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DESIGN OF A NOVEL CLAMP FOR ON-LINE FLUID LEAKS IN PETROCHEMICAL INDUSTRY, OIL REFINERIES AND POWER PLANTS

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ABSTRACT

Most pipelines in petrochemical industries, oil refineries and power plants operate at high temperatures and pressures. Leaks can develop in such pipes when a pressurized fluid is confined at high temperatures. A simple and practical method is desirable to handle these types of fluid leaks. Most methods of repairing pipe leakage involve cutting and welding, which is not recommended when dealing with flammable fluids. This paper presents the design of an innovative clamp for handling such on-line fluid leaks and discusses its advantages over conventional clamps currently used in the industry.

Keywords: Clamp, Pipeline, Leakage, Fluid, Repair

1. INTRODUCTION

Pipelines in power plants, petroleum refineries and other industries vary in terms of type, diameter and length depending on the nature of the work and the type of the fluid which passes through them. Pipelines usually work in difficult working and harsh weather conditions and they often face leakage problems in vulnerable areas, such as weld locations [1, 2]. Fluid leaks are one of the most critical problems when dealing with piping. One of the most common causes of the unscheduled shut-downs in continuously running plants are fluid leaks. There are a limited numbers of techniques for detecting and handling these types of leakages, which are mostly based on practical experience of the personnel or technicians attending to such pipelines [3]. The damaged pipelines can cause huge economic losses because the operation must be stopped while the repair is performed [4].

An alternative methodology to repair localized damage in metallic pipelines is by using epoxy resins. da Costa-Mattos [5] analyzed epoxy repair systems for metallic pipelines undergoing elastic or inelastic deformations with localized corrosion damage that impair their serviceability. Since these platforms are hydrocarbon atmospheres, any repair method using equipment that may produce heat and/ or sparkling is forbidden [5]. Composite repair systems (patches) are also used in the aircraft industry to repair cracks in order to extend the service life of metallic components [6, 7]. Otegui, et al. [8] investigated local collapse of the pipe when repaired with full sleeve reinforcements and concluded that using fillers and better designed repair sleeves could offer higher resistance to breaks and blowouts that cause abrupt depressurisation in gas pipelines.

Information about requirements and recommendations for the qualification, design, installation, testing and inspection for the external application of composite repairs to corroded or damaged pipeline in petroleum, petrochemical and natural gas industries can be found in manuals and specifications like [9-13]. Several other static sealing mechanisms have also been proposed by researchers as in [14-16]. The aim of the design presented in this research, however, is to introduce a new and effective technique for sealing any on-line fluid leaks. The device material selection should be suitable to the sealed fluid, in order to avoid any corrosion or chemical reaction. It should also be noted that this device may not be used with any corrosive fluids.

2. MATHEMATICAL EXPRESSIONS FOR STRESS, STRAIN AND RADIAL DISPLACEMENT

Airy's Stress function, the scalar potential function $\varphi(r,\theta)$ that describes the stress tensor satisfies the following equations in cylindrical (r,θ,z) coordinates:

$$\sigma_r = \frac{1}{r}\frac{\partial \varphi}{\partial r} + \frac{1}{r^2}\frac{\partial^2 \varphi}{\partial r^2}$$

$$\sigma_\theta = \frac{\partial^2 \varphi}{\partial r^2}$$

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$$\sigma_{r\theta} = -\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial \varphi}{\partial r}\right) \quad (1)$$

For radial symmetry, the partial derivatives are replaced by the corresponding total derivatives. Thus, eq. (1) can be rewritten as:

$$\sigma_r = \frac{1}{r}\frac{d\varphi}{dr}$$
$$\sigma_\theta = \frac{d^2\varphi}{dr^2} \quad (2)$$

and $\sigma_{r\theta}$ vanishes. The expressions for strains in the radial and angular directions are given as:

$$\in_r = \frac{\sigma_r}{E_r} - \frac{\nu_{r\theta}\sigma_\theta}{E_r}$$
$$\in_\theta = -\frac{\nu_{r\theta}\sigma_r}{E_r} + \frac{\sigma_\theta}{E_\theta}$$
$$\in_{r\theta} = \frac{\sigma_{r\theta}}{G_{r\theta}} \quad (3)$$

where $\in's$ are the corresponding strains, E_r is the extensional modulus in the radial direction and $G_{r\theta}$ is the shear modulus.

Substituting σ_r and σ_θ from eq. (2) into eq. (3) above,

$$\in_r = \frac{1}{rE_r}\frac{d\varphi}{dr} - \frac{\nu_{r\theta}}{E_r}\frac{d^2\varphi}{dr^2}$$
$$\in_\theta = -\frac{\nu_{r\theta}}{rE_r}\frac{d\varphi}{dr} + \frac{1}{E_\theta}\frac{d^2\varphi}{dr^2}, \quad (4)$$

and $\in_{r\theta}$ vanishes. If the displacements in the angular direction are zero, then

$$\in_r = \frac{\partial u}{\partial r}$$
$$\in_\theta = \frac{u_r}{r} \quad (5)$$

Combining the two seperate equations in (5) into one,

$$\frac{\partial \in_\theta}{\partial r} = \frac{\in_r - \in_\theta}{r} \quad (6)$$

Substituting eq.(3) in eq. (6),

$$\frac{1}{E_\theta}\left(\frac{d^3\varphi}{dr^3} + \frac{1}{r}\frac{d^2\varphi}{dr^2}\right) = \frac{1}{r^2E_r}\frac{d\varphi}{dr} \quad (7)$$

The choice of φ is now constrained by the third order ordinary differential eq. (7). The following expression for φ clearly satisfies eq. (7):

$$\varphi = C_1 + C_2 r\wedge\left(1 - \sqrt{\frac{\in_\theta}{\in_r}}\right) + C_3 r\wedge\left(1 + \sqrt{\frac{\in_\theta}{\in_r}}\right)$$

The radial displacement is obtained as:

$$u_r = -\sqrt{\frac{\in_\theta}{\in_r}} C_2 r\wedge\left(-\sqrt{\frac{\in_\theta}{\in_r}}\right)\left(\frac{1}{E_{\theta\theta}} + \frac{\nu_{r\theta}}{E_{rr}}\right)$$
$$+ C_3\sqrt{\frac{\in_\theta}{\in_r}} C_2 r\wedge\left(\frac{1}{E_{\theta\theta}} - \frac{\nu_{r\theta}}{E_{rr}}\right) \quad (8)$$

As long as the radial displacement in eq. (8) is reasonably low compared to the nominal diameters of the pipelines, it can be assumed that the pipelines can function properly as designed.

3. BACKGROUND

The usual procedure when facing a punctured pipeline having a flammable fluid in any working unit is to shut the entire unit down and then carry out the necessary repair by cutting the vulnerable portion of the pipeline and replacing it with a new one (using a suitable welding process). Shutting down any working unit is very costly because of the associated opportunity cost of downtime. A patch can be welded on the punctured pipeline provided it does not contain any flammable fluid; however, this is not possible for flammable fluids, or if the fluid flow rate is very high. Figure 1 shows different types of patch welding that may be employed in leaking pipes. In some cases, the defective pipeline can be isolated, but because of the passing isolation valves, cutting the punctured pipeline or welding patches may not be possible especially if the fluid is flammable.

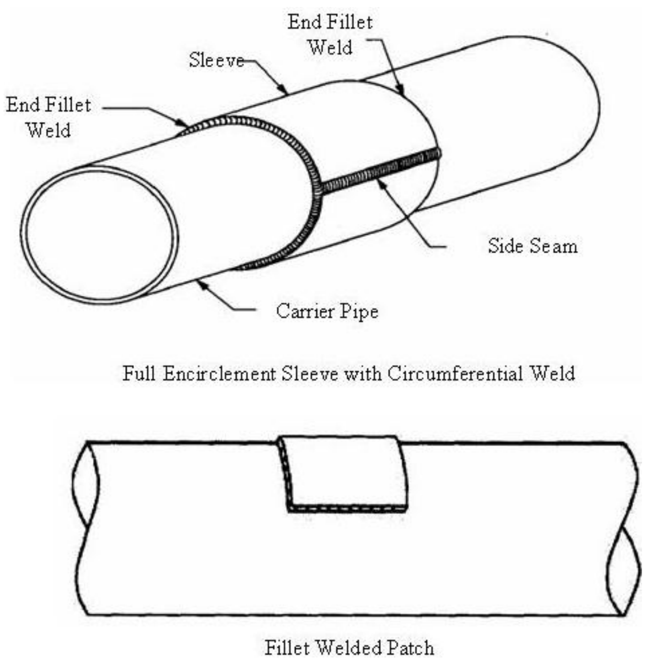

FIGURE 1. Different types of patch welding

There exist a few solutions to these kinds of problems without the need for shutting down the entire unit or performing any type of welding [4]. Some companies like Furmanite Corporation use a box enclosure which is designed and fabricated using criteria found in the ASME Boiler and Pressure Vessel Codes [17]. This box is placed over the punctured pipeline and injected with an isolation compound through the injection valve attached earlier to the box. This solution is acceptable; however, it is very expensive and time consuming.

4. THE NEW DESIGN

From all the above scenarios and practical experience, it is clear that there is a great demand for an alternative solution to the previously mentioned problems and the following issues:

a. Shutting down the entire unit and carrying out the repair. Using the proposed clamp, there is no need to shut down the unit as the clamp may be fixed while the unit is still running.

b. Pipe isolation (making sure that there is no passing from the isolation valves). The proposed clamp may be fixed even if the isolation valves are passing.

c. Long time of repair. The proposed clamp can be fixed within hours; therefore, it does not require a long time like the traditional methods of repair.

d. Criticality when performing welding (especially when dealing with flammable fluids). The proposed clamp can be fixed on any pipeline having any type of fluids, since the proposed clamp does not have any part that requires *in situ* welding.

5. MAIN PARTS OF THE PROPOSED CLAMP

The proposed clamp consists of several parts: upper and lower covers, side bolts and nuts, gaskets, packing, J-bolts, glands, drainage valve and injection valve. Figure 2 shows the main parts of the proposed clamp.

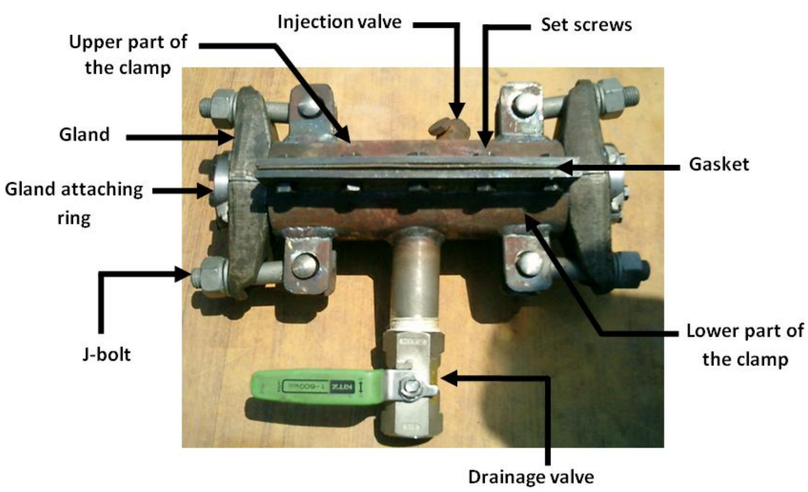

FIGURE 2. Main parts of the proposed clamp

5.1 The upper cover of the clamp

The upper cover of the clamp is one half of a cylindrical tube which has been cut longitudinally and welded from the inside with two C-shape rings (Figure 3). The upper cover has an injection valve attached to it. The injection valve is explained in more details in section 5.9.

5.2 The lower cover of the clamp

The lower cover is the other half of the previously mentioned tube which has been cut longitudinally and also welded from the inside with two C-shape rings. Figure 3 shows the C-shape rings which have been welded from the inside for both the upper and the lower covers. The lower cover of the clamp has a drainage valve attached to it (section 5.8).

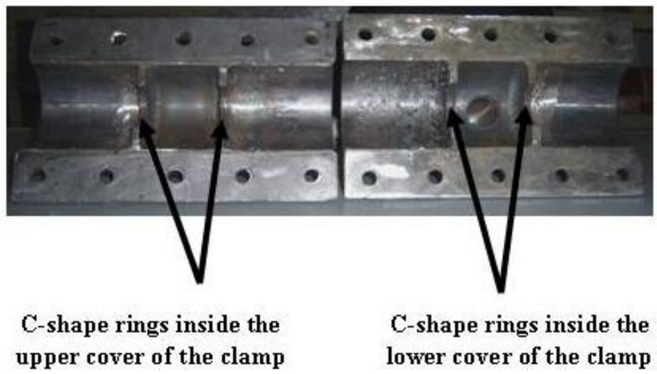

FIGURE 3. C-shape rings inside the upper and the lower covers of the proposed clamp

5.3 Gaskets

The proposed clamp consists of split line gaskets (Figure 4). The lower cover of the clamp is usually placed underneath the punctured pipe and the split line gaskets are then placed on both sides of the clamp such that the holes of the gaskets coincide with the holes in the lower cover. The upper cover would then be placed over the lower cover having the punctured pipe in between them. The C-shape rings from the upper cover would match the C rings from the lower cover.

FIGURE 4. Split line gaskets of the proposed clamp

5.4 Side bolts and nuts

The proposed clamp consists of 10 bolts and 10 nuts, with each side having 5 pairs (Fiure 5). By tightening the bolts and nuts on both sides of the clamp, the upper and the lower covers are firmly brought together, enclosing the gaskets between them.

5.5 Packing

Graphite packing is inserted from both the ends of the clamp. Figure 6 shows the inserted packing from both the ends of the proposed clamp. The packing is intended to stop leakage from either end of the clamp.

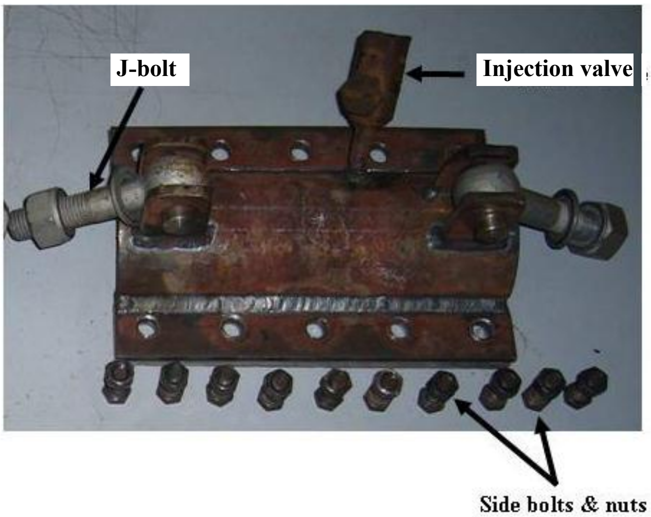

FIGURE 5. Side bolts and nuts of the proposed clamp

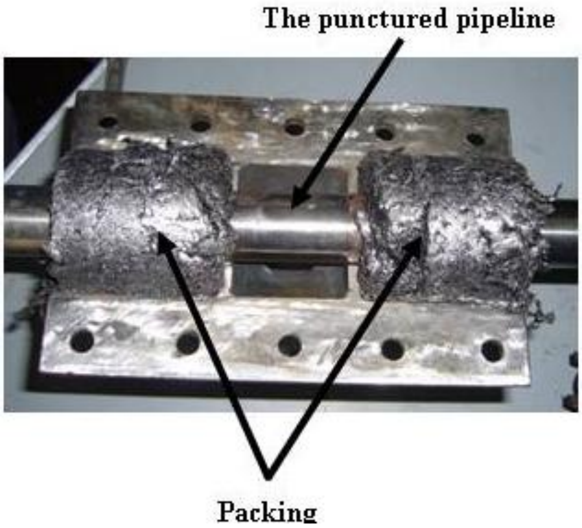

FIGURE 6. Inserted packing from both ends

5.6 J-bolts

There are four J-bolts on the proposed clamp, two on each cover (the upper and the lower covers). Figure 7 shows the J-bolts of the proposed clamp.

FIGURE 7. J-bolts of the proposed clamp

5.7 Glands

The proposed clamp consists of two glands, each sectioned into two halves. The bottom half of the gland has two dowel pins attached to it, while the upper half of the gland is drilled with two holes. The two halves of the gland are attached together using an attaching ring fixed on the gland by six set screws. The gland has a boss to push the inserted packing toward the C-rings of the upper and the lower covers of the clamp. The C-rings would act as stoppers for the inserted packing. Figure 8 (a-b) shows the two halves of the gland, the dowel pins, the attaching ring of the gland and the set screws.

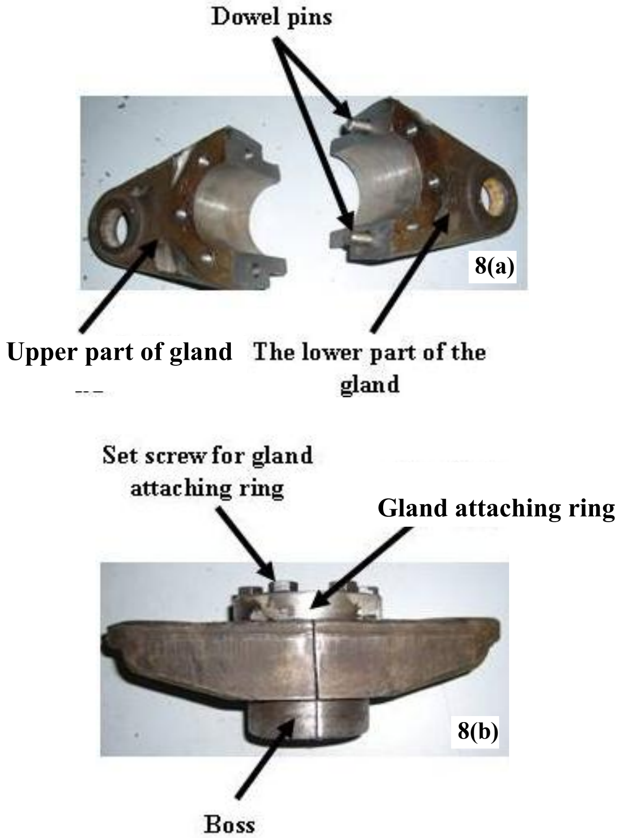

FIGURE 8. (a) Two halves of the gland and the dowel pins, (b) The attaching ring of the gland and the set screws

5.8 Drainage valve

The drainage valve (Figure 9) is used to release as much pressure as possible that is trapped in the cavity of the clamp. It also directs the leaking fluid into the opposite direction in order to ensure safety of the technician handling the repair.

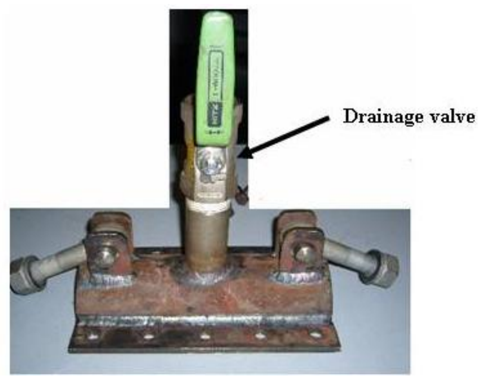

FIGURE 9. Drainage valve attached to the lower cover of the proposed clamp

5.9 Injection valve

The injection valve shown in Figure 5 is used to inject a special compound in the following cases:

a. If the pipeline is deteriorated and is suffering from severe corrosion on the outside, the surface of the pipe would be uneven underneath the packing permitting the fluid to escape. This would make it very difficult for the packing to retain leakage, hence the need for the compound.

b. If the clamp is to be placed on a welded pipeline and especially over the reinforcement of the weld, this will affect the straightness of the pipe surface underneath the packing and will not seal the leak completely.

c. Weld joints sometimes have difference in the coaxiality level of the welded pipes. In other words, the alignment of the welded pipes is not precise.

It is clear that the factors discussed above, viz. the surface integrity, the alignment of pipes in case of welding and the height of weld bead reinforcement, are very important for the clamp to function properly. Therefore, the clamp was welded with an injection valve to inject a special compound if required. The special compound is readily available and can withstand tremendous pressures.

6. ADVANTAGES OF THE PROPOSED CLAMP

6.1 Suitable for all sizes of pipelines

Industries deal with different types of pipelines which may vary in terms of size, diameter and thickness. Most pipelines are at great risk of puncturing due to a multitude of reasons. The proposed clamp is suitable for all type of pipelines regardless of diameter or thickness.

6.2 Able to withstand a wide range of pressures and stops leakage completely

Different types of clamps are being used in industries for sealing fluid leaks. However, these clamps do not stop the leakage completely. They usually tend to reduce the leakage, are therefore not completely effective. The proposed clamp solves these types of problems by stopping the leakage completely for different pressure ranges (low, medium and high). It can also deal with sudden changes in pressure. In other words, the pressure change in any pipeline has no affect on the clamp efficiency.

6.3 Small in size and light in weight

Industries try to reduce their expenditures to a minimum level; therefore they are always seeking products which reduce these costs. The proposed clamp is a product that can reduce some of the expenditures since it is small in size and light in weight. Being small and light reduces the cost and the time of handling. The proposed clamp is small and light compared to other conventional clamps. In remote locations, light clamps are preferred by technicians since handling these is much easier than heavy ones. The proposed clamp does not require any crane for lifting and placing it in the required position. Sometimes if a puncture occurs in a pipeline located between other pipelines, it is very hard to place the conventional clamp since it is bulky. In such cases the usual way of placing the conventional clamps is either by shifting the adjacent pipelines if this is feasible, or making special arrangements in order to fix them. With the proposed clamp, these types of problems no longer exist because it is small in size and light in weight.

6.4 Simple in design

One of the most important issues that are usually considered in manufacturing of a specific product is the ease of manufacturing. Simple design leads to easy manufacturing. In reality, there are some products which have been rejected (even if they are very efficient) because of their complex design, since complex design usually leads to expensive manufacturing. The proposed clamp is very simple in design, therefore it is easy to manufacture and hence it can be produced at an attractive price.

6.5 Easy to assemble on site

One of the most significant issues when dealing with conventional clamps in industries is the ease of assembly on site since time and effort are very important. There are some clamps that are considered very efficient in handling punctured pipelines, but have never been used because they are very difficult and complex in assembly. These complex types of clamps can put the technician at great risk of paying much effort and taking much time for assembly. The proposed clamp may save the costs in two ways:

a. Less time for assembly: The proposed clamp is very easy to assemble on site; therefore the downtime of the unit can be kept as low as possible if the unit is to be stopped and a clamp is to be placed. Usually reducing the downtime of any unit can lead to great saving in costs.

b. Few workmen required for assembly: In most industries, labor costs add on top of the total costs. Labor costs are kept very low when dealing with the proposed clamp, since only few technicians are required to assemble and implement the proposed clamp. Reducing the labor cost will reduce the overall cost in any plant.

6.6 No need to shut down the unit

There are some units in the industry that are considered very critical to production, and the downtime (to perform the necessary repair) of such units can cause the company to lose millions of dollars if they decide to stop them to make necessary repairs. If a leakage is observed in one of the critical pipelines of a certain unit in any plant and if this pipeline were connected to other pipelines by welding, there are two scenarios in which this pipeline can be mended. The first scenario is to stop the unit and cut the vulnerable portion of the pipeline and weld a new one. This means that the unit needs to be shut down in order to carry out the necessary repairs, which may result in financial loss. The other scenario is to let the unit work without making any repair (this could be allowable in some situations) until the next scheduled shutdown. In this case, the efficiency of the unit is reduced. In both these scenarios, there can be significant losses in terms of money and efficiency. With the proposed clamp, there would not be any need for stopping the unit and the clamp can be assembled *in situ*, restoring the unit efficiency with minimal delay.

6.7 Suitable for all types of fluids

The production units in any plant may have different working fluids such as liquids or gases. Different fluids have different properties. If a puncture is encountered in a pipeline, the properties of this fluid must be known in order to prepare a solution that ensures the safety of both the technicians and the plant. Generally speaking, it is the fluid properties that specify the nature of the solution. The proposed clamp does not contain any chemical materials that might react with the fluid inside the pipeline being repaired. This ensures that the chemical properties of the fluid will not be changed and that unwarranted chemical reactions would not take place. If it happened and the packing of the proposed clamp did react with the fluid inside, it would be possible to change the packing material to something that suits the working fluid. These types of packing materials are available cheaply and would not affect the clamp costs significantly. Most conventional clamps can handle liquids only, since they are specifically designed for liquids; the proposed clamp is suitable for both liquids and gases.

6.8 Usable on all types of fittings

Punctures may occur at different locations on the pipelines. They may occur in the body of the pipeline itself or at elbow or tee joints. The proposed clamp may be designed in a way to suit all types of joints. This makes it suitable for use in a variety of locations and places. It can also be used on bolted flanges.

6.9 Can be used irrespective of pipe or joint condition

Pipelines may have a variety of internal and external conditions:

a. Internal surface of the pipeline: There are some factors that may have direct effects on the internal surface of the pipeline. These include pressure, temperature and chemical reactions. These factors can deteriorate and corrode the pipelines over time. This may reduce the thickness at places which may cause the pipeline to fail.

b. External surface of the pipeline: External factors such as temperature, humidity and chemical reactions leading to corrosion. Corrosion may reduce the pipeline to its minimum thickness, which may then lead to cracks on the surface causing leakage. To mend the leakage, a patch may be welded; however, many a time pipelines contain flammable fluids which makes welding impossible. Technicians involved in repair often face difficulties since these pipelines are deteriorated in different locations and over different lengths. When longitudinal cracks are too long, they may reach the joints progressively. Since the proposed clamp is designed to handle long cracks, this possibility is eliminated. The proposed clamp has the ability to handle all types of pipelines and joints, whether welded or bolted.

6.10 May be used underground

One of the most important advantages of the proposed clamp is the ability of burying it underground after assembling it on any punctured buried pipeline. Accordingly, the proposed clamp offers solution to handling punctures in underground piping. Underground pipelines need quite an effort for maintenance and repair. Sometimes on both sides of the pipeline earth needs to be removed to different depths in order to give access to the punctured portion of the pipeline. Using the proposed clamp, only a small amount of earth is needed to be removed in order to assemble it.

6.11 Suitable for long period of time

All industries conduct periodic maintenance of their pipelines. If a puncture occurs after the start up of the unit, it would be replaced by shutting down the unit and carrying out the necessary repair, or it would be left in place until the next scheduled shutdown. One of the advantages of the proposed clamp is that it can be fixed in place for a long period of time until the next scheduled shutdown. It only requires minor care such as tightening the J-bolts or adding more packing periodically.

6.12 May be used at home

Residential water networks are relatively simple but need general maintenance periodically. Homeowners may sometimes face emergencies with plumbing. Defective pipelines at home need to be repaired very quickly if a puncture is encountered, since any delay may damage the building and furniture. The proposed clamp may be kept at home for any such emergency. It may be used on both metal and plastic pipelines.

7. COMPARISON BETWEEN THE PROPOSED CLAMP AND THE CONVENTIONAL CLAMP

Conventional clamps are used widely in industries to attend to punctures in pipelines. A conventional clamp consists of two halves of a pipe, with each half welded with bolts. It has a rubber layer on the inside as shown in Figure 10(a). Both the proposed and the conventional clamps have some features in common; however, the proposed clamp can offer more options as discussed below:

a. The conventional clamp does not stop the leakage completely. One of the most important characteristics of the proposed clamp is that it offers to stop leakage completely by virtue of its design. Practical experience suggests that the conventional clamp can stop the leakage completely in a few cases only if the pressure is very low. Basically, the conventional clamp reduces the leakage whereas the proposed clamp stops the leakage completely. Figure 10 (a-b) shows comparison between the proposed and the conventional clamp when used on similar pipelines with the same fluid and under same working conditions. Evidently, the proposed clamp stopped the leakage completely while the conventional one did not.

b. The conventional clamp does not withstand variable pressures. Most pipelines suffer from sudden changes in pressure due to fluctuations in the fluid-flow rate. The conventional clamp cannot withstand such sudden changes in the pressure and therefore it is more susceptible to leaking or bursting. The proposed clamp takes into account this factor.

c. The material of the conventional clamp may cause chemical reactions with the fluid flowing inside. Usually rubber is placed between the clamp and the punctured pipeline wall. This limits the functionality of the conventional clamp to water and steam leakages and some other fluids only which do not react chemically with rubber. The packing of the proposed clamp can be replaced with suitable ones that can suit the nature of the fluid; therefore it is suitable for all types of fluids.

d. The conventional clamp cannot be used on different joint geometries. On the other hand, the proposed clamp can be used on all types of joints with minor modifications in its design.

e. The conventional clamp is usually used for short periods of time. The rubber used in conventional clamps seals the leaks but usually deteriorates with pressure and temperature; therefore conventional clamps are suitable for short periods of time only. On the other hand, the proposed clamp does not contain any material that might be damaged due to pressure and temperature.

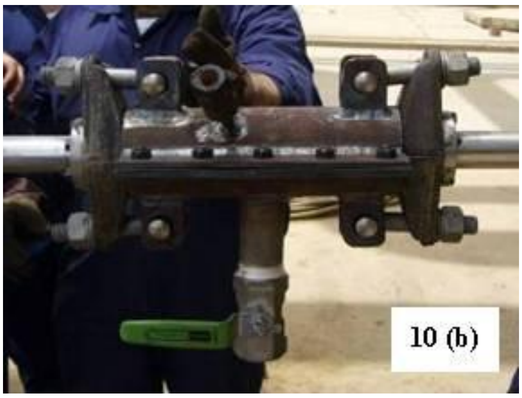

FIGURE 10 (a-b). Comparison between the proposed and the conventional clamp when they have been used on the same pipeline having the same working conditions

8. CONCLUSIONS

There is a great demand for having a clamp similar to the proposed one since it can lead to a great savings in terms of time and money. There is no need to shutdown the unit if a puncture is encountered in any pipeline, or to cut the vulnerable portion out and weld a new one. The proposed clamp enhances workplace safety in operation, since the need for welding patches is eliminated and thus handling flammable fluids becomes easier.

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