LONG TERM PREDICTION OF PIPELINE CORROSION UNDER TROPICAL SEABED SEDIMENT

AHMED MOKHTAR ALBSHIR BUDIEA

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Civil Engineering)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JULY 2015

ALHAMDULILAH

Praise be to Allaah, all glory and honor to Him who says:

"Give thanks to Me and to your parents. Unto Me is the final destination"

[Quraan, Luqmaan 31:14]

ACKNOWLEDGEMENT

Praise be to Allah, The Lord of The Worlds. There are a number of people without whom this task might not have been accomplished, and to whom I am greatly indebted. Prof. Dr. Nordin Yahaya, my supervisor, for his guidance throughout this entire research and thesis writing process and also for believing in my abilities in performing this task. To Assoc. Prof. Dr. Norhazilan Md Noor, thank you so much for a great experience, for believing in me and for your insight and help. I wish to express my gratitude to the staff at several laboratories of Universiti Teknologi Malaysia for their cooperation and assistance.

A very special thank to my beloved mother, who continues to nurture, grow and develop me and who has been a source of encouragement and inspiration to me all my life. There is no suitable word to express my profound gratitude for the continuous active support you have given to me in my determination to find and realize my potential. To my respected father, for providing support and teaching me, to my wife Khairunisa thank you for your support throughout the years, to my children Abdullah, Abdurrahman and Maryam for being source of inspiration, to family members and relatives who offered me love and support throughout my study. My friends, and colleagues for their support during those years, thank you for everything.

ABSTRACT

The corrosion of pipeline steels buried under seabed sediment is not fully predictable, since there are many parameters affecting the pipeline at different degrees. In relation to that, corrosion growth predictive model based on long term experimental study is of great demand to assist in making suitable pipeline integrity decisions. Therefore, research has been conducted to investigate the metal loss behaviour and corrosion mechanism of pipeline steel under seabed sediment conditions. Then, this study developed a predictive model for corrosion under seabed sediment and highlighted corrosion parameters which presented in tropical climate. Two corrosion models were proposed; one based on the results of a long term exposure of steel coupons to the real field condition. Furthermore, another descriptive model was developed using response surface methodology. The most common applied model used to predict corrosion loss is the power law model ($P = kt^n$), where t is exposure time, and k and n are constant regression of the sediment parameters. Carbon steel coupons were buried in seabed sediment up to two years period. The sediment samples were analysed for its contents and properties. The descriptive model was constructed with aid of Statistica 6.0 software for the data obtained from the laboratory experiment. The results were analysed using statistical methods such as correlation test analysis (CTA), principal component analysis (PCA), multiple linear regression (MLR) and ANOVA (analysis of variance). From the analysis, the extraction of sediment variables related to k and n were successfully obtained. In order to get the best fit of predictive model, the extracted variables are modelled using MLR and embedded in the power law equation. Good curve fitting results are obtained between the actual test data and the proposed models. With consideration of pipelines integrity, the prediction of metal loss due to corrosion in SBS environment using the developed power-law model is considered satisfactory with R^2 score of 0.76. The corrosion model based on data from the laboratory has yielded reasonable prediction of metal mass loss with R^2 score of 0.83. Noticeably, several sediment factors play an important role in corrosion process and thus determine the corrosion severity. Corrosion growth models have been developed and proposed to predict corrosion progress for steel pipelines buried under seabed sediment. This research has introduced innovative ways to model the corrosion growth for seabed sediment environment. Moreover, intensive statistical analysis has been utilised to determine the level of influence of sediment parameters towards corrosivity. The models enable the prediction of metal mass loss, thus assessing the corrosivity of seabed sediment condition for Malaysian tropical climate.

ABSTRAK

Kakisan luaran yang berlaku pada paip keluli di dalam sedimen air laut masih belum dapat diramalkan sepenuhnya. Ini disebabkan oleh banyak parameter yang menjejaskan paip pada kadar yang berbeza-beza. Sehubungan itu, model ramalan perkembangan kakisan berdasarkan kajian eksperimental jangka panjang sangat diperlukan untuk membantu dalam membuat keputusan menentukan integriti paip. Oleh itu, kajian ini bertujuan untuk mengkaji kehilangan berat dan mekanisme kakisan pada paip keluli di dalam persekitaran sedimen air laut. Seterusnya, penyelidikan ini telah menjurus kepada penghasilan model ramalan kakisan di bawah sedimen air laut dan mengenalpasti parameter-parameter yang wujud di dalam persekitaran tropika. Terdapat dua model ramalan kakisan yang telah dibangunkan berdasarkan persamaan hukum kuasa dengan penggunakan dua pendekatan yang berbeza iaitu tapak sebenar dan tapak simulasi. Kehilangan kakisan telah diramalkan dengan menggunakan model kakisan yang biasa digunakan iaitu model hukum kuasa ($P = kt^v$), di mana t ialah masa pendedahan, dan k dan n adalah pemalar regresi parameter-parameter sedimen. Kupon keluli karbon telah di tanam di dalam sedimen air laut selama dua tahun. Analisis juga telah dijalankan terhadap kandungan dan sifat-sifat sampel sedimen. Model diskriptif telah dibangunkan dengan bantuan perisian Statistica 6.0 terhadap data-data yang diperolehi melalui ujian makmal. Keputusan tersebut telah dianalisis dengan menggunakan kaedah statistik, analisis ujian korelasi (CTA), analisis komponen utama (PCA), regresi linear pelbagai (MLR) dan ANOVA dua-hala. Daripada analisis, ekstrak pembolehubah-pembolehubah berhubungkait dengan k dan n telah berjaya ditentukan. Bagi mendapatkan model ramalan terbaik, pembolehubah-pembolehubah yang diekstrak telah dimodelkan dengan menggunakan MLR dan diaplikasikan di dalam persamaan model hukum kuasa. Keputusan lengkung terbaik diperolehi di antara data eksperimen dan model yang dicadangkan. Dengan mengambilkira keboleharapan paip, ramalan kehilangan jisim akibat kakisan di dalam persekitaran sedimen air laut dengan menggunapakai model hukum kuasa adalah memberangsangkan dengan R^2 adalah 0.76. Model kakisan yang dihasilkan berdasarkan data dari makmal juga memaparkan ramalan kehilangan jisim yang memuaskan iaitu R^2 bersamaan 0.83. Ternyata, beberapa faktor sedimen memainkan peranana penting di dalam proses kakisan dan seterusnya menentukan kesan kakisan. Model ramalan kakisan telah dihasilkan dan dicadangkan untuk meramal perkembangan kakisan paip keluli di bawah sedimen air laut. Model ini juga mampu dalam meramal kehilangan jisim besi dan juga tahap kakisan tanah di rantau Malaysia. Penyelidikan ini juga telah memperkenalkan kaedah-kaedah inovatif dalam permodelan pertumbuhan kakisan di dalam persekitaran sedimen air laut. Tambahan pula, analisis statistik yang intensif telah digunapakai untuk menentukan kadar kesan parameter-parameter sedimen terhadap kakisan. Model ini juga mampu dalam meramal kehilangan jisim besi dan juga tahap kakisan persekitaran sedimen air laut bagi iklim tropika di Malaysia.