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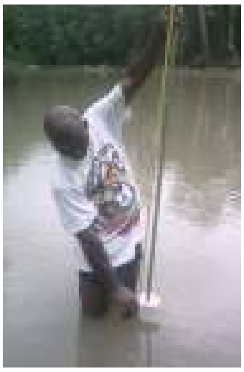
Conception and development of method / apparatus for close-visual inspection of subsea structures in underwater poor visibility condition.



Universitetet i Stavanger

A Thesis submitted to

Department of Mechanical & Structural Engineering and Material Science

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In partial fulfillment of the requirement for the degree of Master of Science

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Acknowledgment

During the selection of the thesis topic, this work presented here was not the first choice. It was Professor Gudmestad O.T., that said to me in his office to reconsider this topic as it may have to be very useful in the future, especially in my part of the continent. Though, I managed to convince him that it may not be possible to handle this within the thesis time frame but the truth was that I was really unsure if I would be able to succeed. When I got home, I knew the professor was right and his last comment was "….even if you do not succeed, that does not mean the thesis is a failure". These words of encouragement from the professor kept me going till the day the equipment was tested in the laboratory. He went beyond limits in assisting in every way, coordinating the activities of the project during the fabrication in Nigeria to the modifications in Norway and provision of literatures and laboratory for the test. Without him, simply put, this work would not have been successful.

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The concrete laboratory Chief Engineer, John, and his colleagues where all available, ready to assist with materials and tools needed in the laboratory. They were always there to find out the progress of the test and what help they could render.

After being away for over a year, I returned home to my family in Warri, Nigeria on 28th of december, 2009. My kids, Favor (7+) and Lionel (2+), and wife were always patient to permit me to use part of the meager time (I suppose to spend with them) for the fabrication of the work in Warri and provision of the electronics parts in Lagos.

My gratitude also goes to my former boss, the Principal Project Engineer of SHELL Warri Nigeria, Engr. Igbinaduwa Emmanuel for all his advice and encouragement.

It would be difficult not to mention some of my good friends and colleaques who have been helpful during my studies, Francis Adedgege, Minli Gu, Adebayo Gbenga and Edwin Chuks.

I am very thankful.

Abstract

Attempt has been made to demonstrate that in unclear water to zero underwater visibility conditions, where ordinarily, underwater divers would be unable to observe objects, it is easily possible to perform inspections and observations adequately and reliably for underwater structures, especially leaking subsea pipelines by simply supplying clean stream-lined steady (laminar) flow of water which displaces the unclear water and flows over the surface of the structure to be observed. A camera eye is then placed to observe through the steady flowing clean water and transmit details to the topside engineers via personal computers.

Different configuration of the equipment was checked and it was found that the equipment with fitted check valves and on/off valve installed in the flooding box in-line with the flowing clean water produced the best result. Also, where 'over-pressure' is defined as the difference between the supply clean water pressure from topside and the sea water column pressure (head), best results were found at over-pressure less than 1-psig.

The volume of water required for the observations appears constantly independent of depth of water except during the first initial stage of flooding. On the other hand, period of time required for clear observations increases with increase in water depth. The performance of the equipment was found independent of nature and degree of underwater visibility.

The benefits of this work has been discussed, ranging from leaking structures' close-visual inspection including pipelines, to subsea pipeline field joint wrap damage inspection for beach pulls. It has also been pointed out that this technique is cheap, robust and flexible.

However, further work is still required to adequately establish the theory and extend the design of the equipment to operate remotely and diverless.

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Abreviations and nomenclature

POSVEM	Pipeline oil spill volume estimation model
g	Earth gravity [m/s^2]
ρ	density [kg/m^2]
fsw	Feet of salt water
clarity	The clearness of the water medium
clearity	The clearness of the observation or photography
psig	pounds per square inch gauge pressure
barg	bar gauge pressure

1.0 Introduction

1.1 Background of the thesis

In the marine/offshore industry, maintenance and in most cases, statutory requirements demand that underwater structures be inspected to guarantee the integrity. On other occasions, inspection is necessary to determine the extent of damage in order to select the most technical and cost effective means of the repair. This is often the case for pipeline leaks and field joint wrap damages.

Muddy/unclear water is a definition given in this work for a description of water, be it river, ocean, sea or lake, where the ability to see through or within is impaired. The result is that close observations or inspections of items existing below the water surface becomes difficult and in some cases, impossible. Maritime geography uses the term brown water environment for the littoral areas, from the coast and estuarial areas to perhaps a hundred miles from shore. Though the water is not necessarily brown, sometimes muddy, generally however, the color would depend on the sediment it is carrying. These sediments include sand, clay, or organic particles stirred up from the bottom, washed in from the shoreline, washed in from the surrounding land, or brought in by the wind and rain. These particulates absorb and scatter sunlight as the light passes through them, poor visibility or unclear water results.

The geography and topographical make up of certain regions of the world most often facilitate this phenomenon. For instance, in Nigeria in West Africa (see figure-1.4), the topography channels runoffs via rivers to common targets, made of loosely sediments and with the coastal areas and delta underlain by soft geologically young loosely sediments, rainfalls then sweep the whole large area of the region, coupled with regular tides that wash the coast-lines, and deposit the contents to the coastal waters. The consequence is that the littoral area, from swamps to the coast and in some instance, some miles from shore is characterized by 'unclear water'.

Other contributors include dissolved organic substances or compounds that can come from many types of terrestrial and aquatic plants (water phytoplankton (greenish color)), humic stain (tea color from decaying leaves or plants) or some combination of these), and can color the water reddish or brown, sometimes even to the point of appearing black. The classification also includes the brackish water.

The team involved in the sampling of water transparency or clarity with a measuring disc called the Secchi disc in the Mediterranean Sea and lakes round the world often use the term water clarity (i.e. how unclear the water is).

Figure-1.1 indicates an improvised type of Secchi measuring disc used for clarity measurement of one of the flowing rivers in the Niger Delta of Nigeria. As at the time of measurement, the clarity depth is about 30cm (12"). The clarity depth is a measurement of how deep one can see when his eyeball is just on top of the water.

The picture was taken at the peak of dry season (January) and the river is over a hundred kilometer away from the coast of Atlantic, so that effect of rainfall sweeping and tides washing into the river is small. The 30cm clarity obtained at this season points to the degradation that would happen in other rainy conditions. The dry season is between November and mid March in the Niger Delta area of Nigeria. By dry season, one means, minimal rainfall within the year.

Figures 1.2 and 1.3 show similar measurement in a swamp in same region. The depth of clarity was found to be only 7.5cm (3”). The diver in this kind of water sees black. Absolutely zero visibility.

Figure-1.1 showing a flowing Ekpan river in Effurun,
Delta State of Nigerian Niger Delta area
(Picture taken January-2010, peak of dry season).

Figure-1.2 Attempting to view a clarity measuring disc in
Edjeba swamp in Warri, Delta State of Nigerian
Niger Delta area.
(Picture taken January-2010, peak of dry season).

Figure-1.3 showing clarity gauging of Edjeba swamp in Warri, Delta State of Nigerian Niger Delta area. (Picture taken January-2010, peak of dry season).

In the Underwater diving industry, the brown, unclear or muddy water, etc, is often the characteristics of underwater poor visibility whereby the inspection diver underwater is denied adequate visual access to structures and equipment positioned below the surface of the water. We will in this work use the term 'muddy/unclear water' to refer to 'water or sea' characterized by underwater poor visibility.

Unfortunately, pipelines from oil and gas fields run through these areas – swamps, deltas, littoral zones and some miles from shore towards offshore, and often, underwater inspection and repairs are required to be carried out. The present technology does not address the problems of observing leaking problems clearly by surface engineers, i.e. leaking from structures such as pipelines, independent of water clarity.

For Pipeline leak repairs for instance, the pipeline engineers often depend solely on the diver for the technical descriptions of the leak underwater. The engineers have no opportunity to see the condition via underwater videos surface due to underwater visibility challenges.

Unfortunately, even in today's modern technology, in this poor visibility condition, the diver obtains information by mere feelings by hand. This subjective information has been a source of various improper pipeline repair operations and inspection works as the information from the diver forms the basis of planning, costing and operations and provides no room for verification by pipeline engineers. The unfortunate consequence might be continued leakages and then another production shutdown and again, another repair.

Most often, these leaking pipelines are aged pipelines that stand the chance of bursting when hole/leak detection pigs are run from one end of the line to the other. The internal corrosion often result to use of pressure higher than operating condition, the pipeline bursting may be inevitable, complicating the problem.

In 2003 for instance, in Batan oil field of Niger Delta in Nigeria (West Africa), a diving company was contracted to inspect and repair a leaking oil line. The pipeline engineers had doubt on the dive report from the first diver. A second diver came up with a different description from the first. An expatriate inspection diver had to make a dive, and combined with past reports of the history of the pipeline, it was discovered that the leak was from an existing clamped leak. The repair then was done by removing the old clamp and replacing with new one. This operation lasted several days longer than necessary (Anon., 2003).

The inability of the pipeline engineers to observe the condition makes the engineers vulnerable to errors, misleads and use of costly approaches for solving a little problem. Pipeline repair clamps are designed for large variety of dimensions. This implies that subsea clamp selection and determination which is dependent on hole-leak configuration is always at the mercy of assumptions of more lengthy crack than necessary.

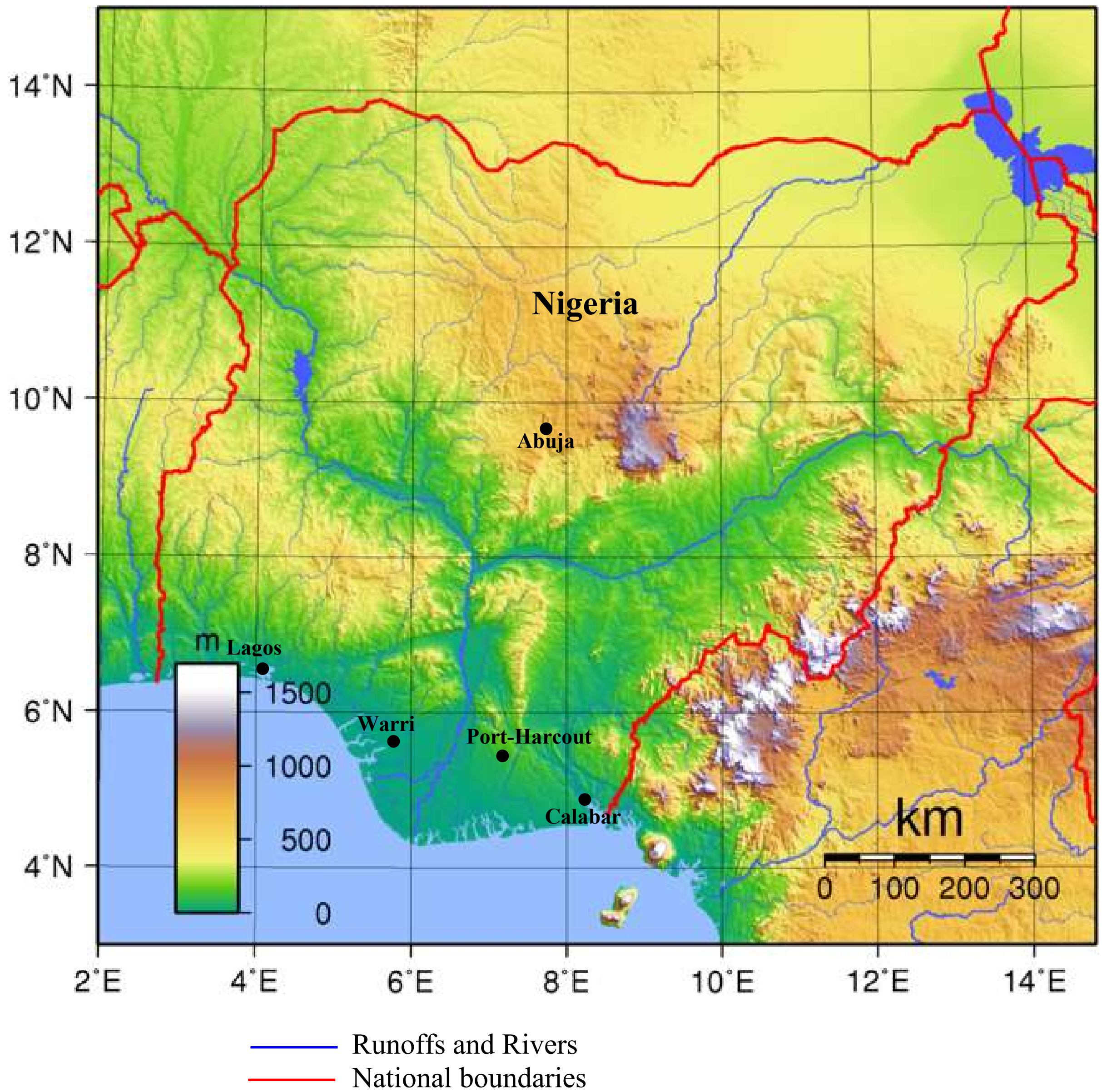

Figure-1.4: The Topography of Nigeria, West Africa showing channel runoffs via rivers to common targets and coastal areas and delta. (Source:http://www.google.com/imgres?imgurl=http://upload.wikimedia.org/wikipedia/commons/d/d9/Nigeria_Topography.png&imgrefurl=http://commons.wikimedia.org/wiki/File:Nigeria_Topography.png).

The key essence of this work is to provide an alternative method and consequently an apparatus that would enable underwater structures under conditions of limited underwater visibility to be observed rather than use of hand feelings/touch that create opportunity for errors that are often costly and that may result in further pollution when the pipeline is put in operations again.

1.2 Underwater poor visibility in the inspection industry.

Charlotte van Weeghel of Dive Global (2007) talks to Larry Goldberg about his career in commercial diving, his many travels, his ups and down in the industry and current projects. He has this to say: ‘My last commercial dive was a memorable one. I was doing an inspection job on a big oil rig. They suspected some cracks. You have to understand that to shut down an operation like that to fix a crack in a dry dock can cost anything from 2 - 5 or 10 million dollars. That's a big responsibility. One of the guys that was working with me said there were two cracks. When I went down to evaluate and sign off on them, the visibility was only a foot. I thought I saw the crack but couldn't see very well. I was 99% sure but I signed off on it crossing my fingers. The crack was there. It took them 40 days to fix it. Phew!’. Larry Goldberg is the Managing director of Sea Test Services, Paramus, USA.

Patrick Conroy, the inspection project manager from Collins Engineers Inc. of Holland, has 20 years of experience as a dive engineer. According to the publication in St. Ignace news (2007), he claimed that many of the bridge inspection projects the engineers perform are in rivers with fast moving, muddy water with limited visibility and that most of the inspections were done by feel, with murky water obstructing visibility. "I've done dives where, in a river six feet deep, it is full of silt and there is no visibility," agreed diver Brian Dillworth who has also long years of experience in inspection diving. "Instead of looking at it, you feel the bridge”. (The St. Ignace News, 2007)

Phil Richards, the director of Commercial and Specialised Diving Services in Bournemouth, Doret, has this to say about visibility problems and Remote Operated Vehicles, ROVs: ‘However good you are at working with ROVs, they are not good for inspection in limited visibility conditions. In those cases, a working diver has to carry out the inspection by touch’ (Professional Engineering, 2004).

The above experiences point to the fact that feeling and touching remains an important assessment method in poor visibility condition. This work targets to answer the question of what could happen where damages are suspected or alerted and there is then need to have a closer and clearer look at the problem before taking an engineering decision. A method and apparatus for close observations in these conditions would be a time saving and certainty verification tool.

1.3 Existing modern technology for observations in muddy/unclear water.

Perhaps, the most modern existing technology for clearer observations in unclear water is of Sea-Viewer's Sea-Clear product. The Sea-clear™ DVIS is a revolution in video editing. The spectral clarification is done in real-time in a live video stream. And you can also use it on stored material - just play back the stored video feed through the Sea-Clear while re-viewing or re-recording. The Sea-Clear™ is specifically recommended to improve the clarity from a Sea-Viewer color Sea-Drop or Offshore underwater video camera. Or also use it to enhance a prior video recording that you had made from a color Sea-Viewer Camera in the past. But without question, the Sea-Clear will clarify most any composite video feed, live or recorded, to show you better definition. And incredibly, the clarification works its absolute best on color video. (Sea Viewer Underwater Video System, 2007).

The Sea-Clear™ is easy to use. Connect it in-between your Sea-Viewer camera and the monitor, TV set or VCR and you are up and running. With controls for clarification level, and size and position of the rectangular selection on the screen, you can always better catch your subject on video, and see it clearer (Sea Viewer Underwater Video System, 2007).

Figure-1.5 is a typical effect of the use of The Sea-Clear product in unclear water.

Figure-1.5 Typical Effects in the use of Sea Clear product in observations in unclear water.

Efforts were made to contact the Sea-Viewer technical centre on 14th of December, 2009 about the product performance. The response: '..the equipment shall see as much as possible but the visibility cannot be compared to when the video is made in clear water. There is no guarantee. It is possible to see nothing if the water clarity is very limited'.

The above definitions of this product and figure-1.5 indicate that, the capability is entirely relative. It has not been known if this equipment has been used for close-visual inspection of underwater structures in muddy/unclear water.

1.4 Benefit of the work.

Cost effective planning and work executions: The success of the apparatus developed in this work will enable surface engineers who are responsible for planning, organizing and mobilizing for underwater structural inspection and repair work to have a clear and real-time understanding of problems subsea. The consequent of this is that the job is adequately planned for. The right materials and equipment are mobilized without guess work.

Ability of the surface engineers to see clearly the underwater facility of interest, independent of nature or source of the unclarity: The Sea-Clear™ invention offers an improvement limited to the water clarity. There is no guarantee. It is possible to see nothing if the water clarity is very limited. This work will deal with the requirement of seeing clearly independent of water clarity.

Today's technology for close observations of structures in unclear water, even with its inadequacies, is still sophisticated, equipment demanding and relatively costly to operate: The focus of this work is to develop new innovation that is robust. The cost of fabrication is hoped to be a minute of the cost of the existing technology using common materials without much engineering complexities.

The improvement of the visibility by spectra clarification by today's technology does not handle larger scaterrers and water unclarity due to the effect of biochemical composition: The method that will be focused in this work is to develop a new innovation that does not see the differences and sources of unclarity.

1.5 Aim of the Work

The objective of this work is to challenge the underwater poor visibility problems in the subsea inspection work. The aim is to explore new approaches to conceive and develop simple, cheap but robust technique to aid surface engineers to observe leaking problems, for instance from structures, clearly and independent of the water clarity.

1.6 Scope of the Work

The scope will be limited to conception of the approach of using a laminar undisturbed steady flow over a surface to mimic a transparent column over that surface. The laminar flow will be under a little over-pressure to enable the steady flow to displace the unclear water from the surface to be observed.

This approach implies that the apparatus configuration could vary depending on the shape and form of the structure to be observed. The common operational characteristic however, will be the same: The flooding of a laminar undisturbed steady flow through an open-bottom system for which the open end encloses on the surface of the part of the structures to be observed, be they pipelines, anodes etc.

Attempts would be made to conceive and develop a description of a technique for close-visual inspection of Sub-sea Pipelines Leak. The idea is that if this works for pipeline leak observations, then the approach could be extended to other structures with different configuration characteristics. This is hoped to be a strategy to the achievement of the objective of this work.

The primary scope will therefore involve the following:

- Conception, design and fabrication of a flow system to deliver laminar undisturbed steady flow of clear water over a surface to be observed.
- Installation of video, photographic and illumination accessories in the design to enable supply of illumination to the location of interest on the structure to be observed and transmit the observations via cabling system to computers surface. This will enable the surface engineers to make observations of their interests.
- Run a Simulation to verify effect of different parameters involved in the test. Provision of laminar flow at all operational conditions is essential.

- Efforts will be concentrated on verifying the conditions underwater by the diver fixing the instrument on the pipeline while the pipeline engineer observes the condition from surface. It is possible to remote control this devise to eliminate the use of diver but that will be beyond the scope of this work for now.

Less attention will be paid to the investigation/analysis of causes and quantification of poor visibility underwater or water unclarity, as the proposed concept will produce clear and visible picture independent of the source and level of poor visibility underwater.

Additionally, we will attempt to investigate the traceability of location of damages following bubbles from the leaking structure, considering the different parameters involved.

2.0 Documentary review

2.1 Documentary review on method of close visual inspection in underwater poor visibility condition.

According to the work of Ronald et al., (2003), diver visibility depends on the photopic beam attenuation coefficient, which is the attenuation of the natural light spectrum convolved with the spectral responsivity of the human eye (photopic response function). Their work also confirms that the visibility is equal to 4.8 divided by the photopic beam attenuation coefficient:

$$\frac{4.8}{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{Eqn.2.1}$$

The equation 2.1 implies that the more the beam attenuation value, the less the visibility.

Equation 2.1 was originally derived by Davies-Colley (1988) being accurate with an average error of less than 10% in a wide variety of coastal and inland waters and for a wide variety of viewing conditions. The work of Ronald et al., (2003) demonstrated that this is well grounded in theory, and is extremely useful to provide divers with a general sense of underwater visibility conditions. However, equation 2.1 does not relate to the observer's position reference to the object.

A fundamental law of visibility as derived by Duntley (1963), Jerlov (1976), and Preisendorfer (1976), is that the difference of the target and background radiances at a given wavelength attenuates as:

e^{-cr}……………Eqn.2.2

where:

c is the beam attenuation coefficient at that wavelength, and
r is the range from the observer to the target

With reference to muddy/unclear water, the beam attenuation coefficient describes light losses due to absorption by dissolved substances, materials and particles and due to scattering by particles.

Ronald et al., (2003) also noted that for looking vertically down, we get the well known Secchi depth dependence:

$c + K$ ……………... Eqn.2.3

Secchi is a measure of water clarity.
K is the secchi depth dependence factor.

Though we refer in this work to visibility underwater which could be horizontal, angular or even vertical observation with the diver in the water, Secchi has strong relationship with underwater visibility vertically.

This work is being carried out based on this fundamental knowledge that attenuation of light due to particles and dissolved substances in the water is wholly responsible for the underwater poor visibility.

Gilbert and Pernicka (1967) worked on improvement of underwater visibility by reduction of Backscatter with a circular polarization technique. Peter et al., (2003) put that most previous research in this area has concentrated on the active illumination of objects with polarized light, and worked on the use of passive or ambient illumination to achieve visibility improvement. Though Peter et al., (2003) claimed an improvement of the underwater visibility, but not for larger scatterers. Their work does not also consider the effect of biochemical composition in the water. Again, for pipeline leak and close visual inspections, not just an improvement is desired, but a clear picture to pinpoint and observe technical deviations.

In the oil and gas industry today, there is no dedicated equipment for leak/damage/crack close visual inspection and observation for underwater structures in zero visibility condition. Even though the Sea-Clear video editing technology discussed in section 1.3 has not been known for use in this category of inspection, it is understandable from the product description that it will be unable to be used at most poor visibility conditions.

The first attempt to use clear water technique in close visual inspection was a clear water displacement column system designed by Almond J. at al., (1977). A poor light transmission with visibility less than 4" prevented visual inspection of repaired corroded concrete bottom of a stilling basin of Webbers Falls Dam in Sallisaw, Oklahoma. For this particular case, visibility was zero even with diving light.

The Almon J. et al., (1977) design utilized an underwater camera, with a corrected lens mounted on a pyramidal frame as shown in figure 2.1.

The pyramidal frame is enclosed on the sides with ¼" plastic and a flexible membrane of nylon across the bottom to act as a terrain diaphragm to accommodate contour changes up to 6". The column was then filled with clear water and pressurized with a hose connection from the water source to displace the turbid river at the object plane. Photographs are taken through the clear water column using strobe or flood lights mounted on the side of the displacement pyramidal housing. (Almon J. et al., 1977).

The photographic pictures from the work of Almon J. et al., (1977) were reportedly clear even in zero-visibility muddy waters of the Arkansas River.

Prior to the use of the equipment of Almon J. et al., (1977), a detailed sonic precision depth finder was conducted resulting in an accurate bottom profile determination. This ensured that the position to be repaired and inspected was 100% known. The equipment then was rigged up and lowered by lifting equipment to the known position of the bottom plate to be inspected and then the water column was allowed to settle calm before photography was taken.

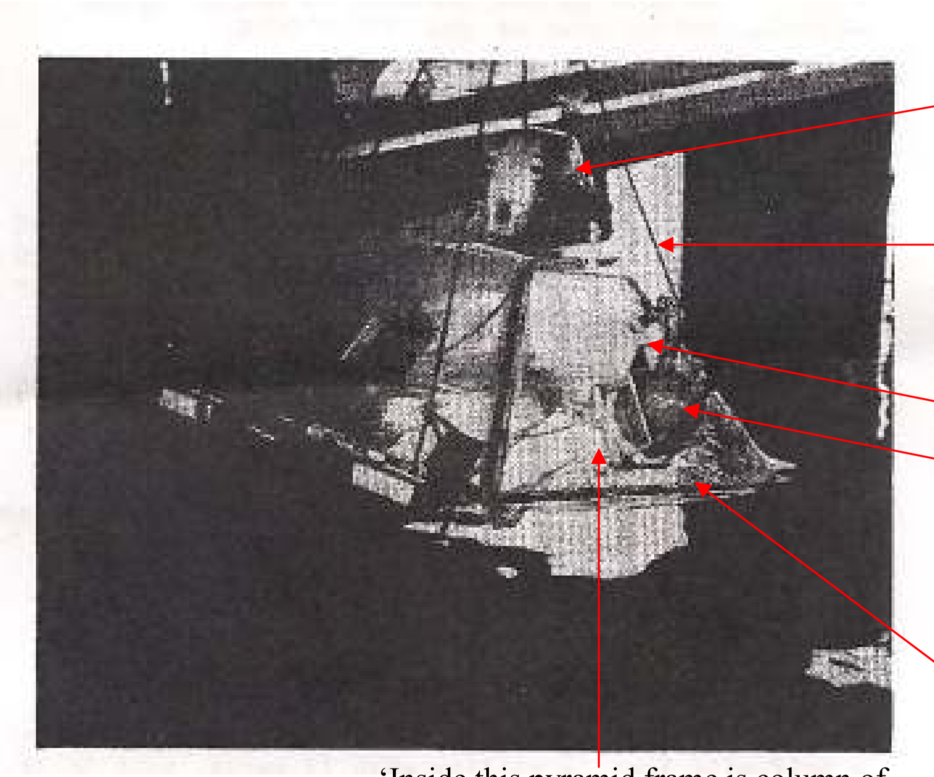

Figure- 2.1 showing the picture of the design work of Almon J. et al. (Source: Almon J. et al., (1977))

The equipment is huge (with bottom base of 9-sq.ft) and mobility would require the use of lifting equipment. The equipment is not handy and would not be usable for cases of non-plate leaking structures such as pipelines etc. The design is restricted to plates with case of known suspected locations as trailing this massive equipment on a structure, even on a plate to identify technical deviation would prove technically cumbersome. For cases of large scatterers and chemical substances, use of this equipment will be very limited. The chemical substances are mixable and would not be easily displaced out of the flexible membrane. Large scatterers such as lumps and vegetations would be incapable of filtering out from the flexible membrane no matter the amount of pressure applied.

Our alternative proposition in this work targets to conceive and develop simple, handy, affordable but robust system for close visual inspection of leaking structures. Two methods are proposed:

a). Instead of the use of water columns as in the case of Almon J. et al., (1977), it is possible to achieve the above target by developing and maintaining steady laminar flow of clear water over a structure and placing a digital video camera over the laminar flow stream. The laminar flow stream could be as small as can be desired depending on the configuration of the object to be observed. The steady laminar flow simply becomes a transparent layer through which the camera sees.

b). Another strategy is to utilize the infrared capabilities in combination with telescope as used by Infrared astronomers in 1960s, allowing studies of the dust-obscured core of the Milky Way Galaxy and the hearts of star-forming regions and has led to many discoveries including brown dwarf candidates and disks of matter around certain stars. (Rieke G.H., 2009)

However it has been known that atmospheric water vapour absorbs many infrared wavelengths, and so observations were carried out with telescopes sited on high mountaintops and from airborne and space-based observatories. This could be the challenge in the use of proposal (b). Efforts therefore would be concentrated in developing the proposal (a).

2.2 Documentary review of plumes and surface spills from pipelines.

In this section, an attempt is made to review the descriptions and methods of measuring the oil/gas underwater plumes and surface spills that often occur as a consequence of failure or otherwise rupture of underwater pipelines.

Reed et al., (2006) proposed a pipeline oil spill volume estimation model for estimation of eventual volume of the oil spill which may be released during an incident. The inputs of the model include parameters describing the pipeline configuration, fluid properties and leak or break from which the discharge occurs. The key output on the other hand are the evolution of the release rate over time, the mass of oil released and the mean thickness of any of the eventual surface slick being formed.

The software used by the Reed et al., (2006) is modularized into two: The release module which consists of the fluid property module and the dynamic flow simulation model for the transient flow calculations. The other module is the Near-field module which also consists of oil and gas plume simulation model and a surfacing module. The work of Reed et al., (2006) was intended to develop plume simulation model that could be applicable to both 'deepwater' and non-deepwater. They tried to achieve this by further improving the work of Johansen (2000) by including the effect of cross currents and ambient stratification, non-ideal gas behavior and dissolution of gas and hydrate formation. The surfacing models deals with simulating formation of surface slicks from oil drops escaping from the plume.

It is interesting to observe from Reed et al., (2006) that for shallow to moderate depth of water, the gas is considered as ideal gas with specific volume decreasing linearly with pressure. However, at great depths, the gas could no longer be presumed to behave as ideal gas and a pressure and temperature dependent compressibility factor (z-factor) must be introduced in the pressure-volume relationship. This then means that the specific volume of the discharged gas will be less than specified. Also at 'deepwater' or great depth according to Reed et al., (2006), the fraction of gas dissolved into the ambient water and oil will increase. There will then be a considerable reduction in buoyancy flux. The buoyancy flux is the field of exhaust of the flume upward from the source of leak. Reed et al., (2006) suggested that natural gas tends to form hydrates at elevated pressures and low temperature and if this occurs, the buoyancy flux will varnish and the small buoyancy caused by gas hydrates and oil will drive the rise of the plume.

A reduction in buoyancy will make the plume sensitive to cross-currents and density stratification in the water masses. In some cases, a stable density gradient in the ambient water could cause trapping of the plume. However, oil may finally arrive at the sea surface due to the buoyancy of individual oil droplets. The surface spreading of the oil will then depend on the size distribution of oil droplets and the strength and variability of the ambient current. (Reed et al., 2006).

Note, however, that in shallow water to moderate depth, the surface spreading of the oil will be governed by the radial outflow of water entrained by the rising gas bubble plume. In deep water where plume trapping has eased off, the plume then reaches the surface and the entrained water will be forced into a radial flow and bring with it the dispersed oil droplets. Plumes can also be trapped at intermediate water, between seabed and sea surface and the oil droplet will rise with their terminal velocity as discussed above. In the rise time, the droplets are moved horizontally by the ambient current which may vary with depth and time. The estimate of the droplet size distribution depends on the density, exit diameter d_o and the interfacial tension.(Reed et al., 2006).

The expected outputs of the plume model include detailed description of the plume geometry and composition in addition to a summary of the results from the plume simulation. The output from the surfacing model includes a detailed description of the development of the surface slick with time, in addition to a summary of the main results in terms of the amount of oil surfaced and the average oil film thickness as a function of time.

The release module produces a time-dependent flow rates of oil and gas. The plume model simulates this time dependent discharge in terms of a series of discharge, each with fixed discharge rates corresponding to the mean discharge rates in the respective time interval. As shown in figure 2.2, high initial discharge rate of oil and gas cause the plume to surface. Subsequently, the plume is trapped by the density stratification in the water masses due to a continuous reduction in the discharge rates.

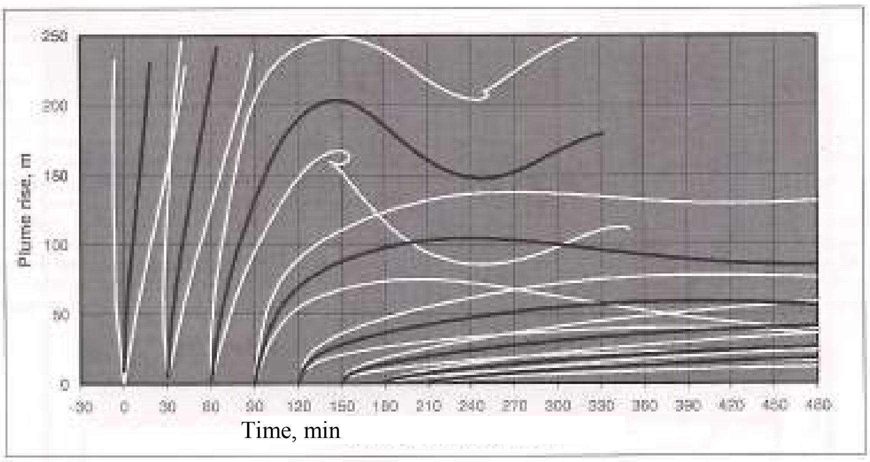

Figure 2.2: Example of plume trajectories computed for a time dependent discharge of oil and gas. Solid lines represent plume centerlines, while white lines indicate the width of the plumes. The discharge is represented by distinct plumes simulated each half hour. Each trajectory is shifted 30m downstream to make the result more readable (Source: Reed et al., 2006. p7)

At the inception of the leak, the release rate project almost vertically to the surface. As time passes, the release rate is slowed due to loss of pressure, and the current speed sweep the trajectory downstream as shown in figure 2.2. The oil surface slick formation that occurs as a consequence of the leak is shown in figure 2.3.

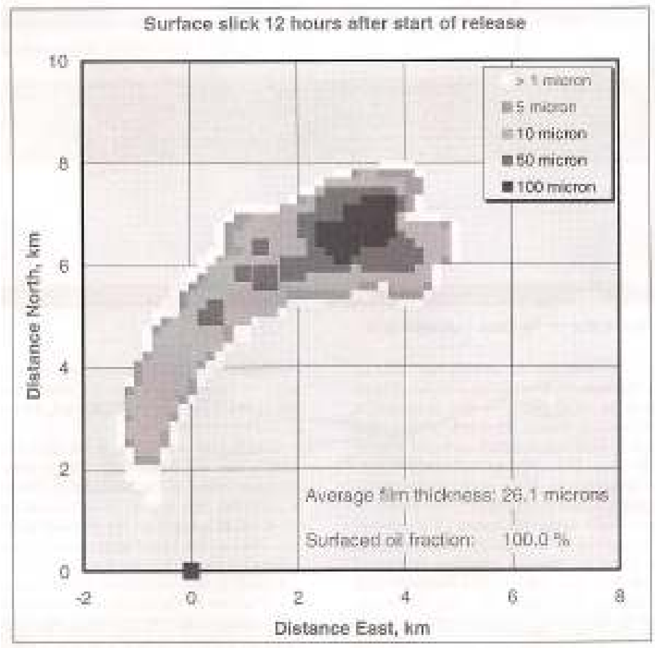

Figure-2.3: Example of surface slick formed from a time dependent discharge of oil and gas lasting for 9-hours. (Source: Reed et al., 2006. p7)

Though Reed et al., (2006) claimed that the near-field model has been tested against full-scale field experimentation data and performed well in those situations, the testing of the Pipeline Oil Spill Volume Estimation Model (POSVEM) software (developed in the work of Reed et al., (2006)) on six spill events and comparing results from reports of the Mineral Management Service (MMS) showed much discrepancy. Though, the discrepancies were claimed to be due to lack of some important input data, the reliability of the model may not be proven till real spill events simulation could prove so. Their work also made different considerations between shallow to intermediate water and deepwater. It appears that the deepwater definition could be a function of the rate of discharge rather than depth definition as given by Reed et al., (2006).

Till the date of publication of their work, Rye & Brandvik (1996) believed that existing models for simulating subsurface oil spill have been difficult to verify against offshore field data due to natural reasons. Their work was then concentrated on comparing a computer model deduced from a combination of Koh & Fan (1970) and Fanneløp & Sjøen (1980) models with the results of two field trials on subsurface releases.

According to Rye & Brandvik (1996) the use of the two models is important because they cover different aspects which are together necessary to produce a realistic model. The Fanneløp & Sjøen (1980) model deals with expanding gas present in a plume, description of the resulting surface flow and thickness of the oil slick produced by the underwater plume. On the other hand, Koh & Fan (1970) include an arbitrary stratification of the recipient water and the orientation of the opening. Common to both models, however, is that they stimulate the mixing of a subsurface jet based on the principle of conservation of mass, momentum and buoyancy.

Rye & Brandvik (1996) noted that a general feature of an underwater blowout is that oil and gas under large pressure are released and 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 will be the content of the gaseous components. It assumes a constant GOR (gas-oil ratio, Sm^3/Sm^3) throughout the water column, although some evaporation of the most volatile components must be expected during the rising of the underwater plume. In the model an adiabatic expansion of the gaseous components is assumed until the water and gas temperatures are equal. From that point on, the gas temperature is assumed to be equal to the water temperature.

Figure-2.4 shows the features of the underwater plume as outlined in the work of Fanneløp & Sjøen (1980).

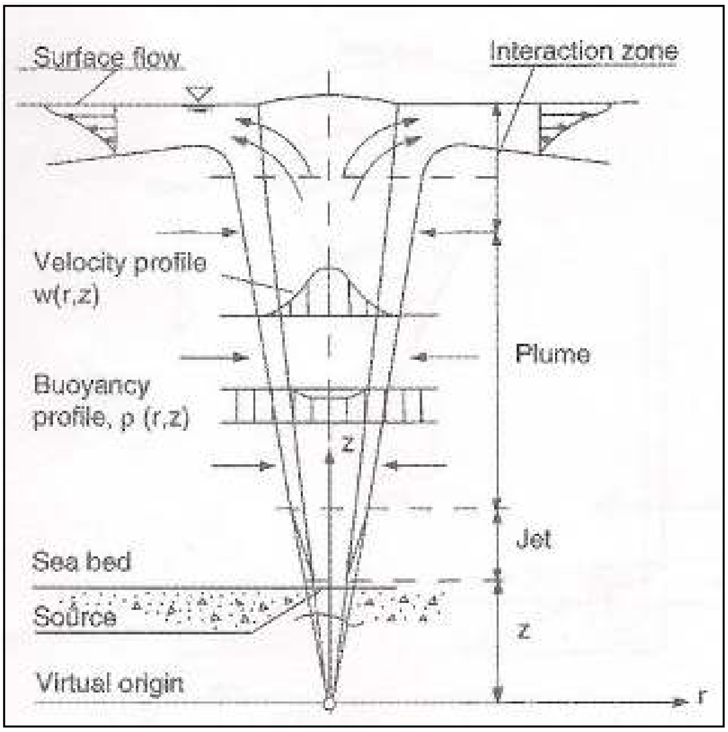

Figure-2.4 showing the features of underwater plume (Source: of Fanneløp & Sjøen 1980).

The introduction of gas in the plume influences the buoyancy of the plume. The stratification in the water masses tends therefore to suppress the buoyancy, but generally the gas lift dominates the buoyancy. The water that is mixed into the plume is taken care of by the entrainment coefficient assumed to be proportional to the velocity and the contact area between the plume and the surrounding water. (Rye & Brandvik 1996)

Rye & Brandvik (1996) proposed that the simulation of the subsurface plume could therefore be assumed to consist of three different stages:

1. The subsurface plume is initially driven by the initial momentum of the release close to the release outlet opening.
2. At some distance from the release, the plume is expected to be driven by the buoyancy of the oil (and gas) droplets within the plume. Thus the plume consists of seawater entrained into the plume, as well as the (buoyant) oil (and gas) droplets in the plume.
3. Because of the stratification of the water masses the entrained sea-water would then be expected to be trapped below the warmer and less salty water masses closer to the surface. For the case

of oil only in the plume, when the velocity of the vertical motion of the plume drops below the rising velocity of the oil droplets, the droplets will tend to leave the subsurface plume. From that point on, the "plume" is expected to consist of oil droplets rising through the (undisturbed) water column on an individual basis.

The model used by Rye & Brandvik (1996) to simulate the behavior of the subsurface plume was designed accordingly. In order to include the rising time of the individual droplets (third stage), the rising velocity of the oil droplets was applied after the subsurface plume momentum had faded out. In addition, the horizontal motion of the oil droplets due to the currents was accounted for so that one could calculate the expected location of arrival of the oil at the sea surface.

The work of Rye & Brandvik (1996) revealed interesting results. The width of the plume that was calculated and observed during the field trials in 1995 (the oil plume) is shown in Figure 2.5.

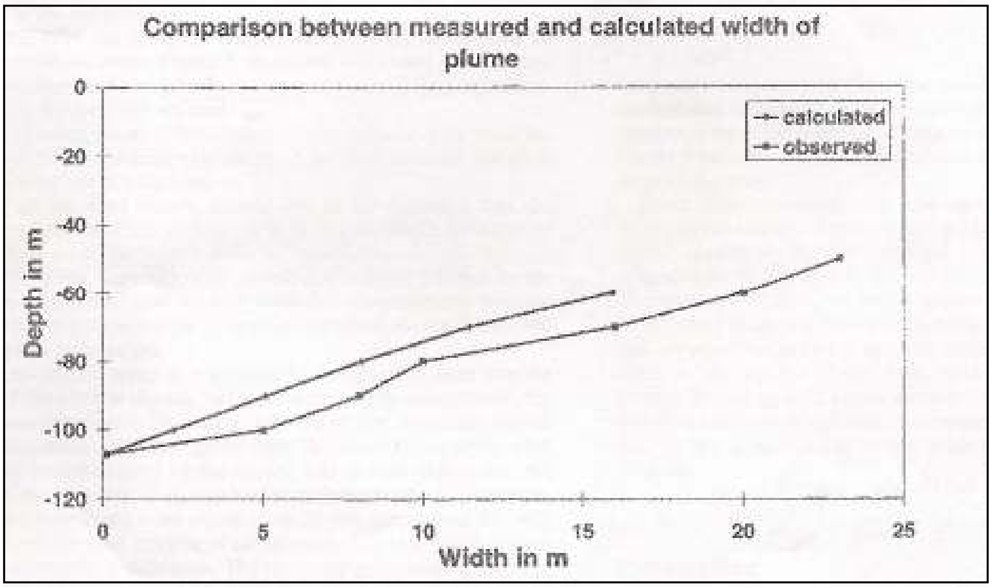

Figure- 2.5 showing the calculated and observed width (diameter) of the ascending plume up to the order of 50m below the sea surface, 1995 sea trial. (Source: Rye & Brandvik 1996)

The calculated width is somewhat smaller than the observed one. Rye & Brandvik (1996) explained the reason as the due to the vertical motion of the release arrangement, which caused some extra initial mixing that is not accounted for by the model.

The width was not calculated for depths shallower than 50 m. The reason for this is the calculated trapping of the underwater plume below 50- to 60-m depth above which, the oil droplets are assumed to rise on an individual basis. Rye & Brandvik (1996) explained that the width of the underwater plume beyond this stage will probably be influenced by the drop size distribution, that is, the smaller droplets are expected to rise more slowly than the larger ones. The smaller droplets are therefore expected to stay in the water column over a longer time span, and thus, are carried away with the currents to a greater extent than the larger droplets. According to Rye & Brandvik (1996), their model was not able to account for this effect, as it uses only one single rise velocity of the oil droplets (for each run).

Fannelop and Sjoen (1980) also calculate the radial outflow of the plume generated at the surface for oil and gas plumes. When the velocities become larger than the current velocities in the recipient, the natural mixing processes in the recipient will tend to dominate. The mixing generated by the plume will then cease to occur. This is because the plume is swept away as quickly as possible by the recipient.

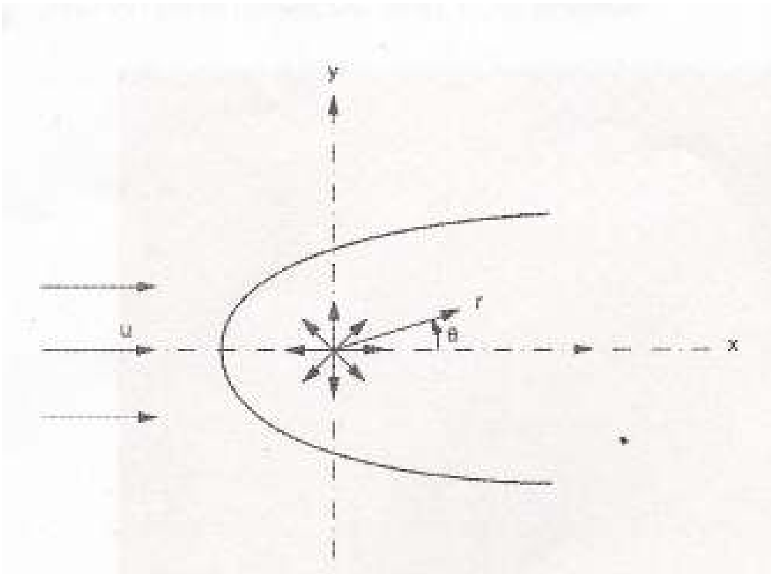

Figure-2.6: The parabolic contour of a spill with current and the velocity field at the surface from an underwater blowout plume (Source: Fanneløp & Sjøen 1980)

The combination of the currents in the recipient and the velocity field at the surface generated by the radial plume would jointly form a parabolic- shaped contour of the spill as shown in Figure 2.6. Figures 2.7 and 2.8 show the surface contour of the slick and the expected thickness of the slick, applying the Fanneløp & Sjøen (1980) experienced during the June 1996 sea trial.

Figure-2.9 shows a photo of the contour of the surface slick from the 1996 sea trials as presented by the report of Rye & Brandvik (1996). The parabolic shape of the slick contour appears as also indicated by the calculations.

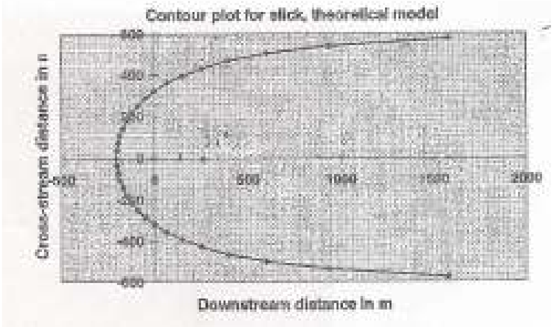

Figure 2.7: Theoretical model of contour plot for slick based on Fanneløp & Sjøen 1980

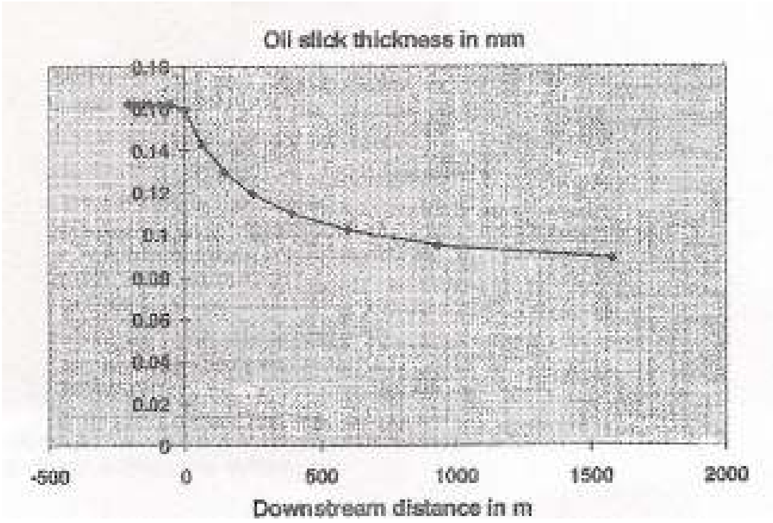

Figure 2.8: Calculated oil slick thickness in mm based on Fanneløp & Sjøen (1980)

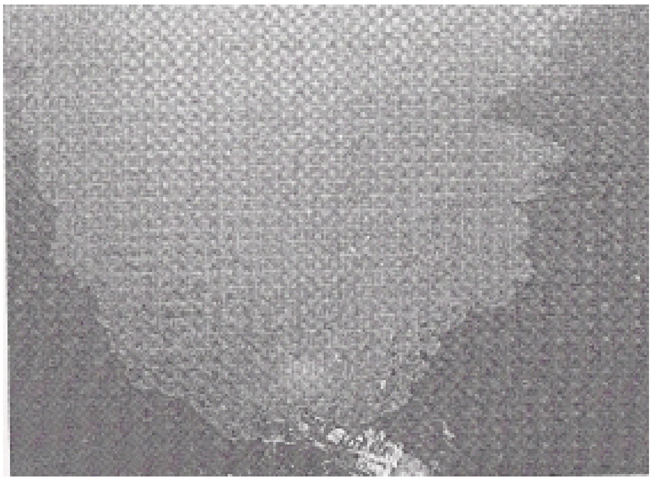

Figure-2.9: Photo of the contour of the surface slick from the 1996 sea trial.
(Source: Rye & Brandvik 1996)

Analysis of the 1996 field results according to Rye & Brandvik (1996), showed upstream penetration of the slick in the field smaller (on the order of 40-50m) than what the results from the model calculations indicate (about 200m). It was also found that the width of the plume downstream is larger for the calculations (about 800-900 m) than what the measurement indicates (about 300 m). Rye & Brandvik (1996) therefore pointed that a revision of the Fanneløp and Sjøen theory from 1980 seems appropriate.

Deviation was also found on the thickness of the slick at the sea surface. According to calculations, Rye & Brandvik (1996) expected the thickness to be close to 100 to 160 µm, (assuming that all oil in the slick was in a non-emulgated state). Because the size of the slick is somewhat overestimated by the model, Rye & Brandvik (1996) expected that the thickness of the oil would be somewhat larger than calculated. However, Rye & Brandvik (1996) recorded the thickness to be about 10 to 30 µm, accounting for only 15% to 20% of the total amount of oil released. The rest of the oil was not traced during the experiment.

According to Rye & Brandvik (1996), the present explanation is focusing on the release arrangement, which created a release velocity close to 15 to 16 m/s. This velocity may be large enough to create small droplets with a small rise velocity. Thus the oil droplets may have been trapped within the subsurface plume instead of rising to the sea surface.

The width of the underwater plume for the 1996 field trails was calculated by means of the mathematical model. The width of the plume at the location where the underwater plume penetrates the sea surface was calculated to be 20-m diameter and this appears to be of the same magnitude as the observed width.

For the same 1996 field trials, some trials were made with varying release rates with tracer instead of oil in the release. At some lower release rate, the plume could not reach the sea surface. The sonar pictures report taken gave an impression that there was no significant regeneration of the underwater plume after the plume was trapped in the water masses. Comparisons of observed and numerical simulations indicate that the stratification in the water masses, tends to prevent the plume from reaching the sea surface when the release flux of air falls below some threshold level. (Rye & Brandvik 1996)

Rye & Brandvik (1996) concluded in their report that many of the features of the underwater plume and the resulting slick on the sea surface could be represented fairly well by their modeling but not the size of the slick at the sea surface as it tends to be overestimated by the model.

For the 1996 oil and air release with high velocity, the content of oil in the slick was found to be significantly lower than expected, and the slick thickness was found to be relatively thin, which would be very difficult to retrieve by mechanical means (booms and skimmers), Rye & Brandvik (1996) suggested that alternative strategies have to be considered for oil spill contingency response against deep water releases.

The 1996 trials indicated a fairly good description of the underwater plume but not the surface slick and this is not surprising. The underwater plume may be fairly unaffected by the surface variation of surface wave velocities but not the surface slick, especially when the momentum of the plume is great as in this case with a discharge velocity of about 16m/s with buoyant gas. Wind and current are rarely the same in direction. Wave velocity near the surface is normally larger than the current velocity. It will not be surprising that these variations could be responsible for the surface slick and thickness parameter discrepancies in the result of Rye & Brandvik (1996) as the effect of increased surface velocity will be to spread the oil and reduce the resulting surface film thickness.

While in the work of Reed et al., (2006) claimed that trapping of the plume below stratified water happens in deepwater (this term of which we argued as being used arbitrarily), we have observed in the work of Rye & Brandvik (1996) that the 'trapping' depends on the release velocities and not the depth (deepwater) definition. The presentation of Rye & Brandvik (1996), Johansen (2003) and Yapa et al (2001) resonated the term deepwater with the concept of depth. We think however, further work is needed to be carried out to define and specifying relationship between velocity of the release, depth and trapping in order to bring about a clear description of deepwater when it comes to underwater releases.

The width of the underwater plume at high depth ('deepwater') is influenced by the oil drop size distribution as they would have individual velocities as they rise along the plume and Rye & Brandvik (1996) could not calculate the width size beyond 50 – 60m. This was also a challenge for Reed et al., (2006).

During the 1996 trials, the release velocity was high, resulting in a high momentum and the availability of gas within the plume also provided a sufficient buoyancy to arrive at surface. It is evidently clear that where momentum of the plume is small due to low release rate, the expectation would be that buoyancy would be suppressed by stratification across water column. This is what happened when Rye & Brandvik (1996) made trials with lower release rates. In case of gas content of the release, Reed et al., (2006) suggest that natural gas would tends to form hydrates at elevated pressures and low temperature (deepwater). A SINTEF presentation by Johansen (2008) believes that Reed et al., (2006) suggestion will rarely happen in practice. However, we believe that due to the dynamic motion of the sea and turbulence, most of the plume content that have not formed hydrates or diffused in the ambient, will eventually regenerate to surface but the time when this could happen and location where this regeneration could occur is another question entirely. We argue that the trapping would not be indefinite and what appeared to have been untraced by the sonar pictures of the ROV in the water column in the presentation of Rye & Brandvik (1996) is the sum of whatever content of the plume that have been hyrdrated or/and diffused plus the regenerated surface oil (and gas) as a function of time.

In conclusion, we believe that further work is still required in this field. For spill circumstances especially within the oil industry, the relevant issue is often on the amount of hydrocarbon lost to the environment. The plume phenomenon is only a means to identifying this parameter. In our opinion, it appears that the existing models for surface slick are still not theoretical enough for practical use and it is most likely that best estimate may still be relying on calculating rate of discharge based on leaking hole/crack/break configuration and suction/discharge pressures. Even at this, most spilling pipelines carry multiphase hydrocarbon which present mathematical complexity in defining the quantities of oil and gas (and also water in some cases) expunging from the leaking holes or cracks or breaks.

Though, the spill volume estimation is a reactive measure in pipeline oil and gas leakages, but it is also considered a proactive measure in determining the degree of remediation required to save marine lives. Considering this importance, it is therefore proposed that where requirement exist for leaking holes or cracks identification in muddy/unclear water, our equipment presented in this work can provide a quick solution, especially when it is ROV operated.

3.0 Method/Apparatus description, operation and design

3.1 Method/Apparatus description

The apparatus would be a simple handy instrument capable of being hand carried by a diver. The apparatus would consist of two main parts:

- The dry box
- The flooding box.

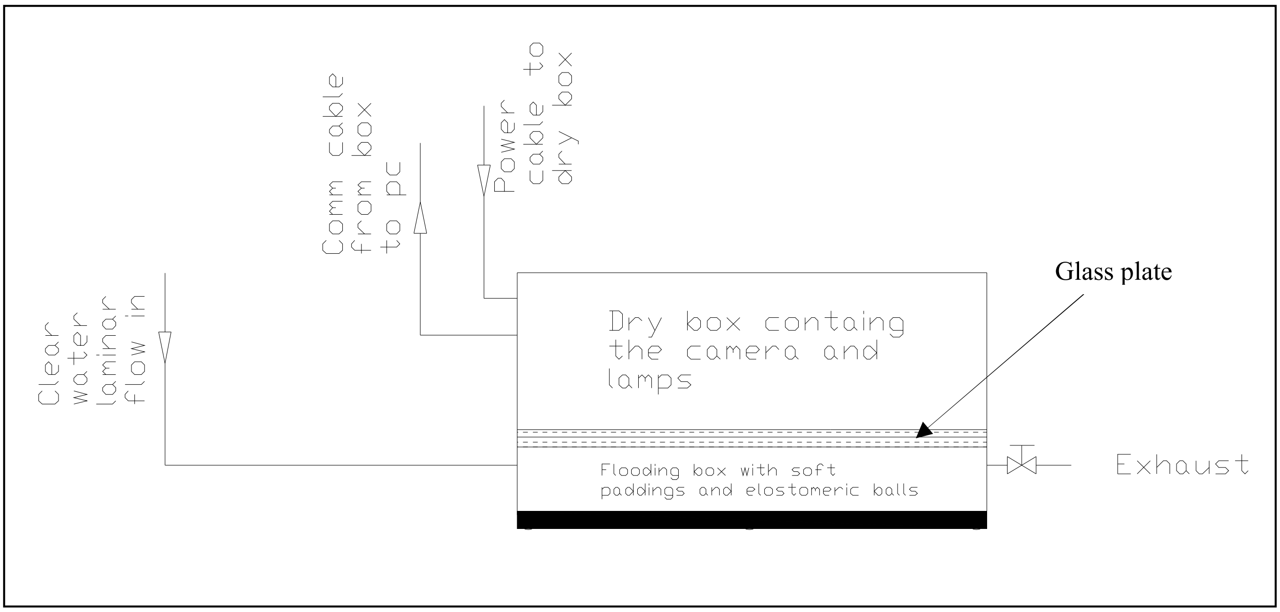

Figure-3.1: Illustrating the description of the apparatus

The dry box houses the digital video camera and the illumination system and would be kept dry subsea by use of gaskets. The capsulated dry box would be attached to the flooding box by set gaskets, sandwiching a transparent glass. The digital video camera would be accessing the structure through the transparent glass. The power is for illumination and the communication line (comm. line) for video and photography. The power and comm. conduit is attached to the dry box. The comm. cable is connected to computer(s) at surface for observations by surface engineers.

The flooding box is the part of the equipment that sits on the surface to be observed. It is directly connected to the bottom of the dry box. Clean water floods into the flooding box from the flood line, flooding the surface to be observed and displacing the unclear water with over pressure that is less than 1.5psig. The flood line is a water hose with necessary collapse resistance. Both the flood line and the power/cable conduit would be designed to have 360-degree flexibility. This capability would enable the equipment to be maneuvered to probe round, across, slanting and along the structure to be observed as desired by the diver or surface engineer.

To ensure steady and adequate clearness, the valve installed in-line with the flooding supplied line is operated to exhaust unclear water and provide laminar steady flow within the box.

As discussed in section 1.6, a sample prototype of this equipment for the 2" pipeline close-visual inspection is made. The idea is that if it works for the 2", it would work for larger diameter pipelines.

For easy maneuvering, four elastomeric balls or wheels are designed onto the flooding box on which it travels on surfaces to be observed. One of the balls is stationed at the rear and another at the front while the other two are installed at the middle of the flooding box. This design is necessary due to surface variations of the pipelines due to corrosion. The elastomeric balls should have the capability to sheltering or springing into the soft pad of the flooding box on application of little hand pressure on the apparatus by the diver to provide partial sealing required to obtain clear observations. The soft pad offers a soft landing of the equipment onto the surfaces to be observed.

The method proposed in this work is diver-assisted. Implying that the diver hand-carries this equipment to place it at the location where close-visual inspection need to be carried out. However, the concept is hoped to be further developed in the future such that the equipment could be remote controlled, excluding the need for divers. In each case, the observations are transferred to surface installed computers which are activated by the communication system installed in the equipment.

Where the part of the structure suspected of leaking is buried, opening up the surrounding soil or sediments would be required to expose the suspected area of interest. This could be done by jetting or side ditching as described in section 3.3.

Note that oil does not stick to the transparent glass when the equipment is used on a leaking oil line. This is because the traditional method of handling oil pipeline leaks involves shutting down oil flow (production) and flushing out the oil in the pipeline with clean water to arrest further spillage. This implies that the section to be observed is filled with water and not oil.

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3.2 *Apparatus design and calculations for a sample prototype for suited 2" pipeline close visual inspection in muddy/unclear water.*

3.2.1 Apparatus requirement.

1. Good heat conductivity.
   This is required such that the heat generated by the illumination lamps can easily be conducted away to the surrouding water. The digital video system may be damaged by high temperature if heat is retained in the dry box.

2. Corrosion resistance.
   Part of the design would be built with metals. Metals experience corrosion when they come into contact with water.

3. Collapse resistance.
   The equipment should be able to withstand collapse due to hydrostatic external pressure, as the inside of the box is unpressuried. This is critical for larger depth situations. Where the application is in shallow water, it may not be a serious matter.

4. Materal strength.
   The requirement is important because the equipment will regularly be pushed , pressed upon and carried about in and out of water. It should have enough strength to survive the stresses involved.

5. Light weight but negative buoyancy requirement.
   This requirement will make the design to be easily hand-carried by divers.

3.2.2 Material selection

Corrosion deals with taking away of mass from the surface of material by their environment and other forms of environmental attack that degrade material properties. It is suggested that the stainless steel type 316 be used as it has excellent forming and welding characteristic and also being free from pitting and weight loss.

Table 3.1 shows some mechanical properties of stainless steel type 316.

S/N	Property	Unit	Value
1	Yield Strength	MPa	205
2	Ultimate Tensile strength	MPa	515
3	Density	kg/m^3	8000
4	Modulus of elasticity	GPa	193
5	Heat Conductivity @100 ^{0}C	W/ (m.K)	16.2

Table 3.1: Properties of stainless steel type 316. (source: The "AZO Journal of Materials Online". Stainless Steel - Grade 316 - Properties, Fabrication and Applications. http://www.azom.com/details.asp?Articleid=863#_Mechanical_Properties)

3.2.3 Apparatus design and calculations

For the 2" pipeline equipment we commence the design of the dry box and related structure by proposing the configuration of the equipment schematically shown (side view) in figure 3.1 as:-

Breath b = 60 mm

Length l = 300 mm

Thickness of the selected stainless steel grade (type) 316 = 2 mm

We then use basic design principles to verify if the proposed is satisfactory or not:

Allowable stress design method would be used, e.g., similar to the approach of Ferdinand P.B. et al., (2006). As a conservative criteria in a simplified design, we put that allowable stress shall not be more than 50% of Characteristics strength.

3.2.3.1 Collapse Resistance check:

The box used in this prototype is empty in the inside. This will expose the box to the external hydrostatic pressure of the water in which it is submerged. The glass is the box material with the weakest strength (tensile strength = 60-MPa and flexural strength = 90-kg/cm^2 {equivalent to 90-bar}) shall be the determining factor for the depth of water specification. (Matweb material property data, 2010).

Figure 3.2 shows the section of the dry box. The bottom section shows the transparent glass while the sides and top are stainless steel material.

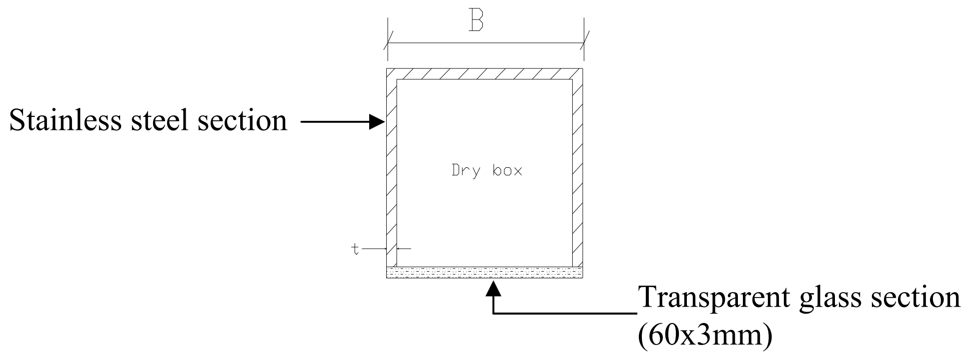

Figure-3.2 Showing the cross sections of the dry box

The maximum depth of water for which the equipment can be used would be calculated:

The external hydrostatic pressure acts all over the surface area of the box, tending to collapse the box. The surface area of the glass = 300*60 = 18000 mm ^{2}

Therefore, the glass will experience a force, $f_c = \rho g d * 18000 * 10^{-6}$ Newton.

Here, d = water depth, acceleration due to gravity, g, is 9.81 m/s ^{2} and taking water density, ρ as 1025 kg/m ^{3} (i.e. worst case of sea water)

f_c = 1025*9.81*d*18000*10 $^{-6}$ = 181d (Newton) ………………Eqn. 3.1

The stress will be experienced in the cross-section of the box.

Transparent glass equivalent cross-section = 60*3 = 180 mm ^{2}

With the flexural strength of 90 bar, the transparent glass will withstand a pressure force of

$(90*10^5)*180*10^{-6}$

=1620 Newton ………………..Eqn. 3.2

Equating 3.1 and 3.2,

181d = 1620

d = 10 m (33 fsw).

This implies that the maximum depth for which this capsulated dry box can be used without the risk of collapsing based on our conservative design criteria is 5 m

For depth beyond this value, the thickness of the plate must be increased, alternatively the self illuminating underwater camera could be used as discussed in section 3.2.3.8.

In general, the dimensions could be made larger depending on the size of the equipment desired. In-fact, the larger the volume size of the equipment, the better the buoyancy (easy to handle by diver).

3.2.3.2 Mechanical strength check:

In this section, the ability of the equipment structure to support a specified load without experiencing excessive stress and undergoing unacceptable deformation is considered.

The maximum load on the box occurs when the diver places the equipment on the structure, put some of his weight (by hand) on it to keep it in position and then crawl it along the pipeline structure. In practice, this load should be less than 10-kg of mass (98.1-N). Due to uncertainties, apply a load factor of 2.5 such that this load becomes 25-kg mass (245.25-N) applied 30^o to the horizontal during crawling. This implies that:

Equivalent vertical load = 245.25 * sin 30 =122.6-N

Equivalent horizontal load = 245.25 * cos 30 = 212.4-N

The simplified diagram of the scenario is shown in figure 3.3

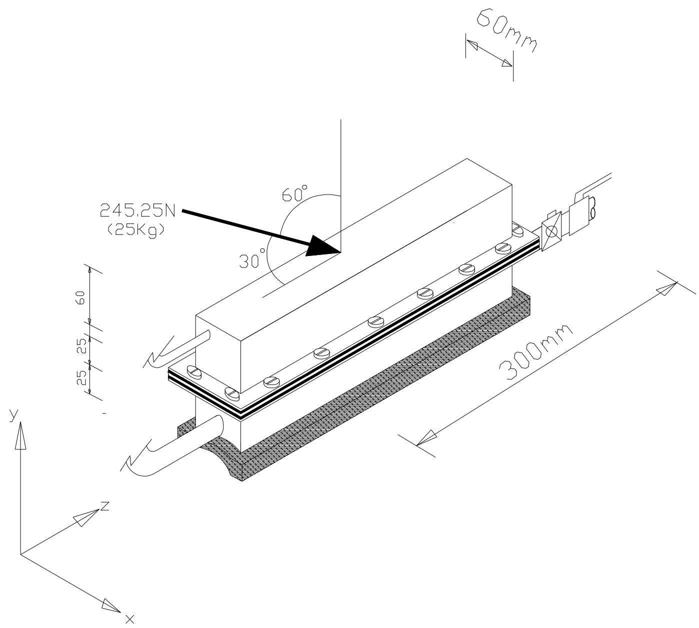

Figure-3.3: The simplified force body diagram of the equipment

Neglecting the appurtenances and considering the structure as rectangular box, a section along the x-plane is shown in figure 3.4, with the characteristic dimensions.

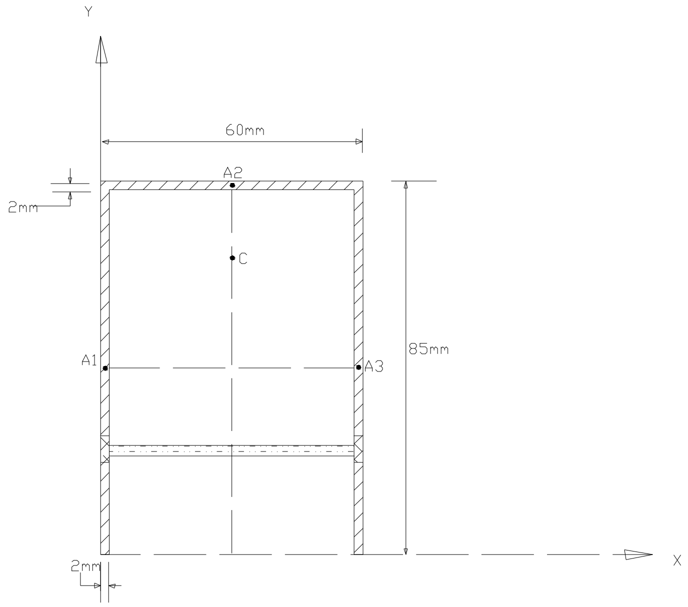

Figure-3.4: showing the section along x-plane of figure 3.3.

Neglecting the appurtenances implies:

-the bolted joints are assumed to be solid enough

-the end plate-faces, (not seen on the section), is regarded as bracings to rigidify the rectangular frame work.

C in figure 3.4 is the radius of gyration of the equipment through which the resultant forces and moments would act.

The rectangular section has three rigid sides, with the corresponding areas designated as A_1, A_2 and A_3 as shown in figure 3.4. The section showing the transparent glass is assumed weightless.

Attempting to locate the position of C along y-axis:

$$(A_1 + A_2 + A_3)\, C = A_1 * \frac{83}{2} + A_2 * 85 + A_3 * \frac{83}{2}$$

$A_1 = 2*(85-2) = 166\ mm^2$

$A_2 = 2*(60) = 120\ mm^2$

$A_3 = 2*(85-2) = 166\ mm^2$

Calculating,

C = 53mm (along y-axis)

Similarly, along x-axis,

$(A_1 + A_2 + A_3)\ C = A_1*1 + A_2*30 + A_3*59$

C = 30mm (along x-axis)

The location of C has been found as in figure 3.5

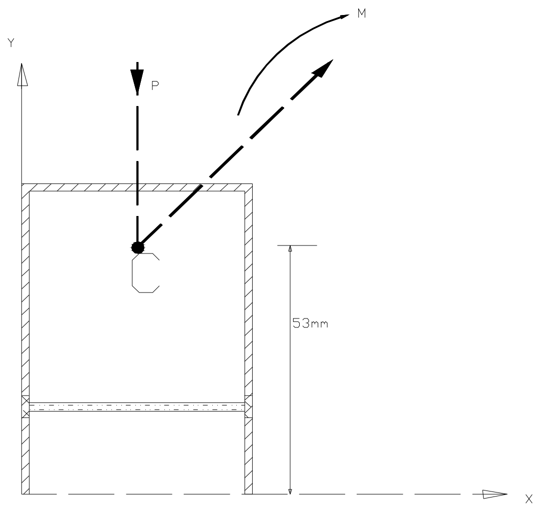

Figure-3.5 showing the location of radius of gyration, C

Calculating moment of inertia, I , about y-plane for each of the corresponding areas (A_1,A_2 and A_3):

$I_{A1} = \frac{1}{12}bh^3 + A_1K_1$ ……………………Eqn. 3.3

Where

b = breath of the area at y-plane

h = height of the area at y-plane and

K_1 =distance of the centroid of the area to the radius of gyration C.

$I_{A1} = 0.5*2*83^3 + 166*(53-41.5)^2 = 593740.5\ mm^4$

$I_{A2} = 0.5*60*2^3 + 120*(84-53)^2 = 115560\ mm^4$

$I_{A1} = I_{A3} = 593740.5\ mm^4$

$I = I_{A1} + I_{A2} + I_{A3} = 1303041\ mm^4$

Ferdinand P.B. et al., (2006) use a stability condition,

$\frac{p}{A} + \frac{MC}{I} \leq \sigma_{all}$ ……………………….Eqn.3.4

Where,

M = moment due to the horizontal load component = 212.4 *85 = 18053.38 Nmm

σ_{all} = allowable stress (in this case taken as 50% of characteristic strength =102.5-MPa).

P = vertical load

A= cross sectional area of the structure on which the force is acting. For the rectangular shaped box of figure 3.3, the cross section = 2(2*300) + 2(2*60) = 1440 mm^2

Inserting the required figures in eqn. 3.4,

$$\frac{122.6}{1440} + \frac{18053.38 * 53}{1303041} \leq \sigma_{all}$$

0.8MPa $\leq \sigma_{all}$ =102.5MPa

This result implies that mechanical loading on the equipment is small. The collapse strength appears to be more critical in the design.

3.2.3.3 Buoyancy checks:

Outer volume of dry box = 60*60*300 = 1080000 mm^3

Total volume of stainless steel material on the equipment = 2(110*2*300) + 2(85*60*2) + (300*60*2) = 188400mm^3

Buoyancy = $\rho g v$

Where v =volume of the dry box.

Buoyancy = 1025*9.81*1.08*10^{-3} = 10.86 N

Similarly,

Weight of the mass volume of the equipment = 8000 *9.81*1.524*10^{-4} = 11.96 N

Let the estimation of the weight of the transparent glass, gaskets, bolt/nuts, lamps, digital video camera, attachments (i.e., of piping, cablings and valves) and pads be 60% of weight of the material (= 7.2 N)

Submerged weight of the equipment = (11.96 + 7.2) – 10.86 $\approx$ 8 N $\approx$ 0.8 kg

This is really light weight for the diver!

3.2.3.4 Considerations of the gaskets, soft pad, transparent glass and valves.

The fastening of the 4mm bolts/nuts discussed in section 3.2.3.6 may not be easily achieved uniformly, especially when fastening is done manually. The surfaces of the mating flooding box and the dry box may have irregularities even during handling, due to the thinness (2mm) of the sheet of the stainless steel. Therefore, compensation against these possibilities will involve the use of elastic gasket such that it tensions out in compression with nearly zero stress accumulation. Figure-3.6 shows the stress versus compression for various gasket materials. Rubber gasket is selected.

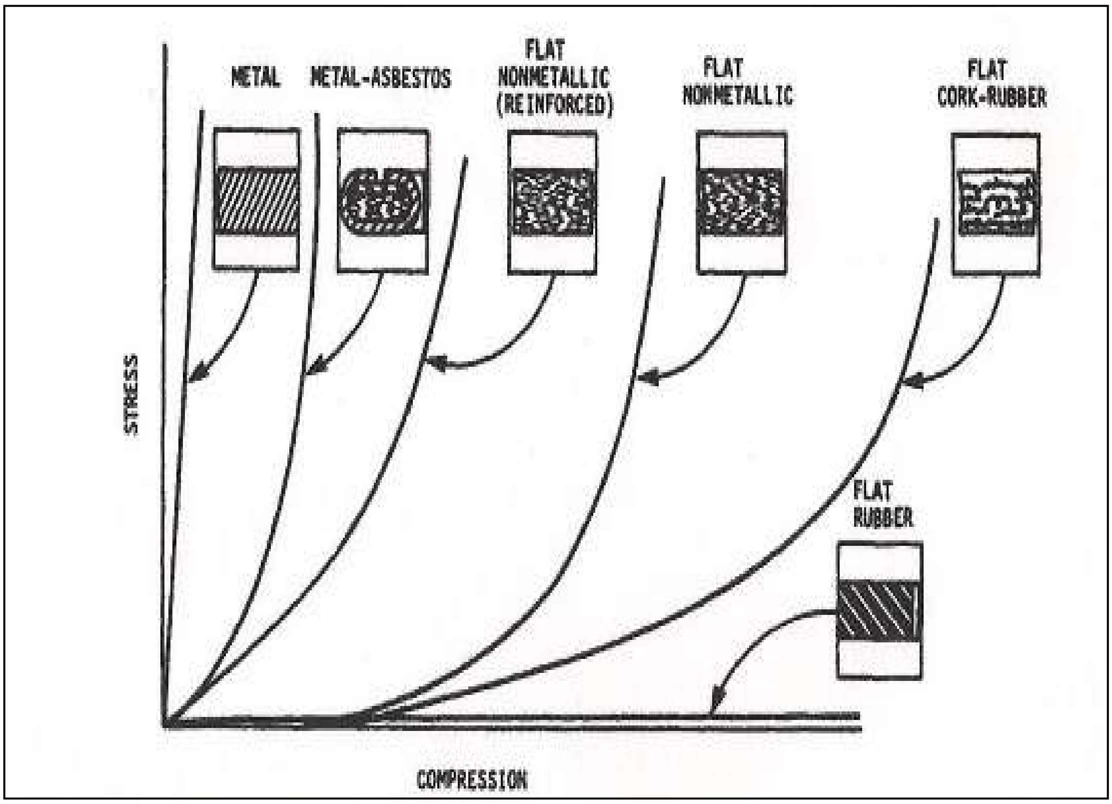

Figure-3.6 Stresses in rubber gaskets on compression.

(Source: Standard Handbook of Machine Design (3rd Edition) © 2004 McGraw-Hill).

For the edge padding, any porous and permeable elastic soft material that would allow water to sip out of the box under over-pressure condition is adequate.

Plain glass made of polycarbonate sheet is excellent for use as transparent glass in case of this equipment. It has distinct advantage over acrylic or metal-grill glasses due to its high impact resistance, good fire and heat resistance and very good light transmission and glass like transparency. Its operating temperature is within $130^{o}C$. Malibu Plastica (2010).

A simple spring return flow check valve is adequate provided the pressure requirement to open such check valve is not more than 0.1psig. The 2” on/off valve installed downstream of the 2” check valve not only opens to evacuate large scatterrers and lumps on the site to be observed but also chokes the out-flow to guarantee a laminar flow condition required for good observations.

Any kind of on/off valve will be adequate, provided:

-little effort is sufficient to operate the valve

-the valve is lever operated and at most, a revolution of the handle is sufficient for fully open or fully close position of the valve. In this configuration, the diver could easily feel how much the valve is opened or closed.

-both the on/off valve and check valve should be made of corrosion resistant material.

3.2.3.5 Heat conductivity

The two lamps in the prototype design are 55watts of power each. Temperature in the box will increase during operation. The design is to ensure that the heat is conducted away to the surrounding flowing cold water as quickly as possible.

Design handbook by Ronald A. E (2000) puts the relationship between the supplied power in 1-hour, Wh and the heat conduction across a given material as:

Watt-hour, Wh = $\frac{KA(T_2 - T_1)t_e}{l}$ ………………….Eqn.3.5

Watt W = $\frac{Wh}{h}$ ……………………….Eqn.3.6

l =thickness of the material

t_e = exposure time in hours, h

T_2, T_1 =temperature across the material, (T_2 is the higher temperature).

A = heat transfer surface area.

= 2(60*300) + 2(60*60) + (60*300) = 61.2 * 10^{-3} m^2

We assume that the transparent glass is insulative.

K = thermal conductivity.

Due to risks associated with dives, in practice, diving is made maximum of one hour at a time.

Applying eqn. 3.6

$$110 = \frac{16.2 * 61.2 * 10^{-3}(T_2 - T_1)}{1 * 2 * 10^{-3}}$$

$(T_2 - T_1) = 0.22\,^0C$

This result implies that the stainless steel material conducts the heat inside the box so good that the temperature of the stainless material inside of the box is approximately same as the outside. Fortunately, the outside of the box is surrounded by relatively moving cold water that act as a heat sink, taking away the heat by both conduction and convection means.

3.2.3.6 Bolts/nuts stress:

Large forces and therefore stresses are not expected on the equipment as found in section 3.2.3.2. Due to corrosion problems, austenitic stainless steel fasteners grade A4 is selected, corresponding to type 316 stainless material. The 16-peices 4mm diameter bolts with nuts spaced 4.5mm is considered satisfactory for fastening of the transparent glass and gaskets, sand-witched between the mating faces of the dry and flooding box.

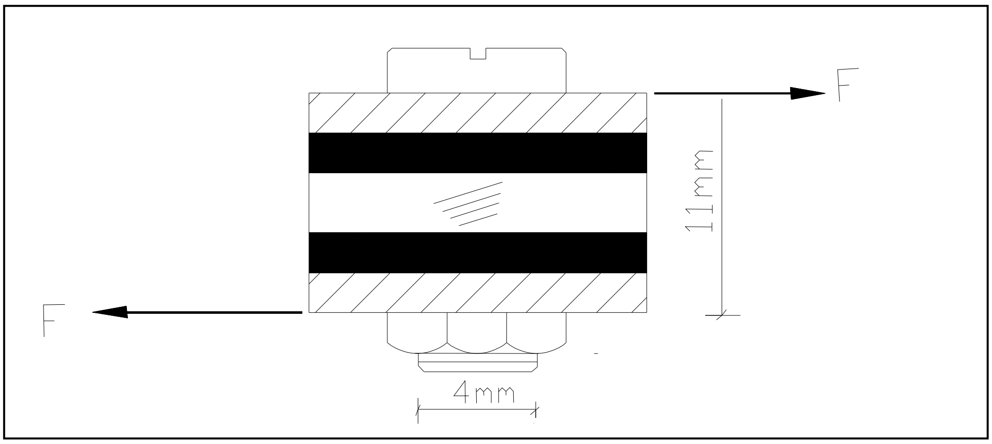

Figure-3.7 showing the forces in the bolts as the equipment slides on the pipeline structure.

British Stainless Steel Association (2009) gives the properties of the grade A4 bolts as:

Shear strength = 145MPa
Yield strength (tensile) = 205MPa

As the equipment is hand pushed by diver to crawl along the pipeline structure, the equipment is exposed two types of stresses:

-shear stress
-bending stress due to the bending moment M

Shear stress = $\frac{F}{A}$ …………………Eqn. 3.7

F = Shearing force
A = cross sectional area of the bolt

Bending stress = $\sigma_b = \frac{M.r}{I}$ ………….. Eqn. 3.8

r = radius of bolt =2mm

For this bolt:

$I = \frac{\pi d^4}{64} = \frac{\pi 4^4}{64} = 12.568 \text{ mm}^4$

$M = 212.4 * 11 = 2336.4 \text{ Nmm}^2$

$A = \frac{\pi d^2}{4} = 12.568 \text{ mm}^2$

From eqn. 3.7,

Shear stress = 17 MPa

Since there are 16bolts, the shear stress per bolt = $\frac{17}{16}$ = 1.06 MPa

Design is ok.

Similarly, from eqn. 3.8,

Bending stress, σ_b = 371.8MPa

Since there are 16 bolts, bending stress per bolt = $\frac{371.8}{16}$ =23.2MPa

Bending strength is often taken as 0.79 of the yield strength (tensile).

Therefore, bending strength = 0.79*205 = 162MPa

Design is ok.

3.2.3.7 The power/communication and water supply lines:

Ball Swivel Connectors such as the ANVER swivel connectors will be adequate. The Anver type of the swivel connectors have designs that provide 360° rotation with up to 45° swivel. They have precision-plated steel construction and large degree of articulation. (ANVER Corp., 2010)

The ANVER suction cup as shown in figure-3.8 would be adequate for the water supply line. Here the suction cup also improves the flexibility and the flexible rubber hose that pipes the clean water is fitted with a metallic head that nuts on the swivel head suspension.

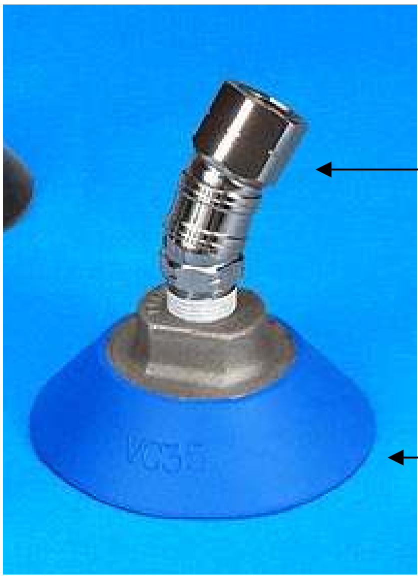

Figure-3.8: The ANVER swivel and suction cup
(Source: Anver corporation, 2010.
http://www.anver.com/document/pdfs/components/suspensions/Ball%20Swivel%20Connectors.pdf)

The suction cup type of the swivel joint would be inadequate for the cablings into the dry box due the watertight requirement of the dry box. Instead, a threaded connector type shown in figure-3.9 is screwed into or even welded on the box and then flexible rubber conduit that houses the cablings (power and communication) is fitted with a metallic head that nuts on the swivel head suspension similar to the water line.

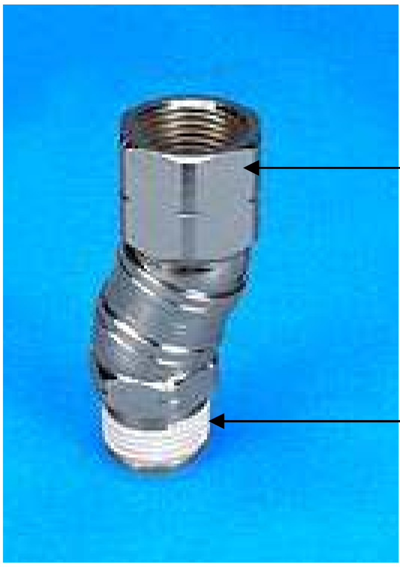

Figure-3.9: The ANVER swivel and threaded connector
(Source: Anver corporation, 2010.
http://www.anver.com/document/pdfs/components/suspensions/Ball%20Swivel%20Connectors.pdf)

3.2.3.8 The Camera

The prototype made in this work employs the use of a simple Webcam setup consisting of a digital camera installed in the dry box and attached to a computer through the USB port. The camera part of the Webcam setup is just a digital camera. Webcam software installed in the computer enables the setup to "grab a frame" from the digital camera at a preset interval and transfers it to the computer screen for viewing.

Frame rate indicates the number of pictures the software can grab and transfer in one second. The Webcam installation in the prototype has 30 frame-rate per second (30-frp), enabling the Webcam to make video coverage of the observation via the attached computer.

The Webcam is a non-underwater camera that must be capsulated if required to be used underwater. It is the requirement of the capsulation that gave rise to the use of gaskets and related seals.

However, underwater cameras exist which can be deployed without capsulation and the need for gaskets against ingress of water. The installation to the flooding box would still be within the ‘dry box’ above the transparent glass without which the development of laminar steady flow in the flooding box required for good observations would be negated.

Underwater camera in use in the industry is often called Offshore underwater video camera (which have various brands and names depending on the manufacturer. For instance SeaViewer™ has the SeaViewer color Sea-Drop etc). These underwater cameras have more photographic and video features than the Webcam but the basic principle is same. The Webcam used in this work does not make a colored photo or video but it is over 100-times cheaper.

3.2.4 The summary of the design procedure.

As discussed in section 3.2.3.8, Webcam and the illumination lamps used in this work are very cheap to afford but the quality of the illumination from the lamps plus video and photography from the Webcam is generally low. The video and photography is black+white quality and the coverage is also limited. The selection of these accessories for the underwater observations will imply use of the capsulated box. Due to the very affordable nature of these accessories, the selection is limited to experimental works and where cost is an important factor. In situations where the quality of video and photography are relevant, use of un-capsulated box using modern underwater camera is often selected.

The design procedure is then dependent on the type of equipment required. The summary of the procedure is shown figure 3.10

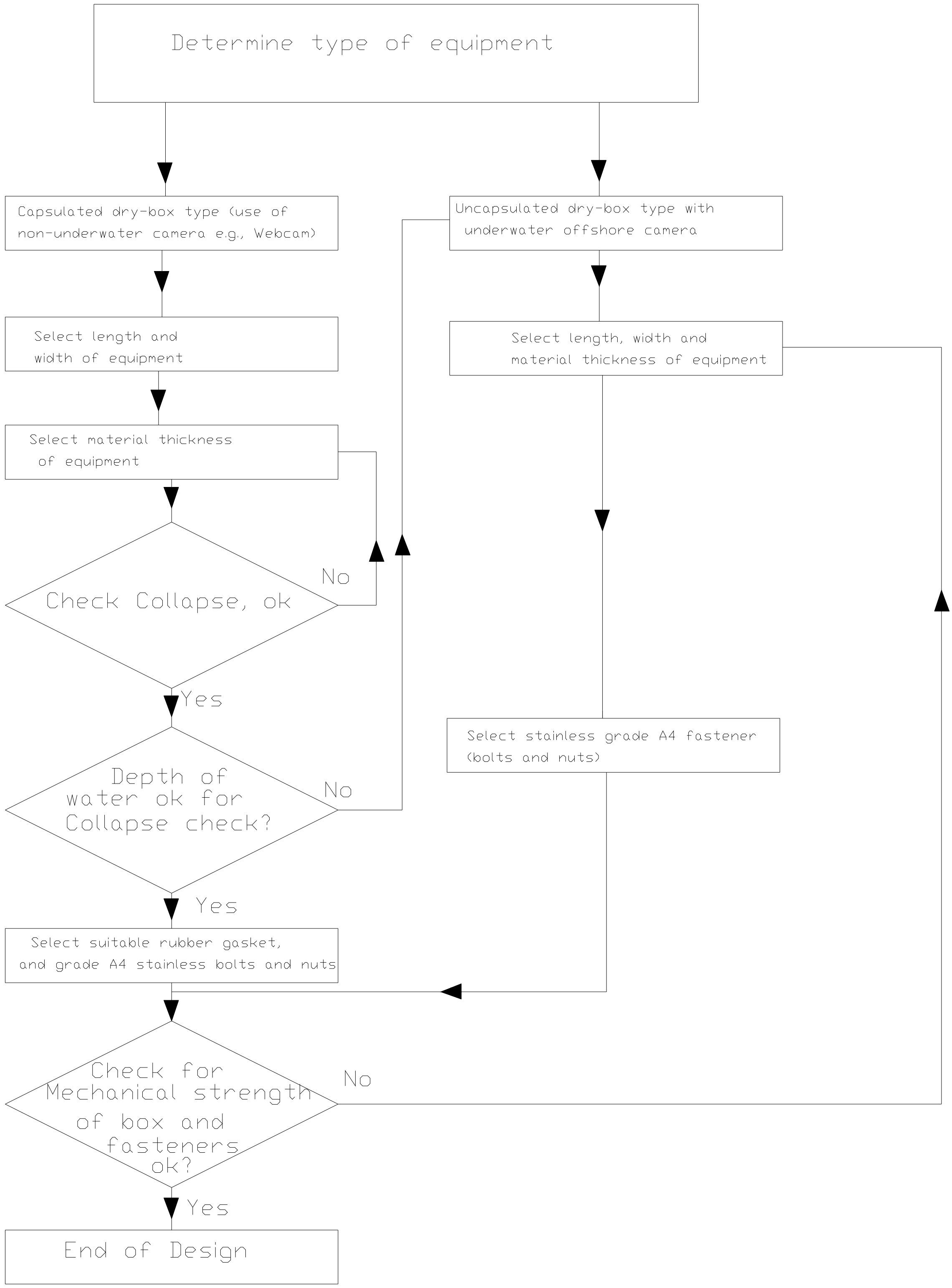

Figure-3.10: The design procedure

3.3 Method of operation

The configuration of the equipment could vary depending on the configuration of the structure to be observed. The common operational characteristic however, is the same: The flooding box encloses on the part of the structure to be observed, be they pipelines, anodes etc.

In the following is given a description of the operation and the technique for Sub-sea Pipelines Leak Close-Visual Inspection in Muddy/Unclear Water. Reference is made to figures 3.11, 3.12 and 3.13 below designed, for a 2" pipeline inspection. For the dimension configuration, refer to drawing no. J001, J002 and J003

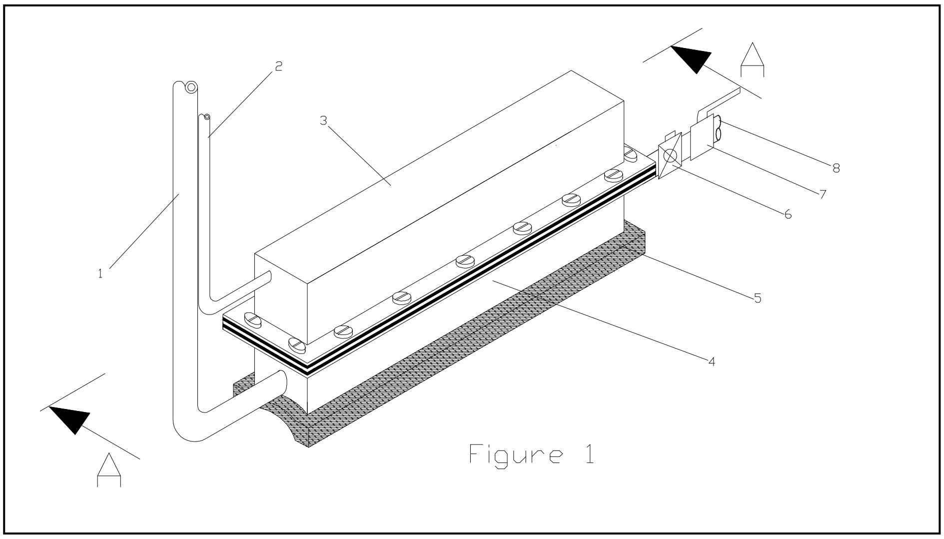

Figure-3.11: View of a sample of the equipment for pipeline leaking hole or crack geometry identification

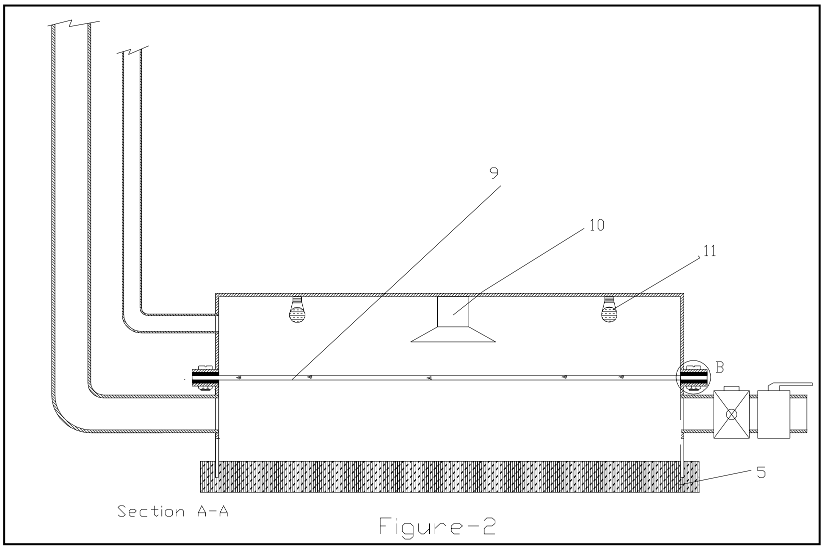

Figure-3.12: Section A-A of figure 3.11, showing the camera, the lamps and the transparent sealing glass above the flooding box.

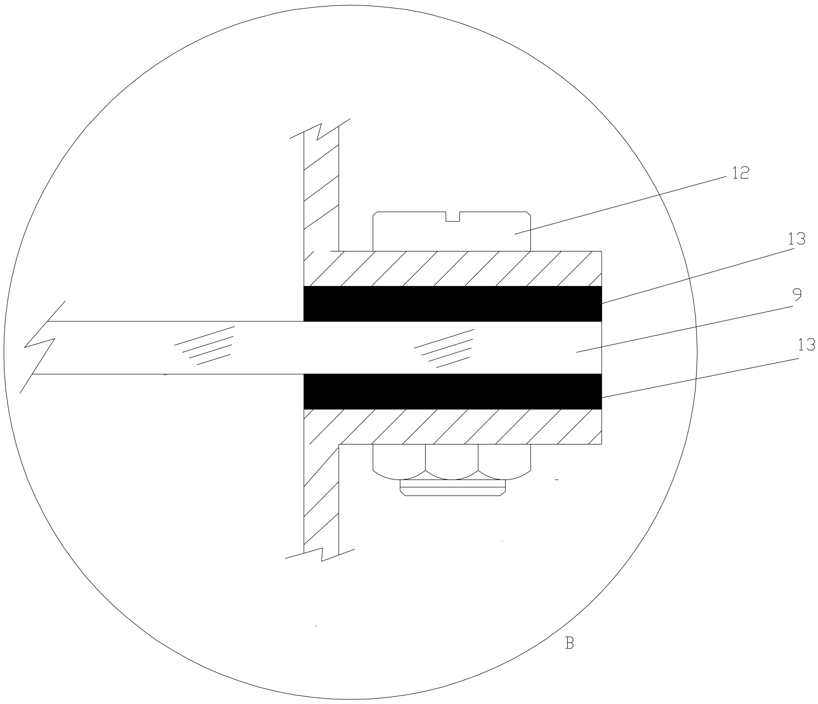

Figure-3.13: A detail of the sealing and fastening of the flooding box below the top-box with the top-box carrying the electrical/electronic gadgets

The equipment, on its soft pad (5) encloses the part of the pipeline to be observed and clean water is flooded from the surface through the flood-line (1). The lines from the power/communication conduit (2) are attached to a computer and the surface engineer monitors the clearness on the computer screen and stops the flooding once clear water is dominating the flooding box (4). For fast clearness and best clear video or photo achievement, the on/off valve (8) is opened half turn initially at inception of the flooding, and then backed to a quarter of a turn from locked position while keeping over-pressure at about 1-psig (to develop a laminar flow).

The pressure is maintained in the flooding box keeping the unclear water away from surfaces of interest while the illuminating lamps (11) illuminate the area and the camera eye (10) in the top box (3) is observing through a transparent glass (9) and the clear water in the flooding box (4). The view of this part of the pipeline enclosed by the equipment remains clear enough for good observations and inspection by the surface engineer.

Figure-3.13 shows a detail of the sealing (13) and fastening (12) of the flooding box (4) below the top-box with the top-box carrying the electrical/electronic gadgets.

The instrument can be moved 360 degrees round the circumference of the pipeline (provided the pipeline is lying freely above the bottom or is trenched free from the bottom sediments) and/or along the pipeline as the operator wishes. However, movements of the equipment round or along the pipeline often results in some reduction in clearness. Clearness is soon regained by keeping equipment steady for few seconds. The continuous running of the flooding water at about 1psig and at a quarter turn of the on/off valve (8) from locked position keeps the clearness of the video and photos interestingly good at all times without further much adjustments.

Should the soft pad of the equipment be displaced away from the pipeline, the process will have to be repeated.

Should there be lumps, sediments or larger scaterers which may not permeate through the soft pad, the valve (8) is opened and the flooding is activated to flood away the sediments from the flooding box through the check valve (6). The floding pressure and the valve (8) are set to original position once clarity is regained.

For pipeline hole/crack geometry identification, an internal pressure in the pipeline, very little above the pressure in the box, put in the line is sufficient for quick and easy finding.

3.4 Limiting application of the method/apparatus and the requirements

As discussed section 3.1, where oil pipelines is involved, the procedure of shutting the production and water flushing of the line to stop environmental pollution would be used so that the pipeline section to be observed is filled with water and not oil. Though this procedure is the traditional method of handling oil leakages from pipelines, it is assumed that oil pipelines for which this equipment would be used would undergo this procedure to ensure the transparent glass is not covered with the oil.

The method/apparatus has limitation of application when it comes to the conditions of buried structures and deepwater application.

3.4.1 Buried structures (e.g. pipelines)

Fully or partially buried structures such as pipelines imply obstruction of the apparatus to operate 360 degrees. For pipeline structures, soil removal by means of jetting (trenching) or side excavation (dredging) by use of diver or equipment would be required prior to deployment of the apparatus for close-visual inspection.

3.4.1.1 Dredging

Dredging involves the removal of marine sediments from the seabed to form the trench. Apart from manual excavation by diver, other dredging techniques include grab dredging; cutter suction and trailer suction dredging depending on the prevailing environmental conditions (eg shear strength of marine deposits). Side dredging using equipment in the post-lay is often risky and time consuming.

Nonetheless, in practice, the suspected length of leaking location is always within less than 1m. Since the equipment proposed in this work is typically less than 1-foot in height, that divers can manually excavate to enable the tool to be used or utilize high pressure jetting system as described in section 3.4.1.2.

3.4.1.2 Jetting (Trenching)

Pipeline jetting in this case is a method that uses water jets to break-up, remove or liquefy the soil from under a marine pipeline allowing the equipment to swim through. If necessary one could employ sucking equipment to suck out the fluidised sediment leaving the pipeline on a span ready for inspection.

3.4.2 Deep water close-visual inspection

Deep diving is a high risk activity. The risks of decompression sickness, nitrogen narcosis and oxygen toxicity which are health problems associated with deep diving increase rapidly with depth, and any dive where these factors need to be planned for may be thought of as a deep dive. The US Navy Diving manual (1996) put the safe dive limit for surface supplied diving where oxygen is provided from dive vessels, a more or less, an advanced diving compared to SCUBA (self-contained underwater breathing apparatus, figure-3.14), as still within 58 meters / 190 feet capability. (Though some recent publications in Wikipedia put this at 100 meters/ 300 ft. No independent confirmation of this figure).

As installation of structures such as pipelines continue to go deeper into the deep waters, it becomes clear that robots and remote operated equipment would have to be employed. The implication is that for deep water operations, equipment such as our proposed apparatus would need to be built to have such automotive and remote capability.

This can be readily achieved by attaching the apparatus to the existing ROV technology and the capability designed into it. In this case, the equipment is remotely controlled to the site of interest and manipulated remotely without the assistance of a diver. This should be the ultimate goal of this further work. This will simply incorporate propelling system, ruder system, global positional system, dynamic positioning system, robotics and contact sensors

Figure-3.14: Surface supplied diving
(Source: The US Navy Diving Manual, 1996. Surface supplied air diving operations. American Dive Centre, Inc., South Florida. Page 1 of chapter 8).

4.0 Prototype fabrication and Laboratory Testing

4.1 The fabrication.

The fabrication requirement of the equipment has to do with the production of the dry and flooding box. The rest of the components parts of the equipment were procured from suppliers and installed.

The detailed engineering drawings showing the pictorial view of the survey tool, the assembly drawing of the survey tool and the section of the equipment showing the installed lamps and camera are shown in drawing nos. J001, J002 and J003 attached in Appendix 1.

Below are some of the pictures, (figure 4.1 to 4.4), taken during the fabrications in the fabrication shop located in Warri city of Niger Delta in Nigeria, West Africa.

Figure-4.1: Fabrication of the dry and flooding boxes.

Figure-4.2: Verifying the fabricated boxes.

Figure-4.3: Checking the equipment for leaks (12hrs)

Figure-4.4: The equipment passed the leak test.

Observe that 1/2" and ¼" galvanised steel pipes were used for the water supply line and the power/communication line. The flexibles and swivels of the proposed design in section 3.2.3.7 are not used because, the fabrication is a prototype to demonstrate the working principle and applicable method of the work presented in this thesis.

4.2 Laboratory testing

The laboratory set-up for the testing to demonstrate the functional principles and operation method to observe structures or leaks in muddy/unclear water is shown in figure 4.5.

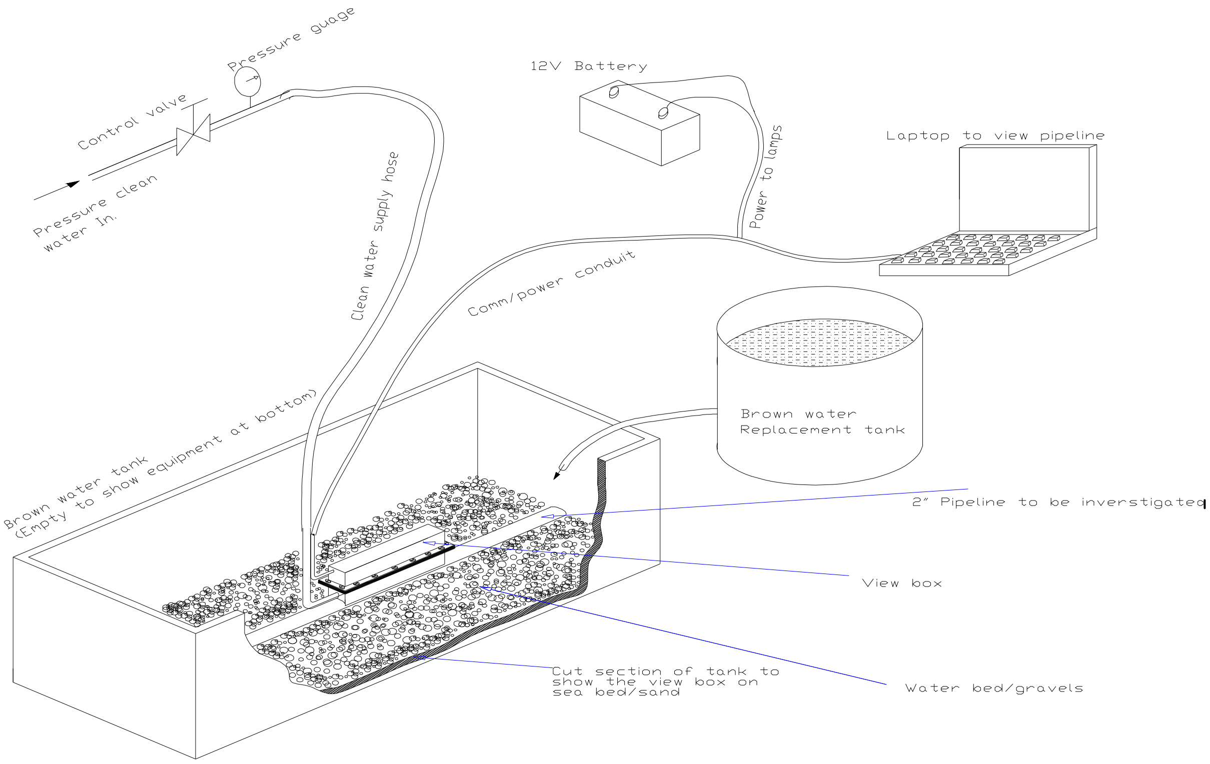

Figure 4.5: Showing the laboratory test set-up.

Figure 4.6 also shows the set-up photo in the laboratory. The Secchi disc measure (see chapter 4.2.1), of the water in the tank is 12mm (0.47") clarity.

Figure-4.6: Set-up Photo for laboratory test (the battery power is right of the computer).

4.2.1 Method of testing:

The water line of the equipment is connected to the water supply system in the laboratory and the power/communication lines are connected to the computer laptop and battery power. The water line has pressure read-out to monitor the pressure of the water from the supply system. The tank volume is recorded so that we can measure approximately the amount of water used to achieve clearness.

Before and after each test run, a hydrometer, secchi disc and finger count are differently used to indirectly measure the underwater visibility of the tank water.

The hydrometer measures the amount of particles in gram/litre of the water in the tank and the secchi disc is a measure of how far, vertically down, the eyes could see from the surface of the water in the tank in a clear day light. These measures have functional relationship with underwater visibility as described in section 2.1. The last measure, that is, depth at which ones fingers can be seen and counted was the measure used in the work of Almon J. et al., (1977). When the finger count is zero, it implies zero underwater visibility.

4.2.2 Apparatus

The following apparatus and items were used in the laboratory testing work

1. Open muddy water tank (135x54x38 cm)
2. Pipeline (plastic pipeline sample)
3. Power source (battery)
4. The designed/fabricated equipment

5. Personal computer (pc)
6. Secchi disc (10cm diameter)
7. Hydrometer
8. Measuring glass tube (1litre)
9. Measuring stick
10. Stop watch.

4.2.3 General procedure

Prior to the beginning of the testing, the clean water supply system pressure was determined for the range of the supply pressure windows for which we could be confident of obtaining a laminar flow in the flooding or observation box.

The supply pressure was set at 2 psig (0.14barg) and 1 litre measuring bottle was filled and the time was observed and the following information and calculations were performed.

Observed flow-rate = 0.91-litre in 1.6 seconds at 2 psig pressure
Therefore, the supply water flow-rate Q_1 = 0.569 litre/sec
Diameter of supply line = ¾" = 1.9 cm
Therefore, the flow cross sectional area of the line, $A_1 = 2.84\ cm^2$

Volume of flow/time Q_1 at supply = velocity of flow $V_1 * A_1$

$$=0.569 \text{ litre/sec} = 569\ cm^3/sec = 2.84 * V_1$$

$$V_1 = 2\ m/s$$

The flow is steady, from the supply line into the flooding box, and from the flooding box, the water sips away from the soft foam or padding sandwiching the box and the pipeline's surface structure.

The flow cross sectional area of box in which clear water flows over the pipeline surface to be observed can be calculated as:

$$(60*60) - \frac{1}{2} * \frac{\pi(pipeline.diamter)^2}{4}$$

$$= 2618\ cm^2$$

Since the flow is steady, we assume the continuity flow equation:

Volume of flow/time Q_1 at supply = Volume of flow/time Q_2 at flooding box

$$2.84*201 = 2618* V_2$$

$$V_2 = 0.22\ cm/sec = 0.22 *10^{-2} m/s$$

Reynolds number Re = $\frac{\rho v D}{\mu}$ for circular sections and $\frac{\rho v l}{\mu}$ for our box section

Where,

ρ = density of clean clear water = 1000 kg/m^3

v = velocity box water m/s

μ =dynamic viscosity of the clean water (at 20^o C) = 1.002 *10^{-3} N.s/m^2

l = cross sectional length

The characteristic flow linear dimension of the flooding box is cross sectional length, l=60-cm

$$Re = \frac{1000 * 0.22 * 10^{-2} * 60 * 10^{-2}}{1.002 * 10^{-3}} = 1320$$

The system test pressure is kept at and below 2 psig for most tests as Reynolds number of 1320 is considered laminar enough to compensate for roughness of the pipeline surface to be observed. One would observe in the results of the following tests that observations made even below this Reynolds number are better.

Notice however, in this procedure that we have assumed that the pressure in the box will be 2-psig. When the equipment is operating underwater, the terms over-pressure and flowing pressure are used. The effect of the supply pressure is to overcome the water column pressure head and result in flow of water through the system at a pressure referred to as the over-pressure. The over-pressure (the balance between the supply pressure and water column pressure) is the effective pressure in the flooding box. It could also be referred to as the flowing pressure of the clean water between the surface to be observed and the supply pump surface.

The laboratory testing procedure is made in seven forms labelled TR001 through to TR007. Each form of the laboratory test has a given procedure to achieve the objective of the test.

4.2.3.1 TR001 – Standardising equipment photo clearness in clean water.

The purpose of this test is to verify the performance of the equipment and its accessories (digital camera and lamps) in a clean and clear water situation.

Test procedure

1. The water tank is 80% filled with clean and clear water.
2. A mark is identified on the pipeline sample and the pipeline is laid and anchored on the water bottom of the tank.
3. The equipment is then powered and linked to the computer and lowered by hand to observe the marking on the pipeline.
4. The two 55 watt lamps in the dry box are powered from full to zero and the photograph of the marking on the pipeline are taken and recorded.

4.2.3.2 TR002 and TR003 – Equipment performance with and without a 2” outlet flow valve system installed on the equipment.

The objective of this experiment is to compare performance of the equipment with and without an outlet flow valve system installed in-line with the supply clean water in the flooding box.

Test procedure

1. The tank is filled with water and mixed with clay/mud to produce muddy/unclear water. Homogeneity is achieved by stirring the filled water.
2. One 1.5 mm hole is drilled on the pipeline and the pipeline is laid and anchored at water tank bottom.
3. The equipment is lowered by hand to observe the 1.5 mm drilled hole. The equipment connects to the power source and the personal computer.
4. The underwater visibility is indirectly measured using the secchi disc and hydrometer tools. The depth of the tank is also measured with the measuring stick.
5. The equipment is powered and flooded with clear water at a given surface pressure. Once the 1.5 mm hole is observed by the equipment, the photograph is taken. The time of the observed clearness is also noted.
6. The sequence is repeated for different water height and water clarity. Prior to the repeat of the sequence, new depth of water in the tank and water clarity are measured and recorded.
7. The 2” outlet flow valve system is installed on to the equipment and the gate valve turned to quarter-open position. Note the gate valve turns four times 360 degrees to fully open or close.
8. Additional two drills of 1 mm diameter holes are made on to the pipeline and steps (1), to (4) of the above are repeated.
9. The equipment is powered and flooded with clear water at a given surface pressure for laminar flow to initiate. The flowing pressure is maintained at 1 psig. Photographs are taken once the holes are observed and the time for the observation is taken.
10. The sequence is repeated once the new depth and tank water clarity are noted

4.2.3.3 TR004 - Supply pressure variations

The aim of the test is to verify the response of the clearness of the photography to variations of system supply water pressure during flooding.

Procedure:

1. Repeat steps (1) to (4) of TR002 except that in (3), markings on the pipeline is used in place of the drilled holes.
2. The underwater visibility is indirectly measured with secchi disc.
3. Decrease the clean water supply pressure: 6 psig, 3 psig and 1 psig, and at each pressure, take the photography.

4.2.3.4 TR005 - Column pressure

The objective of this test is to verify the effect on clearness of photography taken when the system supply pressure is completely shut off and the box pressure due to the water column reduces naturally. It is also aimed to verify the nature of the degradation of the photography with time.

Procedure:

1. Repeat step (1) TR004 above.
2. The supply water line pressure is increased gradually to 2 psig and shut off completely when the markings are observed. The box pressure is then allowed to drop naturally to 0.17 psig.
3. Photography is taken at 1-minute, 2-minute, 5-minute and 20-minute after the shut off of the supply system pressure.

4.2.3.5 TR006 - Parameter verifications

The aim of this test is to generate key parameters that affect clearness of observations in quantitative terms.

Procedure:

1. Repeat steps (1) to (3) of TR003
2. Step (4) of TR003 is repeated with additional clarity measure, depth at which fingers could be seen and counted.
3. Steps (7) to (10) are repeated at a flowing pressure of 1.5 psig and the following parameters are recorded:

-the volume of water used to achieve clearness
-the time it takes to observe the clearness
-the underwater visibility measure.

4.3 Testing Challenges

1. Flexibles and swivels were not used in the fabrication of the prototype. During testing, the equipment could not roll round 360 degrees but about 30 degrees to either side of 12-O-clock position of the pipeline surface. Attempt to roll beyond this angle forced water into the dry-box through the open pipe used as the umbilical conduit.

2. Surface waves were introduced manually by hand and no current was set at bottom similar to open river or sea. Though no effect of the surface waves on the observations was found, it is suspected that if the diver is not steadily keeping the equipment at a given surface at a given time due to current and wave, good observations may be hampered.

3. The prototype used for the test was not perfectly fabricated as proposed in this work. It is believed that a real prototype, fabricated in line with specifications in this work may perform better.

4. Facility to test the equipment for larger depth is not available. The mud water tank was only 38 cm deep.

5. The pressure is measured upstream of the flow of clean and clear water system from the system water supply to the flooding box. The pressure losses along the line, across bends and valves are assumed negligible.

4.4 Test Results

Most of the test results are in photographic form and have been filed in Appendices as shown below. The pictures appear in black + white background because the Webcam used in the equipment as digital camera is not the coloured-type camera.

TR001 results – Appendix 2
TR002 results – Appendix 3
TR003 results – Appendix 4
TR004 results – Appendix 5
TR005 results – Appendix 6
TR006 results – Appendix 7

4.5 Analysis and discussion of the results

TR006 also yielded the following quantitative data:

Max. Depth of water (cm)	Volume of water (litrs)	Clear time (sec)	Over pressure (psig)
17,0	7,3	23,2	1,26
17,5	3,7	24,9	1,25
18,0	3,7	25,9	1,24
19,8	5,8	26,8	1,22
20,5	5,1	27,9	1,21
21,0	3,7	28,4	1,20

Table 4.1: Quantitative measures from test TR006.

Some of the above data were plotted as shown below:

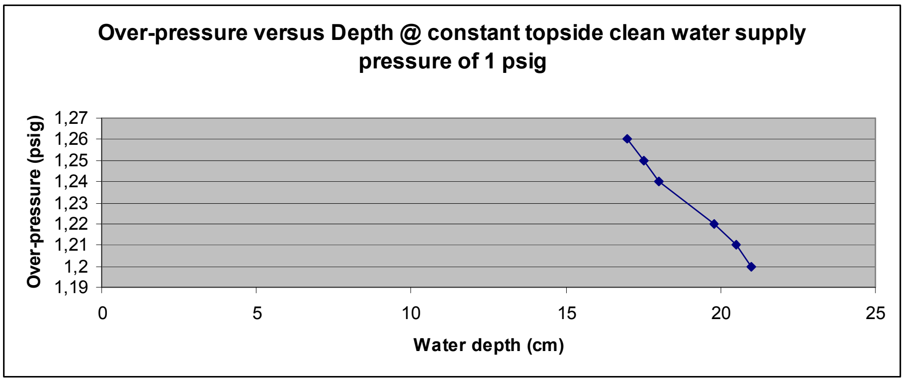

Figure 4.7: Plot of depth of water at flooding and the over-pressure to observe the holes on the pipeline

Figure 4.7 shows a gradual decrease of the over-pressure with increase in depth of water. This is expected because the supply pressure is fixed and it is required to overcome the pressure head of the water column (depth of water above the surface to be observed) in order to displace the unclear water and even cause the clean water to flow.

If the supply pressure is fixed as in our case, and water is the deepening, less sufficient would the supply water pressure be to be able to displace the unclear water and cause flow positively. In-fact, if the pressure due to the column of water becomes equal to the supply pressure, flow would not be achieved as the overpressure would have been zero.

The implication of this relation is that, though over-pressure of 2 psig or preferably less, is best for this equipment, in deeper water, higher supply pressure may be required to operate the equipment as larger water column would have to be balanced for flow to occur from equipment to the surrounding water.

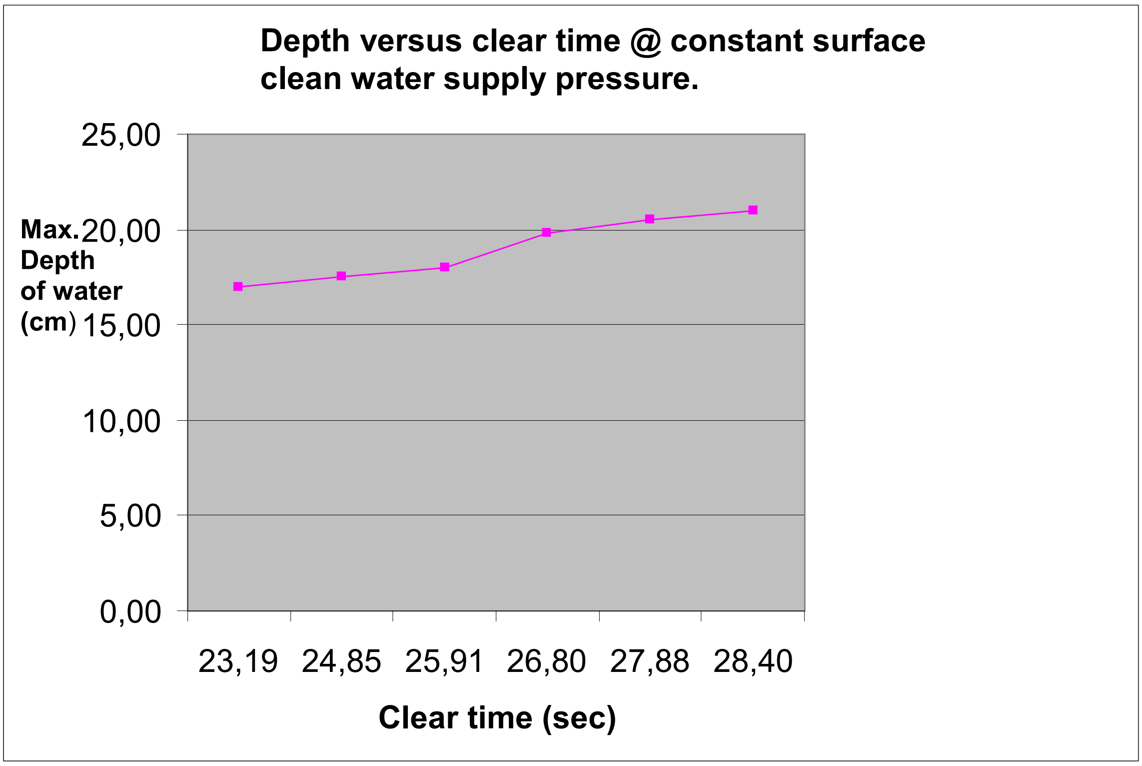

Figure 4.8: Plot of depth of water at flooding and the time to observe the holes on the pipeline

Figure 4.8 indicates that at a fixed clean water supply pressure, the deeper the water depth, the longer time it takes for the observation to be made. The fixed supply pressure implies reduction in over pressure as the water column pressure (head) increases.

The implication of this relation is that with a requirement of the over-pressure of less than 2-psig, the operator/engineer would have to calculate the required clean water supply pressure given the depth of water to be observed.

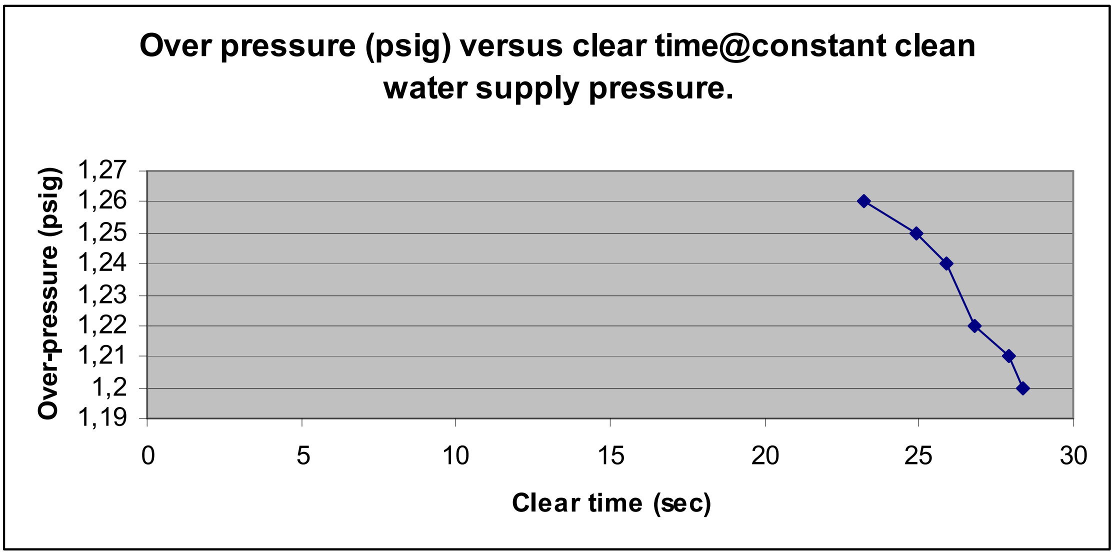

Figure 4.9 plot of over-pressure versus clear time.

The decrease of clearity time with increase in over-pressure as showed in figure 4.9 correlates with the requirement of displacement of the surrounding unclear/muddy water. However, very large supply pressure (which invariably would yield higher over-pressure for a given depth of water) generates non-laminar low over the surface of the pipeline structure, making the picture irregular to observe (for example, see figure 4.10 below).

Notice that TR003 evidences that though it could take longer time to have clear observations, for instance, at very low over-pressure, as low as 0.66 psig and 1.0psig clean water supply pressure, the photography however is better, clearer and sharper.

Figure 4.10 showing non-laminar flow over a pipeline surface.

Referencing the result of the different tests in section 4.2, the following observations and deductions were made:

4.5.1 TR 001

1. Clearity of the observation would improve with wattage of illumination lamps
2. Surface cleaness of the transparent glass contributes to the clearity of the object being observed.
3. A camera that has a zooming capability and best optical power will have better photos.

4.5.2 TR 002

4. Period of time to achieve clearity of observation increases with decrease in over pressure. This is because pressure is required to keep the unclean water away from flooding box enclosement.
5. The soft foam on the equipment (without valve system) enables easy communication between flooding box and external surrounding muddy water. Compared with the installed valve system of TR003, time to achieve clearity of observation is longer (nearly 1.5 times)
6. Also comparing with TR003, volume of water used to achieve clearity of observation is larger. This is not surprising because the time taken to flood is longer.
7. This arrangement has some similarity with the work of Almon J. et al (1977).

4.5.3 TR 003

8. Clearity of observation appears to show a dependence on the overhead pressure.
9. The laminar flow development at 1-psig supply pressure and 0.66 psig over-pressure is the key factor on the reason for the good clearity.
10. Clearity of observation is only achieved when flow is laminar. This was achieved by flooding full the water line and then stabilizing the flow at constant flowing pressure of 1psig. Attempts to increase pressure results in wakes and water separation at the pipeline surface.
11. Period of time to achieve best clearity increases with increase depth of the water.
12. With the installed valve system, time to achieve clearity of observation even at lower overpressure, decreases.

4.5.4 TR 004

13. Relatively lower pressures provide better clearity of observation.
14. Photos appear to be clearer at relatively lower pressures after a gradual flooding at relatively high pressures.

4.5.5 TR005

15. Clearity diminishes with decrease in box pressure.

4.6 Additional inference from the tests

Field experience has shown that beach pulling, results in damages to the field joint wrappings during the pulling process. One can be certain to avoid this, only when the field joint wraps are concreted.

However, contractors and even operators most often, overlook the concreting of the field joint wraps believing that no damage could be made as the beach pulling procedure would always theoretically show, coupled with the time savings that would be made in the pulling process (without the concreting). The point has been that the beach pulling is often made near coasts/beaches where bottom settlements are mobile and therefore underwater visibility is poor. Additionally, in practice, divers are rarely sent underwater to investigate the conditions of the field joint wraps because of the wave condition and poor underwater visibility in these shore approach areas. The consequence is therefore a deception that all is fine when in reality it is not (except of course, if the field joint wraps is concreted), because no investigation could prove so.

In the course of the tests, the pipeline was wrapped and the wrap was damaged at the 12-O-clock position and the pipeline submerged in the muddy/unclear water. It turned out that the equipment can be a reliable tool to investigating the joint wraps to ensure intactness, especially when it is made to operate diverless.

The implication of field joint wrapping damage is the leakage of cathodic protection current which otherwise is meant to flow in the pipeline structure, protecting the pipeline against corrosion.

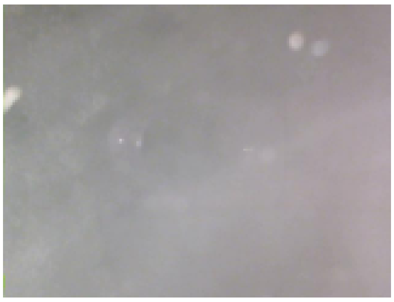

Figure 4.11 showing the photo of the field joint wrap before clean water flooding.

Figure 4.12 showing the photo of the field joint wrap after clean water flooding.

4.7 Conclusions

Within the limits of the experimental work presented in this thesis, it is established that close-visual observations can be adequately and reliably conducted for underwater structures, for example, leaking pipelines irrespective of the degree of underwater visibility by simply flowing a stream-lined steady (laminar) flow over the structure and observing from top of the flow.

The ability to observe a structure even with the use of coloured flavors and clays/mud to generate various levels of underwater visibility implies that the source of the underwater visibility do not matter for the equipment to operate.

The benefits of this work has been discussed, ranging from leaking structures close-visual inspection including pipelines, to subsea pipeline field joint wrap damage inspection for beach pulls. It has also been pointed out that this technique is cheap, robust and flexible.

However, further work is still required to adequately establish the theory and extend the design to be remotely operated and diverless equipment. It is also suggested that further work be made into the oil/gas plume and surface slick phenomena as the present literatures, especially on surface slick is inadequate. It is believed that the adequate determination of surface slick for instance, could be relevant for proper remediation of marine environment for subsea oil/gas leaks.

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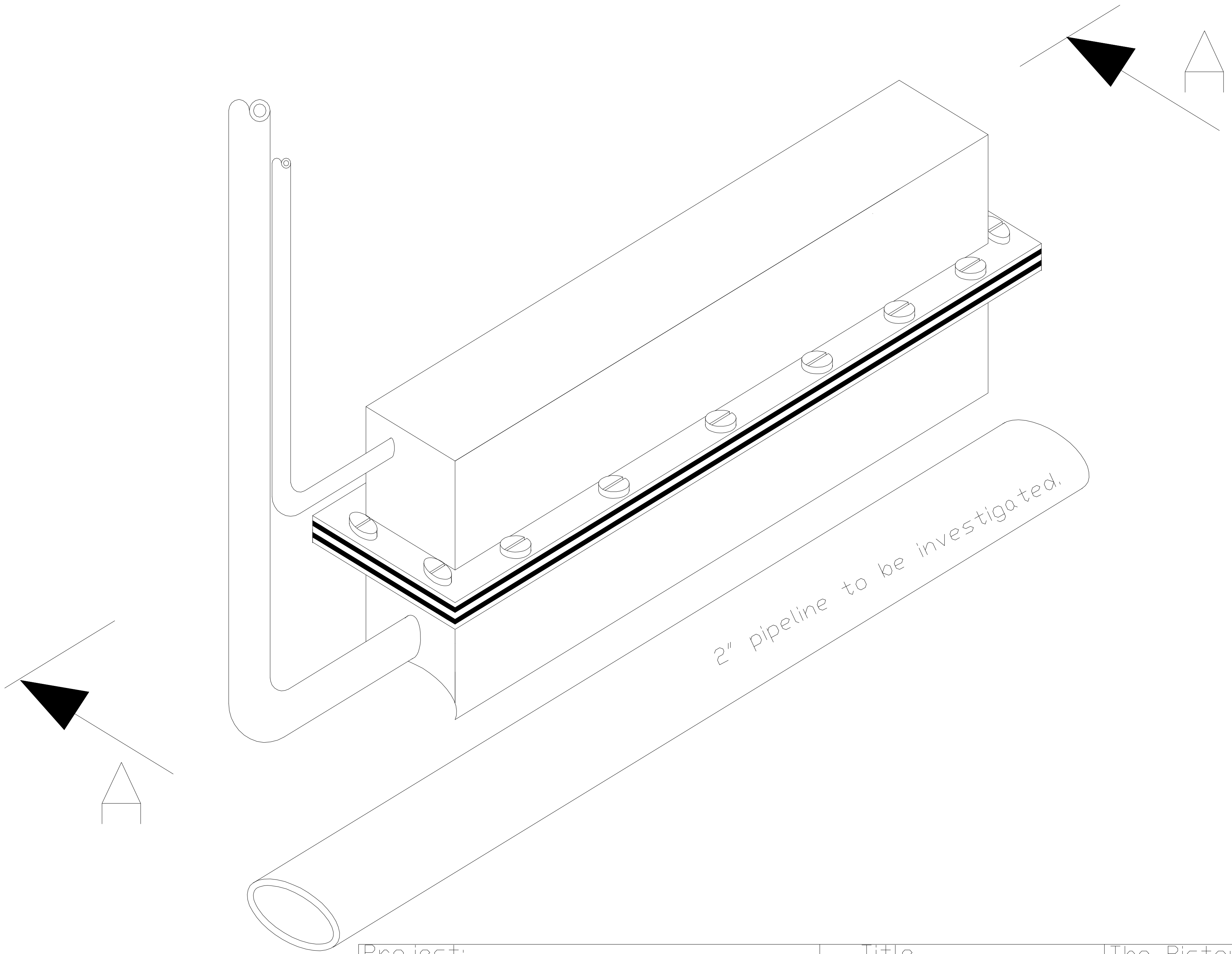
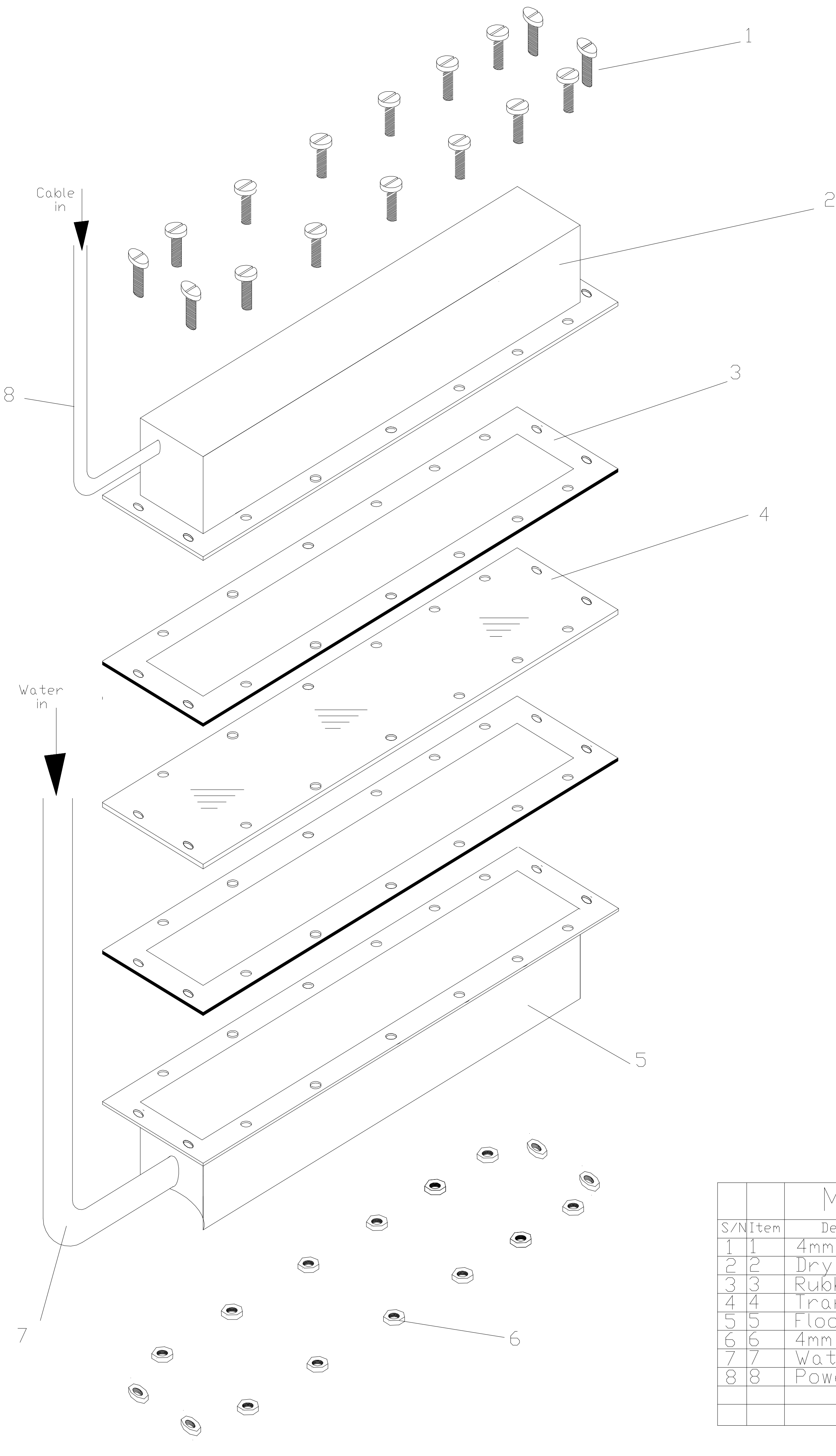
Appendices

Appendix 1 – Fabrication drawings
Appendix 2 - TR001 results
Appendix 3 - TR002 results
Appendix 4 - TR003 results
Appendix 5 - TR004 results
Appendix 6 - TR005 results
Appendix 7 - TR006 results
Appendix 8 – Notarius confirmed document (demonstrating ownership to the invention)
Appendix 9 – Description of further work

APPENDIX 1
(The fabrication drawings)

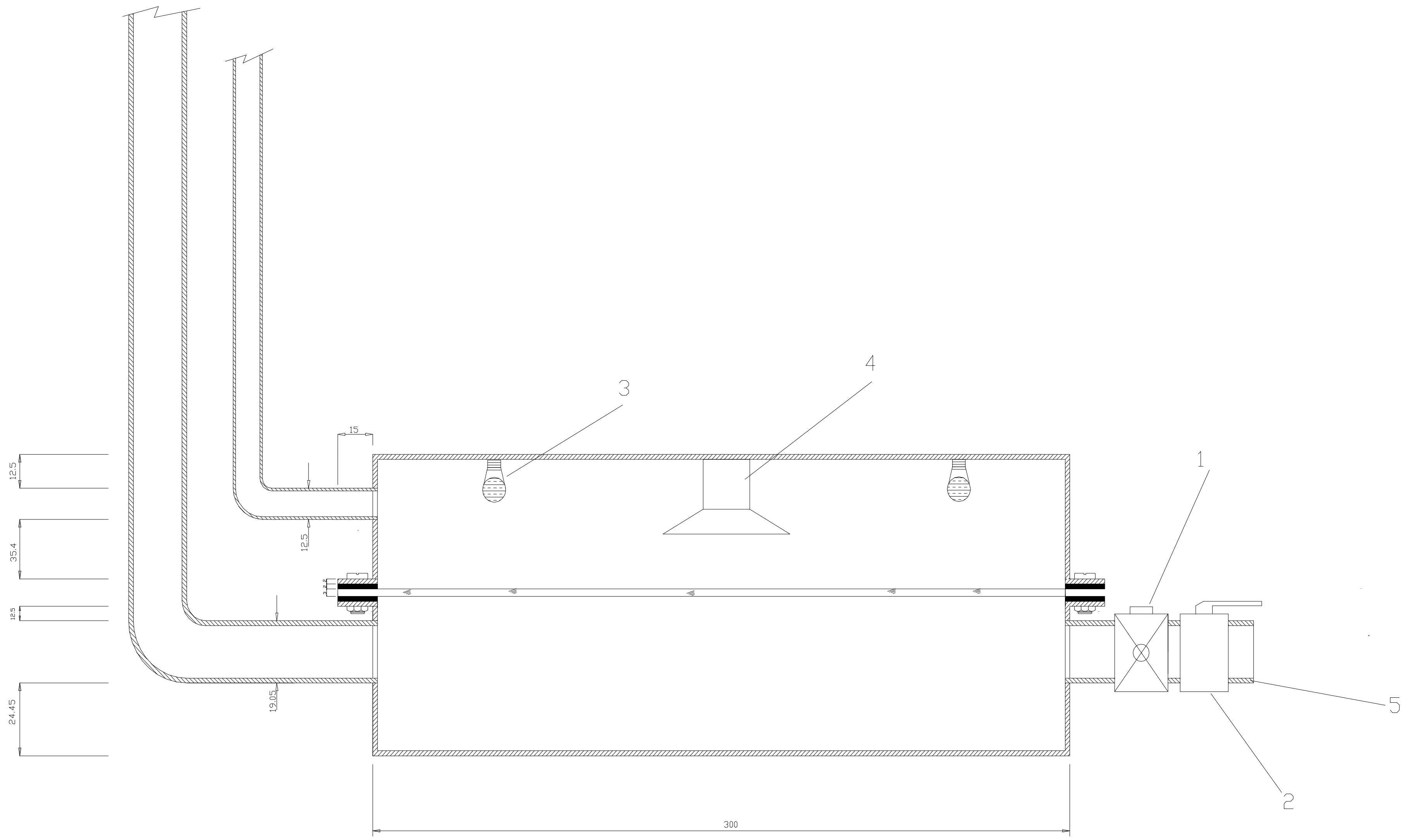


Project: Conception & Development of method/apparatus for close-visual inspection of subsea pipelines leaks	Title	The Pictorial View of the survey tool
	Designed/Drawn by	A.A.Jasper
	Reviewed/Approved by	O.T.Gudmestad
	Scale /Date	1:1 (on A1 paper)1 20.01.2010 All dimensions in mm: DRWG # J001



		MTO	
S/N	Item	Description	Qty
1	1	4mm stainless steel bolts	16
2	2	Dry box	1
3	3	Rubber gasket	2
4	4	Transparent glass	1
5	5	Flooding box	1
6	6	4mm stainless steel nuts	16
7	7	Water inlet line	1
8	8	Power/Comm conduit	1

Project: Conception & Development of method/apparatus for close-visual inspection of subsea pipelines leaks		
	Title	Assembly drawing of the survey tool
	Designed/Drawn by	A.A.Jasper
	Reviewed/Approved by	O.T.Gudmestad
	Scale /Date	1:1(on A1 paper / 20.01.2010 All dimensions in mm : DRWG #: J002

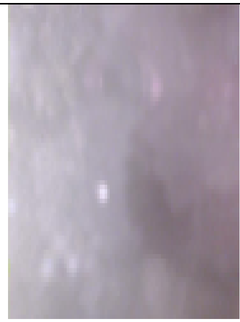


MTO			
S/N	Item	Description	Qty
1	1	Flow check valve	1
2	2	On/Off flow valve	1
3	3	55w illumination lamp	2
4	4	30-frp webcam	1
5	5	Exhaust line	1

Project: Conception & Development of method/apparatus for close-visual inspection of subsea pipelines leaks	Title	Section A - A of the survey tool
	Designed/Drawn by	A.A.Jasper
	Reviewed/Approved by	O.T.Gudmestad
	Scale /Date	1:1(on A1 paper / 20.01.2010
		All dimensions in mm : DRWG # J003

Appendix-2

Test Result s(TR 001): Standardizing equipment photo clarity in clean water (Pipeline marking)

Secchi disk before flooding (mm)	Secchi disk after flooding (mm)	Photo of the test water	Photo taken with the illuminating lamps off	Photo taken with the illuminating lamps on
Infinity	Infinity			

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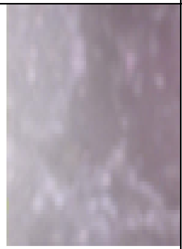
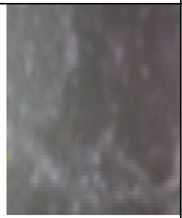
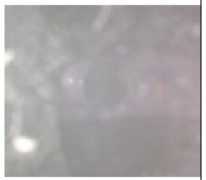
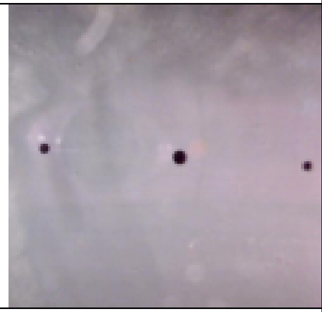
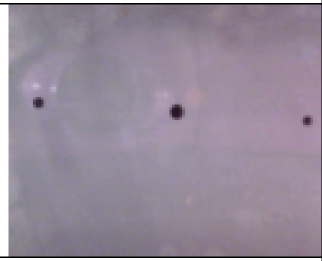
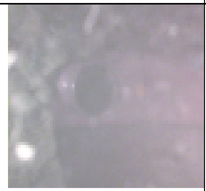
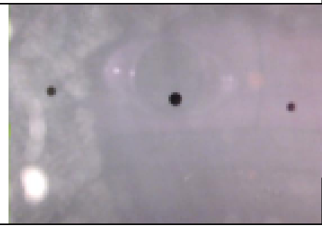
Appendix-3

Test Results (TR 002)- Without an outlet valve system installed on equipment: (Hole is 1.5mm diameter)

S/N	Height of water (m)		Flooding pressure (psig)	Volume of clean water used to get clear photo (l))	Photo of hole clarity before flooding	Photo of hole clarity during flooding	Photo of hole clarity after flooding	Period to achieve clarity (sec)	Hydrometer reading before flooding	Secchi disk before flooding (mm)	Hydrometer reading after flooding (g/l)	Secchi disk after flooding (mm)
	Before flooding	After flooding										
	15	18	2	14				35	14.2	8	12	10
Max. Over-pressure @ clear = 1.74psig												
	20	22	2	9.5				42	10	12	9	14
Max. Over-pressure @ clear = 1.69psig												
	22	24	2	9.5				45	9	14	8	15
	Max. Over-pressure @ clear = 1.66psig											

Appendix-4

Test Results (TR 003): With an outlet valve system installed on equipment: (Hole are 1.5mm and two 1.0mm diameters)

S/N	Height of water (m)		Flood pressure (psig)	Pressure at flood stop at clear water (psig)	Photo of hole clarity before flooding	Photo of hole clarity two 1mm holes and centered 1.5mm hole during the 1psi lamina flooding.	Period to achieve clarity (sec)	Hydrometer reading before flooding (g/l)	Secchi disk before flooding (mm)	Hydrometer reading after flooding (g/l)	Secchi disk after flooding (mm)	Volume of clean water used to get clear photo (l))
	Before flooding	After flooding										
	22.5	23.5	1	No flood stop. 1psig flowing pressure			29	5	17	4.5	20	7.2
	Max. Over-pressure @ clear = 0.66psig											
	23.5	24.5	1	No flood stop. 1psig flowing pressure			33	4.5	20	4	23	7.2
	Max. Over-pressure @ clear = 0.65psig											
	24.5	25.5	1	No flood stop. 1psig flowing pressure			35	4	23	3.5	26	7.2
	Max. Over-pressure @ clear = 0.64psig											

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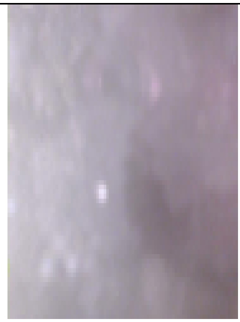
Appendix-5

Test Results (TR 004): Pressure variations (Pipeline marking)

Secchi disk before flooding (mm)	Secchi disk after flooding (mm)	Photo of the test water	Photo of mark clarity before flooding	Photo of mark clarity during flooding at 6psig	Photo of mark clarity during flooding at 3psig	Photo of mark clarity during flooding at 2psig	Photo of mark clarity during flooding at 1psig
12	15						

****Equipment is without an outlet valve system installed**

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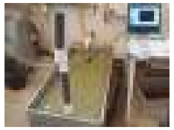
Appendix-6

Test Results (TR 005): Clearity/Flooding Box Pressure variations (Pipeline marking)

Secchi disk before flooding (mm)	Secchi disk after flooding (mm)	Photo of the test water	Photo of mark clarity before flooding	Photo of mark clarity during flooding at 2psig prior to flooding stop.	Photo of mark clarity just immediately the flooding stop	Photo of mark clarity 1-minute after flooding stop. Box Pressure = 78psig (55cm head)	Photo of mark clarity 2-minute after flooding stop. Box Pressure = 68psig (45cm head	Photo of mark clarity 5-minute after flooding stop. Box Pressure = 0.41psig (29cm head)	Photo of mark clarity 20-minute after flooding stop. Box Pressure = 0.17psig (12cm head
30	35								

****Equipment is without a outlet valve system installed**

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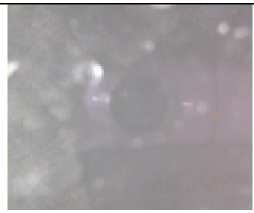
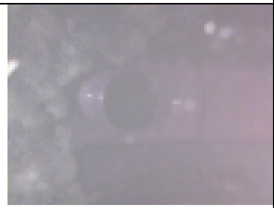
Appendix-7

Test Results (TR 006): Equipment is without a outlet valve system installed (Hole: 1.5 and 1.0mm diameter)

S / N	Height of water (cm)	Flood pressure (psig)	Water pressure maintained at clear view (psig)	Photo of hole clarity before flooding	Photo of hole clarity two 1mm holes and centered 1.5mm hole during the 1psi lamina flooding.	Period to achieve clarity (sec)	Hydrometer reading before/after, g/l	Secchi disk before /after test (mm)	Depth at which fingers could be counted, mm	Volume of water used to achieve clarity (litres)
	Before Flooding: 16 After Flooding: 17	1.5	1.5-psig flowing pressure			23.19	Before Test: 10 After Test: 8.5	before Test: 10 After Test: 12	before Test: 0 After Test: 0	7.3
	Max. Over-pressure @ clear = 1.26 psig									
	Before Flooding: 17 After Flooding:17.5	1.5	1.5psig flowing pressure			24.85	Before Test: 8.5 After Test: 8	before Test: 12 After Test: 13	before Test: 0 After Test: 0	3.7
	Max. Over-pressure @ clear = 1.25 psig									
	Before Flooding; 17.5 After Flooding: 18	1.5	1.5-psig flowing pressure			25.91	before Test:8 After Test: 7.5	before Test'13 After Test: 14	Before Test: 0 After Test: 0	3.7
	Max. Over-pressure @ clear = 1.24 psig									

Appendix-7 (contd)

Test Results (TR 006) contd.

S / N	Height of water (cm)	Flood pressure (psig)	Water pressure maintained at clear view (psig)	Photo of hole clarity before flooding	Photo of hole clarity two 1mm holes and centered 1.5mm hole during the 1psi lamina flooding.	Period to achieve clarity (sec)	Hydrometer reading before/after, g/l	Secchi disk before /after test (mm)	Depth at which fingers could be counted, mm	Volume of water used to achieve clarity (litres)
	Before Flooding: 19 After Flooding: 19.8	1.5	1.5psig flowing pressure			26.8	Before T est: 7.5 After Test: 7	before Test: 14 After Test: 15	before Test: 0 After Test: 0	5.8
	Max. Over-pressure @ clear = 1.22 psig									
	Before Flooding: 19.8 After Flooding: 20.5	1.5	1.5psig flowing pressure			27..88	Before Test: 7 After Test: 6.5	before Test: 15 After Test: 15.5	before Test: 0 After Test: 0	5.1
	Max. Over-pressure @ clear = 1.21 psig									
	Before Flooding; 20.5 After Flooding: 21	1.5	1.5psig flowing pressure			28.4	before Test:6.5 After Test: 6	before Test: 15.5 After Test: 16	Before Test: 0 After Test: 0	3.7
	Max. Over-pressure @ clear = 1.20 psig									

The unclear water: What it looks like.

Water clarity before flooding =10mm, Water clarity after flooding =15mm

Water clarity before flooding =12mm , Water clarity after flooding =15mm

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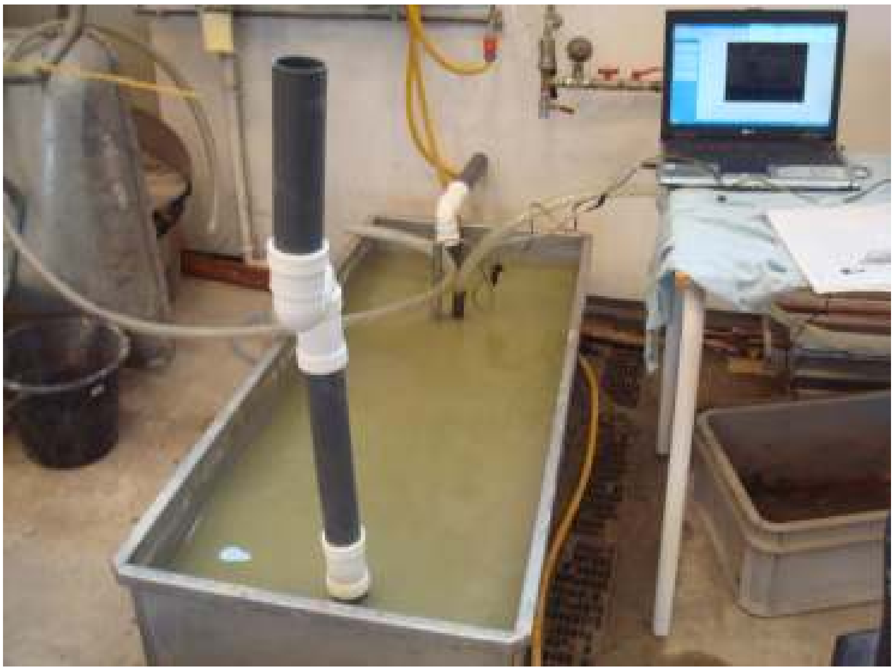
Water clarity before flooding =30mm , Water clarity after flooding =35mm



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APPENDIX 8
(Notarius confirmed document)

Method and apparatus for Close-Visual Inspection of Sub-sea Structures in Muddy/Unclear Waters.

Inventors:

- **Jasper Ahamefula Agbakwuru, Ugleveien 4, 4042 Hafrsfjord, Norway.**
- **Ove Tobias Gudmestad, Søylandsvegen 61, 4365 Nærbø, Norway.**

1. Introduction

In regions where the topography channel runoffs via rivers to common targets, made of loosely sediments and with the coastal areas and delta underlain by soft geologically young loosely sediments, rainfalls then sweeps the whole large area of region, coupled with regular tides that wash the coast-lines, and deposit the contents to the coastal waters.

The consequence is that the littoral area, from swamps to the coast and in some instance, some miles from shore is characterized by underwater poor visibility. This is the case in some Nigeria littoral waters. Unfortunately, pipelines from oil and gas fields run through these areas and often, underwater inspection and repairs are required to be carried out. The present technology does not address the problems of observing leaking problems clearly by topside engineers, i.e. leaking from structures such as pipelines independent of water clarity.

2. The limitation with the present technology is considered to be as follows:

The most advanced technology for observations in poor visibility underwater is a revolution of video editing, a form of video cleaning technology. The spectra clarification is done in real time in a live video stream. It can also be done on stored material by playing back the video.

(a). The existing invention offers an improvement limited to the water clarity. The product specification for the presently used equipment recommends that the equipment shall see as much as possible but the visibility cannot be compared to when the video is made in clear water. There is no guarantee. It is possible to see nothing if the water clarity is very limited.

In the present invention, we will deal with the requirement of seeing clearly independent of water clarity by displacing the unclear water near to the surface of the structure to be observed using pressured-clear-water supplied from equipment placed on the surface. The camera eye would then be placed at top of the clear water for

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har undertegnet dette dokument
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Jæren District Court and Notary Public
Anne Marie Boganes
Anne Marie Boganes

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25.02.10

observations. The clear water simply becomes a path through which the camera eye sees.

(b). The existing technology for close observations of structures are sophisticated, equipment demanding and relatively costly to operate.

In contrast, the new innovation is robust. The cost of fabrication is a minute of the cost of the existing technology. The new innovation achieves this requirement by employing a simple flooding box, a digital video camera and illumination lamps. These can be designed, fabricated and assembled together in shops to sleep-fit on the structure to be observed using common materials without much engineering complexities.

(c). The improvement of the visibility by spectra clarification does not include larger scaterrers and water unclarity due to effect of biochemical composition.

The new innovation does not see the differences and sources of unclarity, it displaces whatever the unclear water is with pressured-clear water that the camera can see through.

The new innovation solves the situation of larger/lump scaterrers or sediments etc that may not easily filter out of the flooding box from the permeable soft foam base by installing a one directional (check) valve in-line with the in-coming flooding water line. The check valve will have on/off valve to shut-in after few seconds of flooding to enable the larger/lump scatterers or sediments to be flooded out of the surface near to the structure to be observed.

3. Description of method and apparatus for Clear-Water-Flooding Technique for Sub-sea Structures' Close-Visual Inspection in muddy/unclear waters.

The configuration of the equipment could vary depending on the configuration of the structure to be observed. The common operational characteristic however, is the same: The flooding box marries to fit on the part of the structure to be observed, be they pipelines, anodes etc.

In the following is given a description for Clear-Water-Flooding Technique for Sub-sea Pipelines Leak Close-Visual Inspection in Muddy/Unclear Water. Reference is made to figures 1, 2 and 3 below.

The equipment, on its soft foam (5) marries the part of the pipeline to be observed and clean water is flooded from the topside through the flood-line (1). The lines from the power/communication conduit (2) are attached to a computer and the topside engineer monitors the clearness on the computer screen and stops the flooding once clear water is dominating the flooding box (4). The pressure is retained in the flooding box while the illuminating lamps (11) illuminates the area of interest and the camera eye (10) in the top box (3) is observing through a transparent glass (9) and the clear water in the flooding box (4). The view of this part of the pipeline enclosed by the equipment remains clear enough for good observations by the topside engineer for some good minutes. Figure 3 shows a detail of the sealing (13) and fastening (12) of the flooding box (4) below the top-box with the top-box carrying the electrical/electronic gadgets.

The instrument can be moved 360 degrees round the circumference of the pipeline (provided the pipeline is lying freely above the bottom or is trenched free from the bottom sediments) and/or along the pipeline as the operator wishes. However, movements of the equipment round or along the pipeline often results in some reduction in clarity. Clarity is again regained by flooding with clean water from topside.

Should there be lumps, sediments or larger scaterers which may not permeate through the soft foam, the valve (8) is opened and the flooding is activated to flood away the sediments from the flooding box through the check valve (6). The valve (8) is closed once clarity is regained.

For pipeline hole/crack geometry identification, an internal pressure in the pipeline very little above the pressure in the box put on the line is sufficient for quick and easy finding.

4. Potential Patent Claims

In view of the above description, the following claims may be set forward to which we seek patent protection:

Claim 1. A method and apparatus for close visual inspection in muddy or unclear water characterized by utilizing a technique of clear water pumping or flooding of a chamber that is placed near to the location to be investigated.

Claim 2. A method and apparatus for close visual inspection in muddy or unclear water as described in claims 1 characterized by observing the location to be investigated in muddy or unclear water by use of lights and cameras or other visual techniques utilizing the clear water flooding technique.

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Claim 3. A method and apparatus for close visual inspection in muddy or unclear water as described in claims 1 and 2 characterized by automating or manually operating the close visual inspection or observation, equipment utilizing the technique of clear water flooding.

Claim 4: A method and apparatus for close visual inspection in muddy or unclear water as described in claims 1 to 3 characterized by use of check and on/off valves to facilitate the clarity in the flooding box in claims 1, 2 and 3.

5. Figures

Figure-1. View of a sample of the equipment for pipeline leaking hole or crack geometry identification

Figure-2. Section A-A of figure 1 showing the camera, the lamps and the transparent sealing glass above the flooding box.

Figure-3. A detail of the sealing and fastening of the flooding box below the top-box with the top-box carrying the electrical/electronic gadgets.

6. Date

Written on 24th February 2010.

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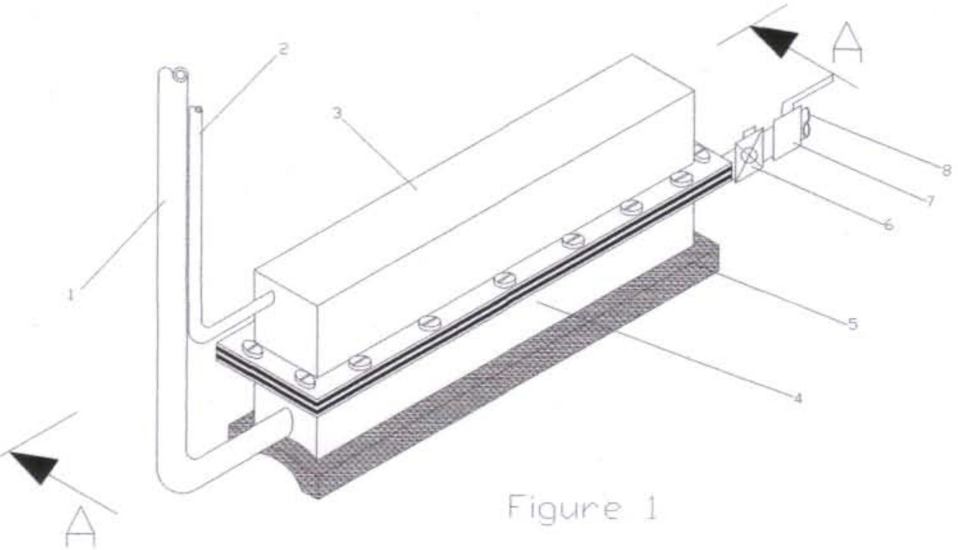
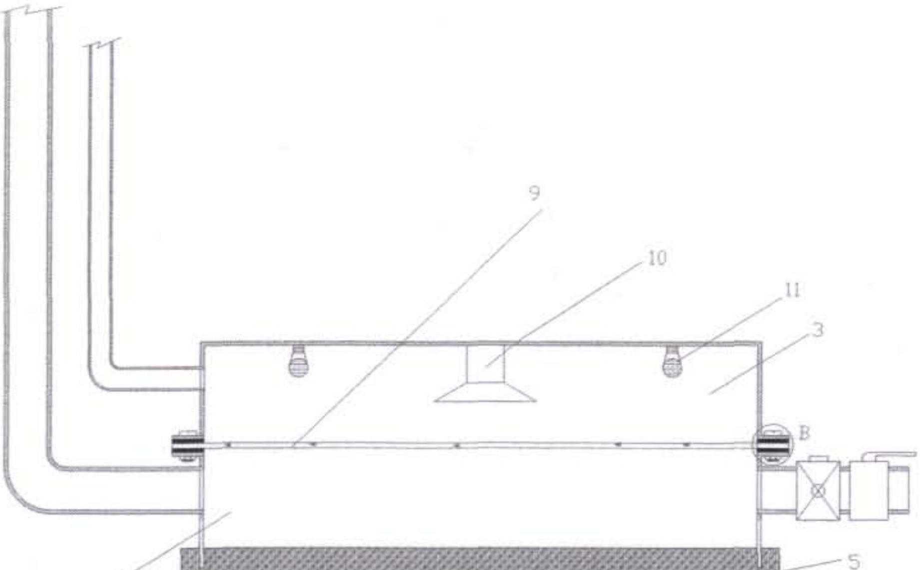


Figure 1



Section A-A

Figure-2

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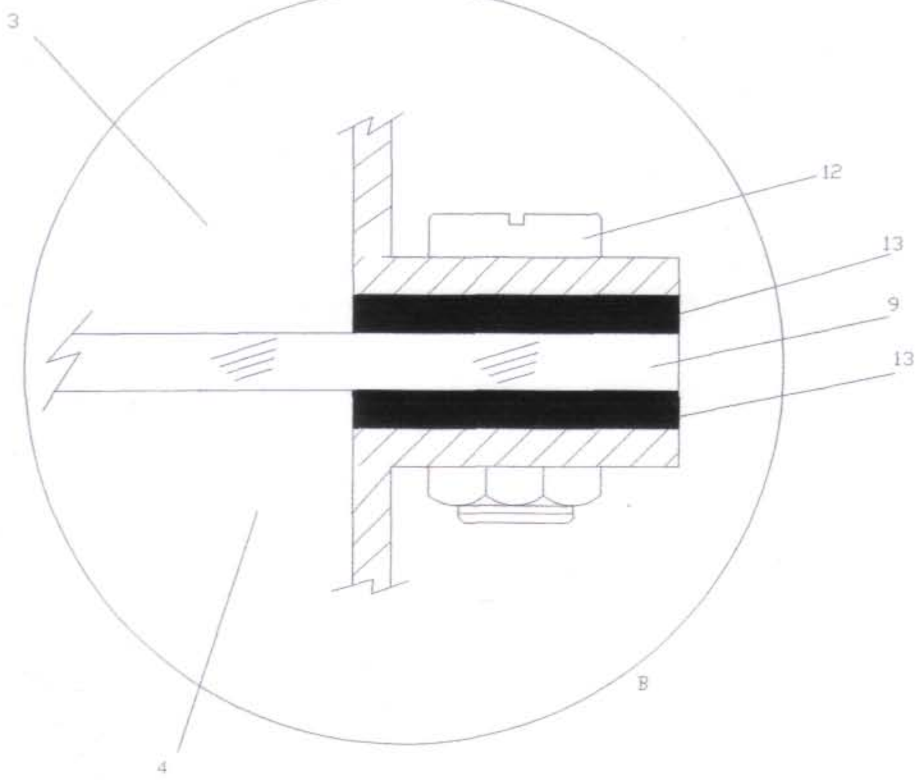

Figure-3

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APPENDIX 9

(Description of further work)

Brief project description

Topic: Further development on the method/apparatus for close-visual inspections of leaks in subsea pipelines: a diverless and plume tracking concept.

Key words: Pipelines, Diverless, Leaks, Plumes, Jetting

Summary
Our master thesis, (Agbakwuru, 2010) on this subject firmly established that we can clearly observe structures, including leaking structures such as pipelines, submerged in muddy/unclear water from surface, independent of the degree or source of poor underwater visibility. As part of a suggested PhD work, this principle would be explored and developed further to enable the equipment to operate diverless and with jetting capability to be able to assess pipelines that are fully or partially buried in subsea characterised by underwater poor visibility.

One of the technical interests would be to be able to trace the position of a pipeline or structural leaks with an accuracy of $\pm 0.3m$ without a diver or an intelligent pigging facility (which are risky, costly and time demanding). This is rather suggested to be achieved using a proposed simple tool we hope to call 'the plume-hole tracker'.

When the diverless observation is achieved with the plume-hole tracking device, we will further demonstrate that the plume-hole tracker's capability can be harnessed for the development of a system to temporarily arrest leaks from pipelines within certain range of operation pressure within a relatively short time, cheaply and diverless, keeping production time, till permanent repair works can be planned and executed.

As it was shown in the master thesis work, every attempt would be made to ensure the design is simple, cheap and robust especially for easy use in **SHELL Petroleum and Development Company West and East swamps and estuaries oilfields of Nigeria in West Africa, which we hope to use as a case study for this work**.

Problem formulations:

The work of Reed et al (2006) and Rye & Brandvick (1996) agree that oil and gas plume that form when an oil and gas subsea pipeline leaks, is conical and rises vertically towards the surface with the plume vertical momentum fading as pressure drops or water column gets larger. In other-words, a plume, even when artificially generated by pressurized gas/air with good momentum can generate vertical velocity and acceleration of motion of fluid which could be tracked and used as guide to track the pipeline point of leak. This would be the basis of operation of the plume-hole tracker. Note that the natural sequence of handling oil pipeline leak is to shut-down production through the line and water flush to minimize spillage to the environment. This work proposes an extension of this sequence to application of air/gas pressure in the pipeline to reproduce gas plumes.

Once the leaking point is tracked and the global position is taken and encoded into a remotely operated type of the close-visual inspection apparatus, the equipment then approaches the identified pipeline section, jet away surrounding soils and capsulate the pipeline for clear observations as described in our master thesis work. In this further work, the equipment would be designed as two half-shells hinged like a caliper with the jetting system installed on the dry box. The capsulation capability of this equipment would be employed for the temporary repair work as proposed above.

The benefit of this work cannot be over emphasized as the inability of the pipeline engineer to observe the conditions of the leaks makes him vulnerable to errors, misleads and use of costly approaches for solving a little problem. This work targets to enable the pipeline engineer to have the opportunity to see the technical condition of leaking subsea pipelines in muddy/unclear water in order to make best economic decisions and plan the repair strategy without the involvement of a diver.

Also the proposed work on the temporary repair technique using the plume tracking phenomenon and capsulation capability of the equipment would be a pillar in combating production losses due to pipeline leaking problems especially in Niger delta areas of Nigeria where the pipelines are aged and communal and security issues militate against mobilization of new pipeline construction projects.

Based on the above description, we propose the following to SHELL;

1. That SHELL shall receive rights and privileges to use the technology/equipment in any form. For instance, SHELL could decide to manufacture or have others to manufacture the equipment as part of the tools to be used by the Spill Emergency Team to quickly arrest leaks in swamps, estuaries and even offshore and enable production within short period of time and with minimal manpower. It will again, go a long way to further demonstrate SHELL's commitment to the protection of the environment in the regions where they operate, especially in sensitive areas such as the Niger Delta of Nigeria.

2. That SHELL provide part finance for a PhD programme of the University of Stavanger for Jasper Agbakwuru, under the supervision of Professor Ove T. Gudmestad , over a period of three (3) years, within which the technology/equipment would be fully developed for use. The programme should commence in August, 2010.

3. That SHELL has collaboration with the University of Stavanger on environmental issues, especially as regards surface slicks of oil and gas where we identified in the master thesis work that the present existing model is inadequate.

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References:

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