Chapter 6
Maintenance of water injection pipelines and injectors

In order to sustain continuous water injection at desired flow, health of water injection lines and injectors needs to be maintained and monitored. As discussed in earlier chapters, failure to meet the quality parameters of the injected water and due to aged equipment, the threat of corrosion is real. To avoid corrosion of lines and impairment in injectivity of wells/ strings, timely maintenance is required. The maintenance and monitoring activities of injection lines and injector consist of the following activities:

(a) Maintenance and monitoring of injection lines:

- Chemical injection at process platforms to maintain injection water quality.
- Monitoring of corrosivity of injection water at main injection pump outlet and at respective water injection pipeline segments.
- Maintenance of water injection pipelines by pigging[25] of injection lines based on corrosivity and flow parameters, external health assessment of pipelines.
- Need based repair of pipelines using in-house resources.
- Periodic replacement of pipelines as per replacement policy/ need based.

(b) Injector health maintenance:

- Workover of injector wells by rig intervention.
- Well stimulation[26] jobs for injectivity enhancement.
- Regular backwash[27] of injectors for improving injectivity.

Audit examined the maintenance activities of pipelines and injectors during 2014-15 to 2018-19 and observed shortcomings which impacted the planned water injection operations and crude oil production/ recovery. These shortcomings are discussed in the subsequent paragraphs.

6.1 Corrosion monitoring

Corrosion monitoring programme plays a vital role in corrosion control. The offshore pipeline group of the company carries out corrosion monitoring studies through linear polarisation resistance probes. The safe limit of water injection pipelines corrosion is <2 mils per year mpy[28]. Corrosion above 5 mpy is considered high and above 10 is considered severe. The work of corrosion monitoring of water injection lines was

---

[25] ***Pig is a small, sphere or disc apparatus that is used to sweep a flow line. Pigging is done for pipeline cleaning (commissioning, debris cleaning), line management (liquid removal, corrosion inhibitor dispersal and wax removal), and line inspection.***

[26] ***Well stimulation is a well intervention on water injection well to increase flow of water into reservoir.***

[27] ***Backwashing water injector is a method to remove the near wellbore damage and restore a significant amount of lost injectivity.***

[28] ***Mils per year is used to give the corrosion rate in a pipe, a pipe system or other metallic surfaces. It is used to calculate the material loss or weight loss of metal surfaces (Mils is 1000th of an inch).***

entrusted to third party (corrosion technologist) who monitors the corrosion rates at the designated pipeline location.

Audit examined 45 *per cent* of linear polarisation resistance probe study reports (261 out of 582 studies) for Mumbai High field, and 100 *per cent* of study reports (68 studies) for Neelam and Heera field, which were conducted by third party during 2014-15 to 2018-19. Audit observed that in all the study reports examined, corrosion rate was above the safe limit of <2mpy. The average corrosion rate of linear polarisation resistance probe studies is given at table 6.1.

Table 6.1: Average corrosion rate of injection lines

Field	Platform	LPR probes (Nos.)	Average corrosion rate (mpy)	
			Min	Max
Mumbai High	Water Injection North	15	3.57	5.73
	Water Injection South	57	5.14	8.24
	Infill Complex Water Injection	56	4.25	6.55
	South High Water Injection	37	5.03	8.16
	Mumbai North Water Injection	96	3.72	5.55
Neelam & Heera	Neelam	20	1.69	10.76
	Heera	48	4.32	6.61

LPR: Linear Polarisation Resistance
Source: Reports of third party probe reports

As reported by in-house committees[29] and the corrosion technologist, low dosing of oxygen scavenger and other chemicals contributed to corrosion of water injection network at faster rate.

Further, Audit observed that location of most of the linear polarisation resistance probes was at the main injection pump end. The purpose of conducting an independent probe-analysis so close to the point where it is monitored internally (main injection pump end) is not clear. Linear Polarisation Resistance probe can assess performance/ efficiency of the water corrosion inhibitor chemical and other corrosion related parameters up to a limited distance. It would be better served if it is taken at multiple locations rather than only at the main injection pump end.

Management/ Ministry (February/ June 2021) stated that corrosion monitoring is undertaken at representative selective locations at injection water pipeline sector; however, as suggested by Audit more locations will be taken up in future contracts.

Recommendation No. 12

Considering large number of pre-mature failure of lines, the company may strengthen corrosion monitoring system urgently. More locations away from the main injection pumps should also be taken up for corrosion monitoring in future.

[29] ***IRS report on Water quality and Injectivity Assessment of Mumbai High (2011), Institute of Oil & Gas Production Technology (2012), In-house committee on pre-mature failure of water injection lines (August 2014).***

6.2 Pigging of water injection lines

Pigging helps to remove debris deposited in pipelines and is one of the most effective and economical methods for control of microbes and monitoring of pipeline integrity. As per the company's Standard Operating Procedure (SOP) of November 2016, pipelines required periodic pigging. The annual workload for pigging is assessed based on the inputs given such as pigging frequency, availability of pipelines, flow characteristics, fluid composition etc. The pipeline group prepares annual pigging plan based on pigging frequency as per OISD code/ inspection and report requirement and SOP of the company. There was substantial shortfall in pigging operations *vis-à-vis* annual pigging plan as could be seen from the table 6.2.

Table 6.2 Pigging plan versus actual

Year	Mumbai High			Neelam & Heera		
	Approved workload (Nos.)	Actual pigging (Nos.)	Pigging achieved v/s approved (%)	Approved workload (Nos.)	Actual pigging (Nos.)	Pigging achieved v/s approved (%)
2014-15	326	83	25	104	66	63
2015-16	344	101	29	88	75	85
2016-17	405	61	15	72	47	65
2017-18	386	73	19	72	43	60
2018-19	460	148	32	72	79	110
Total	**1,921**	**466**	**24**	**408**	**310**	**76**
Source: Reports and replies furnished by the company						

It is further seen from the table 6.2 that actual achievement was only 24 *per cent (*Mumbai High field) and 76 *per cent* (Neelam and Heera fields) of the approved workload.

SOP of the company prescribed to collect sample after completing flushing for analysis for iron count, sulphate reducing bacteria, total suspended solids and turbidity. SOP also prescribed to continue flushing of the line and check Millipore[30] rate. Water injection is resumed only when the Millipore level is achieved.

In this regard, Audit observed the following:

6.2.1 Mumbai High field

- As against 981 actual pig runs, samples were reported in only 246 pig runs. Out of 246 samples, in 235 cases (95.52 *per cent*) Millipore test results were not reported and thus, to that extent the utility of pigging was diluted. Resumption of water injection without clearing Millipore test was a deviation from the SOP.

- In none of the samples, iron count and total suspended solids was within the required quality parameters and turbidity was within limits in only one sample.

[30] ***Millipore test is a quality check of treated water to analyse the presence of suspended solids before and after filter, before injection pumps and injection wells. Millipore rate of flow above 6 litres/ 30 minute is considered an acceptable parameter.***

- In 161 samples, sulphate reducing bacteria was observed and in 33 samples, it was shown 'under observation' and in 25 it was kept blank.

6.2.2 Neelam-Heera fields

- Only 129 pigging samples were reported as against 310 pig runs (41.6 *per cent).*

- Sulphate reducing bacteria was found present in 34 out of 83 pigging samples in Heera and in 35 out of 48 cases in Neelam.

- 49 cases were denoted with blank data/ as 'under study' in Heera and 13 such cases observed in Neelam.

- General aerobic bacteria presence was found in 67 pigging samples out of 83 in Heera and 37 pigging samples out of 48 in Neelam.

- In Neelam, all recorded cases (40) were found with iron content more than the desired level of 0.05 ppm. Heera field did not analyse the iron content in the pigging sample.

Management stated (March/ April 2020) that lesser number of pigging operations against plan was primarily due to disruption/ non-performance of service contractor (four months in 2016-17), non-availability of pigging contract for more than one year and due to manpower (chemist) constraints. It was also stated that reporting of Millipore test will be ensured in future and higher iron count and total suspended solids may be a cumulative effect of less corrosion inhibitor dosing, at times ingress of dissolved oxygen due to malfunctioning of de-oxygenation towers. Management further stated that efforts are being made for optimum doses of corrosion inhibitor and to keep the sulphate reducing bacteria count as 'nil' through sterilisation using three types of bactericides alternately and in future, the results for the iron content analysis shall be recorded as part of the monthly progress report in Heera. Management/ Ministry further added (February/ June 2021) that with the contract for pigging in place, efforts are being made to pig all pipelines as per their scheduled frequency and collection and analysis of post pigging samples are being carried out as per SOP and will be ensured in future as well.

The reply needs to be viewed in light of the fact that (i) recommendations for periodic pigging and sampling analysis made in the previous in-house reports on water injection were not considered, (ii) though the SOP of the company mentioned for analysis of post pigging samples for every line after pigging, there is substantial shortfall in carrying out pigging of lines against requirement, inadequate sample analysis, off specifications quality of water injected into reservoir. Reply is silent on lab results awaited/ not available cases.

Recommendation No. 13

The company should adhere to defined frequency of the pigging of lines to ensure health of pipelines and to prevent its faster corrosion. The company should follow pigging operation strictly as per SOP by taking samples on each pig run and analyse them for required quality parameters and microbial growth for corrective actions.

6.3 Pre-mature failure of water injection lines

In-house committees[31], international consultants and the company's research institutes (1994 to 2018) had expressed concern over the accelerated corrosion of water injection lines due to poor quality of water, inadequate pigging of lines and low/ stagnant velocity of lines and recommended remedial measures to restore the quality of water within quality parameters, increase frequency of pigging, etc. The in-house committee had concluded that internal corrosion was the primary reason for premature failure of lines.

Rather than mitigating the corrosion issues, Audit observed that the company reduced (October 2003) the design service life of water injection lines from 25 to 15 years. This was done due to failure of large number of lines on account of internal corrosion. Review of pipelines replaced during 2014-15 to 2018-19 revealed that number of lines had even failed much before attaining the revised design service life of 15 years due to the reasons highlighted above. Further, during 2014-15 to 2018-19, 85 leakages of 44 lines were attended in Mumbai High and eight lines were attended in Neelam and Heera fields. Considering the time lag between date of leakage and date of repair of lines/ replacement, there is substantial loss of water injection. As of March 2019, 48 wells (60 strings) in Mumbai High and eight wells in Neelam and Heera were closed due to line leakages. In WN1 platform of Neelam, injection suspended since 2011 could not be resumed even after a new injection line was commissioned to connect Neelam Water injection (NLW)-WN2 due to pending leakage line replacement. The WN2-WN1 line was subsequently replaced in Pipeline Replacement Projects (PRP)-V in 2018. The Committee appointed for augmentation and distribution of water injection in Mumbai High also reiterated (October 2018) that frequent leakages can be minimised by maintaining the injection water quality as per recommended parameters and preventive maintenance of equipment.

Management stated (April 2020) that failure of pipelines is mainly caused by low flow rate in a sector and when wells were closed for reservoir monitoring. Management accepted that due to line leakage, there is decrease in liquid deliverability and pressure drop. It was also stated that maximum water injection lines of Neelam and Heera fields are now coflex[32] lines in view of its corrosion resistance property and lower maintenance. Management/ Ministry further stated (February/ June 2021) that collection and analysis of post pigging samples are being carried out as per SOP and will be ensured in future as well.

---

[31] ***Caproco International (1998), in-house committees (2012, 2014).***

[32] ***A flexible pipe is a configurable product made up of several layers. The main components are leak proof thermoplastic barriers and corrosion-resistant steel wires.***

The response has to be seen in the light of inadequate implementation of the recommendations of in-house committees/ international consultants and failure to maintain the quality of injection water.

6.4 Workover of injectors

A workover or well servicing is any operation performed on a well to restore or improve its performance. Once a well is put on injection, at some stage of its operating life, it may inject water below its capacity due to either formation related or mechanical problems or both. Therefore, injection well needs repair or replacement of surface facilities. Institute of Oil and Gas Production Technology (IOGPT), research institute of the company, had suggested that the condition of tubing needs to be checked periodically in the interval of 5, 8, 11 and 15 years from last workover. In Mumbai High field, against 123 wells planned for workover, it was carried out only in 61 wells (49.6 *per cent*). The major reason for deviation/ shortfall was non-availability of rigs.

In-house committee constituted for study on water injection improvement in Mumbai High observed (July 2012) that one of the reasons for less water injection is poor well conditions. The committee observed that large number of water injection wells were having tubulars older than ten years and needed servicing. These wells over the period with continuous water injection were suspected to have injectivity loss due to corroded/ damaged tubing and casings and plugging of wellbore and required immediate servicing. Committee recommended 104 wells for workover jobs for wellbore clean out, tubing change, casing repair, gas lift installation for facilitating flow back of wells. It estimated servicing of these 104 wells would enhance the injection of wells by 117,000 bwpd.

The Company hired (April 2015) two dedicated rigs for three years for workover jobs for servicing these identified wells. Only 62 *per cent* of the rig days were used for workover operation while the rig was diverted for additional drilling activities based on work priority for remaining 821 days. During the period 2015-16 to 2017-18, out of identified 100 wells (4 wells already serviced before deployment of dedicated rigs), only 23 could be covered leaving 77 wells pending for workover. It was observed that injectivity in these 23 wells had improved after workover operations. During subsequent period, no separate rig was hired for servicing the remaining wells. This indicated that more emphasis was given for oil production ignoring the long-term impact of less water injection on reservoir pressure and ultimate recovery of oil.

Management stated (March 2020) that workover plan is worked out considering the rig resources available and priority of the wells. Management/ Ministry further added (February/ June 2021) that to address reservoir related issues, wells are planned for intervention on development schemes and other rig interventions are prioritised on need base to address safety.

The reply indicated that due importance was not given for water injection wells. Dedicated rigs hired for workover of water injection wells were diverted to other operations and there is no plan to service left over identified wells to improve injectivity. The need for

servicing of wells was also emphasised in the subsequent in-house committee report (August 2014) which stated that "…*several water injector wells/ strings which are more than 20 years old and require workover job to rectify tubing leakage and/ or casing damage for effective water injection… backwash, stimulation and workover must be regularly adopted to keep the well bore clean and maintain injectivity*".

The workover plan of Neelam and Heera fields was not made available to Audit and hence, Audit is unable to verify whether the water injection wells due for workover were attended to. IOGPT had commented (September 2016) on long gap between workover of water injection wells leading to damages to tubings and increased workover costs. Of the 63 wells under injection in Heera field, 39 were not worked over even once since beginning. Of these 63, eight wells are in operation since 1991 to 2010 and the wells were worked over after a gap of 15-20 years. In Neelam field, out of 24 wells under injection, 11 have not been worked over at all, of which, nine wells were more than 17 years old.

Audit observed that injector wells were closed permanently/ temporarily due to casing damages. An injection well in Heera was closed since December 2017 due to annular valve leakage resulting in less water injection of 12,000 bwpd. Casing leak is a serious safety issue. The safety rules in Chapter XVI of Oil Industry Safety Directorate Manual lays down the stipulations for well barriers and corrective action in case of well barrier failures. Non-compliance of safety regulations could lead to serious implications. Considering the huge gap between two workover jobs and some water injection wells were not worked over since its inception, there is a need for a comprehensive policy for workover/ maintenance of water injection wells.

Management/ Ministry stated (February/ June 2021) that based on outcome of regular monitoring from injection rate, pressure recorded, survey and other reservoir diagnostic plots/ analysed studies, wells are planned for workover. If the desired quantity of water injection is not achievable/ achieved by stimulation, then well is shortlisted for workover. Management/ Ministry further stated that the audit recommendation for preparing an action plan for workover of injection wells was noted.

Management reply needs to be viewed in light of the fact that there is a long gap of 10-15 years between workover jobs of water injection wells and shortfall against the planned workover jobs.

Recommendation No. 14

The company needs to institute a mechanism to workover these water injection wells in a timely manner and prepare action plan accordingly. This will help the company to keep water injection wells in healthy condition and ultimately to attain the goal of maintaining the reservoir pressure for increasing productivity of oil wells.

6.5 Stimulation jobs of injection wells

Well stimulation[33] is a well intervention procedure adopted as water injection wells were prone to plugging of wellbore with scaling/ microbial growth/ residual biomass and microbial induced corrosion. Frequent stimulation job is required to maintain the desired injectivity. In the past, stimulation job in the company was strictly driven based on the resource available. An in-house committee observed (August 2014) that inadequate stimulation is one of the reasons for less water injection and recommended that procedures of stimulation jobs must be regularly adopted to maintain injectivity. Against the desired frequency of once in two years as suggested by the international consultant M/s. GCA, the frequency of stimulation was once in 5.8 years (Mumbai High) and 4.4 years (Neelam and Heera). The company reviewed (2013) its trouble shooting approach of stimulation jobs and decided to have proactive preventive approach as recommended by the consultant to make it in line with the best industry practices. Based on this, stimulation methodology with frequency of once in two years was worked out and one stimulation vessel was hired for a period of three years for western offshore.

In this regard, Audit observed that despite hiring dedicated stimulation vessel, the company, on annual basis planned less number of stimulation jobs of injection wells against the approved workload. In Mumbai High, against approved workload of 680 stimulation jobs, only 157 jobs were planned (23 *per cent*); of this only 120 jobs were carried out (18 *per cent*). Similarly, in Neelam and Heera, against the approved workload of 176 jobs, only 69 stimulation jobs were carried out (39 *per cent*). To the Audit query seeking annual plan details, Neelam and Heera stated that "*Plan of stimulation wells is not prepared and the stimulation workload in water injection wells is worked out on a continuous basis throughout the year*".

Management/ Ministry stated (February/ June 2021) that workload for stimulation jobs is optimised as per available resources and additional stimulation vessel is being hired so that focus can also be given for water injection stimulation jobs.

Reply needs to be viewed from the fact that dedicated stimulation vessel was diverted to stimulation of oil wells. The allotment of stimulation vessel resources to the water injection wells for all fields was only 3.5 *per cent* in 2016-17, 3.8 *per cent* in 2017-18 and 1.4 *per cent* in 2018-19. This showed prioritisation of stimulation of oil wells over injection wells at the cost of reservoir health.

Recommendation No. 15

The company should review its present practice/ policy of need based approach of stimulating water injection wells to make it in line with the best industry practices. This will help in taking preventive measures before serious damage occurs to the system or wellbore and to improve injectivity of wells.

[33] ***Stimulation jobs include acid, solvent and chemical treatments to improve the permeability of the near-wellbore formation, enhancing the injectivity/ productivity of a well.***

6.6 Backwash of injectors

Over a period, some unwanted material like corrosion particles, dead micro-organisms, etc., get accumulated near wellbore and are required to be removed/ cleaned to improve wellbore conditions. Backwashing water injector is an additional method to remove the near wellbore damage and restore a significant amount of lost injectivity. In the backwash process, the injector is flowed back to clean up any formation damage. Samples of backwash fluid are an important indicator of quality of injected water and offer insights about the water injection process. Injector wells needs to be backwashed at regular intervals to avoid impairment of reservoir permeability or reduction in injectivity. Audit observed that there was substantial shortfall in backwash activities against plan as given in table 6.3.

Table 6.3: Plan v/s actual backwash jobs

Year	Mumbai High field			Neelam & Heera field	
	Plan (Nos.)	Actual (Nos.)	Achievement (in percentage)	Plan	Wells backwashed (Nos.)
2014-15	377	433	114.9	NA	8
2015-16	406	408	100.5		4
2016-17	366	344	94.0		12
2017-18	355	235	66.2		4
2018-19	314	178	56.7		7

Source: Data furnished by Management

It may be seen from the table that there is decreasing trend in achievement of backwash of injectors in Mumbai High fields.

6.6.1 Mumbai High: An internal committee observed (July 2012) that in Mumbai High, back flow of limited number of water injection wells was being done. Committee observed that out of 291 strings only 132 strings were equipped with gas lift valve and thus could be backwashed regularly; the remaining 159 strings needed gas lift valve provision and hence, the committee proposed remedial action. Status of compliance to the recommendations was not provided to Audit. A Task Force constituted in Mumbai High reiterated (October 2018) that regular backwashing of injectors has a positive impact on well injectivity and recommended backwash of injectors once in six months.

Examination of the data of water injection backwash samples furnished to Audit revealed that periodicity for backwash is more than a year per injector[34]. Of 334 injectors, no backwash was carried out in 26 injectors and around 158 injectors were due for backwash considering time interval of more than six months from their last backwash. Audit observed that wells where gas lift valves were not installed were overdue for backwash. In Mumbai North West platform, in 42 cases out of 77 records made available to Audit, backwash samples were not taken thereby rendering backwash process ineffective. Management did not offer any comment on non-achievement of backwash plan and details of wells which are backwash compliant.

[34] ***Injection well/ string - Injection well is a well through which water is injected into reservoir to maintain reservoir pressure. Injection well may have single string or dual strings.***

6.6.2 Neelam & Heera: As compared to Mumbai High field which has monthly plan for backwash of water injection wells, Neelam and Heera field does not have a streamlined approach for backwash. Only in 35 cases, backwash of water injection wells was carried out during 2014-15 to 2018-19 against the requirement to carry out once in six months for each injector. The backwash details shared by the company indicated that the process was not regularly followed. The samples were not analysed, thereby rendering the efforts ineffective.

Management stated (December 2019/ February 2020) that no sample was collected during the process of backwash due to non-availability of sample point required for the equipment and hence lab analysis of samples was not available. However, it has been decided to carry out at least 3-5 water injector backwash jobs every month in Neelam and Heera fields and prepare a detailed chemistry analysis report of the backwash water sample collected. Management/ Ministry assured (February/ June 2021) that backwash plan will be strictly adhered to in future.

Recommendation No. 16

The company should regularly backwash the wells as per defined periodicity to improve injectivity of wells and increase water injection. Also resources planned/ mobilised for water injection may be considered separate from the requirements for producer wells.

6.7 Summing up

Audit noticed higher levels of corrosion in all the platforms than the desired level which is a matter of concern. The company could not adhere to the periodic pigging plan for removal of debris deposited in the pipelines. Besides, non-monitoring of pigging samples defeated the purpose of carrying out the exercise. Audit also noticed pre-mature failure of pipelines in view of high dissolved oxygen and non-maintenance of flow velocity. It was also noticed that periodical workover/ stimulation of injectors were not carried out leading to loss of injectivity/ safety issues. Resources hired exclusively for water injection wells were diverted to oil wells at the cost of reservoir health. Thus, pipelines and injection wells were not maintained as per requirement and the workover, stimulation and backwash operations of injection wells were not carried out effectively, leading to drop in injectivity.