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Corrosion Control in Pipelines from Carbon-II-Oxide Enhanced Oil Recovery (Co_2 – EOR)

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Abstract

CO_2-enhanced oil recovery (EOR) from captured carbon, has been a research hotspot stemming to provide an economical and effective method for the reduction of carbon emissions in our atmosphere. However, corrosion is a challenging issue in the whole chain process of CO_2-EOR production utilizing a mild steel pipeline with water running through it. In this research, the corrosion risk of pipeline at different stages of CO_2-EOR production is thoroughly assessed based on a detailed analysis of the activities going on in the pipeline as well as the characteristics of the fluid in motion. According to the fluid state of CO_2, water and crude oil, current understandings on the corrosion behavior of steel materials in multiphase flow conditions are reviewed. Furthermore, the intermittent water wetting phenomena and the fluid behaviour of water droplets or clusters in an electrolyte/non-electrolyte emulsion are correlated with the steel corrosion performance, providing new insights into the corrosion phenomena. Besides application of corrosion resistant materials and corrosion inhibitors, tailoring of processing parameters, such as enhancing the water entrainment, shortening the water contact time, and reducing the solution corrosively, is highly recommended as an effective method for corrosion controlling high CO_2-EOR production conditions.

Keywords: CO_2-EOR, Corrosion, Captured carbon.

1. Introduction

Corrosion is a typical issue experienced in the oil and gas industry. Oil and gas pipelines, treatment facilities and petrochemical plants have genuine erosion issues. Interior erosion in industry is regularly brought about by water, carbon dioxide, (CO_2) and hydrogen sulfide (H_2S). It is additionally brought about by miniature organic action. The stream conditions of multiphase liquids extraordinarily impact the erosion rate (Rahuma *et al.*, 2014). For instance, at high stream rates, it prompted utilization and deterioration

disintegration may occur, while at low stream rates, fighting utilization in industry is winning since the monetary adversity in these endeavors on account of utilization is incredibly high. They are various methods of fighting utilization in oil and gas industry, the use of disintegration inhibitor is genuinely exceptional and unobtrusive procedures. There are many kinds of erosion inhibitors, and they are been ordered into anodic, catholic or blended consumption inhibitor. There is likewise group dependent on their compound nature. The inhibitor may add to the nature of the metal surface to such an extent that the metal enters the inward segment where a characteristic guarded oxide film structures and the inhibitor may respond with the materials and eliminate it from the media. A considerable lot of the normal consumption inhibitors utilized in the business are exceptional combinations that might contain surfactants, film enhancers, or oxygen scroungers, while adding to inhibitor moiety (Rahuma *et al*., 2014). Main part of the consumption inhibitors right now has nitrogen containing atoms. To be sure, there are other non-nitrogenous inhibitors that contain phosphorous, sulfur, or oxygen particles, yet they are not use regularly. For successful utilization of consumption inhibitors in the business, the inhibitor should be viable with the normal climate, efficient, and give assurance to the metal as well as not to bring on any critical bothersome incidental effects that may influence the activity/process. The warm soundness of the inhibitor is additionally a significant property. For instance, low thickness of the inhibitor is fundamental to give sufficient siphoning rates or stream rates. Generally, the inhibitor is added to infusion to work on its quality, during chilly climate. In industry, drag out the toughness of hardware, forestall mishaps and harms relating mechanical issues, try not to harm of item and forestall loss of hotness move. Adequate savings for this to be achieved must be draft to set a program of corrosion struggle using inhibitors will be economical (Rahuma *et al.,* 2014). There are several things associated with use of inhibitors. in adding to inhibitor cost, the cost of mounting injection equipment, service of injection equipment, purchase of inhibitor chemical(s), surveillance of inhibitor volume, system changes to house the inhibitor, system cleaning, waste disposal and personnel safety equipment, must be made into any economic review of the use of corrosion inhibitors. Some costs are difficult to sum in industry, but the best way is to get data on maintenance, replacements. Is from the past and make adequate selections (Rahuma *et al.,* 2014).

This study aims at suggesting effective ways by which corrosion in pipelines most especially incorporating CO_2 EOR can be controlled, while focusing on essential objectives such as (a) to concentrate in general chain response of liquid stream ready to go previously, during and after transport, (b) to analyze the flow of each fluid in the pipeline and their corrosive ability and finally (c) to suggest adequate corrosion control measures.

2. Field analysis

2.1 Whole chain reaction

There has been a long history of the preliminary use of CO_2-EOR procedure in oil and gas industry. Nonetheless, the mix of this method with CCS was as of late embraced. The entire chain associated with this cycle can be separated into carbon catch, CO_2 transportation, CO_2 infusion, and oil creation, during which an incredible part of CO_2 are forever put away underground and the other is reutilized in the reusing system. In this entire chain process, CO_2 can be seen as a feedstock and unrefined petroleum is the item. At the point when the net outflow of CO_2 is under nothing, i.e., the measure of CO_2 put away underground is bigger than that delivered in the wake of consuming the CO_2-EOR unrefined petroleum, the raw petroleum will turn into "carbon negative."

Presently, consumption is one of the huge worries for wide utilization of the CCS-EOR method, as water might be fermented in a CO_2-containing climate. The presence of unrefined petroleum could tremendously change the erosion execution of steel materials, suggesting that the liquid design may altogether influence consumption. Accordingly, the condition of water and the liquid properties will be featured in this study.

2.2 Fluid properties

2.2.1 Pressure and temperature

Tension and temperature are two significant boundaries that decide the properties of the CO_2-containing liquids, including the province of CO_2 stage, solvency, and pH-values, just as the properties of unrefined oils. CO_2 can be shipped in various states; however, a solitary stage state is liked in pipeline for a security reason. By and large, a supercritical stage or a gas stage is chosen, since it needs less energy for

significant distance transportation. Now and again, CO_2 is condensed to a little volume and moved by tanks. Fluid CO_2 may likewise be experienced when CO_2 is moved in a supercritical state, as the disappointment of the hotness safe coatings outwardly surface of a pipeline might bring about a diminishing of temperature beneath the basic point.

In CO_2-EOR creation, the substance of CO_2 in gas stage can be just about as high as 70% in volume (Wang *et al.,* 2015). The oil get-together and transportation framework is for the most part worked at a tension from 0.3 to 2.0 MPa, generally low contrasted with the strain in well conditions. Its temperature is for the most part lower than 60◦C, yet for some exceptionally thick raw petroleum it might arrive at 80◦C for acquiring a decent smoothness.

2.2.2 CO_2 Phase

In CO_2 transportation and infusion, the province of CO_2 stage is dictated by its strain and temperature. As seen with different state conditions from soaked to super-warmed and others, the supercritical province of CO_2 might be broadly experienced in the CO_2 transportation, infusion, and oil creation processes. Contingent upon the innovation of carbon catch and the asset of CO_2, follow measures of pollution gases may stay in the CO_2 after decontamination. These contaminations by and large incorporate water, O_2, SOx, NOx, and H_2S. Water is the most widely recognized pollutant compound in CO_2 during transportation and infusion, whose fixation limit is prescribed to be <500 ppm. Albeit these pollutions are for the most part controlled at an exceptionally low level; they might influence steel erosion in water-containing supercritical (SC) CO_2 conditions.

In the oil creation and transportation stages, CO_2 gas is mixed in with combustible gas at a piece around 30-70 vol.%, according to the CO_2-EOR creation in Sinopec Shengli oilfield (Wang *et al.,* 2015).

2.2.3 Water Phase

During CCS and EOR creation, water is immersed with CO_2 shaping carbonic corrosive. The pH-worth of the fluid arrangement is relying upon the incomplete tension of CO_2 and the temperature, just as the saltiness of arrangement (Ingham *et al.,* 2012); a direct relationship can be seen between pH-worth and CO_2 pressure. It ought to be seen that the dissemination coefficient of CO_2 in water is around $10{-}8$ m_2/s in stale conditions, as indicated by which it needs a few to several minutes to diffuse through the mass arrangement layer (Barker *et al.,*2018). It ought to be seen that CO2 consumption is by and large constrained by cathodic responses, where various types of ionic species (like H+, HCO−, and even H_2CO_3) would be partaken in the decrease cycle contingent upon pH-values (Ingham *et al.,* 2012). The development of consumption item layer for the most part depends on the nearby arrangement science at the area close to the steel surface where the groupings of ferrous particle and CO_2- are over the solvency furthest reaches of $FeCO_3$ for precipitation (Bian *et al.,* 2015). Thusly, the arrangement of $FeCO_3$ layer will impede the anodic response relying upon its morphology and defense (Barker *et al.,*2018). The presence of a follow measure of S_2- (Yang *et al.,* 2017) and Ac− (Amri *et al.,* 2010) particles in fluid stage can change the arrangement and the strength of $FeCO_3$ layers.

2.2.4 Crude Oil

This is a mind-boggling combination of hydrocarbons and it is for the most part classified into three kinds as indicated by its thickness. A weighty raw petroleum has an American Petroleum Institute (API) gravity lower than 20, a medium unrefined petroleum has a halfway API gravity of 20–34, while a light raw petroleum has an API gravity higher than 34. The API gravity is a factor conversely corresponding to the thickness of raw petroleum. It is for the most part acknowledged that heavier oils are more defensive than lighter ones concerning consumption (Rostami *et al.,* 2017).

2.3 Solid particle and scale deposition

Other than the oil, water and gas stages, strong particles may likewise be introduced in CO_2-EOR creation liquids. The strong stage might come from the supply and the precipitation of scales because of variety of brackish water science. For the most part, amazingly huge (>1 mm) strong particles are infrequently seen in the oil and water transportation frameworks, as various channels are prepared on pipeline in front of a siphon.

2.4 Corrosion risk analysis

2.4.1 CO_2 transportation and injection

Corrosion can possibly happen when CO_2 meets water. Hence, the convergence of water in CO_2 during

transportation and infusion is for the most part controlled under a basic worth. There are a few proposals as indicated by effective undertaking encounters, as seen in explored literary works. For instance, a suggested worth of H2O in thick stage CO_2 was 500 ppm in the DYNAMIS project (Jacobson, 2014). Underneath this focus, it was accepted that erosion would not be an issue during CO_2 transportation and infusion conditions (Cole *et al.,* 2011; Sandana *et al.,* 2012; Jacobson, 2014). Be that as it may, in the event of CO_2 and water being on the other hand infused into supplies to lessen CO_2 relocation, the well cylinders might experience the ill effects of genuine erosion harm (IEAGHG, 2010). Incidental entrance of water into the transportation pipeline may likewise instigate erosion. One more chance of water entrance is started from the dissemination of water after infusion stops. Hypothetically, this requires a couple of months to frame a water immersed CO_2 stage in the well cylinder as a rule inside a length of a few and many meters from wellbore, since the dissemination of water in stale CO_2 is moderately lethargic. In any case, in a drawn out fixed well, consumption actuated by water dissemination from the repositories should be thought of. (Incorporate the reach from book and refer to writer)

2.4.2 Oil gathering and transportation

The delivered liquid is in this way shipped by pipelines to a treatment station for detachment. Unique in relation to the well condition, the transportation pipeline is for the most part a level or slanted way. Its erosion hazard is exceptionally reliant upon the blending condition of oil and water, which is dictated by the stream boundaries (Kee *et al.,* 2014, for example, the stream rate, portion and smoothness of various stages and the strain and temperature of the framework. The settlement of free water at the lower part of pipeline can start consumption (Jiang and Cheng, 2013; Wang *et al.,* 2014). An enormous gas-to-fluid proportion will additionally entangle the blending condition of oil, water, and gas (Wang *et al.,* 2015), which can likewise bring about an altogether expanded genuine stream speed of the fluid stage. On one hand, this might prompt stream sped up consumption if water can't be totally entrained into the oil stage or disintegration erosion harm when strong particles are engaged with the transportation. Then again, a combination of oil and water might lessen the consumption at the pipeline base, as the water stage might be exceptionally scattered and hence ceaseless water wetting of the steel surface is kept away from.

2.4.3 Water treatment

CO_2 can't be totally taken out from water stage after partition of the delivered liquid at the treatment station. At times, antacid arrangement might be acquainted with kill the CO_2 containing arrangement, further lessening its destructiveness. Nonetheless, balance of the CO_2 containing liquid might actuate a scaling issue, attributable to the presence of Ca_2+ and Mg_2+ particles. By and large, these scale shaping cautions are broken down from the supply rocks in CO_2-EOR conditions. When the salt scale is shaped and appended on the internal surface of pipeline, under-store erosion and whole consumption will happen, prompting limited consumption harm of the pipeline in CO_2-containing conditions (Zhang *et al.,* 2016).

2.5 Multiphase flow corrosion

2.5.1 Single-phase CO_2

The presence of a follow measure of water in the thick stage CO_2 is the beginning of consumption; the development of CO_2-soaked water layer on steel surface triggers erosion. Hence, in a stream condition, a particularly thick stage CO_2 might act more like an oil stage instead of a petroleum gas stage.

As of late, it was tracked down that the consumption morphology was profoundly depended on the stream rate and the level of water immersion (Liu *et al.,* 2018); a higher stream rate and a more significant level of water immersion delivered bigger erosion item particles and patches, inferring a potential erosion component identified with the immediate barrage of water drops on steel surfaces and these beads are probable entrained in the thick CO_2 stage, instead of straightforwardly nucleated on steel surfaces.

2.5.2 Water-CO_2 slugs

Although CO_2 is dried prior to transportation, water ingress may happen in some occasional conditions. It has been reported that the corrosion rate of mild steel in a dense-phase CO_2- water flowing conditions can be as high as several to tens of mm/y depending on their fluid parameters (Dugstad *et al.,* 2011; Barker *et al.,* 2017), because the aqueous solution was saturated with high pressure CO_2. There

are many experimental results on the corrosion rates and corrosion morphologies of steel materials in high-pressure CO_2 environments (Cui *et al.,* 2006; Cao *et al.,* 2012; Zhang *et al.,* 2012; Hua *et al.,* 2015), from which it can be deduced that the steel materials suffer from severe corrosion attack and the flow can vastly accelerate corrosion (Dugstad *et al.,* 2011; Wei *et al.,* 2018) in the presence of a bulk volume of water during the transportation of dense-phase CO_2.

2.5.3 Oil-water mixtures

The presence of raw petroleum might decrease the erosion hazard of CO_2-EOR pipelines. The consumption execution of pipeline might be affected by raw petroleum's physical properties, like its thickness (Wang *et al.,* 2014), consistency (Zheng *et al.,* 2008), conductivity (Zhang *et al.,* 2012), and wet ability (Wang *et al.,* 2015). As of late, Wang and Zhang (2016) summed up four distinct components for the restraint impact of raw petroleum on consumption: (1) water entrainment, (2) unrefined petroleum wetting, (3) dissolvable compound apportioning, and (4) erosion item layer alteration. Wei *et al.,* (2018) tracked down that weighty oil was less destructive than light one in an oil-water two-stage stream condition, which could be ascribed to the development of w/o scatterings. A straightforward thought for consumption hazard examination has been proposed dependent with the understanding that erosion would happen just when free water was isolated from w/o emulsion during transportation (Wang *et al.,* 2014). At some very high-water cuts, w/o emulsion can likewise be shaped. For instance, the tentatively estimated emulsion reversal point (EIP) is by and large answered to be just about as high as 70 wt%.

The event of erosion might be identified with the bead conduct in a w/o emulsion or scattering, and the drops may develop to bigger ones during transportation, prompting the settlement on pipeline base.

2.5.4 Oil-water-gas/solid flow

The multiphase liquids are normally experienced in CO_2-EOR creation, in which an enormous part of CO_2 in the gas stage is involved. Past endeavors were chiefly centered on the connection among erosion and the stream qualities of a gas-fluid two-stage stream. Albeit exceptionally predetermined number of studies have been centered on the consumption marvels in CO_2-EOR multiphase stream conditions, the outcomes with respect to erosion in ordinary oil creation can be utilized for reference. For example, in a slug stream, the consumption hazard of pipelines can be firmly identified with the shallow gas speed (Cai *et al.,* 2012), slug recurrence (Wang *et al.,* 2015), and Froude number (Zheng *et al.,* 2008). By and large, direct perception is utilized to decide the stream designs. Different techniques are likewise broadly acknowledged, for models, pressure drop (Wang *et al.,* 2015), wetting conduct (Cai *et al.,* 2012), and stage thickness circulation (Hoffmann and Johnson, 2011). As of now, many examination establishments have created multiphase stream circles for consumption tests (Zheng *et al.,* 2008; Wang *et al.,* 2015). In view of the stream circle tests, the connection among erosion and stream qualities has been assembled. It was tracked down that a higher slug recurrence might build the erosion pace of pipelines, attributable to a sharp expansion in the neighborhood divider shear pressure (Yang *et al.,* 2010), which was seen as a significant boundary in consumption (Zheng *et al.,* 2008)

3. Control strategies

It ought to be seen that the activity conditions for CO_2 transportation, infusion and oil creation are unique; consequently, their control techniques can't be as old as in Table 1. As a rule, CRAs are best, which have been endeavored in many undertakings (IEAGHG, 2010). There is no question that the utilization of CRAs is a protected decision when we have little information on the erosion hazard of an activity framework, however it is financially inadmissible. Coatings and liners are additionally embraced in CO_2-EOR creation wells (IEAGHG, 2010), yet there are as yet testing issues, like rankling and separation in profound well conditions.

Table 1: Corrosion control strategies in CO_2-EOR systems (Wang, 2019)

	Materials	**Corrosion inhibitors**	**Process control**
CO_2 Transportation	Mild Steel	Effective in highly acidified, high pressure and	Controlling impurity gases. Limit water concentration.

		temperature conditions.	
CO_2 Injection	Mild Steel Stainless Steel	Injected with water slugs	Reduce water/gas alternate frequency
Oil Production	Mild Steel Stainless Steel	Effective in the process of oil, such as tailoring wet ability.	
Oil Transportation	Mild Steel Stainless Steel for Valves Liners for Separators		Water separation before transportation
Water Treatment	Mild Steel Glass Fiber Reinforced Plastics	Effective in CO_2 aqueous environments	Reducing dissolved CO_2 by N_2 stripping

As of late, a few sorts of consumption inhibitors were tried in mimicked CO_2 infusion or transportation conditions (Turgoose *et al.,* 2014; Choi *et al.,* 2017; Xiang *et al.,* 2017; Cen *et al.,*2019), which may hypothetically be a sensible decision in the forceful conditions. In any case, the consumption inhibitors ought to be viable in high temperature conditions. Consumption inhibitors have additionally been broadly utilized in water infusion frameworks where CO_2 was involved. The presence of raw petroleum in the CO_2-EOR creation framework might harm the inhibitors (Horsup *et al.,* 2010), lessening their adequacy. Consequently, the assessment of erosion inhibitors in oil-water blended liquids becomes basic for the commonsense inhibitor determination (Li *et al.,* 2014, 2016; Wang *et al.,* 2019). By and by, there is still absence of viable and relevant techniques for the assessment of consumption inhibitors in oil-water blended conditions (ASTM G202−12, 2016), which for the most part depends for a huge scope multiphase stream circle test (Cai *et al.,* 2012; Wang and Zhang, 2016). Most as of late, Wang et al. given a potential strategy to the quick assessment of erosion inhibitors in oil/water substitute conditions by utilizing an uncommonly planned "Substitute Wetting Cell" (Wang *et al.,* 2019), with which a sort of ODD consumption inhibitor has been assessed to be powerful (with a high hindrance productivity of 99.9%) in oil-water media (Wang *et al.,* 2019). In a multiphase stream climate containing raw petroleum, the wet ability at the oil/water/pipe interface and the emulsion state may be changed by the expansion of a follow measure of natural specialists, like erosion inhibitors (Foss *et al.,* 2009; Li *et al.,* 2014; Wang *et al.,* 2019) or some surfactant synthetic compounds (Wang Z. L. *et al.,* 2014; Quej-Ake *et al.,* 2018), at last upgrading or diminishing the erosion relief proficiency of unrefined petroleum. As far as anyone is concerned, dealing with the interaction boundaries is one of the most appealing techniques for erosion control in CO_2-EOR creation (Cai *et al.,* 2012; Wang *et al.,* 2015), as it is by and large appropriate, viable and modest, however the control procedures should be depended on a profound comprehension of the consumption execution and consumption component of pipeline materials (Store *et al.,* 2011). For instance, to keep away from erosion harm of pipelines, CRAs were typically utilized and water was completely restricted under an extremely low focus in an early pilot CO_2-EOR project due to little information on steel consumption in a thick CO_2 stage. At present, it is by and large accepted that consumption won't be an issue in case there is no free water or water drop settlement on the pipeline base. Notwithstanding, the basic water focus limit to trigger erosion can be unique, contingent upon pressure, temperature, stream rate, just as the convergences of pollutants. Notwithstanding, restricting water consideration is as yet the most ideal decision for erosion alleviation in CO_2 transportation (Sim *et al.,* 2014; Barker *et al.,* 2017). It very well may be found from the exploratory reproduction that compressing CO_2 could broaden the solvency of water (Wang and Song, 2018) and in this way diminish the chance of water wetting on steel

surface. Dialing back the stream rate might lessen the likelihood of the barrage of water groups entrained in thick stage CO_2 and subsequently decline the thickness of iron carbonate particles on steel surface (Liu *et al.*, 2018). Along these lines, moving water containing CO_2 at a high strain and with a sluggish rate might be useful for consumption improvement.

4. Conclusion

In this study, the consumption of pipeline in CO_2-EOR creation is completely investigated from a liquid insight. At first, the consumption hazard of pipeline at different phases of CO_2-EOR creation was assessed relevant to the liquid properties it perceived that the presence of water in liquid was the key for setting off corrosion.

In oil creation and delivery frameworks, the presence of unrefined petroleum might lessen consumption, while the stream diagram and the blending condition of oil and water were imperative for deciding the erosion hazard of well cylinders and pipelines. In water treatment stage, the scaling issue ought to be seen with a reduction in CO_2 fractional tension. After an audit of the erosion conduct of steel materials in multi-phase stream conditions as indicated by the liquid territories of CO_2, water and unrefined petroleum, consumption should be connected with the liquid design, where the reliance of the consumption rate on water fixations was attributed to the liquid conduct of water trickle or bunches in an electrolyte/non-electrolyte paired framework. An exchanging wetting test strategy was presented for improved understanding the consumption peculiarities in oil/water sporadic stream. At long last, the consumption control procedures were summed up. Other than the utilization of consumption safe materials and erosion inhibitors, fitting the handling boundary was prescribed to be an appealing technique for forestalling erosion in ruinous CO_2-EOR creation conditions. For the CO_2 transportation and infusion frameworks, restricting water fixation, dialing back the stream rate and diminishing contact time would be gainful for consumption alleviation. For the oil creation framework, upgrading the water entrainment, expanding the uproar of stream and supporting the destructive climate would be useful.

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Effect Of Storm Water Drainage Systems Modelling for Owakadi Community of Obubra L.G.A Of Cross River State Nigeria.

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Abstract:

The modeling of storm water drainage systems of Obura catchment area of Cross River State, Nigeria to address problem of local flooding. A current metre was used alongside a speed boat to carry out measurement of discharge as a dependable variable while cross sectional area, velocity, width and depth of channel was also determined as independent variables. The data so measured were subjected to developed a model whose result was Q = -2417.75 +11.68D + 0.33W + 1772.15V + 1.24A. The model gave a correlation r value of 0.994. Verification of the model was carried out and an r value of 0.995 was obtained all indicating a strong correlation. Rainfall records for the period of thirty—six years 91979 – 2014) and 24 months were used to developed regression analysis of the study area. Furthermore, a validation test was conducted using velocity-area method for water flow measurement having a relationship as Q = AV, a correlation value of 1.0 was obtained. The model when applied will enhance the prediction of the adequate of the density of the drains to accommodate the storm runoff generated in the area. The study recommends that, proper design, computations, adequate constitutions and routine maintenance of drainage channels be made ensuring that the velocity satisfied the minimum requirement.

Keywords: storm water. Drainage, urbanization, discharge, flooding

Introduction:

Drainage systems are needed in urban areas because of the interaction between human activity and the natural water cycle. This interaction has two main forms: the abstraction of water from water bodies to provide water supply for human life, and the covering of land with impermeable materials to divert rainwater away from the local natural system of drainage. These two types of interaction give rise to two types of water that requires drainage (Butler and Davies, 2004). Waste water is water that has been supplied to maintain standard of living and satisfy the needs of industry after use, if not drained properly, it could cause pollution and create health risks. Wastewater contains, fine solids and large solids originating from water closet (WCs), from washing of various sorts, from industry and other water uses.

The second type of water requiring drainage, storm water, is rain water (or water resulting from any form of precipitation) that has fallen on a built –up area. If storm water is not drained properly, it will cause inconveniences, flooding and further health risks. It contains some pollutants, originating from rain, the air or the catchment surface.