Review paper on:
Flow Pattern at Pipe Bends on Corrosion Behaviour of Low Carbon Steel

Muhammadu Masin Muhammadu[1] , Jamaluddin Muhammad Sheriff[2] and Esah Binti Hamzah[3]

[1]*Department of Mechanical Engineering, Federal University of Technology, Minna*
[2,3]*Faculty of Mechanical Engineering, Universiti Technologi, Malaysia*
muhammadmasin@yahoo.com, jamal@fkm.utm.my and esah@fkm.utm.my

ABSTRACT

Most importantly the identification of positions or sites, within the internal surface contact areas where the maximum corrosion stimulus may be expected to occur, thereby allowing better understanding, mitigation, monitoring and corrosion control over the life cycle. Some case histories have been reviewed in this context, and the interaction between corrosion mechanisms and flow patterns closely determined, and in some cases correlated . Since the actual relationships are complex, it was determined that a risk based decision making process using selected ‗what' if corrosion analyses linked to ‗what if' flow assurance analyses was the best way forward. Using this in methodology, and pertinent field data exchange, it is postulated that significant improvements in corrosion prediction can be made. This paper outlines the approach used and shows how related corrosion modelling software data such as that available from corrosion models Norsok M5006, and Cassandra to parallel computational flow modelling in a targeted manner can generate very noteworthy results, and considerably more viable trends for corrosion control guidance. It is postulated that the normally associated lack of agreement between corrosion modelling and field experience, is more likely due to inadequate consideration of corrosion stimulating flow regime data, rather than limitations of the corrosion modelling.

Keywords: *ALARP (As Low As Reasonably Practicable) Co_2 corrosion, corrosion resistant alloy (CRA), decision gates, erosion-corrosion, life cycle performance, risk basis*

1. INTRODUCTION

The situation of flow separation, for example inside a sudden expansion in the pipe, turbulence is moved downstream from the objective of separation (1). There is no simple relation involving the bulk flow parameters as well as the local near-wall, hydrodynamic, mass transfer and erosion-corrosion conditions as well as the latter ought to be determined either experimentally [1,8, 13] or by record simulation both by [1,8,13]. This paper focuses the bond between flow pattern and corrosion behaviour at pipe bends as well as the advances in using turbulence models for the record simulation of erosion-corrosion throughout yesteryear decade.

The development of water pipeline infrastructure in a few part of World remains rapid growth within the last few years. If you have been new projects plus much more tie backs into existing systems. This helps it be crucial that you acknowledge, identify, and develop, the critical associations between corrosion conjecture and flow systems at pipe bends. Most substantially the identification of web sites where maximum corrosion stimulus can be expected thus enabling better understanding, minimization, monitoring and corrosion remedies for the whole existence cycle. Some situation histories are actually examined in this particular context, as well as the interaction between corrosion systems and flow designs carefully determined for a number of design campaigns. The specific associations are complex, too for basic reasons some risk based making choices procedure using ―what if‖ corrosion analyses connected with ―what if‖ flow assurance analyses was considered our advice [15-23].

The experience based on formerly looked into work by [24] and [25] has generated an instantaneous final results of corrosion rate of low carbon steel loss and fluid flow designs. A modification of flow pattern can lead to significant improvements in tube existence by remaining from impinging flow. The mechanism in the internal corrosion rates aren't fully understood but appears being linked strongly towards the particulate matter inside the flow [24-29]. Even if pollutants are simply inside the micrometre size range, they could still deviate from fluid streamlines to make sure that glancing flow can lead to abrasion in the protective surface layer [31-37]. Rapid positioned on by corrosion-erosion will result when the layer is soft in compliance while using particulate matter.

By using this methodology, and area data exchange, it's thought significant enhancements in corrosion behaviour are achievable. This paper outlines the approach used and shows how relevant corrosion modelling software data for example that supplied by corrosion models available Norsok M5006, and Cassandra Software [15,30] to parallel computational flow modelling within the specific manner can generate very significant results, and sometimes unforeseen trends for corrosion control guidance. The methodology offers good semi-quantitative arguments for justification and a variety of references are really used.

Having considered the basic characteristics of flow in curved open channels are fairly understood, theoretically and numerically the configuration of the side wall has significant effects on the flow structures [29].

Since the streamlines ought to be curved inside the same sense since the pipe itself there is a radial pressure gradient, so pressure is bigger round the outer wall in the pipe compared to the related point round the inner wall.

The mechanism which supplies birth for the stagnation pressure gradient is not considered incorporated within the secondary flow phenomena, although there's evidence of mutual interaction involving the two inside the turning passage to ensure that as result causes turbulent which in turns involve some unwanted effects round the pipe bend.

This paper is tried to give consideration towards the approaches and techniques familiar with identify, develop, and verify critical associations between corrosion behavior and flow programs systems. Used this frequently reduces with a practical interpretation in the outcomes of flow on corrosion turbulence systems.

2. Turbulence Models and methods

The task of turbulence models is always to provide equations that will enable calculation in the Reynold stresses,liuj, as well as the turbulent diffusion fluxes,lm5uj, which arise when the time-averaged equations for turbulent flow and mass transport are acquired within the immediate equation [14]. The k- $\in$, turbulence models [15] which are currently [16] broadly useful for the computation of business flows are eddy viscosity model which be a consequence of the concept recommended by Boussinesq and assumes caused by turbulence round the mean flow can be considered through viscosity. The turbulent viscosity, μ,t is made the decision within the kinetic energy of turbulence, k, which is rate of dissipation,

$$\mu_t = C_\mu f_\mu (\rho k^2)/\in \quad (1)$$

The effective viscosity is provided by

$$D_{eff} = \mu + \mu_t \quad (2)$$

similarly the effective diffusivity is given by

$$D_{eff} = \mu/\rho\sigma t + \mu_t/\rho\sigma t \quad (3)$$

Where σ_t is the turbulent S chmidt number [13].The conservation equations for mass, momentum, kinertic energy of turbulence which is dissipation, and species, m, might be witten in the general form. For axisymmetrical flow in 2D round co-ordinates [8]:

$$\frac{\partial}{\partial x}(\rho\varphi u) + \frac{1\partial}{r\partial x}(r\rho\varphi v) = \frac{\partial}{\partial x}(\tau_\varphi\frac{\partial\varphi}{\partial x}) + \frac{1}{r}\frac{\partial}{\partial r}(r\tau_\varphi\frac{\partial\varphi}{\partial r}) + s_\varphi \quad (4)$$

Where $\varphi = u, v, k, m \text{ and } \in$

The values of τ_m, general diffusion coeffients and s_m , the source terms.

Flow separation with recirculation and reattachment for example inside a sudden expansion and understanding in the concentration area enables the rate of mass transfer being calculated [1,13] with the expansion. The calculation in the concentration area near the wall requires utilizing a low Reynolds number [LRN] k-$\in$ model since the mass transfer boundary layer is deeply embedded within the viscous sublayer. The concentration is required at y ~ .1, insidewithin all the viscous sublayer where the mass transport is diffusion controlled, to have the ability to calculate the wall mass transfer rate. The 2nd requirement is because of the bit of turbulence inside the vjscous sublayer obtaining a significant effect on mass transfer within the high Schmidt amounts Sc ~ 1000 frequently familiar with aqueous mass transfer. Low reynold number (LRN) models utilize turbulence damping functions [13,32] as the easiest way of modelling wall-boounded flow with warmth/mass transfer under separated flow conditions [9]. The option wall function (WF) closure places the initial computation mode inside the logarithmic law region ($30 < y^+ < 150$) and bridges over the important viscous sub-layer.

Furthermore, the motion of a dispersed particulate phase within a turbulent flow field can be modelled by either a Lagrangian or Eulerrian approach [34]. He further lamented that in Lagrangian models a large number of individual particle trajectories are calculated in the flow domain whereas in the Eulerian approach the particles are treated as a second fluid. From an erosion modelling standpoint the direct calculation of particle/wall interaction statistics, impact frequency, angle and velocity with the Lagrangian approach is an advantage: at least in dilute particulate suspensions. As pointed out by Nesic [8], the Eulerian approach would be more appropriate in concentrateed suspensions.

Also [10] review and revealed that particle breakage may cause quality control problems, whereas wall erosion increases equipment maintence costs and environmental burden, and causes loss of productivity and a requirement to replace damaged components. Under normal operating conditions, erosion rates in pipe bends are much higher than those in straight pipe sections due to local turbulence and unsteady flow behaviour. Lamented that therefore, the time for failure piping systems is often dependent on the life of pipe fittings (valves, bends, elbows, flow metres), flow pumps, turbines, and compressors [56-59]. It is, therefore imperative to improve the protection of these components from solid particle erosion by better understanding the physics of particulate flows.

Many investigators [58-61] have carried out both physical and numerical modelling of the erosion of pipe bends, elbows, tees and related geometries. Since the early 1990's, computational fluid dynamics (CFD) has been widely used for solid particle erosion prediction in curved pipes and ducts, with various analytical, semi-empirical and empirical models having been developed. In 1979

provided a critical review of some of the erosion models that had been developed since Finnie (1960) proposed the first analytical approach, and found 28 models that were specifically for solid particle-wall erosion. The authors [66,67] reported that 33 parameters were used in these models, with an average of five parameters per model. These parameters influence the amount of of material eroded from a target surface and the mechanism of erosion. The review revealed that each model equation was the result of a very specific and individual approach, hence it is clear that no single equation exists that can be used to predict wear from all known standard material or particle parameters, and that some reliance on experimental measurement will always be required to provide empirical constants necessary in the various erosion models. The following review is limited to models that have been used in CFD-based erosion modelling and which have received wide usage in applications to erosion in pipes bends and pipe fittings.

In 1987 [69] developed an empirical erosion model for AISI 1018 steel. Mclaury (1993-1996) extended this model for aluminium and used it to predict particle erosion resulting from both direct and random impingements in two-dimensional geometries. This erosion model was developed at the Erosion-corrosion Research Centers. In 1996

predict erosion in elbows, plugs, tees, sudden contractions, and sudden expansions for pipes with circular cross-sections, and was subsequently referred to as erosion -corrosion Research Centres models. Also in 1973 [52] applied this model to investigate the effects of elbow radius of curvature on erosion rates in circulate pipe. Meanwhile,

developed mechanistic models for predicting erosion in elbows based on the E/CRC model. In 1998 and 2001, [67] and [68] used a commercial CFD code to model fluid-solid flow and added routine to predict erosion on particle impact using the E/CRC models. The [67] and [68] also modelled the erosion in oilfield control valves using a commercial CFD code, accouting for both deformation and cutting erosion. They obtained a good agreement for the predicted wear rates and wear locations in pipe bends with the experimental gas-solid erosion results of Bourgoyne, added [63 and 64] the stochanstic rebound model of [61 and 62] and the E/CRC model [56] to a commercially available CFD code and investigated the relative erosion severity in elbows and plug tees found in oilfield geometrics. Numerical simulations showed that particle rebound behaviour played an important role in determing the motion of the particle [65 and 71].

The performed their erosion research on 90 degree elbows and bends of circular cross-section. The fluid phase was modelled using a simple modefied mixing-length model. The predicted fluid axial velocity was validated against the experimental data of [56], with erosion modelled using the E/CRC model [68]. They compared their predicted penetration rates with the experimental data of [65], obtaining good qualitative agreement but poor qualitative agreement between the predictions and data. The poor agreement occurred because most of the data available were from erosion experiments with high particle rates. The authors also found that erosion in long radius bends was reduced when the carrier phase was changed from liquid to gas. They further reported that the effect of the squeeze film, secondary flows and turbulent flow fluctuations may all play important roles in erosion prediction when the carrier fluid is a liquid.

In 1991 studied [4]the local erosion in chokes and determining the local fluid velocity and particle impingement. Also, in 2006 [21] used a commercial CFD code coupled with an in-house particle tracker to predict fluid particle flow in a full 180 bend. He further implemented two erosion models, namely those of finite (1961) and [1 and 65] investigated erosion-corrosion problems in U-bends. However, there was no comparison was made with experimental data ; hence, the validity of the model could not be ascertained. Attempted to account for the shape of wear scars in predicting the life of pneumatic conveyor bends undergoing erosive Wear. However, these Authors did not use the shape of the scar to alter the computational mesh used in the fluid phase calculations.

Fan and co-workers [55] used Eulerian-Lagrangian approaches with the empirical restitution coefficient of [63] to model particle rebound velocities, and subsequently employed the semi-empirical erosion equation of [64] to study erosion in a vertical-to-horizontal bend. The authors used this technique to predict the erosion of tube banks in heat exchangers (65 and 66), to study protection techniques against tube erosion (67), and to investigate anti-erosion in 90^0 bends (68, 69, 70 and 71). In all the studies, the authors used the standard k-ϵ turbulence model, except in [62] where the authors used large eddy simulation LES to obtained flow and turbulence field predictions. The LES solution was not, however, validated against previous experimental or numerical results. In 1994 and 2004 [69 and 70] also used the semi-empirical erosion equation of [63] in 1998 to estimate the erosion rate in tube banks.

In 2007 [70] conducted a number of CFD-based erosion modelling investigations using a commercial CFD code. The erosion equation developed at the University of Tulsa (Albert, 1994; Edwards et al, 2001; McLaury 1993, 1996;Mclaury and [49] in 2000; [50] in 1995; [64] in 1995 and

in 2006, were included in the through user-defined-function. Particle trajectories were validated against the authors' experimental data for liquid-solid flows obtained using laser diagnostics. The entire CFD -based erosion authors' modelling procedure was then validated by comparison with the authors' experimental data obtained in 90^0 standard elbows with air flows, measured using a sensitive electrical-resistance probe. In 2009 [66] investigated particle motion in the near-wall region using a commercially available CFD code, modifying the code to account for particle size effects in this region before and after particle impact. For turbulent flow in a 90^0 bend, their results showed that the near-wall modifications and turbulent particle interactions significantly affect simulation results when compared with experimental data.

In 2009 [66] applied an Eulerian-Lagrangian approach with particle-particle interaction and a erosion model to simulate solid particle movement as well as the particle erosion characteristics of a solid-liquid two-phase flow in a choke. The authors used the standard k-ϵ model to treat the turbulence, the discrete particle hard sphere model to accommodate inter-particle collisions and the semi-empirical correlations of [65] in 1979 to study anti-erosion effects.

Despite all this work, there is continued interest in pipe wall erosion modelling because the prediction of erosion, in particular, is of value in estimating the service life of pipe bends systems, as well as in the identification of those locations in a particular pipe geometry most prone to erosion. In this review, [55] a study on three-dimensional computational fluid dynamic model of erosion is developed to investigate the erosion of both the concave and the convex walls of cross-sectioned ducts of different bend geometries and orientations due to particle collisions with the wall surfaces. Results are discussed in terms of eroded depth and the location of primary and secondary wear, and are compared with available experimental data

In practice after corrosion risk appraisal, this can be reduced to:

Total CA = Uniform CA + erosion allowance + localized (pitting) allowance. The predictive corrosion rates can be based on the predicted temperature profiles and the published top of line corrosion correlations for example, the Nyborg-Dogstad correlation [69]. There are few published such [equation 5] can be used on an iterative basis, to determine top of line activity [50,67].

Corrosion rate = 0.004*Rc*Cfe*(12.5 - 0.09*7) (5)

Where:

Corrosion rate: given in mm/y, Rc: Condensation rate g/m2/s, Cfe: Saturation iron levels in condensation (difficult variable, 50 - 200ppm often select), and T: Temerature in degree centigrade (^{0}c) respectively.

3. Flow Accelerated Corrosion

The key factor factor response to determine flow faster corrosion (FAC) might be the oxide film on structure surfaces, which evolves consequently of corrosion and, simultaneously, controls the corrosion rate within the role like a protective film

The primary parameters to discover FAC they fit into material parameters, flow dynamics parameters and atmosphere parameters (48). Metallic ions, mainly ferrous ions (Fe^2), are released for the water within the boundary layer where a number of within the supersaturated Fe^2 ions become oxide pollutants and in addition they deposit over the metal surface being magnetic oxide layer [48]. The oxide layer plays an important role in preventing further relieve Fe^2 (corrosion reaction). The thickness inside the boundary layer is impacted by flow dynamics of people processes, oxygen concentration (O_2) inside the boundary layer plays an important role for oxidizing magnetite to hematite, which contributes to achieving much greater corrosion resistance

Generally, subsea pipelines flow assurance covers all multiphase transport phenomena. Diligent design techniques, understanding and capabilities are very important to make sure safe, continuity of fluids transport from reservoir to topsides processing plant. The main areas involve steady condition and transient multiphase flow hydrates, sand, oil, emulsions, wax, scale and corrosion

phenomena. The interaction between corrosion/scaling and flow assurance can therefore be instrumental in determining true production rates, and software packages such as the Scand energy or Non-destructive test types codes can certainly give reliable predictive modelling. Delivering an exact and reliable advantages of flow assurance and corrosion modelling is regarded as as as one of the primary challenges facing the today. The overriding performance fingerprint is often best known to as tub curve and also to help facilitate this better, corrosion needs to be recognized to love an operating hazard. Once that's recognized the benefits of a soundly planned and faithfully applied corrosion management strategy becomes self apparent along with a pronounced reliance upon important water subsea infrastructure and tie back [25,27, and 30].

The beginning of issues with corrosion integrity throughout early existence is important, though mid existence is often better handled since area existence is extremely frequently well below design existence and for your reason options and time can be expected to favour planned retrofit as needed. Existence extension beyond the situated on out zone is generally more tightly related to older researches whereupon original design life‘s are actually exceeded and continuing production needed [28,31].

4. Enabling Presumptions

Uncover the dominant corrosive species usually CO_2, with defined or understood water chemistry content.

Review, verify, and prioritize or assume the dominant flow programs, e.g. single or multiphase flow, stratified, slug, annular flows etc. forecasted while using existence cycle. This might require review of the steady condition and non-steady activities or transient flow situations. Frequently the flow assurance report examines the likely situations and phone connection, and with this judgment [37].

Validate the H_2S souring inclination because this greatly impacts cracking and corrosion behaviour. As being, this is often less influenced by flow programs provided the most effective scales remain intact.

Corroborate dissolved chloride and oxygen levels, and the existence of aggressive organic species for example acetic/formic chemicals additionally for their types.

Assume the bottom corrosion is uniform but validated by real-time inspection and monitoring and via analysis of coups/probes, and deposits. However anticipate to witness localized corrosion when unsteady conditions occur.

Confirm threat and chance of biofilm formation assuming pattern of growth follows laminar or fluid stagnation sites, identify microbe species and MIC within the existence cycle.

Corroborate the extent of sand production (steady and episodic), along with the effect on materials degradation. Determine sand concentration, and particulate dimensions, and review interactions with inhibitor performance [53].

Determine the role of small-stagnant zone corrosion under primary flow conditions per small locations where pollutants and biofilms may proliferate [37].

Establish extent of pigging and inhibitors to both create sustainable inhibitor films and repair such inhibitor films even at high flow rates under sanding nd erosion conditions [54].

5. Impact of Temperature and Flow

Temperature and flow regime are carefully linked since CO_2 corrosion is dynamics and very mindful to electro-chemical and physical fluctuations (for example changing P, T, V). Generally steady condition (P, T, V) Conditions frequently promote protective film compaction as well as for your reason passivation, and low corrosion rates. Lower temps < 120^0F (50^0C) tend to promote patchy corrosion with softer multi-layer iron carbonate scales providing some barrier protection increasing up to ∩ 140 to 160^0F (60-70^0C). Above these temperatures damaging localized corrosion is observed as films lose stability and spall off giving rise to galvanic ‗mesa‘ attack. Though there is evidence of a down turn in the plateau after 80^0C for certain cases. In reality the project design basis usually insists on a maximum value for temperature, as it does for other critical parameters such as pressure, materials characterization (yield stress, hardness, toughness, etc.). Regarding flow, the production rates can be influenced by flow regimes such as slug flows and annular gas flows. This can prove critical for vertical risers connecting the flowline to the offshore structure or topsides. The geometry can act almost like a ‗specification break‘ whereupon the flow regime shifts largely due to the effects of gravity as the flowline transforms from a horizontal to a vertical member. The sag bend at the touch down zone can become a high risk corrosion component warranting greater degree of corrosion control, such as a thicker section, increased local CA, internal coating epoxy or increased monitoring routines etc.

Furthermore, as lamented earlier most likely probably the most challenging conjecture is less whether localized corrosion will occur but much more likely at this point you request , generally where? An thorough study on the expected flow regime curves and maximum flow velocities might help help with that judgment [25, 26]. It's also likely that whenever flow line localized corrosion starts, then it is more probably being self propagating (auto catalytic) and is less influenced by modifications inside the majority conditions though more jobs are needed in this region (42,45 50).

For operating profiles examined in that way, for example stratified flow, annular flow, slug flow and bubble flow, it should be assumed that essence turbulent as with line using the typical flow line Reynolds number, but realize that within each flow regime you will observe complex inter-facial behavior, including laminar, stratification and turbulence. The level of smoothness of people activities isn't necessarily expected, however reliable online monitoring results might help minimization and control, given to seize control of the feelings at a great choice.

6. Internal Corrosion Direct Assessment

Harmful internal corrosion in addition to failures have happened on pipelines carry gas /liquid specified being dry [37]. The process referred to as internal corrosion direct assessment (ICDA) remains designed to look at the corrosion impact of short-term upsets on pipeline integrity. The process is anticipated to boost pipeline integrity, reliability, and public safety. ICDA might come to terms with enhance the assessment of internal corrosion in gas transmission pipeline and help ensure pipeline integrity. The process is primarily positioned on gas transmission lines that normally carry dry gas/liquid but they're affected from temporary upsets of wet gas/liquid water (or electrolyte). The understanding basis must be readily transferrable together with other media liquids.

7. Single phase flow

An low Reynolds number (LRN), k-€ model has lately been positioned on the calculation of pipe-wall mass transfer rates in the sudden change or expansion [5], an immediate constriction [1] and flow round the groove [8]. They pointed out, in addition mass transfer rates are really calculated for that pipe wall in the sudden bend where small patches in the protective _rust' film were assumed to possess been removed. The above mentioned pointed out stated results indicate the mass transfer regions of erosion- corrosion processes in flow pattern conditions may be satisfactorily laboured with through turbulence models.
A much more intractable issue is an chance to calculate protective film removal under single phase aqueous flow conditions. The partial elimination of a protective surface film is frequently the precursor to rapid corrosion and component failure. For instance failures in copper piping in apartment structures frequently connect to rapid corrosion in the sudden difference in the geometry in which the normally protective film remains broken using the enhanced turbulence. Recent findings have proven that although point about this kind of corrosion happens near the outlet of 90^0 bends the film breakdown and subsequent failure began inside the sudden step in which the downstream pipe was soldered towards the elbow. The idea of an essential shear stress for eliminating protective layers remains asked for because the small stresses involved wouldn't be sufficient to robotically remove a surface oxide film. As pointed out by Launder, B. E., 1998 pressure fluctuations unlike velocity fluctuations don't vanish inside the wall. In 1991, [4] has recommended that pressure fluctuations inside the wall, in flow pattern, raise the overall shear stress and could produce mechanical damage.

8. Liquid/Solid flow

The presence of solid particles enhances the destruction of protective films giving rise to increased corrosion rates and may add to the overall metal loss by the mechanical erosion of the underlying metal. As with single phase flow these destructive effects are more pronounced under flow pattern condition.
In 1991 [4] have developed a predictive model for localized erosion- corrosion under flow pattern conditions based on the application of a two phase flow version of an low Reynolds number (LRN), k-ϵ model of turbulence. The motion of the particles was predicted by means of a Lagrangian Stochastic-Deterministic (LSD) model. The model which was applied to various pipe geometries including a sudden expansion, constriction and a groove was based on an oxygen-mass-transfer controlled corrosion model with the assumption that the particles removed the protective rust film, and an erosion model based on the cutting wear erosion equations [58].
The successfully applied a two phase k-ϵ model to the numerical simulation of uniform CO_2 erosion-corrosion under separated flow conditions at a sudden expansion. The particles were modeled by an Eulerian approach [62].

9. Summary of previous works

Year(s)	Researcher(s)	Method(s)	**Flow Pattern**	
			Reynolds number	Size(D=depth/L=length)
1966	Burgraff O.	Numerical: modified relaxation	Up to 400	Square bend (D/L = 1)
1979	Benjamin A., et al	Numerical: ADI Scheme for linear system and Newton-like method for non-linear system	Up to 10000	D/L =1 and 2
2004	Yao H., et al	Numerical: Finite difference for unsteady 3D incompressible Nevier-Stoke equation	1000 to 10000	D/L = > 0.1
2005	Cheng M., et al	Numerical: Lattice B0ltzmann	Range of 0.01 to 5000	D/L range from 0.1 to 7
2006	Thierry M., et al	Experimental: Doppler Velocimetry	1150 < Re < 10670	0.5 < D/L = 2
2009	Ozalp A., et al	Experimental: PIV	1230, 1460, and 1700	Rectangular, Triangular and Semi-circular with D/L = 2
2011	Muhammad R. M.	Experimental: PIV (tape as fluid) and Numerical: 2-D fluent	23144, 32963 and 39275	D/L =extend surface, X = 0, 5, 10, 15, 20cm
2012	Muhammadu M. M.	Experiment: PIV (Seawater as fluid) and Numerical: 3-D fluent	On going	On going
Corrosion Behaviour				
1960	Bitter J. G.A.	2-D model	the result could not ascertained	
1993 to 1996	Fan J., et al	E/CRC and Eulerian-Lagrangian 3-D models	Invesgate Concave and Convex walls of square duct, and no significant results	
1990	Nesic S., et al	K-∈model	Determined gas flow pattern near-wall turbulence intensity	

		(under gas flow)	
1991	Nesic S.	K-∈model to low Reynolds number	Determined wall-pipe mass transfer rates
1993	Postlethwatte S., et al	2-D (under disturbed flow)	Determined local mass rates and s Products at sudden expansion
2009	Binder S., et al	Norsok M506 (Multiphase gas /liquid flow)	Generate noteworthy results but lack agreement b/w modelling and field data
2011	Mamat M. F.	Immersion and Salt spray tests	Determined corrosion rate of the welded and unwelded joint
2012	Muhammadu M. M.	Non-destruction test (NDT) and X-ray test	To determine the effects of fluid flow at pipe bends on the corrosion behaviour of low carbon steel

Further Work

Further work is required to clarify the stability of corrosion behaviour un- der the condition of turbulence fluid flow at pipe bend where are amenable to both experiment observation and numerical simulation in relation to Reynolds number or particle image velocimetry (PIV). Also, identification of positions or sites, within the internal surface contact areas where the maximum corrosion stimulus may likely to occur, thereby allowing better understanding, mitigation, monitoring and corrosion control over the life cycle.

Conclusion

Corrosion and its interactions with the flow phenomena is a complex discipline, neither one dominates the other. Corrosion modelling results are often found not to agree with field data. The discrepancy is often blamed on the inadequacy of the models. However, this article or review has concluded that the differences are better explained by the rationalization of the effects of flow pattern on the base and localized corrosion rates. The core postulate is that the lack of agreement between corrosion modelling data and field experience is due more to inadequate account of corrosion stimulating flow regimes, rather than limitations of the modelling: thus reverting the onus for corrosion prediction away from corrosion modelling to the flow regime side.

The arguments are new and on going and a paradigm shift in thinking is needed to explore further the links between flow pattern and corrosion behaviour. In other word, a computational fluid dynamic model coupled to a Lagrangian particle tracking routine and a number of erosion models have been used to predict the solid particle erosion in square cross-section bends for dilute particle-laden flow. The results obtained were clearly affected by uncertainties in the empirical restitution coefficients. However, the results obtained do demonstrate the ability of the CFD techniques employed to predict erosion location and the depth of material eroded, and hence their usefulness in providing estimate of the service life of pipe systems as well as in the design of mitigation measure.

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