Chapter 13

Risk Assessment for Corrosion, Plugging and Health

13.1 Using the Bart tester analytical system for the projection of Risk.

There are three widely recognized microbiologically influenced risks (corrosion, C; plugging, P; and health, H) in water. Corrosion commonly relates to impacts on the surfaces of metal alloys (such as mild steels), iron reinforcements in concrete (e.g. rebar) and directly on concretes. Plugging refers to the growth of a biomass that could form a sludge, slime or deposit that then interferes with the free flow of water in engineered systems. Health risks can be of two types in which the first is caused by known human pathogens (e.g. dysentery and typhoid) while second is more of an opportunistic pathogen and causes diseases only under certain conditions associated with the human host. One condition that commonly causes these nuisance opportunistic infections is when the human host has a dysfunctional immune system that is not able to cope with the infection. Risk in this sense is based upon the Bart reactions observed during BART testing and also the time lapses (i.e. shorter time lapses mean higher populations and implied activity and hence a greater perceived risk). The Bart analytical system is primarily qualitative (generating reactions and activities) and secondarily quantitative based upon the populations projected from the time lapse information. Projecting risk is therefore primarily on the basis of the types of reactions that are observed in the testers when applied to a specific sample with secondary predictions of population. .

There are three major risks evaluated each calculated on a risk scale from zero to nine where zero would indicate no Bart definable risk and nine would be an extreme level of risk on the basis of Bart data. There are five categories for risk from negligible (0 to 1), minor (2 to 3), medium (4 to 5), major (6 to 7) and extreme (8 to 9). Risks relate to the data achieved from testing and relate to corrosion, plugging and health risks. These are described in more detail below.

Corrosion risks relate to microbiologically influenced activities that primarily cause damage to metal or concrete structures. This usually begins with compromises to the surfaces where the microbes are active and then penetrates into the structures. These compromises lead to erosive corrosion, pitting and eventually full perforation or collapses of the metal or concrete structures. There is also an ongoing loss in strength as the metals or concretes corrode which can also be accompanied by increases in porosity.

Plugging risks are generated from the growth of biomass (commonly initiated as biofilms) which develops from the occupation of the voids or fractures. Here the significant volume of biomass now displaces the resident (flowing) liquids or gases leading to reduced productions and hence plugging. This biomass can grow into slimes (commonly seen in cooling towers and heat exchangers) or as growths within porous media (e.g. sands, gravels), or even within fractured rock. Plugging can also affect hydraulic flows not just for water but also impacting gas or oil flows. This is because some of the biomass can directly intercept of flow-through characteristics through forming bio-colloidal structures or encrustations that then change the viscosity of the water. Biomass can also cause plugging within various grades of crude oil when the biomass begins to bind water in crude locking it into defined structures often with subsequent coatings of asphaltenes. Gas flows (e.g. natural gas, methane) can also be affected by the biomass plugging in formation materials as well as around the perforations of the well itself. Here the impact of the biomass in binding water closer to the well would initially cause diversionary flow. This would then diminish gas flowing into the well. In water wells the most commonly "observed" plugging is in the screened slots or perforations in the well casing. Video logging the well would commonly show where plugging is occurring as growth and it is these zones that are the most affected. It should be remembered that this is most relevant when there is historical data available not only on flows but also on water content and bacteriological loadings (which should periodically increase as the plugging develops).

Health risks relate to humans or farmed animals that are using the water as a source for drinking. Traditionally health has been defined using the presence (bad) or absence (good) of coliform bacteria. Coliforms are more commonly associated with normal intestinal infestations and are detected as either total coliforms (broad sweep), fecal coliforms (narrow focus), or as *E. coli* (specific health risk). The health risk generated here is a broader assessment of risk to humans and animals from the associable coliform bacteria that might be present in the water. This risk includes some of the opportunistic bacteria that can be active in the environment but can also cause disease in humans or animals (nuisance or nosocomial pathogens).

13.2 Confidence rating

Risk assessment is always given on a scale from zero (no detected risk) to nine (extreme probability of risk. Precision for risk predictions is obtained when five types of tester are employed. A full complement of all five testers is essential to assure all risks are addressed. Risk assessment allows the prediction of corrosion risk (CR), plugging risk (PR), and health risk (HR). These may be may be calculated where the IRB-, SRB-, HAB-, SLYM-, and DN- testers are employed. If less than the five BART testers are used then risk analysis will lose its precision. Note testers that are negative (detectors) should still be included by default but do not contribute to a positive risk assessment.

13.3 Predicted Corrosion Risk (CR)

Corrosion risk is generated by all five testers and the reactions relevant to corrosion are shown as “C risk weight” data established from 0 to 9 with an ascending degree of risk. Relevant corrosion by C risk weights are given separately for each tester group: IRB- (Table 13.1), SRB- (Table 13.2), HAB- (Table 13.3), SLYM- (Table 13.4), and APB- (Table 13.5). In this assessment the major corrosion risk is primarily based on the SRB- tester which would deliver a C weight of 9 if BB was observed and 3 if a BT was observed. Generally the BB reactions occur when there is a potential for radical pitting and perforation particularly of steels. APB- tester will detect fermentative activities that could lead to the pH dropping into the 3.5 to 5.8 range which could now create corrosive conditions particularly under conditions where high organic loadings exist under reductive (anaerobic) conditions. Corrosion risk is equal to the sum of all corrosion reactions bearing a significant C risk weighting (1 or higher). The risk is calculated as the sum of all positive C risk weighted reactions observed for all five tester types divided by the number of reactions observed. Risk for corrosion can therefore be 9 (severe risk), 3 (moderate risk), 1 or 2 (minor risk) exists.

Table 13.1 Corrosion risk, IRB- Tester

	RX	C Risk
IRB	**BC**	1
	BG	2
	BL	1
	BR	0
	CL	1
	FO	3
	GC	0
	RC	0

Table 13.2 Corrosion risk, SRB- Tester

	RX	C Risk
SRB	**BT**	3
	BB	9

Table 13.3 Corrosion risk, HAB- Tester

	RX	C Risk
HAB	UP	0
	DO	2

Table 13.4 Corrosion risk, SLYM- Tester

	RX	C Risk
SLYM	DS	1
	SR	0
	CP	0
	CL	1
	BL	1
	PB	0
	GY	1

Table 13.5 Corrosion risk, APB- Tester

	RX	C risk
APB	**DY**	5
	DYB	3

The corrosion risk involves five tester types that indicate different levels of corrosion risk depending upon the reactions (RX) observed and interpreted. In the determination of risk only the highest corrosion risk generated by reactions may be selected for each tester type employed. Table 13.6 shows the minimum and maximum values for each tester type based on the reactions recorded. Summation of the highest possible risks now generate a maximum value to the risks which would be equivalent to nine (9) on the scale of risk.

From Table 13.6 the maximum summated corrosion risk point (max C risk) is set at 20 while the summated minimal risk (min C risk) is set at 10. The calculated minimum and maximum corrosion risk is presented in Table 13.7. Calculated potential corrosion risk (PCR) incorporates the entire tester types listed and, if all the testers react positively, then the C risk will range between the min and max C risk. However testers not displaying a C risk reaction would be considered zero. Calculation of the C risk for a given tester set performed on a given sample would be calculated using equation 13.1.

PCR = (sum CR from testers)* / 2 (equation 13.1)

Sum CR testers is the sum of the risk potentials generated by the different types of reactions from each of the five selected testers used in the CR prediction (*). The PRC prediction can be between 0 and 10 and relates directly to the risks of corrosion associable with the samples site. Table 13.7 gives the relationship of the CPRC to the severity of corrosion that could potentially occur at the site from which the sample was taken.

Table 13.6 Summation of Corrosion Risk Points (CRP) generatable using Five Tester types

Tester type	Minimum positive C risk recordable (min CRP risk)	Maximum C Risk recordable (max CRP risk)
IRB-	1	3
SRB-	3	9
HAB-	2	2
SLYM-	1	1
APB-	3	5
Total Corrosion Risk (TCR):	**10**	**20***

Note: ND, not determinable for this risk; maximum risk for each tester type gives the highest risk that can be associated with that tester; minimum risk shows the minimum value that can be associated with a positive declaration of risk; negative declarations of risks are not included in the calculation of corrosion risk; and asterisk (*) indicates the maximum corrosion risk (MCR) that can be obtained; CRP are the corrosion risk points that can be awarded based on Tables 13.1 to 13.6.

Table 13.7 Interpretation of PCR values to Corrosion risk

Severity of Corrosion Risk	PCR	
Extreme	8.0 to 10.0	
High	6.0 to 7.9	
Moderate	4.0.6 to 5.7	
Low	2.0 to 3.9	
Negligible	<2.0	

Note: colors are used to denote severity of corrosion risk with extreme being purple; high risk in red; moderate risk as yellow; low risk as light green and negligible risk in grass green.

13.4 Predicted Plugging risk (PPR)

Plugging is primarily an expression for evaluating the manner in which the biomass form and volume generated by the biofouling now interferes with liquid and/or gaseous flows through porous media or over surfaces. Net effects of biomass plugging would be restricted flows in the designed production, greater generation of back-pressures and consequently smaller yields. Generally these types of activities are step-wise through periods of stability to sudden dramatic changes (e.g. drops in flow) in a manner that is repeated in consistent manners. Relevant plugging by weighted P values are given separately for each tester group: IRB- (Table 13.8), SRB- (Table 13.9), HAB- (Table 13.10), SLYM- (Table 13.11) and DN- (Table 13.12). Plugging risk is the assessment of all reactions generating a positive P weighting. Note that the maximum value that can be ascribed is 9 and the minimum value of 0 only in the case of no plugging risks being observed.

Table 13.8 Plugging risk, PR, IRB- tester

	RX	PR
IRB	BC	4
	BG	6
	BL	6
	BR	7
	CL	2
	FO	1
	GC	3
	RC	0

Table 13.9 Plugging risk, PR, SRB- tester

	RX	PR
SRB	BT	0
	BB	0

Table 13.10 Plugging risk, PR, HAB- tester

	RX	PR
HAB	UP	4
	DO	2

Table 13.11 Plugging risk, PR, SLYM- tester

	RX	PR
SLYM	DS	3
	SR	5
	CP	0
	CL	3
	BL	4
	PB	0
	GY	3

Table 13.12 Plugging risk, PR, DN- tester

	RX	PR
DN	FO	3

The plugging risk involves five tester types that indicate different levels of risk depending upon the reactions (RX) observed and interpreted. In the determination of risk only the highest corrosion risk generated by reactions may be selected for each tester type employed. Table 13.13 shows the maximum and minimum values for each tester type based on the reactions recorded. Summation of the highest possible risks now generate a maximum value to the risks which would be equivalent to nine (9) on the scale of plugging risk from the site sample.

Table 13.13 Summation of Plugging Risk using Five Test types

Tester type	Minimum Plugging Risk recorded (min PR)	Maximum Plugging Risk recorded (max PR)
IRB-	1	7
SRB-	1	1
HAB-	2	5
SLYM-	3	5
DN-	3	3
Total Plugging Risk (TPR):	**10**	**21**

Note: maximum plugging risk (max P risk) for each tester type gives the highest risk that can be associated with that tester; minimum plugging risk (min P risk) shows the minimum value that can be associated with a positive declaration of risk if all testers declare a linkable reaction; negative declarations of risks are not included in the calculation of plugging risk.

From Table 13.13 the maximum summated risk is 21 while the minimum summated risk is under half that value (10). Given that the maximum accredited value is set at nine (9) then the summation of risk as Calculated Potential Plugging Risk (CPPR) would be calculated using equation 13.2 based upon the sum total of the potential plugging risk factors (STPR) calculated from Tables 3. 8 to 3.12:

$$\text{CPPR} = \text{STPR} / 2.1 \quad \text{(equation 13.2)}$$

Table 13.14 differentiates the risk of plugging on the basis of the acquired CPRC based the reactions observed for the six tester types used in the plugging risk evaluation. Note that the DN-tester is included in the plugging evaluation but not in the corrosion risk assessment.

Table 13.14 Interpretation of CPPR values to Plugging risk

Severity of Plugging Risk	CPPR	
Extreme	7.0 to 10.0	
High	5.0 to 6.9	
Moderate	2.6 to 4.9	
Low	1. 5 to 2.5	
Negligible	<1. 5	

Note: colors are used to denote severity of plugging risk with extreme being purple; high risk in red; moderate risk as yellow; low risk as light green and negligible risk in grass green.

13.5 Health risk (HR)

Health Risk (when it occurs from water) can potentially be very serious. Here the risk (HR) is generated as a number in the scale of 3 to 9 based on a summation of all of the recognized reactions with 9 being the highest risk number for the HR. There is no averaging or allowances for the number of reactions. Hence a HR of 3 would only be reported is GY was the only recognized reaction. In the case of multiple reactions then it is most likely that the risk would be cumulative reaching 7, 8 or 9. There are only two Bart tester types that are employed in the HR calculation: IRB- tester, Table 13.15; and SLYM- tester, Table 13.16. The only reactions included are those that are most likely to present health risks. Where the HR is found to be significant (see 13.17) then confirmation should be undertaken using the total and fecal coliform tests and such other tests that the public health authority might consider potentially significant.

Table 13.15 Health risk, HR, IRB- tester

	RX	HR
IRB	**BL**	9
	GC	5
	RC	5

Table 13.16 Health risk, HR, SLYM- tester

	RX	HR
SLYM	**BL**	9
	PB	7
	GY	3

The health risk involves only types that indicate different levels of risk depending upon the reactions (RX) observed and interpreted. In the determination of risk only the highest health risk generated by reactions may be selected for each tester type employed. Table 13.17 shows the maximum and minimum values for each tester type based on the reactions recorded. Summation of the highest possible risks now generate a maximum value to the risks which would be equivalent to nine (9) on the scale of risk.

Table 13.17 Summation of Health Risk using Two Tester types

Tester type	Minimum health risk recorded (min HR)	Maximum health risk recorded (Max HR)
IRB-	5	9
SLYM-	3	9
Total Health Risk (THR):	**8**	**18**

Note: maximum health risk (max HR) for each tester type gives the highest risk that can be associated with that tester; minimum plugging risk (min HR) shows the minimum value that can be associated with a positive declaration of significant risk; negative declarations of risks are not included in the calculation of health risk. Calculation of the sum total potential health risks (TPHR) is achieved by adding all of the RX factor observed in the testers as weighted in Tables 13 - 15 and 13 – 16.

From Table 13.17 the max HR is 18 while the min HR is 8. Given that the maximum accredited value is set at ten (10) then the calculated potential health risk (CPHR) for the sampled site from the TPHR would be calculated using equation 13.3.

$$CPHR = TPHR / 1.8 \quad \text{(equation 13.3)}$$

Calculation of the Calculated Predicted Health Risk (CPHR) would fall within the scale from 0 to 10. Table 13.18 differentiates the health risk based upon the reactions from the two selected five tester types (see Table employed are 13.15, -16, and -17).

Table 13.18 Interpretation of CPHR values to Health Risk

Severity of Health Risk	CPHR	
Extreme	5.0 to 10.0	
High	4.0 to 4.9	
Moderate	2.0 to 3.9	
Low	1.00 to 1.9	
Negligible	<1.0	

Note: colors are used to denote severity of health risk with extreme risk being purple; high risk in red; moderate risk as yellow; low risk as light green and negligible risk in grass green.