Petroleum and Coal

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Pipe Integrity Analysis and Evaluation using Multi Finger Imaging Tool (MIT) - Field Case Studies

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Received December 22, 2020; Accepted January 26, 2021

Abstract

A pipe integrity is highly influenced by the damage or defect produced during the process of production. Therefore, the main objective of this paper is to study and analyze the pipe integrity of two Romanian fields. The logging data recorded by a multi finger imaging tool (MIT) are used to evaluate the interity of 128 pipes. The MIT components and functions are reviewed. Further, several types of pipe damage and defects are presented. Damage classification scheme is also presented and discussed.

Keywords*: Well integrity; MIT; damage types; Romanian fields; damage profile, statistics.*

1. Introduction

Well integrity issues might occur and lead to potential loss of well, expose people's live to danger, loss of oil and gas production, capital cost, deform company's reputation and other indirect consequences. Casing or pipe integrity is considered a critical component to maintain a drilled well and the main mechanical barrier envelop that provides a conduit between the surface and the reservoirs during the well lifecycle [1]. Casing or pipe is subjected to local loads, degradation, induced stresses during well stimulation, slip and shear [2-3]. Exploration and production encounter various difficulties while drilling such as deep-water wells, high pressure high temperature wells, and shale gas, and wells with high H_2S or CO_2. These fields encounter various difficulties during drilling, completion, production and well barrier integrity during the lifecycle of a well. Degradation is a gradual and irreversible increase of damage that happens occur throughout a drilled life cycle. In a well barrier, it could be hard to notice and precisely survey the actual Degradation. This is because of the unavailability of real time monitoring system and because of a presence of different degradation mechanism.

In situ stress, tectonic movement and earthquakes are all high potential of well pore failure that may damage casing and lead to loss well integrity. In situ stress in zone may change before and after drilling attribute to rock removal and effect well configuration. According on stress variation and the rock consolidation degree and well bore instability issues that can occur while drilling. Tangential and radial stresses are critical to wellbore stability that may lead to plastic deformation of casing. Bad bond between cement and casing can cause severe variation in stresses long the radial and tangential direction that would end up with collapse of casing [4]. Horizontal well hydraulic fracturing resulted on casing deformation. Jiang Ke [5] studied the correlation between casing deformation and quality of cement. A finite element software system was used to build the model and numerical calculations of cement channelling, casing off centre, and wellbore diameter variation. Results confirmed that poor well cement is key factor for casing deformation.

Hydraulic fracturing and acid fracking can lead to reservoir deformation, issues of well integrity, and casing failure. In changing Weiyuan national shale gas reported 32 of 101 wells that had severe casing deformation due to hydraulic fracturing. Resulting, difficulties while setting bridge plugs and reduce the desired number of fracturing stages. Consequently, high-operating costs as reducing number of fracturing stages leads to low permeability well yield, which would reduce the well life span [6].

Main reasons of oil and gas well leakages such as casing corrosion, casing threads problems, micro annulus in cement, mud channels and migration of gas through cracked cap rock [4]. Corrosion due to acidic fluid or age during production operations can cause leak from improper make-up torque. Therefore, the use of artificial intelligence technology in automated power tongs can reduce casing integrity issues consequently a long-term well integrity [7].

Casing deformation is highly expected in salt formation because of well tortuosity, as salt severely creep to wellbore. Casing not centred or aligned on the wellbore would get a faster creep behaviour that uneven the load distribution around casing [8]. Increase of temperature leads decrease on cement sheath tangential stress. High differential temperature and stress between salt pressure and wellbore within the salt dome formation would increase the creep rate 10 times faster. Consequently, cement sheath tangential stress reduction and increase in compressive stress on casing leading to likely buckling the well casing [9].

Continuous monitoring and inspection of well integrity is essential during life cycle of any type of wells. There are variety of tools available to inspect and assess pipe integrity in the oil and gas industry which can be classified as casing-hole callipers, electro-magnetic tools or ultra-sonic tools. This case study evaluates and analyses casing integrity using multi finger imaging tool (MIT) [10].

Multi finger imaging tool is being used extensively to evaluate existing wellbore for optimum well integrity. It is deployed on the well after drilling and before RIH new completion to confirm casing integrity in order not to have any potential problem while RIH the new completions. Likewise, after RIH completion string, MIT is required to be deployed to confirm and document proper depth and exact place for completion components. Furthermore, it is vital to periodically perform casing and tubing inspection campaign to ensure wellbore integrity [13].

2. MIT description

Multi finger imaging tool is a casing hole calliper tool that provides high-resolution with detailed information about the existing condition of various casing sizes and even in small tubing sizes. It consists of finger section, sensor head, and sensor electronics. Each finger moves freely. Sensor head accommodates all sensor coils and structurally supports electronics [16]. It measures precisely the interval radius of casing and identify exact measured depth for any physical wear, holes, build up scale, Paraffins, mineral depositions, parted casing, cracks, restrictions, deformation and casing corrosion. It has multi fingers that varies from 24 to 60 arms depends on well condition and size of targeted tubulars. It can be run in hole and deployed on slickline, wireline or coil tubing. All data received from tool is 3D radius image for pipes. It is run in hole in different well conditions like drilling, workover, well intervention, injection wells, and production wells [10].

Multi finger imaging calliper tool provides quick and accurate evaluation of pipe damage as it has 3D visualization. It is used to correlate between pipe damage in the well and the wellbore geometry. Hence, it facilitates and improves technical decisions for well intervention such as installing casing patches, run in hole plugs, or set whipstocks [11]. It is used to identify casing wear that was caused by drill pipe during tripping. Such wear may weaken the casing and lead to casing collapse. Therefore, well monitoring and inspection is paramount [12].

Data transmitted to surface from all fingers are reflecting the maximum and minimum IDs of casing segments. These data are simplified at various rates depending on vertical resolution needed. MIT can be deployed with GR and CCL tools for depth correlation [14]. Perforation mapping is considered great aspect of MIT as it allows well analyses and technical decisions to be precisely taken as it was not previously possible [12]. Pipe corrosion measurement refers to internal diameter and thickness of pipe. Mechanical finger calliper measures the internal diameter with high resolution image [18]. Ultrasonic tools are able to measure both thickness of pipe and internal diameter [15]. Table 1 lists available callipers with various number of arms, the resolution and accuracy reduced effected by the number of arms and tool outside diameter [17].

Table 1. Multi-finger callipers available size range and specifications [17]

	No./Finger	Casing Size, in.	Accuracy, in	Resolution, in
24	Slandered	1.75-4.5	0.020	0.0020
	Extended	1.75-7.0	0.020	0.0030
40	Slandered	3.0-7.0	0.020	0.0015
	Extended	3.0-10.0	0.025	0.0022
60	Slandered	4.5-10	0.025	0.0030
	Extended	5.0-14.0	0.030	0.0050
80	Slandered	8.5-14.0	0.030	0.0070
	Extended	8.5-20.0	0.030	0.0140

Table 2. Data of zones of study

Zone	Dimension, mm	Weight, kg/m	Length, m	Internal diameter, mm	Quality
1	73	0.0	242.4	62	Unknown
2	60	0.0	939.1	50	Unknown

3. Field data description

One hundred and twenty eight pipes were selected to test their intergrity using MIT tool for two Romanian fields in different locations. The setting depthes of these pipes range between 2.80 m and 1181.46 m. Figure 1 shows the MIT tool used for detecting the failure type of each pipe. Based on the tool configuration and from Table 1, it would be easy to classify our tool. Description of zone to be study is shown in Table 2. The study results are generated semi-automatically, using sondex WIPER analysis software. A total of 128 joints were analyzed, of which 1 have possible hole. Logging data were taken on 10.08.2020.

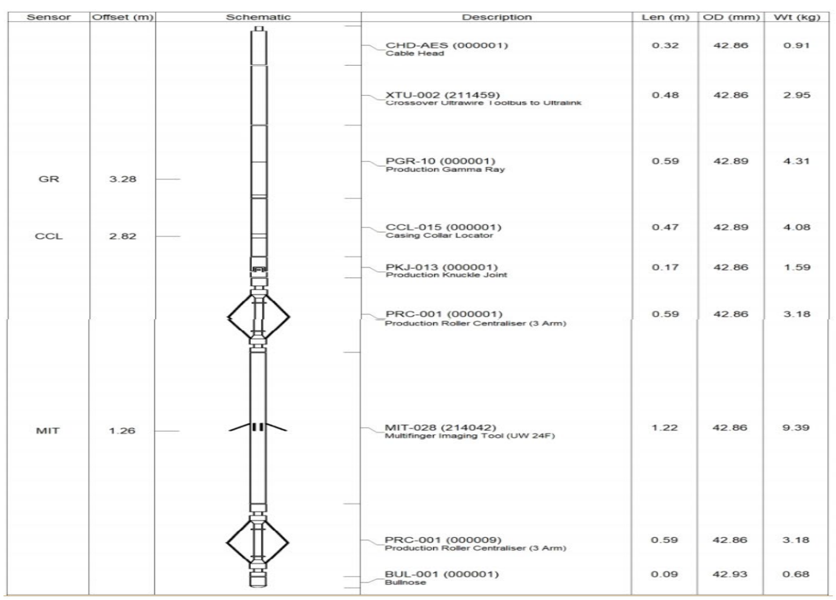


Figure 1. MIT tool

4. Damage classification scheme

Penetration/projection, which appeared in the study analysis, is classified as follows:

- Penetration refers to point damage, measured as absolute units or as a % of nominal wall thickness which projection exceed 0.02" (the damage reporting threshold).
- Projection refers to scale in the inside of the pipe, measured as absolute units or as a % of nominal well radius which projection exceed 0.02" (the damage reporting threshold).

- Metal Loss refers circumferential damage, weakening the pipe. Measured as a % of cross-sectional wall area.
- Very Small Damage: These are likely to be noise and are rejected as damage items.
- Isolated Pitting refers to small, isolated points of penetration which Damage depth range does not exceed 4 x ID or extends more than 30% of circumference.
- General Corrosion refers to large areas of penetration, may be any shape which damage depth range exceeds 2 x ID and/or extends more than 30% of circumference.
- Line Damage is a narrow area of penetration running along the length of the pipe Which the damage depth range exceeds 4 x ID, but extends less than 30% of circumference.
- Ring Damage is the penetration damage that is spread around the circumference of the pipe which the damage area exceeds 50% of circumference, but depth does not exceed 2 x ID.
- Possible Hole is a penetration exceeds 75% of nominal wall thickness that may be deep enough to have caused a hole through the pipe wall

Appendix shows tables and recorded data for 128 pipe. Further, tables show the type of damage, percentage, and effect. Results tables include: •Joint which refers to the number of the joints in the well; •Depth which is the depth of the top of the joint; •Nom ID is the nominal ID of the joint; •Mode ID which is the measured ID of the joint, estimated from "good" areas of pipe; •Modal Change % refers to the % difference between measured and nominal ID; •Penetration is the worst penetration point in the region as absolute value and % of nominal wall thickness; Projection is the worst projection point in the region as absolute value and % of nominal wall thickness; •Body refers to the damage in the body region of the region of the joint (between coupling regions); •Coupling refers to the damage in the coupling regions of the joint; Metal Loss is the worst % loss of wall area in the joint; Min ID refers to the smallest ID measurement made in the joint; •Area loss is the worst % loss of flowing area in the joint; •Description is the text description of the damage within the joint; •Damage Profile represents the graph of damage within the joint; and Avg Dev is the average deviation in the joint.

5. Field results and analysis

MIT is one of the logging tools used in petroleum industry for evaluating pipe integrity. Analysis of recorded data by MIT helps to select immediate remedial action plan which leads to increase production with less problems. The MIT (Figure 1) was used to investigate 148 production pipes in two Romanian fields for a wide range of depths 2.80 m to 1181.46 m. Two zones of recorded data are shown in Table 1. Appendix shows the results of recoded logging data using MIT. Based on the data analysis (Appendix and Figures 2 through 5), the following results were obtained:

General data analysis

- Analyzed pipes = 128
- Analyzed depths = 2.80 m - 1181.46 m
- Pipes with possible holes = 1

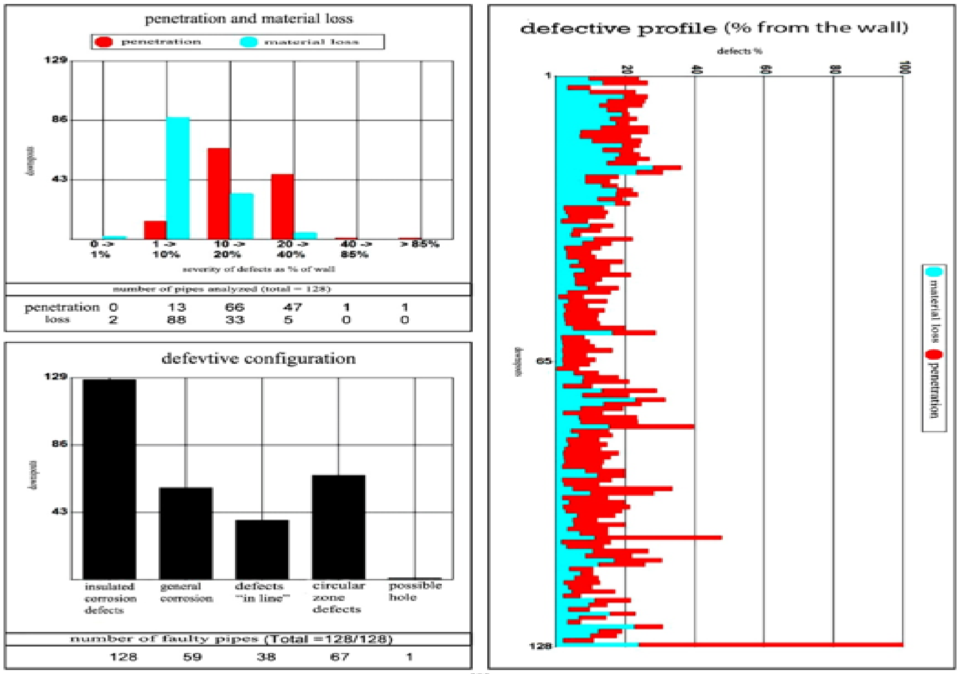
The pipes with the highest penetrations

- Penetration of 100% (5 mm) in pipe 128 at a depth of 1178.3 m
- Penetration of 47.89% (2.39 mm) in pipe 104 at a density of 946 m
- Penetration of 39.77% (1.99 mm) in pipe 79 at a depth of 714.7 m

The pipes with the greatest prominences

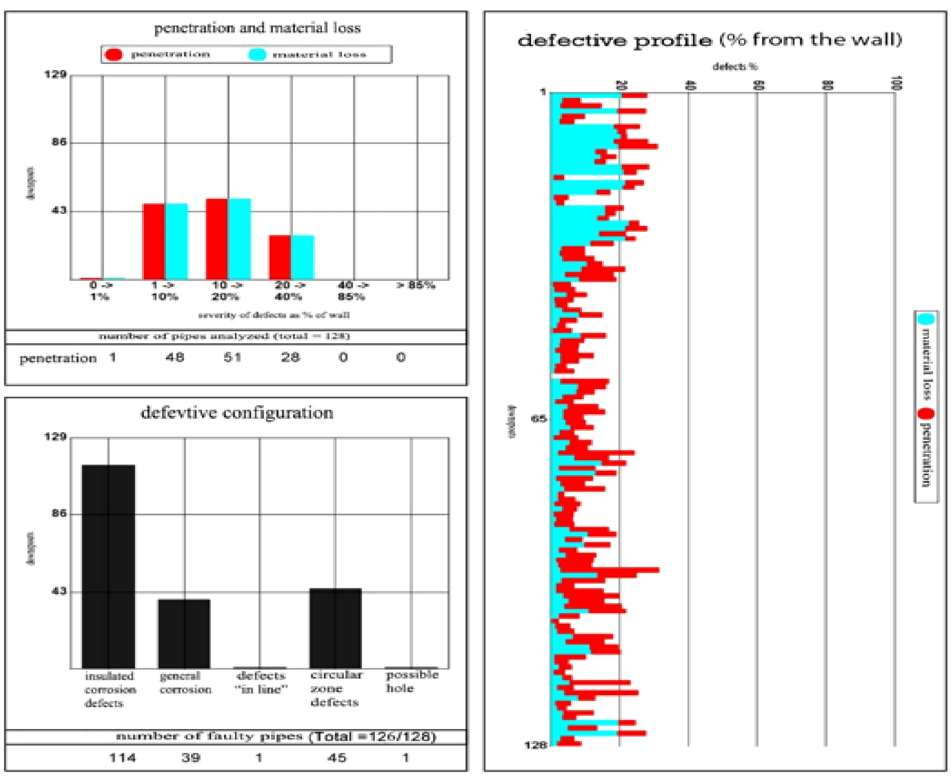
- The prominence of 76.54% (19.13 mm) in pipe 128 at a depth of 1177.6 m
- The prominence of 19.93% (4.98 mm) in pipe 77 at a depth of 696.1 m
- The prominence of 13.22% (3.31 mm) in pipe 104 at a depth of 949.1 m

Overall, statistics of MIT results for 128 fields in Romania are shown in Figures 2 through 5. Firstly, the damage produced from penetration is more than that resulted from material loss as appeared from the damage profile in Figure 2. Moreover, the degree of damage severity reached to 40 % for pipe numbers among 1 and 86. Among all damage types appeared from the logging data, the isolated corrosion is the widest defective configuration through all 128 pipes. However, the other types of configuration damage represent the lower configuration defective for pipes below number mostly 50 such as general corrosion, inline defect, and circular zone damage. There is also one pipe or joint with a hole through its body. For the damage regarding pipe coupling region penetrations, the damage produced from penetration is nearly the same as that of material loss as shown from the defective profile (Figure 3).



[2]

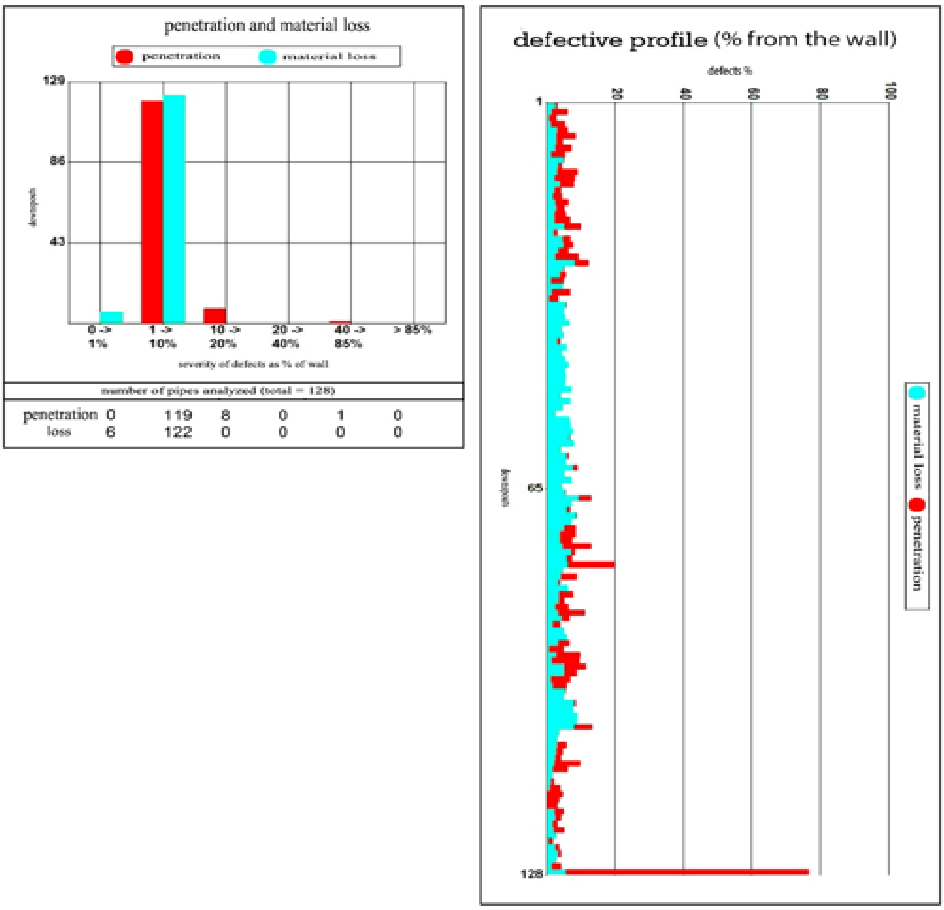
Figure 2. Damage regarding pipe body region penetration



[3]

Figure 3. Damage regarding pipe coupling region penetrations

The severity of damage ranges from 10 to 40% for fewer number of joints. Also, the isolated corrosion is still the highest damage among the other types of damage. The first joint suffers from inline and possible hole damages. Further, the penetration damage is lower compared with body and coupling previous cases and is nearly the same that produced from material loss damage regarding pipe joint projections and prominence (Figure 4). There are 119 joints subjected to penetration damage while 122 joints suffering from material loss damage. Finally, the penetration damage, which appeared in the pipe cross section view, is not too worse for joints' section view shown in Figure 5 except the last two joints which are suffering from a higher percentage of penetration and material loss damages through their entire cross sections.



[4]

Figure 4. Damage regarding pipe joint projections

6. Conclusions and recommendations

Overall, the tubing is still in good condition but there is recommend the periodic tubing integrity monitoring for these fields such as once per year to study the erosion, corrosion and projection rate and better planning to handle the tubing leaks/scale build up in future. Additionally, there are some few pipes need to be changed because they are suffering from higher corrosion damage and the existing of wall hole. The damage resulted from scale deposition is small compared with others.

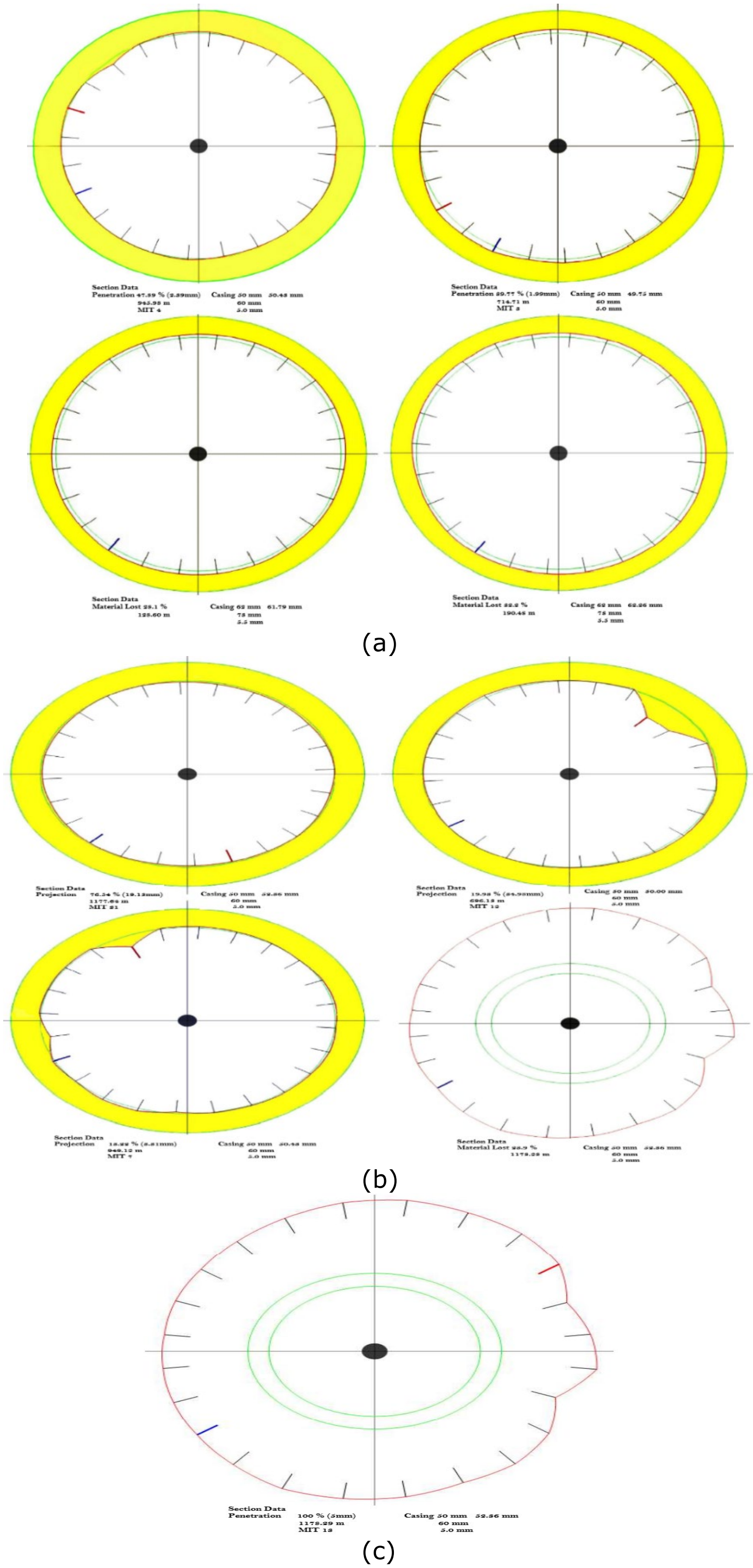


Figure 5. (a, b, c) Pipe integrity after running MIT (damage through pipe cross section view)

Appendix

Table A1. Pipe sheet analysis MIT (penetration)

Pipe	Depth m	ID Nom mm	ID Model mm	Penetration					MIT quality	Damage description
				Body mm	%	coupling mm	%	Material loss in %		
1	2.8	62.000	62.00	1.32	24.0	1.54	28.0	20.7	2	Slight defect 'circular area ' defect 'in line' moderate
2	11.5	62.000	62.57	1.46	26.5	0.49	8.9	13.6	2	Moderate defect 'circular area' slight corrosion
3	20.5	62.000	62.84	0.55	9.9	0.81	14.7	3.5	1	slight collision ; corrosion defect small
4	29.0	62.000	62.00	1.27	23.0	1.53	27.8	19.3	2	Slight defect 'circular area ' defect 'in line' moderate
5	38.0	62.000	62.85	1.46	26.5	0.55	10.1	19.7	2	Moderate defect 'circular area' slight corrosion
6	46.3	62.000	62.66	1.41	25.7	0.39	7.1	14.8	2	Moderate defect 'circular area' slight corrosion
7	55.0	62.000	62.00	1.37	24.9	1.43	26.0	18.3	2	Moderate defect 'circular area' defect 'in line' moderate
8	63.7	62.000	62.00	1.14	20.7	1.21	22.0	19.5	2	Moderate defect 'circular area' slight collision
9	71.4	62.000	62.00	1.17	21.2	1.22	22.1	20.3	2	Moderate defect 'circular area' defect 'in line' moderate
10	80.5	62.000	62.00	1.29	23.5	1.56	28.3	18.4	2	Moderate defect 'circular area' defect 'in line' moderate
11	88.7	62.000	62.00	1.16	21.1	1.71	31.0	19.7	2	Moderate defect 'circular area' defect 'in line' moderate
12	97.8	62.000	62.00	1.47	26.8	0.90	16.4	13.0	2	Moderate defect 'circular area' slight collision
13	105.8	62.000	62.00	1.47	26.7	1.06	19.2	14.7	2	Slight defect 'circular area ' defect 'in line' moderate
14	114.5	62.000	62.00	1.19	21.6	0.89	16.2	12.8	2	Slight defect 'circular area ' defect 'in line' moderate
15	122.8	62.000	62.00	1.36	24.7	1.57	28.6	20.6	2	Moderate defect 'circular area ' defect 'in line' slight
16	131.9	62.000	62.00	1.34	24.3	1.37	25.0	21.1	2	Moderate defect 'circular area ' defect 'in line' moderate
17	140.7	62.000	62.57	1.24	22.5	0.22	4.0	13.7	2	Moderate defect 'circular area' slight corrosion
18	148.9	62.000	62.00	1.34	24.3	1.49	27.1	21.8	2	Moderate defect 'circular area ' defect 'in line' moderate
19	157.5	62.000	62.00	1.48	26.9	1.35	24.6	21.0	2	Moderate defect 'circular area ' defect 'in line' moderate
20	166.0	62.000	62.00	1.29	23.5	0.96	17.4	14.7	2	Moderate defect 'circular area' moderate corrosion
21	174.2	62.000	61.79	2.00	36.6	0.29	5.3	28.1	2	Moderate defect 'circular area' strong corrosion
22	182.2	62.000	62.26	1.70	30.9	0.22	3.9	23.2	2	Moderate defect 'circular area' strong corrosion
23	190.6	62.000	62.00	1.00	18.1	1.16	21.1	15.8	2	Slight defect 'circular area ' defect 'in line' moderate
24	199.0	62.000	62.00	0.86	15.7	1.03	18.8	15.9	1	Slight defect 'circular area ' defect 'in line' moderate
25	207.8	62.000	62.00	0.99	17.9	0.92	16.8	13.6	1	Moderate defect 'circular area ' defect 'in line' moderate
26	210.5	62.000	62.00	1.22	22.2	1.41	25.6	22.7	2	Moderate defect 'circular area ' defect 'in line' moderate
27	216.8	62.000	62.00	1.30	23.6	1.54	27.9	21.8	2	Moderate defect 'circular area' moderate corrosion
28	225.3	62.000	62.00	1.07	19.4	1.20	21.9	14.1	2	Moderate defect 'circular area' slight corrosion
29	233.8	62.000	62.00	1.19	21.6	1.36	24.8	21.6	2	Moderate defect 'circular area' defect 'in line' moderate
30	242.7	50.000	51.72	0.69	13.8	0.93	18.5	11.5	1	Moderate defect 'circular area' medium corrosion defect
31	251.8	50.000	50.47	0.76	15.2	0.50	10.1	3.1	1	medium corrosion defect
32	261.5	50.000	51.39	0.71	14.3	0.51	10.1	3.6	1	moderate corrosion medium corrosion defect
33	271.9	50.000	50.38	0.46	9.2	0.64	12.9	3.4	1	Small corrosion defect
34	281.2	50.000	50.00	0.84	16.7	0.75	15.0	10.5	1	Slight defect 'circular area ' defect 'in line' moderate
35	291.4	50.000	50.02	0.65	13.1	1.08	21.6	8.9	2	Slight defect 'circular area ' medium corrosion defect
36	301.3	50.000	50.95	0.36	7.2	0.92	18.4	4.3	1	Small corrosion defect
37	310.8	50.000	50.00	1.11	22.3	0.95	19.1	11.0	2	Moderate defect 'circular area' defect 'in line' slight
38	320.9	50.000	50.00	0.80	16.0	0.30	6.0	7.8	1	Slight defect 'circular area' defect 'in line' slight
39	330.1	50.000	50.09	0.65	13.0	0.37	7.3	2.6	1	medium corrosion defect
40	339.7	50.000	51.11	0.52	10.4	0.53	10.6	4.8	1	medium corrosion defect
41	348.8	50.000	50.16	0.57	11.4	0.34	6.8	3.1	1	medium corrosion defect
42	358.0	50.000	49.74	0.98	19.5	0.25	5.0	6.7	1	Slight defect 'circular area ' moderate corrosion
43	367.2	50.000	50.35	0.78	15.6	0.45	9.0	4.2	1	medium corrosion defect
44	376.3	50.000	50.87	0.79	15.7	0.75	15.0	8.3	1	Slight defect 'circular area ' medium corrosion defect
45	385.6	50.000	49.04	1.09	21.8	0.38	7.7	5.2	2	Moderate defect 'circular area ' medium corrosion defect
46	395.1	50.000	49.48	0.67	13.4	0.22	4.4	5.8	1	Moderate defect 'circular area ' medium corrosion defect
47	404.3	50.000	49.48	0.58	11.6	0.31	6.3	5.6	1	medium corrosion defect
48	413.6	50.000	49.98	0.90	18.1	0.80	16.0	9.3	1	Slight defect 'circular area ' medium corrosion defect
49	423.2	50.000	50.41	0.79	15.8	0.49	9.8	3.5	1	medium corrosion defect
50	432.2	50.000	50.00	0.40	7.9	0.41	8.2	2.8	1	defect 'in line' Slight Small corrosion defect
51	441.3	50.000	50.09	0.74	14.8	0.40	7.9	3.6	1	moderate corrosion: medium corrosion defect
52	450.4	50.000	50.15	0.46	9.2	0.63	12.5	3.0	1	Small corrosion defect
53	459.8	50.000	49.28	0.70	14.1	0.41	8.2	3.0	1	medium corrosion defect
54	469.1	50.000	49.40	0.62	12.3	0.23	4.6	2.5	1	medium corrosion defect
55	478.5	50.000	48.43	0.60	12.0	0.35	7.0	2.7	1	medium corrosion defect
56	487.7	50.000	50.00	0.64	12.9	0.00	0.0	3.0	1	defect 'in line' Slight; moderate corrosion
57	497.1	50.000	48.27	0.99	19.9	0.84	16.8	4.9	1	moderate corrosion: medium corrosion defect
58	506.6	50.000	50.00	1.44	28.8	0.81	16.2	16.5	2	Moderate defect 'circular area ' moderate corrosion
59	517.2	50.000	50.00	0.42	8.3	0.64	12.8	7.5	1	Slight defect 'circular area' defect 'in line' slight
60	527.1	50.000	49.62	0.49	9.7	0.48	9.5	3.5	1	Small corrosion defect
61	535.7	50.000	49.76	0.57	11.4	0.33	6.6	2.2	1	medium corrosion defect
62	545.2	50.000	49.49	0.82	16.4	0.69	13.8	4.8	1	medium corrosion defect
63	554.2	50.000	49.65	0.45	9.0	0.80	15.9	3.7	1	Small corrosion defect
64	563.3	50.000	49.58	0.58	11.6	0.47	9.4	3.6	1	medium corrosion defect
65	572.5	50.000	49.36	0.49	9.7	0.51	10.2	4.4	1	Small corrosion defect
66	581.8	50.000	50.00	0.33	6.7	0.62	12.4	5.7	1	defect 'in line' Slight; moderate corrosion

Pipe	Depth m	ID Nom mm	ID Model mm	Penetration					MIT quality	Damage description
				Body mm	%	coupling mm	%	Material loss in %		
67	590.9	50.000	48.84	0.62	12.4	0.35	7.1	5.3	1	moderate corrosion: medium corrosion defect
68	600.0	50.000	50.00	0.90	18.0	0.40	8.0	8.0	1	Slight defect 'circular area' defect 'in line' moderate
69	609.4	50.000	50.00	1.06	21.2	0.60	12.0	7.7	2	Slight defect 'circular area' defect 'in line' moderate
70	619.8	50.000	48.85	0.52	10.4	0.54	10.7	4.5	1	medium corrosion defect
71	628.9	50.000	50.00	1.46	29.2	1.23	24.5	13.4	2	Moderate defect 'circular area' defect 'in line' moderate
72	639.2	50.000	50.00	1.06	21.1	0.85	16.9	7.8	2	Slight defect 'circular area' defect 'in line' moderate
73	648.4	50.000	50.00	1.58	31.5	1.09	21.8	22.9	2	Moderate defect 'circular area' defect 'in line' moderate
74	658.4	50.000	50.00	1.24	24.7	0.65	13.0	13.9	2	Moderate defect 'circular area' defect 'in line' moderate
75	668.6	50.000	50.00	0.98	19.5	0.96	19.2	13.1	1	Slight defect 'circular area' defect 'in line' moderate
76	678.0	50.000	50.55	0.68	13.5	0.62	12.4	2.1	1	medium corrosion defect
77	687.7	50.000	50.00	1.17	23.4	0.50	10.1	6.7	2	Slight defect 'circular area' defect 'in line' moderate
78	696.7	50.000	50.21	1.19	23.8	0.80	16.0	7.3	2	Slight defect 'circular area ' moderate corrosion
79	705.9	50.000	49.75	1.99	39.8	0.20	4.0	15.4	2	Moderate defect 'circular area' strong corrosion
80	714.8	50.000	50.44	0.76	15.3	0.36	7.1	4.5	1	moderate corrosion medium corrosion defect
81	724.2	50.000	50.50	0.82	16.4	0.43	8.6	6.7	1	Slight defect 'circular area ' moderate corrosion
82	733.7	50.000	49.96	0.62	12.5	0.39	7.8	3.4	1	medium corrosion defect
83	742.8	50.000	50.19	0.75	15.0	0.34	6.8	3.7	1	medium corrosion defect
84	752.0	50.000	50.40	0.65	13.0	0.33	6.5	2.6	1	medium corrosion defect
85	761.4	50.000	50.21	0.90	18.1	0.35	6.9	2.2	1	medium corrosion defect
86	770.3	50.000	51.09	0.79	15.9	0.84	16.9	5.4	1	medium corrosion defect
87	780.4	50.000	50.58	0.70	14.0	0.96	19.1	10.7	1	Moderate defect 'circular area' medium corrosion defect
88	789.8	50.000	49.43	0.66	13.2	0.46	9.31	4.2	1	medium corrosion defect
89	798.9	50.000	50.51	1.00	20.0	0.87	17.3	9.8	2	Slight defect 'circular area ' moderate corrosion
90	809.1	50.000	50.08	1.00	20.0	0.38	7.6	12.2	2	Moderate defect 'circular area ' moderate corrosion
91	818.3	50.000	50.82	0.80	16.1	0.67	13.4	4.4	1	medium corrosion defect
92	827.4	50.000	50.26	0.62	12.5	0.63	12.6	2.5	1	medium corrosion defect
93	836.6	50.000	51.57	1.69	33.7	0.60	12.1	4.9	2	High corrosion defect
94	845.9	50.000	50.74	1.41	28.2	1.57	31.5	9.9	2	Slight defect 'circular area ' moderate corrosion
95	855.1	50.000	49.85	0.75	15.0	1.25	25.0	13.7	2	Moderate defect 'circular area' medium corrosion defect
96	864.4	50.000	50.81	1.00	20.0	0.79	15.8	3.8	1	moderate corrosion medium corrosion defect
97	873.6	50.000	51.41	1.07	21.4	0.35	7.1	2.2	2	medium corrosion defect
98	882.7	50.000	50.28	0.95	19.1	0.77	15.4	2.8	1	medium corrosion defect
99	893.1	50.000	49.72	0.86	17.2	1.00	19.9	6.2	1	Slight defect 'circular area ' medium corrosion defect
100	902.5	50.000	50.00	0.61	12.2	0.78	15.7	5.2	1	defect 'in line' Moderate : moderate corrosion
101	913.0	50.000	49.77	1.00	19.9	1.03	20.6	5.1	2	medium corrosion defect
102	922.9	50.000	49.92	0.76	15.1	1.09	21.8	11.0	2	Moderate defect 'circular area' medium corrosion defect
103	933.4	50.000	49.95	0.76	15.1	0.43	8.5	7.0	1	Slight defect 'circular area ' medium corrosion defect
104	943.1	50.000	50.43	2.39	47.9	0.12	2.4	11.4	3	Moderate defect 'circular area' high corrosion defect
105	952.5	50.000	51.14	0.79	15.8	0.29	5.7	1.8	1	medium corrosion defect
106	962.1	50.000	50.62	0.69	13.8	0.35	7.0	3.2	1	medium corrosion defect
107	971.4	50.000	50.00	1.34	26.8	0.90	18.0	10.7	2	Moderate defect 'circular area' defect 'in line' slight
108	980.5	50.000	50.00	1.10	21.9	0.79	15.7	8.6	2	Slight defect 'circular area ' defect 'in line' moderate
109	989.7	50.000	50.00	1.53	30.6	0.99	19.7	16.9	2	Moderate defect 'circular area ' moderate corrosion
110	998.7	50.000	50.00	1.28	25.7	1.03	20.5	12.3	2	Moderate defect 'circular area' defect 'in line' slight
111	1007.9	50.000	51.96	0.54	10.8	0.51	10.2	4.0	1	moderate corrosion: medium corrosion defect
112	1018.2	50.000	51.08	0.53	10.7	0.26	5.2	7.2	1	Slight defect 'circular area ' Small corrosion defect
113	1027.8	50.000	50.48	0.61	12.2	0.31	6.2	5.6	1	moderate corrosion: medium corrosion defect
114	1037.4	50.000	50.76	0.64	12.8	0.21	4.3	2.3	1	moderate corrosion: medium corrosion defect
115	1046.4	50.000	50.93	0.53	10.5	0.31	6.2	3.7	1	medium corrosion defect
116	1055.4	50.000	52.02	0.86	17.2	1.17	23.3	5.5	2	medium corrosion defect
117	1065.7	50.000	51.41	0.36	7.2	0.33	6.6	2.2	1	Small corrosion defect
118	1074.8	50.000	51.38	1.09	21.8	1.28	25.6	11.2	2	Moderate defect 'circular area' Small corrosion defect
119	1084.6	50.000	51.21	0.74	14.9	0.65	13.1	9.4	1	Moderate defect 'circular area' medium corrosion defect
120	1094.1	50.000	50.62	0.48	9.7	0.30	5.9	3.8	1	Small corrosion defect: Small corrosion defect
121	1103.8	50.000	50.61	1.15	23.0	0.24	4.7	15.5	2	Moderate defect 'circular area' medium corrosion defect
122	1112.5	50.000	51.29	0.73	14.6	0.63	12.7	6.7	1	Slight defect 'circular area ' moderate corrosion
123	1121.7	50.000	51.16	0.36	7.2	0.38	7.6	3.4	1	Small corrosion defect
124	1130.9	50.000	50.00	1.55	30.9	1.24	24.8	22.7	2	Moderate defect 'circular area' strong corrosion
125	1141.2	50.000	50.87	0.95	19.1	0.68	13.7	12.2	1	Moderate defect 'circular area' Small corrosion defect
126	1149.9	50.000	50.00	0.89	17.7	1.38	27.7	19.4	2	Slight defect 'circular area ' defect 'in line' slight
127	1158.8	50.000	50.65	0.55	11.1	0.34	6.9	3.0	1	medium corrosion defect
128	1164.0	50.000	52.36	5.00	100	0.46	9.1	23.9	5	Possibly multiple holes: Moderate defect 'circular area'

Table A2. Pipe sheet analysis MIT (prominent).

Pipe	Depth m	ID Nom mm	ID Model mm	Projection					Loss 'area ' In %	prominent description
				Body mm	%	coupling mm	%	ID Min. mm		
1	2.8	62.000	62.00	1.02	3.3	0.73	2.3	60.35	2.6	Minor deposits
2	11.5	62.000	62.57	1.90	6.1	0.95	3.1	60.22	1.6	Minor deposits
3	20.5	62.000	62.84	0.79	2.6	0.94	3.0	60.43	0.9	Minor deposits

Pipe	Depth m	ID Nom mm	ID Model mm	Projection					Loss 'area ' In %	prominent description
				Body mm	%	coupling mm	%	ID Min. mm		
4	29.0	62.000	62.00	1.65	5.3	0.48	1.6	59.97	1.3	Minor deposits
5	38.0	62.000	62.85	1.95	6.3	0.76	2.4	59.83	3.3	Minor deposits
6	46.3	62.000	62.66	2.67	8.6	1.24	4.0	59.72	2.8	Minor deposits
7	55.0	62.000	62.00	1.42	4.6	0.49	1.6	59.84	2.9	Minor deposits
8	63.7	62.000	62.00	2.28	7.3	0.00	100	59.43	2.6	Minor deposits
9	71.4	62.000	62.00	1.67	5.4	0.00	100	60.37	1.4	Minor deposits
10	80.5	62.000	62.00	1.58	5.1	0.14	0.5	59.47	4.9	Minor deposits
11	88.7	62.000	62.00	1.39	4.5	0.57	1.8	59.99	3.4	Minor deposits
12	97.8	62.000	62.00	2.76	8.9	0.18	0.6	59.36	3.3	Minor deposits
13	105.8	62.000	62.00	2.56	8.3	0.72	2.3	59.62	2.4	Minor deposits
14	114.5	62.000	62.00	2.46	7.9	0.62	2.0	59.54	3.8	Minor deposits
15	122.8	62.000	62.00	1.28	4.1	1.19	3.8	60.27	2.4	Minor deposits
16	131.9	62.000	62.00	1.41	4.5	0.82	2.7	59.89	2.0	Minor deposits
17	140.7	62.000	62.57	2.03	6.5	0.59	1.9	59.66	2.6	Minor deposits
18	148.9	62.000	62.00	1.59	5.1	0.00	100	59.22	2.8	Minor deposits
19	157.5	62.000	62.00	1.77	5.7	0.79	2.6	59.81	2.4	Minor deposits
20	166.0	62.000	62.00	2.15	6.9	0.13	0.4	59.77	2.3	Minor deposits
21	174.2	62.000	61.79	3.11	10.0	0.42	1.4	59.86	5.2	Minor deposits
22	182.8	62.000	62.26	0.99	3.2	0.44	1.4	60.21	2.2	Minor deposits
23	190.6	62.000	62.00	2.16	7.0	1.24	4.0	58.80	4.8	Minor deposits
24	199.0	62.000	62.00	2.37	7.6	0.31	1.0	59.37	5.0	Minor deposits
25	207.8	62.000	62.00	2.00	6.5	1.23	4.0	59.85	3.3	Minor deposits
26	210.5	62.000	62.00	2.89	9.3	0.90	2.9	59.29	2.6	Minor deposits
27	216.8	62.000	62.00	3.78	12.2	0.16	0.5	57.01	8.1	Minor deposits
28	225.3	62.000	62.00	1.59	5.1	0.37	1.2	59.37	4.9	Minor deposits
29	233.8	62.000	62.00	1.79	5.8	1.07	3.5	59.69	3.8	Minor deposits
30	242.7	50.000	51.72	1.21	4.9	0.74	2.9	48.77	1.3	Minor deposits
31	251.8	50.000	50.47	1.11	4.5	0.39	1.5	48.21	4.7	Minor deposits
32	261.5	50.000	51.39	1.77	7.1	0.68	2.7	48.99	1.7	Minor deposits
33	271.9	50.000	50.38	0.85	3.4	0.23	0.9	48.83	1.0	Minor deposits
34	281.2	50.000	50.00	1.46	5.9	1.29	5.2	47.56	5.7	Minor deposits
35	291.4	50.000	50.02	0.87	3.5	0.64	2.6	47.84	5.0	Minor deposits
36	301.3	50.000	50.95	0.58	2.3	0.64	2.6	48.01	5.4	Minor deposits
37	310.8	50.000	50.00	1.24	4.9	0.98	3.9	47.82	6.6	Minor deposits
38	320.9	50.000	50.00	0.82	3.3	1.13	4.5	48.48	4.4	Minor deposits
39	330.1	50.000	50.09	1.20	4.8	1.22	4.9	47.89	5.0	Minor deposits
40	339.1	50.000	51.11	0.98	3.9	0.48	1.9	48.67	3.1	Minor deposits
41	348.8	50.000	50.16	0.83	3.3	0.20	0.8	48.00	6.1	Minor deposits
42	358.0	50.000	49.74	0.98	3.9	0.71	2.9	48.18	4.3	Minor deposits
43	367.2	50.000	50.35	0.51	2.1	0.60	2.4	47.90	5.5	Minor deposits
44	376.3	50.000	50.87	0.94	3.8	0.55	2.2	47.59	6.5	Minor deposits
45	385.6	50.000	49.04	0.95	3.8	0.24	0.9	47.92	5.5	Minor deposits
46	395.1	50.000	49.48	0.84	3.4	0.47	1.9	47.93	5.6	Minor deposits
47	404.3	50.000	49.48	0.63	2.5	0.23	0.9	48.29	5.5	Minor deposits
48	413.6	50.000	49.98	1.07	4.3	0.19	0.8	47.57	7.1	Minor deposits
49	423.2	50.000	50.41	0.61	2.5	0.52	2.1	48.09	4.3	Minor deposits
50	432.2	50.000	50.00	1.58	6.3	1.27	5.1	47.41	7.1	Minor deposits
51	441.3	50.000	50.09	1.02	4.1	0.74	3.0	47.86	4.8	Minor deposits
52	450.4	50.000	50.15	0.63	2.5	0.51	2.0	48.66	2.6	Minor deposits
53	459.8	50.000	49.28	0.77	3.1	0.96	3.8	47.29	6.8	Minor deposits
54	469.1	50.000	49.40	1.08	4.3	0.29	1.2	47.62	7.0	Minor deposits
55	478.5	50.000	48.43	0.58	2.3	0.35	1.4	47.31	7.8	Minor deposits
56	487.7	50.000	50.00	1.77	7.1	1.67	6.7	47.25	6.7	Minor deposits
57	497.1	50.000	48.27	1.88	7.5	1.48	5.9	46.97	8.1	Minor deposits
58	506.6	50.000	50.00	1.06	4.2	0.77	3.1	48.38	4.3	Minor deposits
59	517.2	50.000	50.00	1.60	6.4	1.08	4.3	47.71	6.0	Minor deposits
60	527.1	50.000	49.62	0.97	3.9	0.69	2.8	47.88	5.7	Minor deposits
61	535.7	50.000	49.76	2.27	9.1	0.71	2.9	46.76	7.7	Minor deposits
62	545.0	50.000	49.49	0.51	2.1	0.67	2.7	47.44	5.3	Minor deposits
63	554.2	50.000	49.65	1.38	5.5	1.58	6.3	47.35	7.3	Minor deposits
64	563.3	50.000	49.58	0.94	3.8	0.99	4.0	47.89	4.4	Minor deposits
65	572.5	50.000	49.36	1.46	5.8	0.26	1.1	47.94	5.4	Minor deposits
66	581.8	50.000	50.00	3.29	13.2	2.58	10.3	45.57	9.2	Minor deposits
67	590.9	50.000	48.84	0.66	2.6	0.62	2.5	46.92	7.3	Minor deposits

Pipe	Depth m	ID Nom mm	ID Model mm	Projection					Loss 'area ' In %	prominent description
				Body mm	%	coupling mm	%	ID Min. mm		
68	600.0	50.000	50.00	0.83	3.3	1.73	6.9	47.00	6.0	Minor deposits
69	609.4	50.000	50.00	2.21	8.8	2.00	8.0	46.41	8.5	Minor deposits
70	619.8	50.000	48.85	0.95	3.8	1.13	4.5	47.53	7.1	Minor deposits
71	628.9	50.000	50.00	2.10	8.4	1.66	6.6	47.14	5.1	Minor deposits
72	639.2	50.000	50.00	2.12	8.5	1.10	4.4	47.50	3.8	Minor deposits
73	648.4	50.000	50.00	1.58	6.3	1.89	7.6	47.55	4.0	Minor deposits
74	658.4	50.000	50.00	3.29	13.1	1.96	7.8	46.65	4.7	Minor deposits
75	668.6	50.000	50.00	1.84	7.4	2.09	8.4	46.96	7.2	Minor deposits
76	678.0	50.000	50.55	1.85	7.4	0.52	2.1	47.29	6.1	Minor deposits
77	687.7	50.000	50.00	4.98	19.9	1.41	5.6	45.14	6.2	Minor deposits
78	696.7	50.000	50.21	0.91	3.7	0.44	1.8	47.90	4.8	Minor deposits
79	705.9	50.000	49.75	2.20	8.8	0.20	0.8	47.53	4.1	Minor deposits
80	714.8	50.000	50.44	0.97	3.9	0.33	1.3	48.70	3.5	Minor deposits
81	724.2	50.000	50.50	1.44	5.8	1.27	5.1	47.57	6.2	Minor deposits
82	733.7	50.000	49.96	1.92	7.7	0.25	1.0	48.40	3.6	Minor deposits
83	742.8	50.000	50.19	1.33	5.3	0.35	1.4	48.47	3.6	Minor deposits
84	752.0	50.000	50.40	1.60	6.4	0.80	3.2	48.22	2.6	Minor deposits
85	761.4	50.000	50.21	2.82	11.3	0.39	1.5	47.98	3.4	Minor deposits
86	770.3	50.000	51.09	1.70	6.8	1.10	4.4	47.44	4.5	Minor deposits
87	780.4	50.000	50.58	1.00	4.0	0.58	2.3	48.97	2.0	Minor deposits
88	789.8	50.000	49.43	0.79	3.2	0.53	2.1	47.52	4.8	Minor deposits
89	798.9	50.000	50.51	1.44	5.7	0.86	3.4	47.61	6.0	Minor deposits
90	809.1	50.000	50.08	1.71	6.8	0.51	2.0	48.01	3.4	Minor deposits
91	818.3	50.000	50.82	1.24	5.0	0.43	1.7	48.62	1.0	Minor deposits
92	827.4	50.000	50.26	2.44	9.8	0.66	2.6	48.01	3.0	Minor deposits
93	836.6	50.000	51.57	2.39	9.6	0.70	2.8	47.77	1.6	Minor deposits
94	845.9	50.000	50.74	2.88	11.5	1.22	4.9	47.26	5.1	Minor deposits
95	855.1	50.000	49.85	2.17	8.7	0.84	3.4	47.43	5.1	Minor deposits
96	864.4	50.000	50.81	1.77	7.1	0.33	1.3	48.50	1.4	Minor deposits
97	873.6	50.000	51.41	1.48	5.9	0.78	3.1	48.84	1.8	Minor deposits
98	882.7	50.000	50.28	1.35	5.4	1.45	5.8	47.62	5.6	Minor deposits
99	893.1	50.000	49.72	1.20	4.8	0.76	3.0	46.93	4.9	Minor deposits
100	902.5	50.000	50.00	2.11	8.5	1.17	4.7	46.97	8.1	Minor deposits
101	913.0	50.000	49.77	1.00	4.0	0.82	3.3	47.32	7.8	Minor deposits
102	922.9	50.000	49.95	2.04	8.1	0.94	3.7	46.39	9.1	Minor deposits
103	933.4	50.000	50.43	0.72	2.9	0.60	2.4	47.07	8.8	Minor deposits
104	943.1	50.000	51.14	3.31	13.2	0.15	0.6	45.88	8.0	Minor deposits
105	952.5	50.000	50.62	0.85	3.4	0.52	2.1	48.45	3.6	Minor deposits
106	962.1	50.000	50.00	0.76	3.0	0.54	2.2	48.86	3.0	Minor deposits
107	971.4	50.000	50.00	1.49	6.0	1.14	4.5	48.32	3.1	Minor deposits
108	980.5	50.000	50.00	1.20	4.8	1.04	4.1	48.22	3.0	Minor deposits
109	989.7	50.000	50.00	1.07	4.3	0.81	3.2	48.07	2.7	Minor deposits
110	998.9	50.000	51.96	2.44	9.7	1.67	6.7	47.60	2.4	Minor deposits
111	1007.9	50.000	51.08	1.56	6.2	1.04	4.1	48.71	1.8	Minor deposits
112	1018.2	50.000	50.48	0.50	2.0	0.29	1.2	49.11	1.8	Minor deposits
113	1027.8	50.000	50.76	0.56	2.3	0.49	2.0	48.92	1.5	Minor deposits
114	1037.4	50.000	50.76	0.96	3.8	0.20	0.8	49.35	1.2	Minor deposits
115	1046.4	50.000	50.93	1.17	4.7	0.25	1.0	49.53	0.0	Minor deposits
116	1055.4	50.000	52.02	0.84	3.3	0.90	3.6	49.01	0.2	Minor deposits
117	1065.7	50.000	51.41	0.79	3.2	0.23	0.9	49.82	0.0	Minor deposits
118	1074.8	50.000	51.38	0.89	3.6	1.23	4.9	48.69	2.4	Minor deposits
119	1084.6	50.000	51.21	1.03	4.1	0.24	1.0	48.68	2.6	Minor deposits
120	1094.1	50.000	50.62	0.79	3.1	0.29	1.2	48.98	1.8	Minor deposits
121	1103.8	50.000	50.61	1.31	5.2	0.31	1.2	48.11	2.2	Minor deposits
122	1112.5	50.000	51.29	0.71	2.8	0.24	0.9	48.81	2.9	Minor deposits
123	1121.7	50.000	51.16	0.51	2.0	0.47	1.9	49.36	0.5	Minor deposits
124	1130.9	50.000	51.29	0.49	2.0	0.92	3.7	48.39	2.6	Minor deposits
125	1141.2	50.000	51.16	1.02	4.1	0.28	1.1	48.79	3.5	Minor deposits
126	1149.9	50.000	50.00	0.68	2.7	0.61	2.4	48.92	3.0	Minor deposits
127	1158.8	50.000	50.65	1.02	4.1	0.27	1.1	49.20	1.8	Minor deposits
128	1168.0	50.000	52.36	19.13	76.5	0.40	1.6	47.91	5.8	Minor deposits

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