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TRACKING OF BUOYANCY FLUX OF UNDERWATER PLUMES FOR IDENTIFICATION, CLOSE VISUAL INSPECTION AND REPAIR OF LEAKING UNDERWATER PIPELINES IN MUDDY WATERS

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ABSTRACT

The importance of close visual inspection of leaking sections of pipelines prior to repair activities cannot be over-emphasized. Underwater optical cameras are important tools for most underwater inspection vehicles and submarines. However, the optical camera ordinarily immersed in a gaseous or liquid plume in muddy water condition will see no reliable trace but nearly blank or the scatter of diffused light of illuminating lamps. The implication is that underwater water tools that could be used in clear water to inspect and identify point of leaks on pressure containment structures would not be useful when such structure is installed in muddy or poor underwater visibility conditions.

Recent developments have demonstrated a diver assisted technique of close visual inspection of leaking containments structures installed in muddy water using clean water injection. This present paper demonstrates a technique of tracking and identifying leaking points on pipelines installed in unclear/muddy water conditions using optical cameras installed in a novel manner. The method leads a remotely operated or hyperbaric system to the point of leak in muddy water conditions for close visual inspection and subsequent repair.

The tool performance is validated in a muddy water of Secchi measure of less than 1 cm and in a number of trials, the tool is found sitting at the leak point. Secchi measure is the visual depth into the water column.

Forces that could be found in the plume and the consequences of buoyancy loss to floating or submarine equipment are also examined. Some techniques using remotely operated vehicles and manned hyperbaric bells for leak identification, close visual inspection and repair of pipelines installed in muddy water using the benefit of this presented methodology are proposed and discussed.

KEYWORDS: Plume, Leak point, Muddy water, Pollution, Underwater Poor visibility, Pipeline Inspection, Buoyancy flux, ROV

NOMENCLATURE

N-S-E-W axis	North-South-East-West axis
ROV	Remotely operated vehicle
CVI	Close visual inspection
psig	Pounds per Square Inch (gauge)

1. INTRODUCTION

The traditional method of visually identifying leaking points on subsea pipelines is predominantly the use of underwater inspection remotely operated vehicles (ROVs) installed with optical cameras or the use of underwater divers. To arrive at the point of leak in clear water, the exiting plume is visually seen and tracked. In other cases, different forms of acoustic/sonar methods and improved technology in fluorescence and hydrocarbon sensing systems is integrated in a ROV system for tracking locations of leak. The ROVs can therefore, be led to the leaking point by visualizing exiting leaks (plume) or tracking the signals of acoustic, fluorescence or hydrocarbon sensing systems. The uses of these and the precision with respect to identifying points of leak have been described elsewhere [1, 2].

Where optical visual output is not required, an Intelligent Pigging system may be deployed. Intelligent Pigs have the capability to record defects and holes within the pipeline system as it is pressurized through, from one end of the pipeline to the other. By referencing a point on the pipeline, the tool could identify the approximate location of a defect or a leaking hole. This technique is, however, costly, time demanding and in some cases it requires relatively high operating pressure to run.

The importance of leading an underwater system such as a ROVs to a point of leak on a containment structure in this subject is to perform close visual inspection. The most common type of inspection in the subsea industry is the visual inspection. When leaks occur in a structure, close visual inspection is often required to uncover the details of the damage. Visual inspection is inspection performed directly with human eyes, by still cameras or videos. Close visual inspection, as the name implies, examines closely the damages to uncover the extent, mechanisms and suggests best approach to solving the problem. According to [3], close visual inspection is the best available method for detecting all threats and for providing the best understanding of the pipeline conditions. Close visual inspection which offers an easy identification of visible observations and quick interpretation by operators would naturally be impossible to perform in muddy water conditions. However, as demonstrated by [4] and latter [5], it is possible to perform close visual inspection independent of the water clarity. Diverless applications of such systems require that a tracking technique to the point of leak be provided. This requirement is a huge challenge in muddy water conditions.

A guide is required that threads from the point of leak and guarantees no loss of target when ROV system is deployed in a muddy water mass. The requirement for zero error in guiding underwater tools in unclear water is because mislead can be a costly event. An acoustically operated leak finder in such muddy water condition could be misled by errors in the sound selective technology. Sonars have been one of interesting tools in leak detections. The introduction of the visual 3D elements into the sonar systems has made sonar very unique. However, it is noted that acoustic close range detection of underwater objects is more difficult when the objects are buried in the seabed. Sediments generate high backscattering noise due to heterogeneous scatters within the sediments clouding the object. The acoustic wave attenuation in sediments is also much higher than in water [6, 7 and 8]). Though with 3D imaging technology, it is possible for the ROV operator to have a visual window but there are some margins of error. It is currently not possible to design a 3D imaging system that does not have some errors [9]. The proposal of a standard for assessing the performance of 3D imaging is an indicator that errors do exist in 3D imaging systems [10]. If the point of leak cannot be found, it is difficult to perform close visual inspection of damage.

Hyperbaric systems are useful tools that provide suitable habitat for underwater divers. It is challenging to use bell for inspection and repair of pipelines in poor visibility state. This is because, the visibility is required to make sealings and to fit onto the pipeline, the bell needs to be guided in the water mass to the position of leak.

Reference [2] has suggested tracking of the buoyancy flux of the exiting plume motion. This present paper documents a method of tracing a leaking point on underwater pipelines/structures installed in muddy water conditions using such methodology. Buoyancy flux is the field of motion created by an exiting plume. The theory of oil and gas plumes as found in the literature will be reviewed. The consequences of pluming gases to floating bodies will also be examined. The latter part of this paper will consider the application of the methodology in leak identification, close visual inspection and repair of damaged structures installed in muddy water in hyperbaric and ROV systems. The ROVs and hyperbaric bell are led to the point of pipeline leak using a device presented. The purpose is to enable close visual inspection and repair to be performed.

2. THE THEORY OF AN OIL/GAS PLUME AND ITS RELEVANCE TO LEAK IDENTIFICATION

A subsea release of liquid and/or gas from a pressured containment such as a pipeline results in the formation of a buoyancy flux. The release is often caused by leaks in a pressured containment. Figure 1 shows the features of an underwater plume.

Reference [11] noted that a general feature of an underwater blowout is that when oil and gas under large pressure are released, an intense mixing between the oil, gas, and water masses takes place. Except during the initial phase, the dominant parameter for the behavior of the underwater plume is the content of the gaseous components. The subsurface plume is initially driven by the initial momentum of the release close to the release outlet opening. At some distance from the release (or height above the release point), the plume is driven by the buoyancy of the oil and gas droplets within the plume. Thus the plume consists of seawater entrained into the plume of buoyant oil and gas droplets in the plume.

. Reference [12] has considered the gas as an ideal gas with a specific volume decreasing linearly with pressure for shallow to moderate depths of water. However, at great depths, the gas is no longer presumed to behave as an ideal gas and a pressure and temperature dependent compressibility factor (z-factor) must be introduced in the pressure-volume relationship. Also at 'deep water', according to [12], the fraction of gas dissolved into the ambient water and oil will increase. There will then be a considerable reduction in the buoyancy flux.

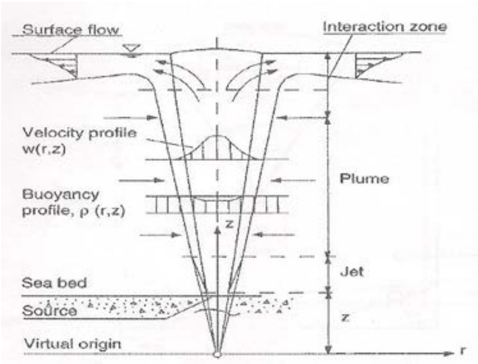

Figure-1: Features of an underwater plume (Source: [16]).

Contrary to the real gas assumption of [11, 12], [13] employed real gas behavior in their model using an Eularian approach (i.e., a fixed control volume is assumed that traces the path of the plume trajectory). The shallow water results did not vary much from the description of [12] and [16]; the shape of the plume is approximately conical except at near the water surface.

In concluding this section, it is noted that an underwater plume is an approximately conical formation of release from leaking subsea structures such as pipelines. The formation is full of momentum provided by the initial pressure of the leaking containment and density differences of the mixing fluids, enabling the plume to emerge to the water surface. Therefore, opportunity exists in plume formation from underwater leaking pipelines, especially when controlled. Once the path of the plume could be tracked, the source of the leak or plume base could be found with greater confidence than any other technique. Development of a tool to track a plume presents a reliable methodology to locate the point of leak on a pipeline structure in muddy water conditions.

3. GAS PLUMES AND BUOYANCY LOSS OF FLOATING/SUBMARINE BODIES

It is important to point out the experience found in underwater gas releases and the consequent effects on floating and submarine systems. Underwater shallow gas releases have occurred in offshore oil and gas drilling processes and several cases have been reported in the past [14]. Consider for example the case of the 99% methane shallow gas release in the 1985 drilling operation of the West Vanguard Semi-Submersible rig on the Norwegian continental shelf. The release resulted in explosions, fire and loss of a human life. The release was caused by failure of the drilling system to contain the gas struck below the seabed in the drilling process, allowing a large amount of the gas with over-pressure of about 1 bar, underneath a water depth of 220 meter to escape in the vicinity of the rig [14].

One of our interests in this report however, is the consequence of this release to the buoyancy of the floating body. A discussion made with a member of the investigation team that studied the incident confirmed there was no loss of buoyancy of the Semi-submersible due to infiltration of gas bubbles in the water mass in about 60 m diameter at free water surface [15]. This is reasonable because the gas release/supply was not shut-off.

Had the gas release been shut off and the Semi-submersible remained in position within the gas plume, the water mass immediately below the vessel would be made less dense and the up-thrust (i.e., water density x gravity acceleration x volume of the submerged part of the structure) on the vessel would be reduced. This would likely have caused the Semi-submersible to sink due to the loss of buoyancy.

The importance of the forgoing discussion is that testing equipment or ROVs following a gas plume must be prevented from a sudden collapse to sea bottom due to sudden shutdown of the gas plume being tracked. This is an important safety consideration for floating and submarine operations in this work.

4. CONTROLLED PLUME TRACKING AS MEDIUM TO LEAK DETECTION METHOD IN MUDDY/UNCLEAR WATER CONDITIONS

In clear water, visual observations can provide an appropriate observable condition of physical phenomenon such as an emerging plume activity of gas or oil pipeline leaks. In muddy water condition, the proposal is to provide a condition where the plume activity of gas, oil or water can be watched by the ROV operator via an underwater camera from the top of the water surface to the origin of the plume base (i.e., the point at the pressure containment where the leak is taking place). The plume activity is the buoyancy flux.

A simplified system as shown in Figure 2 is used in the tests. It is equipped with a camera installed in the head (camera housing), gas inlet system connected to the head and air-tube for buoyancy control. A Plume tray is fixed to the camera head to funnel the flux to the camera view. A Gauze as shown in Figure 3 is omitted.

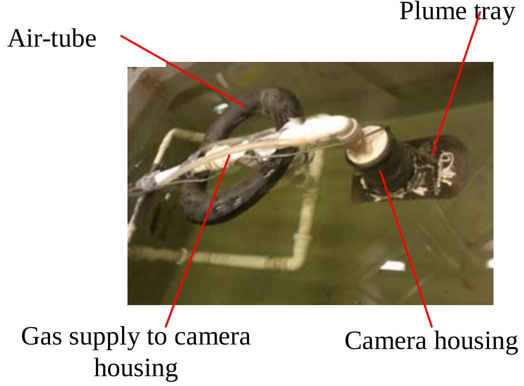

Figure 2: Simplified test for buoyancy detection.

Detector description

The detector is simply an optical camera installed in such a manner that it watches directly over a free water surface and transmits output to the operator. A pressure head equivalent to the water column is maintained in the assembly as the detector transits from top of water surface to the leaking or pluming bottom. A section of the detector is shown in Figure 3.

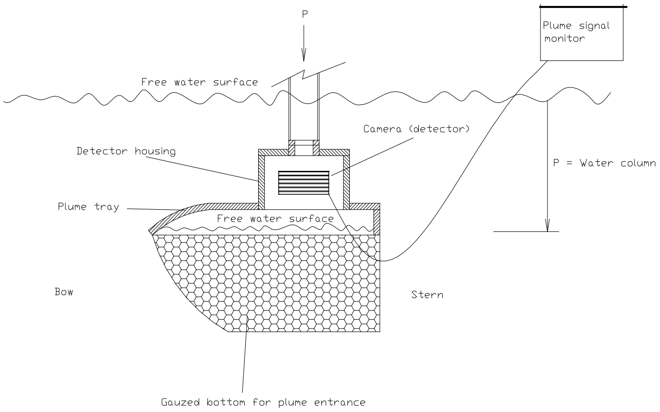

Figure 3: Orthographic section of the plume detector for plume tracking

The camera used is an infra-red output camera. Infra-red output camera means that at dark conditions, the camera naturally produces infra-red light to enable it function in the dark condition. Exposing Infra-red light to visible light makes it to operate as a non-infra-red output camera. The gauze bottom of Figure 3 provides entrance for the buoyancy flux to be trapped and detected

Leak simulation

Muddy water is prepared in a 90 cm wide x 200 cm length x 90 cm deep tank. The vertical Secchi value of the muddy water is below 1 cm (Figure 4). A gas leak was introduced at water bottom to simulate gas plume formation. The detector was then made to approach the emerging plume to visualize the buoyancy flux. Water leaks were also simulated in the unclear water mass in same manner as the gas leak.

Figure 4: The photo showing the tank and muddy water content

The Leak tracking

Gas is fed into the detector to develop a free water surface in the detector (Figure 3). In case of gas leaks, it is possible to utilize the gas from the exiting plume. The tool is lowered towards the emerging plume to generate the visual signals on the screen. The plume effects are seen as the detector peeps to follow the plume formation down to bottom. The test is repeated with water leak. At any time where the signal is lost, the operator sweeps through the N-S-E-W axis through the origin until signal is restored. It is recommended that tracking be made in the downstream of the flowing water.

In all cases, successful tracking was made, provided there is a water free surface as shown in Figure 3. Video coverage of gas and water leaks detections is also available. Notice that in Figure 3, a pressure of $\rho * g * H$ is directly over the free water surface in the detector. Pluming oil or other contaminants in water do not clog the face of the camera. H is the column of water between surface and plume tray as shown in Figure 3.

The preferred gas in the detector is the natural gas instead of air. This is due to possible explosion that could occur when air and natural gases are mixed. Natural gas in this case could be from the pipeline content. Any exiting pipeline content (gas or liquid can be tracked successfully by the methodology provided a plume is formed. The buoyancy flux from the leaking gas and water is detected as shown in Figure 5 and Figure 6. When the system is not tracking the flux, visual signal is not seen (Figure 7). The light on Figure 7 is the reflection of infra-red tubes in Figure 8.

The minimum expected pressure that could cause leak in a broken subsea pipeline is estimated:

$$P = \rho * g * D + \textit{Pressure loss to and at point of leak} \;\ldots\ldots\; (1)$$

P is the pipeline internal pressure, ρ is the water density, g is the acceleration due to gravity and D is the maximum water depth to the leaking surface. The pressure, P^1 in the pipeline to generate the plume is required to be as minimal as possible. By “controlled” plume, one implies that equation (1) is adjusted to yield minimal pressure that generates just an observable plume on the sea surface. P^1 is:

$$\rho * g * D + \textit{Pressure loss to and at point of leak} + \textit{Minimum over-pressure} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Buoyancy flux shown on TV/PC

Figure 5: The Buoyancy flux is detected

The manner in which the buoyancy flux is detected in muddy water is similar to the way human eye or visual camera observes plume exhuming on water surface.

Figure 6: Leaking water detected in similar manner as gas

Figure 7: Reflection of the camera light; no flux detection

Figure 8: The face of the camera showing the infra-red light tubes

One of the great concerns of this methodology is the plume forces and their effects on the plume tracking system. Unfortunately, force generation in an oil or gas plume system has not been discussed in the literature. Effort is made in this paper to conduct few tests to enable an approximate understanding of the plume forces.

5. PLUME FORCES AND LEAK DETECTOR DESIGN

A plume's geometry is approximately conical. The forces would depend on many variables such as the size of the leak opening, pipeline internal pressure, water depth, the buoyancy of the leaking substance, the compressibility of the leaking substance, the water current etc. To reduce the complexity of the estimation, a simple experiment is performed. The purpose is to objectively optimize the geometry of the leak finder that could follow the plume from surface to bottom. Note that the detector is meant to peep and not to swim inside the plume.

5.1 Apparatus

i. Underwater optical camera (Seaview underwater video camera technologies)
ii. Visual system such as PC or TV
iii. Circular bucket, 50 cm maximum OD (Figure 9) and V-shaped object (Figure 10)
iv. Gas (air) pressure, 6 bar (maximum)
v. Variable water pressure (1.5 bar to 0.5 bar)
vi. Air pressure regulator (0.5 bar to 6 bar)
vii. 90 cm wide x 200 cm length x 90 cm deep water tank
viii. Guide frame
ix. Known mass

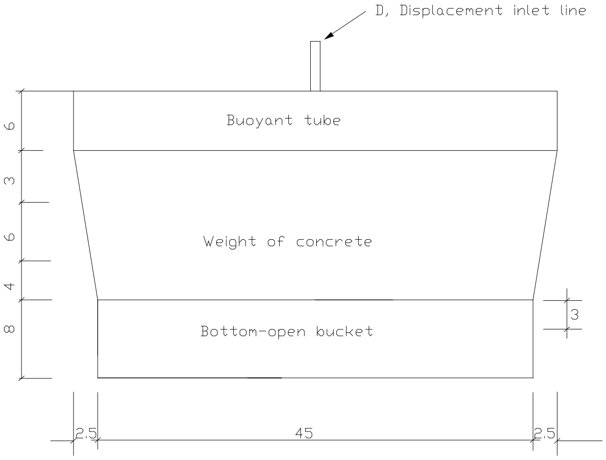

Figure 9: Side view and dimensions of the neutrally buoyant circular bucket in centimeters

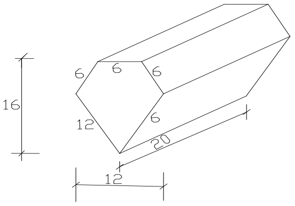

Figure 10 Dimensions of the prismatic plume tracking object in centimeters

5.2 Method

The 90 cm x 200 cm x 90 cm tank is filled with water and a gas leak was positioned at the bottom of the water tank. A circular bucket was prepared and made neutrally buoyant such that:

$$F_{upt} = \rho_f * V_f * g \qquad \text{…………….…………….(3)}$$

F_{upt} is upthrust force on the neutrally floating circular bucket

ρ_f= Density of water
g = Acceleration due to gravity
V_f =Volume of floating body (circular bucket)

A guide frame is fixed around the circular bucket to guide it vertically under the influence of the plume forces. The gas is then turned on for the plume to be formed. The plume exit is a 10 mm hole. Figure 11 is the plan view of the test set up.

Figure 9 gives the dimensions and features of the circular bucket. Figures 12 and 13 are photos of the plume and the effect of plume forces acting on the bucket.

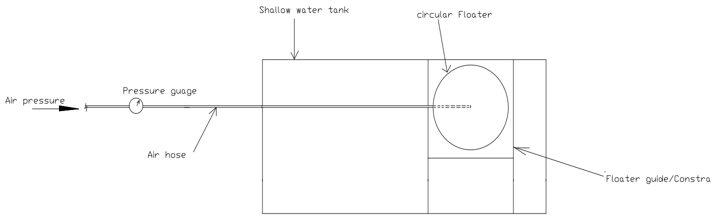

Figure 11: Plan view of the test set up with a circular bucket system

Figure 12: Plume Simulation in the tank, 4 bar pressure.

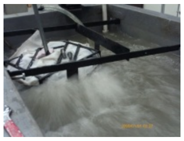

Figure 13: Plume forces acting on the circular bucket

With the full plume developed, the neutrally buoyant circular bucket is observed to be forced upwards on the water surface. This effect is represented by equation (4):

$$F_{pl} + F_{upt} = \rho_p * V_f * g + upward\ force\ on\ the\ circular\ bucket \ldots ..(4)$$

Or simply as:

F_{pl} = Upward force on bucket = Plume force …. ………(5)

The upward force on the circular bucket is due to the action of the plume force.

To determine the quantitative value of the upward force on the circular bucket in equation (5), mass was added on the circular bucket until it tended to sink into the plume. This mass was noted. The test was repeated using leaking water from a 5 mm hole made on a 1-inch plastic pipe.

The neutral buoyancy of the circular bucket ensures that the plume force, F_{pl} is made independent of the mass of the circular bucket.

The procedure described for the circular bucket was repeated using a prismatic V-shaped object, Figure 5.4. Plastic floaters were attached to the prismatic object to set the object on neutral buoyancy. On simulating the plume, mass was added to the prismatic object under neutral buoyancy till it tended to sink into the plume in a similar manner as the circular bucket.

The gas pressure available in the laboratory was varied as 0.5 bar, 1 bar, 2 bar, 3 bar to 4 bar, and the low pressure water leak as, 0.5bar, 1 bar to 1.5 bar. The prismatic object was tested on the highest pressure.

5.3 Result and deduction

Readings were noted as given in Tables 1 and 2:

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Table 1: Readings of tests conducted to balance plume forces on the circular bucket

Circular bucket (Figure 9): Surface area of the bucket on the plume = 1964 cm^2 Maximum water depth of test tank (Figure 12) = 85 cm			
Leaking line delivery pressure (Bar)	**Mass to balance the developed plume forces (kg)**	**Leaking substance**	**Comments**
0.5	0.2	Water	The plume surface flow diameter is within the diameter of the bucket
1	0.3	Water	The plume surface flow diameter is within the diameter of the bucket
1.5	0.6	Water	The plume surface flow diameter is within the diameter of the bucket
1	8	Air	The plume surface flow diameter is within the diameter of the bucket
2	8.9	Air	Bucket is at center of plume. Some emerging plume at water surface is not within the bucket
3	9.6	Air	Bucket is at center of plume. More of the emerging plume at the water surface is not within the diameter of the bucket
4	9.9	Air	Bucket is at center of plume. Most plume volume emerging at the surface is not within the diameter of the bucket

Table 2: Readings of tests conducted to balance plume forces on the prismatic object.

Prismatic object (Figure 10): Surface area of the bucket on the plume = 240 cm^2 Maximum water depth of test tank (Figure 12) = 85 cm			
Leaking line delivery pressure (Bar)	**Mass to balance the developed plume forces (kg)**	**Leaking substance**	**Comments**
4	0.9	Air	Object is at center of plume. Most plume volume emerging at the surface is not within the position of the object

5.4 Key relevant observations

i. The force on the objects depends on the surface area exposed to the plume. For a surface area reduction to about 12% of the circular bucket, equivalent to the prismatic object, the mass to balance the plume force reduces drastically to about 9% of that of the circular bucket.

ii. The more the containment pressure of the exiting fluid, the more the mass is required to balance the plume forces. This is more obvious in the leaking water than the air leak. The reason was because the diameter of the plume formation of the air is somewhat larger than the bucket size resulting in some losses, unlike in the water plume (Table 1).

iii. The gas plume formation produced more force than that of water (compare Table 1 and Table 2). This point seems to show that the forces may be difficult to handle when expandable gases at high pressures are involved.

iv. The forces in the plume appeared to depend on the stages of the plume. During the test with air pressure, some instability was observed as the loaded neutrally buoyant bucket is sinking and approaches the plume bottom (i.e., the jet boundary). The different phases of the plume are shown in Figure 1. This is perhaps because the force drivers at the different plume phases vary. The force within the jet boundary is primarily due to pressure of the exiting fluid and the pressure within the fluid (due to its compressibility). Beyond the jet boundary is the pure plume which is driven by buoyancy, initial momentum from the jet stage and also the compressibility factors. At the surface flow stage, where there are large currents, surface flows and horizontal wave forces, the emerging plume forces is further reduced due to the horizontal shear force effects. *This is a pointer that an actual computation of in-field plume forces may be complex to perform, especially when expanding hot gases are involved.*

v. Of importance is also the “angle of attack” of the plume forces on the circular bucket and V-shaped objects. The plume exit is nearly 90^o to the plane of the plume impact on the circular bucket bottom. The full force of the plume is felt. For the prismatic object, the plane receives the plume impact at 45^0 reducing the “normal” force effect.

vi. Based on the above tests, the proposed means of following exiting plumes to lead a system to inspect leaking pipelines in muddy water is deduced; a structure with a combination of a plume minimal angle of attack, an optimized limited surface area towards the plumes forces and having a controlled buoyancy capable of having an adequate negative weight to position near the underwater initial exit jet plume pressure.

6. DISCUSSIONS ON THE LEAK DETECTOR

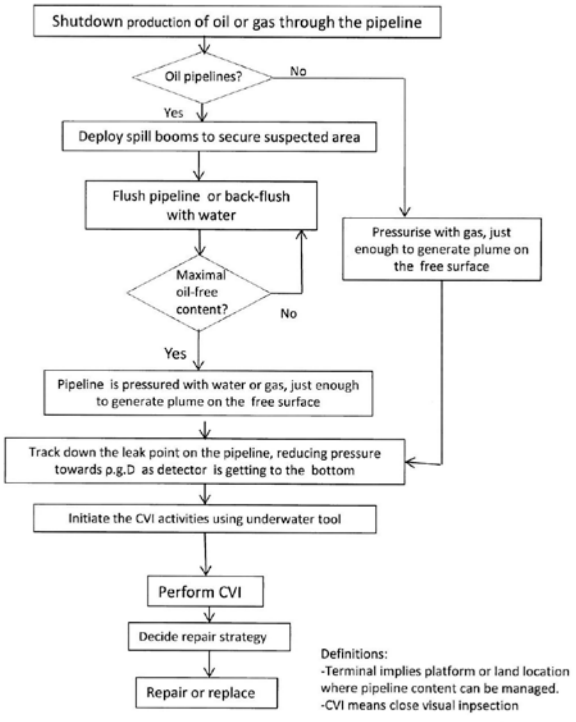
The implication of the unidirectional buoyancy flux of plumes is that plumes can be tracked from the top of the water surface to the bottom, where the leak is taking place. This approach offers enough accuracy and reliability required for any leak point search in muddy water and eventually positioning of a CVI tool for inspection of leaking structures in a muddy water situation.

Two prescriptions are suggested to be important in the use of this system for pipeline leak identification: First, shut-down of production and then the possibly boom off the suspected leak area. Back-flush or flushing with water is required to minimize spills to the environment. Back-flushing is often achieved by batching water from the valve closest to the suspected leaking point, and receiving the content at the terminal. It is characterized by very minimal pressure pumping. At a minimum, water is pumped through the supply of the pipeline and received at the terminal or vice versa. Though it is possible to utilize any plume found in this process for the tracking, the main reason for the flushing activity is to displace most of the oil in the pipeline. In small oil pipelines with large breaks, there could be the possibility of sucking from the terminal end, enabling sea water to ingress the pipeline and the content being released at the terminal, thus minimizing oil that could pollute the environment. This is followed by the application of gas or water in the pipeline at a minimum pressure, just sufficient for plumes to be observed on the free surface in order to identify locations of pipeline leaks from surface to subsurface of the unclear water mass. For instance, such low pressure could be:

ρ.g.D + Pressure loss in the pipeline to the point of leak + < 6 Bar over-pressure to produce a plume on water surface.

Over-pressure of 6 bar represents about 60 meters of water depth. Permanent unclear or muddy water offshore is often found in water depths less than 50 meters.

Once the detector is at location, the over-pressure is taken away and the inspection equipment could be positioned. D is the depth of the pipeline in the water. The procedure suggested is shown in Figure 14



Definitions:
-Terminal implies platform or land location where pipeline content can be managed.
-CVI means close visual inpsection

Figure 14: The procedure for the use of plume detector in oil or gas pipeline leaks

Terminal is a term that symbolizes the reception end of the pipeline content. Shutting down of production means, for instance, that oil pumping through the pipeline is stopped.

7. SOME PROPOSED METHODS OF LEAK IDENTIFICATION, INSPECTION AND REPAIR IN PIPELINES INSTALLED IN MUDDY/UNCLEAR WATER CONDITIONS

This section discusses examples of methods that could be used, together with the identification tool discussed in Section 4 to conduct a close visual examination and perform repair where necessary.

7.1 Pipeline leak Identification, Inspection and Clamping ROV system (IIC)

A diverless technology of identification, close visual inspection and repair of leaking pipelines in unclear/muddy water condition is presently not developed. In the following is given a conceptual description of an underwater pipeline leak identification, inspection and clamping method on a common remotely operated platform (Figures 15 to 17). The configuration of the system could vary depending on the form of the underwater pipeline structure. The common operational characteristic however, is the same.

7.1.1 Description of the method

Referencing Figure 15, the method consists of one or several of an Identification/detection tool (22), an Inspection tool (25) and a repair (e.g. clamping) tool (28). These are mounted or latched (27) to the ROV (21).

The identification tool (22) discussed in Sections 4 and 6 is mounted on an ROV (21) to track the leaking point. The ROV is the vehicle that drives the tool. The identification tool (22) is detecting the plume signal from a broken subsea pipeline system, leading the ROV from the top of the water surface to the sea bottom where the leak (plume) is originating from. The leak identification tool (22) operates by monitoring the plume signal. Installed aligning tools (23 and 26) grab (and align the ROV with the leaking structure. Position (29) is the position during operation to hold on a pipeline and (30) is the un-actuated or free swimming position). Sonars and magnetometers could be used to supplement the alignment process. Then the pipeline steel structure is uncovered by jetting and de-coating methods. The ROV camera (24) is used to guide and steer the ROV (21) where possible. Note that the jetting and de-coating tools are not shown on the Figures.

With the pipeline exposed adequately, the overburden and coating removal system is de-latched and the inspection (25) and repair (28) tools are latched on (27). The inspection tool (25) enables surface engineers to visually perform close inspection on the pipeline's break. The visual tool (25) in unclear water is based on laminar clean water flooding described in [5]. The laminar system (Figure 16) has two cameras installed at 90^o to each other such that a 45^o turn on both sides of the pipeline from vertical enables full visual coverage (360^o of the pipeline). This concept was produced and tested successfully. It is a modification of a known and proven technology. (See the picture in Figure 16). Thereafter a decision could be made on the repair method:

- If mechanical clamps are required to arrest the leak, for instance, the clamping tool (28) installs a subsea clamp.
- For pinhole leaks ≤ 5 mm, a combination of these could also be envisaged where a mold is clamped on the pipeline and thereafter filled with, for example, poly-products at a

certain pressure to ensure tightness. Figure 17 with inner clamp (41), inner seal (43) outer clamp (44) and epoxy fill (40). Here (33) is the leaking pipeline. The force (34) required for clipping and installing the assembly could be generated from flat jacks or any other form of hydraulic or pneumatic system. Clippers are shown as the female clip (35), male clip (36) and the clipped mode (38). The poly substance is reinforced (39) for strength. A hinged type of this description is shown in Figure 17. The advantage of the hinged system over the earlier system is the ease of alignment.

Figure 17 system was made and tested to the maximum of a pressure test pump system of 60 bar without failure. It could take a higher pressure. The hole was 5 mm in 104 mm OD pipeline (Figure 17 picture).

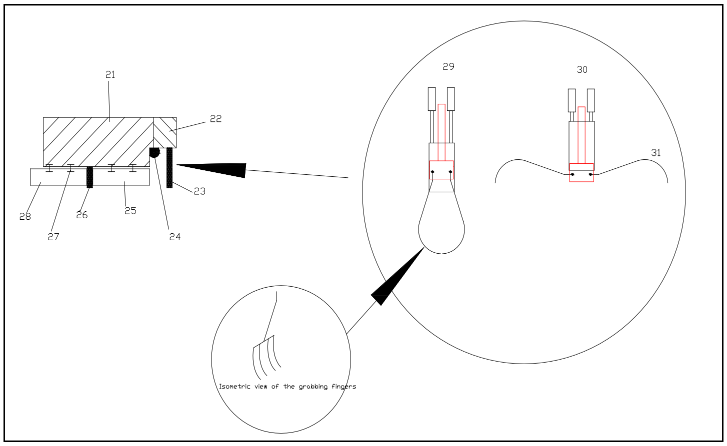


Figure 15: Concept of leak identification, inspection and repair of pipelines in muddy water

The engineering and test details of the leak repair design and methodology is to be given in another literature. The spring-loaded contact of Figure 18 must be positioned to close-up the pinhole prior to epoxy injection.

7.2. Manned detector-led motorized hyperbaric bell for identification, inspection and repair of leaking pipelines installed in unclear water

Use of the state-of-the art hyperbaric systems in muddy or unclear water is challenging due to two reasons:

1. The point of the leak and therefore, the drop-down position of the hyperbaric object is not known.
2. The diver has no visual window to position and operate the hyperbaric object for sealing. The sealing must be installed before initiating a hyperbaric condition in the diver's habitat The habitat is the dry part of a bell when water is displaced

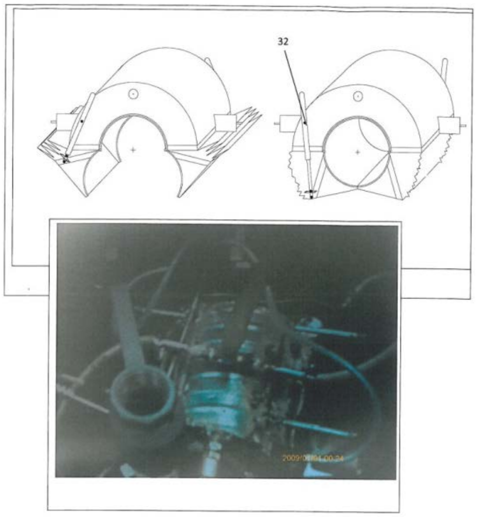


Figure 16: The 360^o CVI system for inspection in muddy water. Picture in Figure 7.2 is the tested version.

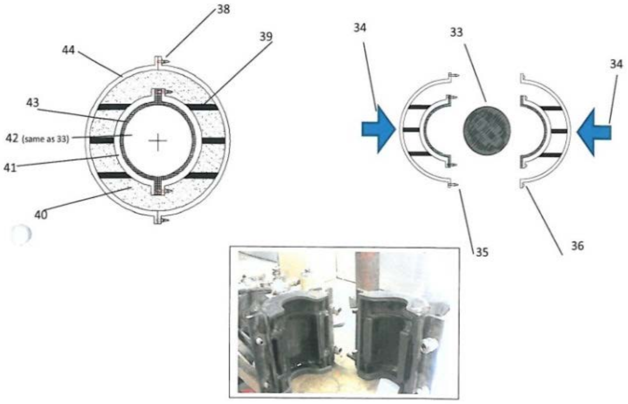


Figure 17: Pin hole leak repair system

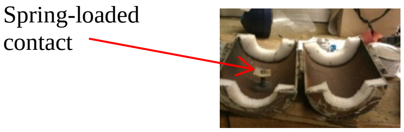


Figure 18: Pinhole leak with spring loaded contact

…..Another proposed method for identification, inspection and repairing leaking pipelines installed in unclear shallow water is using a hyperbaric manned bell. This is *characterized by* the bell being led to the point of the leak using the tool described in Sections 4 and 6 at a safe distance from the exiting plume. The technique enables adequate inspection and proper repair of the pipeline system by divers. The bell is also equipped with an inflatable system to adjust the submerged weight. The inflatable system enables it to operate with correct tension when hung by crane or related equipment; thus, avoiding extra load on pipeline during the inspection and repair process. Details of this method is found in [17]

8. CONCLUSION

This paper has described the development of an underwater optical system for plume identification that maintains a free water surface within itself. The optical system is then able to monitor the free water surface in a similar manner as the plume would be monitored if the optical system were on topside. In laboratory experiments buoyancy flux of liquid and gas were successfully tracked from the top of the water surface to the plume bottom (leaking target).

Repairs performed by divers in unclear water without adequate understanding of the damage, due to poor underwater visibility often results in a leak-repair-leak cycle, causing pollution to the environment. The use of this simple technique is effective in leading full ROVs or manned submarine systems such as motorised or non-motorised bells to the leaking target. Thus, the technique makes adequate provision for proper inspection to be performed, especially by surface engineers/experts for making the best decision on the repair process. One of the benefits of this simple tool is its simplicity in design. It is furthermore, suggested that more work be made in the area of estimating plume forces to adequately improve the plume detector design.

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