force for calcium carbonate scale formation and growth. The LSI can also be utilized to assess scaling risk. The calcium carbonate saturation is useful in determining if a specific water quality is aggressive/corrosive, balanced, or scale-forming (high LSI). Although the index is useful in determining whether the water quality is scale forming or corrosive, it does not indicate how much scale or calcium carbonate will precipitate to bring the water to equilibrium. Furthermore, it does not consider film formation by phosphates and silicates.
Equation	$$LSI = pH - pH_s$$ Whereby pH$_s$ is given as follows – $$pH_s = (9.3 + A + B) - (C + D)$$ Whereby the factors are given by – $$A = \frac{Log_{10}[TDS] - 1}{10}$$ $$B = -13.12 \times Log_{10}(°C + 273) + 34.55$$ $$C = Log_{10}[Ca^{2+} as\ CaCO_3] - 0.4$$ $$D = Log_{10}[Alkalinity\ as\ CaCO_3]$$

	Ryznar Index (RI)
Adverse Effect	Corrosion and scaling
Dependent Parameters	pH, temperature, TDS, hardness and alkalinity
Definition	The Ryznar index is considered in conjunction with the LSI index as it affords greater protection against corrosion, than does the more familiar Langelier Index. It boosts the calcium hardness to a point, where scale begins to form, which actually helps protect the equipment, from corrosion. This index aims to quantify the relationship between the calcium carbonate saturation state and scale formation.
Equation	The Ryznar index is calculated as follows – $$RI = 2 \times pH_s - pH$$ Whereby pHs is given as follows – $$pH_s = (9.3 + A + B) - (C + D)$$ Whereby the factors are given by – $$A = \frac{Log_{10}[TDS] - 1}{10}$$ $$B = -13.12 \times Log_{10}(°C + 273) + 34.55$$ $$C = Log_{10}[Ca^{2+} as\ CaCO_3] - 0.4$$ $$D = Log_{10}[Alkalinity\ as\ CaCO_3]$$
Risk Implication	If the RI calculated is greater than 8.5, there is a high risk of corrosion. If the RI calculated is within the ranges of 7.8 to 8.5 there is a low risk if corrosion The acceptable RI calculated should be within the ranges of 6.8 to 7.8

	Pitting Resistance Equivalent (PREN)
Adverse Effect	Corrosion (Pitting)
Dependent Parameters	pH, chloride, temperature, the material of construction and presence of an oxidizing agent.
Definition	Many alloys, such as stainless steels and Al alloys, are useful only because of passive films, which are thin (nanometre-scale), oxide layers that form naturally on the metal surface and greatly reduce the rate of corrosion of these alloys. However, these passive films are often susceptible to localized breakdown resulting in the accelerated dissolution of the underlying metal. This type of corrosion occurs when the passive film is damaged and becomes exposed. This can occur through chemical attack, mechanical damage, presence of microstructure irregularities such as non-metallic inclusions which is caused by machining. Pitting is dependent on the metals PREN number and critical pitting temperature.
Equation	A particular steel's resistance to corrosion pitting can be evaluated as its chromium equivalent or PREN (pitting resistance equivalent) through the following equation: $$PREN = \%Cr + (3.3 \times \% Mo) + (16 \times \%N)$$

Risk Implication

Acceptable PREN values and Critical Pitting Temperatures for specific Grades are listed below:

Grade of Stainless Steel	Typical PREN Value	Critical Pitting Temperature
304/304L	20	18°C
316/316L	25	20°C
Alloy 20	30	90°C
904L	36	40°C

	Larson-Skold Index
Adverse Effect	Corrosion
Dependent Parameters	Alkalinity, sulphate and chloride concentration
Definition	The Larson-Skold index refers to an empirical scale used to measure the degree of corrosiveness of water relative to mild steel metal surfaces. This index looks at the potential corrosivity of iron and steel. The Larson-Skold index scale presents the following outcomes of corrosion tendency.
Equation	$$Ratio = \frac{(Sulphate \ \times 2) + Chloride}{Alkalinity}$$
Risk Implication	If the Larson Skold Index calculated is greater than 1.2, there is a possibility of severe pitting corrosion. If the Larson Skold Index calculated is less than 0.8, there is a possibility of minimal pitting corrosion.

	Aggressive Index
Adverse Effect	Corrosion
Dependent Parameters	Alkalinity and Hardness
Definition	The aggressive index relates to the corrosive tendency of water. It is particularly important in pipes that contain cement and asbestos.
Equation	$$AI = pH + \log(A \times H)$$ Where – A is the alkalinity in mg/L $CaCO_3$ and H is the hardness in mg/L $CaCO_3$.
Risk Implication	If the Larson Skold Index calculated is greater than 1.2, there is a possibility of severe pitting corrosion. If the Larson Skold Index calculated is less than 0.8, there is a possibility of minimal pitting corrosion.

	Corrosion Rate
Adverse Effect	Corrosion rate of stainless steel
Dependent Parameters	Chloride, sulphate, alkalinity, dissolved oxygen, calcium, pH, alkalinity, TDS temperature
Definition	The corrosion rate of stainless steel is based on an eight-variable empirical mode. The models suggest that increasing chloride, sulphate, alkalinity, and dissolved oxygen levels would accelerate corrosion, whereas increases in calcium, buffer capacity, saturation index, and exposure time would lead to decreasing corrosion rates. This index was used to predict the corrosion rate based on these variables.
Equation	$$Corrosion\ Rate = \frac{(Cl^{-1})^{0.509} \times (SO_4^{2-})^{0.025} \times (Alkalinity)^{0.423} \times (DO)^{0.799}}{(Ca)^{0.676} \times \beta^{0.030} \times (10^{SI})^{0.107} \times Day^{0.381}}$$ Where: DO = dissolved oxygen (mg/l as O_2) Ca = calcium (mg/l as Ca^{2+}) β = buffer capacity (mg/l as $CaCO_3$) SI = Langelier Saturation Index Day = Days of exposure between material and water

	Calcium Phosphate Stability Index
Adverse Effect	Scaling
Dependent Parameters	pH, calcium and phosphate
Definition	Calcium phosphate (CaPO4) is less soluble in neutral and alkaline conditions and dissolve in acidic conditions. Aluminum and iron phosphates, however, are less soluble at moderately acidic conditions. Thus it is important to remove aluminum and iron in a pretreatment step as well. Because of the complexity of phosphate chemistry, it is not easy to predict a threshold level of phosphate scaling.
Equation	$$SI = pH_a - pH_c$$ Where pH_a is the actual pH of the water and pH_c is the critical pH. The critical pH is calculated by – $$pH_c = \frac{11.755 - \log(CaH) - \log(PO_4) - 2\log(t)}{0.65}$$
Risk Implication	If the SI calculated is greater than 0 there is a scaling potential and treatment is recommended If the SI calculated is less than 0 there is no scaling potential.

	Magnesium Silicate Scale Formation
Adverse Effect	Scaling
Dependent Parameters	Magnesium and silica
Definition	Magnesium silicate is a common scale produced in industry. Magnesium silicate can form in a cooling system via two distinct mechanisms, namely the formation of a stoichiometric $MgSiO_3$, and through interaction with precipitating magnesium hydroxide.
Equation	Ion product – [Mg (mg/l)] x [SiO_2 (mg/l)]

	Calcium Sulphate Scale Formation
Adverse Effect	Scaling
Dependent Parameters	Calcium and sulphate
Definition	Calcium sulphate is also another common scale produced in industry. Gypsum is the expected form of calcium sulphate scale in cooling systems whereas anhydrite is more prevalent at temperatures above those normally encountered in cooling water.
Equation	Ion product – [Ca (mg/l)] x [SO_4 (mg/l)]

Silt Density Index (SDI)	
Adverse Effect	Fouling
Dependent Parameters	Suspended Solids and colloidal matter
Definition	Silt is composed by suspended particulates of all types that accumulate on the membrane surface. The SDI is a method for estimating the rate at which colloidal and particle fouling will occur in water purification systems, especially using reverse osmosis systems or nanofiltration membranes systems. The SDI is purely a measurement of the fouling potential since each suspended particulate matter differs in size and shape. The test is dependent on the site-specific details and should be performed according to the standard test method.
Equation	None – Determined experimentally
Risk Implication	• If the SDI<1 there is a minimal risk of colloidal fouling • If the SDI>5 there is a high risk of colloidal fouling