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METHOD AND APPARATUS FOR LINING PRESSURE VESSELS

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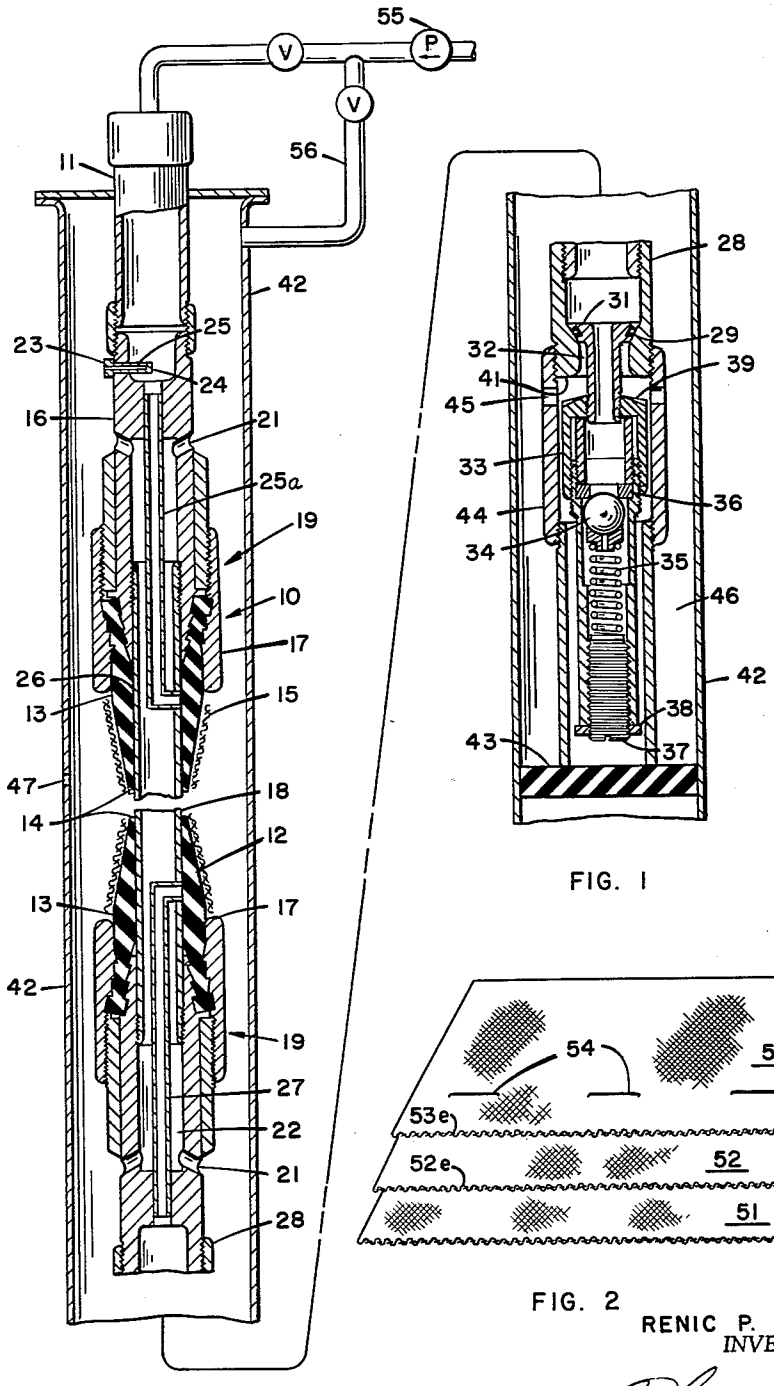


FIG. 1

FIG. 2

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METHOD AND APPARATUS FOR LINING PRESSURE VESSELS

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This invention relates to lining a pressure vessel. More particularly, this invention is directed to an improved method and apparatus for patching a well casing to plug holes or perforations therein.

Liners have been placed in pressure vessels such as well casing for many purposes including plugging leaks or perforations. When a plastic sleeve is set in a well casing to patch a hole, the hole is first located and then an unset thermosetting resin sleeve is lowered into position at the elevation of the hole, expanded and allowed to polymerize or harden in place. The installation of such liners has generally been difficult, the results have been somewhat unpredictable, and the patches have sometimes been unsatisfactory in that they have unnecessarily reduced the open area of the casing and accordingly the producing efficiency of the well.

It is, therefore, an object of this invention to provide an improved method and apparatus for setting a plastic liner in a pressure vessel. Other objects of this invention will become apparent from the following description. In this description reference will be made to the accompanying drawings in which:

FIGURE 1 shows partially in vertical cross section, a well casing and an apparatus suitable for setting a liner therein; and

FIGURE 2 shows a preferred arrangement for assembling the layers of fabric in a multilayer resin-impregnated fabric liner.

This invention may be described in brief as an improved procedure and apparatus for setting and curing a fiber reinforced plastic liner in a well casing. An important element of this invention is in prestressing the liner or patch to prevent fluid migration between the liner and the casing.

Reference will now be made to the drawings for a more detailed description of the apparatus and procedure for making up and setting a fiber reinforced plastic liner in a pressure vessel, particularly a well casing. The liner setting tool includes primarily an expandable mandrel 10 which is made up at the surface and attached to the lower end of tubing string 11. This mandrel includes a resilient expansion member such as a rubber tube 12. This tube is expanded diametrically by inflating it with a gas or liquid under pressure. Longitudinal or spiral reinforcing cords may be molded in the tube to increase its strength. This tube may be of any length, typically between about one and about 50 feet or more, depending upon the length of the liner which is to be placed in a well. The wall thickness of the tube may also be varied over a substantial range depending upon the diameter and particularly upon the pressure used to inflate the tube, i.e., the differential between the pressure in the vessel surrounding the tube and the pressure within the tube. A thickness of from about ¼ inch to about 1 inch, typically about ½–¾ inch at the end sections 13 for an inflation pressure of about 100–500 pounds has been found satisfactory. The wall thickness of the tube at the center section 14 is generally much less, typically about ⅓–⅔ of the thickness of the tube at the end sections 13 so that when the tube is expanded as described hereinafter, the center section expands before the end sections expand. The external diameter of the tube unstressed is desirably about 1–2 inches less than the diameter of the casing or other pressure vessels in which the liner is to be placed or through which the liner is to be run so that the resin-impregnated fabric sleeve 15, which is built up around this tube and which eventually will become the liner, can be lowered easily through the vessel to the position at which the liner is to be set.

This elastic or expansible tube is connected at the ends to a tubular body 16 by clamps 17 which hermetically seal the tube to the body so that fluid pressure applied internally will expand or inflate the tube. The body has a central tubular member 18 threaded into the upper and lower heads 19 which with ports 21 form a fluid bypass 22 through the tube so that fluid pressure in the annular space outside the mandrel above and below the tube will be equalized at all times, particularly when the tube is expanded and while the resin in the liner is curing as hereinafter described. A knockout or shear plug 23 is threaded into the body 16 near the upper end where it will be exposed to and broken by a go-devil or the like dropped down the tubing. It has a closed end 24 protruding a substantial distance inside the body and a central opening 25 which permits fluid to flow through the plug when it is broken. This shear plug, as will be described in greater detail hereinafter, provides a means for equalizing the pressure inside the tube with the pressure outside the tube so that at the proper time the tube will contract to its normal or unstressed diameter and can be removed from the inside of the liner.

A small conduit 25*a* which forms a fluid seal with the body above the upper ports 21 connects at the lower end to the annular space 26 between tubular member 18 and the rubber tube 12 to supply fluid for inflating the tube. Another small conduit 27 connected at the upper end into the same annular space 26 forms a seal at the lower end with the body below the lower ports 21 so that fluid injected down the tubing 11 in excess of that required to inflate the tube 12 is displaced from the tubing and mandrel through a combination standing and relief valve unit which is connected via adapter 28 to the lower end of the body 16. The standing valve comprising a seat 29 in adapter 28 and a tubular standing valve member 31 serves as a tubing loading valve which permits well fluids to enter the mandrel and tubing through the annular opening 32 as the mandrel is lowered into the well thereby filling the tubing with well fluids and equalizing the pressure in the mandrel with the external or well pressure. The lower end of the tubular standing valve member 31 is threaded into a movable relief valve cage 33. A ball valve member 34 together with compression spring 35 which holds the ball against seat 36 form a relief valve. This relief valve prevents well fluids from entering the lower end of the tubular standing valve member 31 but permits fluids to be released from inside the body through this standing valve member when the differential pressure across the relief valve is greater than the pressure at which this relief valve is set to open by the adjustment of spring tension adjusting screw 37. The adjusting screw is set at the surface to maintain sufficient differential pressure, typically 100–500 p.s.i., to inflate the rubber tube but to open before the differential pressure is great enough to rupture the tube. This screw is held in a fixed position in the relief valve cage 33 by a lock nut 38. Fins 39 on the upper end of the cage provide a fluid passage between the base 41 of the standing valve seat and the relief valve cage when the standing valve member is in its extreme upper position.

In my preferred process, as hereinafter described, it is often desirable to plug the casing 42 below the point at which the liner is to be placed. The plug may be set before the mandrel is lowered into the well. Preferably, however, a packer or bridging plug 43 is connected via a collar 44 to the adapter 28. Ports 45 in

the collar provide fluid communication between the tubing and annular space **46**. Centralizers (not shown) may be mounted on the tubing string above or below the mandrel or both above and below the mandrel to protect the sleeve **15** from rubbing against the casing as the sleeve and mandrel are lowered into the well. In some cases for the additional protection of the unset resin in the sleeve as it is run in the well, a solid gauge or a junk pusher larger than the assembled mandrel and sleeve may also be mounted on the bottom of the assembly for protection to the sleeve. If the vessel has not been previously cleaned, steel brushes, scrapers or the like may also be mounted on the lower end of the tubing to abrade the surface before the sleeve is expanded.

In operation, the elevation at which the liner or patch is to set set is first ascertained. The area in which the casing **42** or other pressure vessel is leaking or is otherwise perforated or is corroded and about to leak, if not known, may be determined by any of various known procedures such as by a magnetic survey to determine the cross sectional area of the casing metal or by first plugging the bottom of the casing and then making a fluid velocity or temperature log of the well as the well is produced or as fluid is injected into the casing. Knowing from any of such logs the general area in which the liner is to be set, the exact elevation can best be determined by obtaining an impression of the inside of the pipe. An impressionable material such as heavy paste wax which is not soluble in the well fluid or a thin metal foil is placed on an expanding mandrel such as the outer surface of the tube **12**. The mandrel is then lowered into the well, preferably on the same tubing string or wire line that will be used to place the liner, fluid is injected into the tubing to inflate the tube to the inside diameter of the pipe. The tube is deflated by equalizing the pressure inside and out, and the mandrel is then removed from the well. The image of the inside of the vessel is then available in the impressionable material on the tube so that the exact elevation, the size and shape of a hole **47** or potential hole in the wall of the vessel can be determined by measuring the tubing or wire line and adding the distance to the impression made in the material.

With the mandrel assembled, as described in detail above, the sleeve **15** which will eventually form the well liner is made up on the expandable tube **12** in substantially the following manner. The tube is first treated on the external surface with a parting compound to prevent the base resins from adhering to the tube surface. At times it is found desirable to apply a heavy coating of wax such as a high-softening-point carnauba wax to the complete surface to be covered by the sleeve, allow to harden and then buff smooth. Various silicone mold-releasing agents may additionally or alternatively be applied to the surface of the tub so that the cured resin will not adhere and the setting tool may be released from the liner and withdrawn from the well. The sleeve is made up of a multiplicity, for example, up to five or more layers of a natural or synthetic fabric, e.g., nylon, glass or the like, which is available commerically as woven roving or in various weaves and weights of fabric. Each layer consists generally of one piece of this fabric as long as the desired liner and as wide as the inner circumference of the vessel in which the liner is placed. The first layer **51** as indicated in FIGURE 2 is first cut to size, then laid out flat and impregnated with a resin, desirably a thermosetting resin. Excess resin, i.e., more resin than is necessary to saturate the fabric, is desirably applied in addition to or in lieu of impregnating the fabric by brushing, trowelling, or buttering on the fabric a viscous resin containing sufficient finely divided fillers such as fuller's earth and/or a small amount (2–5%) of a thickening or thixotroping agent such as porous silica aerogel to make it of trowel consistency. Additional layers **52** and **53** of the fabric as desired for strength are then placed, as indicated in FIGURE 2, with their side edges **52***e* and **53***e* offset. The amount of offset at each layer is not critical but generally it is about equal to the width of the layer divided by the total number of layers so that the joints in the liner are equally spaced. As each layer is placed on the pile, it is coated or impregnated and coated with the resin. As the layers are placed, or preferably after all of the layers have thus been laid out and coated, they are fastened or bound together, for example, by a line of office type staples **54**. By thus binding the layers together, I have found that when the sleeve is expanded the joints all move together and, therefore, that in the final liner the joints are equally spaced circumferentially so that the patch is uniform and no two joints fall on the same line azimuthally. The number of layers depends generally upon the thickness and strength of the liner desired, upon the conditions of the casing surface, and the amount of resin which is to be used. The greater the number of layers the more resin that can be applied and the stronger the liner. The number of layers is, however, limited in some cases by the permissible thickness of the liner.

This assembly of resin coated fabric is wrapped around the tube and held in place by lightly fastening the lapped ends or by a binding which is wrapped around the tube and the fabric. After the resin-saturated or coated fabric has thus been placed on the tube, it is desirably covered and surrounded by a thin impermeable plastic sheet (not shown) which is wrapped tightly to hold the fabric in place and to protect it from the well fluids.

Any resins which will cure or set hard, either naturally or artificially, in the well may be employed. Typically, these resins are thermosetting resins, i.e., resins which are capable of undergoing a permanent physical change under the influence of well temperature or an artificially induced higher temperature. Polyester or epoxy resins are examples. Other suitable resins include urea, resorcinol, and phenol formaldehydes, and the like. Epon 828, an epoxy resin manufactured by Shell Chemical Company, is an example of a preferred epoxy resin. As is well known in this art, these resins may be combined and various catalysts or curing agents employed in various concentrations so that the setting or curing time or pot life for various well depths or various temperatures may be controlled. Versamid resin 140, a polyamide manufactured by General Mills, Inc., is an example of a preferred catalyst which, in the ratio of about 30 parts by volume to 70 parts of the Epon 828 epoxy resin, has a pot life at room temperature of about 3–3½ hours. Such resins when set, i.e., when they are cured sufficiently to be self-supporting and relatively rigid, are referred to herein as plastics.

After the sleeve or patch has thus been made up on the expansible tube and mandrel and the shear plug **23** has been installed and after the relief valve opening pressure has been set as previously described, the mandrel is ready to be lowered into the well. The mandrel and sleeve are then lowered into position on tubing string. As the mandrel is lowered into the liquids in the well, the standing valve member **31** is raised by the differential pressure to permit the well fluids to enter the mandrel and the tubing string and thus substantially equalize the pressures inside and outside the tube and prevent it from being collapsed. When the mandrel has been lowered to the proper depth so that the sleeve is located at a position opposite the zone to be lined, the packer **43** is set, i.e., expanded to form an enclosed pressure vessel. The packer may be of the type shown and described on page 2471 of the 1951 edition of the Composite Catalog published by the Gulf Publishing Company of Houston, Texas. The method of setting the packer is described on the same page. After the packer is set, fluid is injected via pump **55** into the tubing string **11** and sufficient pressure applied to expand the tube **12**, break the fiber binding or tacking, and expand the sleeve **15** out against the surface of the pressure vessel. Typically, sufficient pressure is applied to this fluid to produce a

bearing pressure of 50–100 or more pounds per square inch between the tube and the wall of the casing **42** and to thereby squeeze the unset resin within the fibers into any voids or holes **47** therein. The amount of pressure applied at the surface will, of course, depend upon the pop-off pressure of the relief valve, the static liquid level within the well, the density of the fluid in the tubing, the depth of the sleeve in the well, etc.

After fluid is injected into the mandrel to expand the tube and the laminated sleeve out against the wall of the casing and seal any holes **47**, fluid may be and normally is injected into the casing or other pressure vessel outside the mandrel until a pressure at least as great as the working pressure of the vessel is built up. It is often desirable to increase and maintain the pressure in the vessel to substantially above the working pressure until the resin has cured. Thus, the liner is placed under a compressive stress when the mandrel is removed. Since the resin does not form a bond with the wall of the vessel, this compressive stress aids in forming a seal between the liner and the vessel wall. Fluid may be injected into the pressure chamber surrounding the mandrel via the tubing and relief valve or may be injected directly through line **56**. In any case, the pressure within the tube **12** is maintained higher than the pressure in the vessel for a period of several hours, typically from about 10 to 24 hours, or more, while the resin is cured or set and produces a hard immobile liner. During the time that the tube **12** is thus expanded the liquid level in the well may tend to vary, especially in wells which are not initially at static equilibrium and in which no bottom packer is employed to form an enclosed pressure chamber. During this time the pressures above and below the mandrel are equalized by permitting fluid flow through bypass **22** so that the well fluids will not unseat the expanded tube and flush away the unset resin. Where heat is desired to accelerate curing of the resin, a heat source may be lowered through the tubing string to heat the mandrel and adjacent areas or an electric heater may obviously be built into the mandrel.

After the resin has cured sufficiently to produce a self-supporting strong liner, the setting tool is released by deflating the expanded tube. This may be accomplished by any of a number of means such as by injecting gas into the tubing string to displace liquid through the relief valve and then releasing the pressure on the tubing string at the surface so that the internal and external pressure on the expansible tube is balanced or otherwise sufficiently equalized through the standing valve to collapse the rubber tube. In the preferred embodiment, the pressure within the mandrel may be equalized with the external pressure by dropping a go-devil down the tubing. When it strikes the shear plug **23**, the plug is broken and the port **25** therethrough is opened to permit liquid within the mandrel to flow to the annular space outside the tubing and equalize the pressures inside and outside the resilient tube so that the tube **12** is contracted by its own resiliency.

With the expansible tube contracted away from the set liner, the tubing string and mandrel are pulled from the well or other pressure vessel. As they are removed from the well, the liquid within the tubing string discharges through the open port **25** maintaining only a small differential pressure between the inside and outside of the mandrel. The resilient tube can, therefore, normally be withdrawn from the well without difficulty and reused as many times as desired.

The thickness of the plastic liner left in the well depends generally upon the number of layers of fabric or laminae used in the sleeve. It may vary from about $\frac{1}{16}$ inch to about ½ inch or more but the liner is typically about ⅛–¼ inch thick. The liner thus leaves sufficient space to permit the mandrel with another sleeve mounted thereon to be run through a well containing previously placed liners to a greater depth so that additional holes or perforations can subsequently be plugged.

From the foregoing, it can be seen that various modifications of the apparatus and procedure can be made without departing from the spirit of this invention. For example, whereas in the preferred embodiment an apparatus and procedure for placing a plastic patch in a well casing or other cylindrical pressure vessel have been particularly described, I have found that generally the same procedure can be employed to place a liner in a vessel having a different shape and even a vessel under vacuum. And whereas in the above description, reference has been made to running the mandrel on a tubing string and expanding it by injecting a fluid into the tube through the tubing string, the mandrel can be run on a wire line and in such instance the tube can be expanded either mechanically as by manipulation of the wire line or by an electric motor, or pneumatically as by the use of gas generating chemicals, or the like. This invention should, therefore, be construed not to be limited by the description which has been given by way of example. It should instead be construed to be limited only by the scope of the appended claims.

I claim:

1. A method of patching a hole in the wall of a substantially vertical elongated cylindrical pressure vessel comprising building up on an expansible tube an expansible sleeve having at least one layer of fabric impregnated with unset thermosetting resin, inserting said tube and said expansible sleeve built up thereon into said vessel until said tube is substantially centered on said hole, injecting fluid into said tube before the resin in said fabric is set to expand said tube and said sleeve against the wall of said vessel and plug said hole, injecting fluid into said vessel until a pressure is built up therein substantially as great as the working pressure of said vessel, maintaining said pressure in said vessel substantially as great as said working pressure of said vessel and the pressure in said tube greater than said pressure in said vessel outside said tube so that said vessel and said tube remain expanded until said resin is set, equalizing the pressure in said tube with the pressure in said vessel to contract said tube and release it from said sleeve, and then withdrawing said tube from said vessel.

2. A method of patching a hole in the wall of a substantially vertical elongated cylindrical pressure vessel comprising inserting an expansible impression cylinder into said vessel to a position opposite said hole, expanding said cylinder against the wall of said vessel to make an image of said hole on said cylinder so that the elevation, size and shape of said hole can be accurately determined, contracting said cylinder away from said wall of said vessel, withdrawing said cylinder from said vessel, subsequently building up on an expansible tube an expansible sleeve having multiple layers of fabric impregnated with unset thermosetting resin, the number and size of layers being adapted to seal the size and shape of hole which has been determined, inserting said tube and said expansible sleeve built up thereon into said vessel until said tube is substantially centered at said elevation, injecting fluid into said tube before the resin in said fabric is set to expand said tube and said sleeve against the wall of said vessel and plug said hole, injecting fluid into said vessel until a pressure is built up therein substantially as great as the working pressure of said vessel, maintaining said pressure in said vessel substantially as great as said working pressure of said vessel and the pressure in said tube greater than said pressure in said vessel outside said tube so that said vessel and said tube remain expanded until said resin is set, equalizing the pressure in said tube with the pressure in said vessel to contract said tube and release it from said sleeve, and then withdrawing said tube from said vessel.

3. An apparatus for placing a thin plastic liner in a well casing which includes a tubular body, means to

attach said body to a running string, a radially expansible tube on said body, means to seal the ends of said tube to said body so that said tube can be inflated, a fluid passage from the inside of said body to the inside of said tube for inflating said tube, a multilayered fabric sleeve impregnated with unset thermosetting resin on said tube, said tube having a wall thickness which tapers continuously from a thick section at said ends to a relatively thinner section at the center so that when fluid is injected through said fluid passage into the inside of said tube and said tube is inflated, said thinner section at the center expands and causes said sleeve to contact said well casing before said ends expand and cause the ends of said sleeve to contact said casing whereby any excess unset resin in said resin-impregnated sleeve may be squeezed out of the fabric in said sleeve to produce a thin sleeve in said casing.

4. An apparatus according to claim 3 wherein each of the layers of fabric within said sleeve is substantially as long as said tube and substantially as wide as the inside circumference of said casing and wherein said layers are bound together with their side edges offset before they are wrapped around said tube whereby when said sleeve is expanded in said casing said layers move together and the joint in each layer is spaced from the joint in each other layer.

5. A method of patching a hole in casing in a well comprising building up on an expansible tube an expansible sleeve having at least one layer of fabric impregnated with unset thermosetting resin, lowering said tube and said expansible sleeve built up thereon into said well until said tube is substantially centered on said hole, injecting fluid into said tube before the resin in said fabric is set to expand said tube and said sleeve against the wall of said casing and plug said hole, injecting fluid into said casing until a pressure is built up therein substantially as great as the working pressure of said casing, maintaining said pressure in said casing substantially as great as said working pressure of said casing and the pressure in said tube greater than said pressure in said casing outside said tube so that said casing and said tube remain expanded until said resin is set, equalizing the pressure in said tube with the pressure in said casing to contract said tube and release it from said sleeve, and then withdrawing said tube from said well.

6. A method of patching a hole in the wall of a casing in a well comprising lowering an expansible impression cylinder into said well to a position opposite said hole, expanding said cylinder against the wall of said casing to make an image of said hole on said cylinder so that the elevation, size and shape of said hole can be accurately determined, contracting said cylinder away from said wall of said casing, withdrawing said cylinder from said well, subsequently building up on an expansible tube an expansible sleeve having multiple layers of fabric impregnated with unset thermosetting resin, the number and size of layers being adapted to seal the size and shape of hole which has been determined, lowering said tube and said expansible sleeve built up thereon into said well until said tube is substantially centered at said elevation, injecting fluid into said tube before the resin in said fabric is set to expand said tube and said sleeve against the wall of said casing and plug said hole, injecting fluid into said casing until a pressure is built up therein substantially as great as the working pressure of said casing, maintaining said pressure in said casing substantially as great as said working pressure of said casing and the pressure in said tube greater than said pressure in said casing outside said tube so that said casing and said tube remain expanded until said resin is set, equalizing the pressure in said tube with the pressure in said casing to contract said tube and release it from said sleeve, and then withdrawing said tube from said well.

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