

CONTROLLED ACTUATION OF A REACTIVE METAL

TECHNICAL FIELD

5 The present disclosure relates to the use of a reactive metal element, and more particularly, to methods and apparatus for controlling the actuation of a reactive metal element.

BACKGROUND

10 In some wellbore operations, a swellable material may be used for sealing and/or anchoring. A few examples of apparatus that utilize swellable materials include packers, sealing elements, and liner hangers. A packer may be used to seal and isolate a wellbore zone. Expandable sealing elements may be used for a variety of wellbore applications including forming annular seals and zonal isolation. Liners may be suspended from a casing string or set cement layer with a liner hanger. The liner hanger anchors and seals to the interior of the casing string or set cement
15 layer and suspends the liner below the casing string or set cement layer.

 Some species of swellable materials comprise elastomers. Elastomers such as rubber may swell when contacted with a swell-inducing fluid. The swell-inducing fluid may diffuse into the elastomer where a portion of the fluid may be retained within the internal structure of the elastomer. Swellable materials such as elastomers may be limited to use in specific wellbore
20 environments (e.g., those without high salinity and/or high temperatures). In some wellbore operations, it may be important to time the actuation of the swellable material to prevent premature actuation. The present disclosure provides improved apparatus and methods for controlling the actuation of a reactive metal element in wellbore applications.

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BRIEF DESCRIPTION OF THE DRAWINGS

Illustrative examples of the present disclosure are described in detail below with reference to the attached drawing figures, which are incorporated by reference herein, and wherein:

FIG. 1 is an illustration of a reactive metal element shaped into a lattice structure in accordance with the examples disclosed herein;

FIG. 2 is a cross-section of an example downhole device comprising a reactive metal element in accordance with the examples disclosed herein;

FIG. 3 is a cross-section of the example downhole device of FIG. 2 after breaking of the frangible casing in accordance with the examples disclosed herein;

FIG. 4 is a cross-section of the example downhole device of FIGs. 1 and 2 with an additional modification in accordance with the examples disclosed herein;

FIG. 5 is a cross-section of another example downhole device comprising a reactive metal element in accordance with the examples disclosed herein;

FIG. 6 is a cross-section of the example downhole device of FIG. 5 after breaking of the frangible casing in accordance with the examples disclosed herein;

FIG. 7 is a cross-section of an example setting tool comprising a reactive metal element in accordance with the examples disclosed herein; and

FIG. 8 is a cross-section of the example setting tool of FIG. 7 after breaking of the frangible casing in accordance with the examples disclosed herein.

The illustrated figures are only exemplary and are not intended to assert or imply any limitation with regard to the environment, architecture, design, or process in which different examples may be implemented.

DETAILED DESCRIPTION

The present disclosure relates to the use of a reactive metal element, and more particularly, to methods and apparatus for controlling the actuation of a reactive metal element.

In the following detailed description of several illustrative examples, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration examples that may be practiced. These examples are described in sufficient detail to enable those skilled in the art to practice them, and it is to be understood that other examples may be utilized, and that logical structural, mechanical, electrical, and chemical changes may be made without departing from the spirit or scope of the disclosed examples. To avoid detail not necessary to enable those skilled in the art to practice the examples described herein, the description may omit certain information known to those skilled in the art. The following detailed description is,

therefore, not to be taken in a limiting sense, and the scope of the illustrative examples is defined only by the appended claims.

Unless otherwise indicated, all numbers expressing quantities of ingredients, properties such as molecular weight, reaction conditions, and so forth used in the present specification and associated claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the following specification and attached claims are approximations that may vary depending upon the desired properties sought to be obtained by the examples of the present disclosure. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claim, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. It should be noted that when “about” is at the beginning of a numerical list, “about” modifies each number of the numerical list. Further, in some numerical listings of ranges some lower limits listed may be greater than some upper limits listed. One skilled in the art will recognize that the selected subset will require the selection of an upper limit in excess of the selected lower limit.

Unless otherwise specified, any use of any form of the terms “connect,” “engage,” “couple,” “attach,” or any other term describing an interaction between elements is not meant to limit the interaction to direct interaction between the elements and may also include indirect interaction between the elements described. Further, any use of any form of the terms “connect,” “engage,” “couple,” “attach,” or any other term describing an interaction between elements includes items integrally formed together without the aid of extraneous fasteners or joining devices. In the following discussion and in the claims, the terms “including” and “comprising” are used in an open-ended fashion, and thus should be interpreted to mean “including, but not limited to.” Unless otherwise indicated, as used throughout this document, “or” does not require mutual exclusivity.

The terms uphole and downhole may be used to refer to the location of various components relative to the bottom or end of a well. For example, a first component described as uphole from a second component may be further away from the end of the well than the second component. Similarly, a first component described as being downhole from a second component may be located closer to the end of the well than the second component.

Examples of the methods and apparatus described relate to the use of a reactive metal element, and more particularly, to methods and apparatus for controlling the actuation of a reactive metal element. The reactive metal element comprises a reactive metal which, after reaction, provides an expansion of its metal to seal, anchor, and/or fill voids in the annular space. The reactive metal provides this expansion after contacting a specific reaction-inducing fluid,

such as a brine, where it produces a reaction product having a larger volume than the base reactive metal reactant. This increase in metal volume of the reaction product provides for an expansion of the metal reaction product into any adjacent void space. This expansion may be sufficient to seal the adjacent void space, to anchor a conduit proximate the adjacent void space, and/or to simply fill the adjacent void space. The reaction product solidifies within the adjacent void space in order to perform for further wellbore operations. The formation of the reaction products results in the volumetric expansion of the reactive metal element allowing for an improvement in zonal isolation. The solidified reaction products also improve the anchoring of any surrounding conduit, positioning it in the wellbore and allowing for secure suspension. Advantageously, the reactive metal elements may be used in a variety of wellbore applications. Yet a further advantage is that the reactive metal elements provide expansion in high-salinity and/or high-temperature environments. An additional advantage is that the reactive metal elements comprise a wide variety of metals and metal alloys and react upon contact with reaction-inducing fluids, including a variety of wellbore fluids. The reactive metal elements may be used as replacements for other types of expandable elements (e.g., elastomeric elements), or they may be used in combination with other types of expandable elements. One other advantage is that in some examples, the reactive metal elements may be placed on existing conduits without impact to or adjustment of the conduit outer diameter or exterior profile to accommodate the reactive metal element. In some examples, the reactive metal elements are free of elastomeric materials and may be usable in wellbore environments where elastomeric materials may be prone to breakdown.

In some wellbore applications, the timing of the actuation of the reactive metal elements may be important. As such, controlling the time of contact of the reaction metal element and the reaction-inducing fluid may prevent premature actuation of the reactive metal element such that the reactive metal element is not actuated until in the desired position and at the desired time. Advantageously, the reactive metal element may be sealed from contact with the reaction-inducing fluid by a barrier with a controlled rupturing. As a further advantage, the reactive metal element may be interspersed with a non-reactive fluid which would prevent reaction until dispersed by the inflowing reaction-inducing fluid.

The reactive metals expand by undergoing a reaction in the presence of a reaction-inducing fluid (e.g., a brine) to form a reaction product (e.g., metal hydroxides). The resulting reaction products occupy more volumetric space relative to the base reactive metal reactant. This difference in volume allows the reactive metal element to expand to fill void space at the interface of the reactive metal element and any adjacent surfaces. It is to be understood that the use of the term "fill" does not necessarily mean a complete filling of the void space, and that the reaction product may partially fill the void space in some examples. Magnesium may be used to illustrate

the volumetric expansion of the reactive metal as it undergoes reaction with the reaction-inducing fluid. A mole of magnesium has a molar mass of 24 g/mol and a density of 1.74 g/cm³, resulting in a volume of 13.8 cm³/mol. Magnesium hydroxide, the reaction product of magnesium and an aqueous reaction-inducing fluid, has a molar mass of 60 g/mol and a density of 2.34 g/cm³,
5 resulting in a volume of 25.6 cm³/mol. The magnesium hydroxide volume of 25.6 cm³/mol is an 85% increase in volume over the 13.8 cm³/mol volume of the mole of magnesium. As another example, a mole of calcium has a molar mass of 40 g/mol and a density of 1.54 g/cm³, resulting in a volume of 26.0 cm³/mol. Calcium hydroxide, the reaction product of calcium and an aqueous reaction-inducing fluid, has a molar mass of 76 g/mol and a density of 2.21 g/cm³, resulting in a
10 volume of 34.4 cm³/mol. The calcium hydroxide volume of 34.4 cm³/mol is a 32% increase in volume over the 26.0 cm³/mol volume of the mole of calcium. As yet another example, a mole of aluminum has a molar mass of 27 g/mol and a density of 2.7 g/cm³, resulting in a volume of 10.0 cm³/mol. Aluminum hydroxide, the reaction product of aluminum and an aqueous reaction-inducing fluid, has a molar mass of 63 g/mol and a density of 2.42 g/cm³, resulting in a volume
15 of 26 cm³/mol. The aluminum hydroxide volume of 26 cm³/mol is a 160% increase in volume over the 10 cm³/mol volume of the mole of aluminum. The reactive metal may comprise any metal or metal alloy that undergoes a reaction to form a reaction product having a greater volume than the base reactive metal or alloy reactant.

The reactive metals undergo a chemical transformation whereby the metals chemically
20 react with the reaction-inducing fluid, and upon reaction form a metal hydroxide that is the principal component of the expanded reactive metal element. The solidified metal hydroxide is larger in volume than the base reactive metal, allowing for expansion into the annular space around the reactive metal element (e.g., an adjacent void space).

Examples of suitable metals for the reactive metal include, but are not limited to,
25 magnesium, calcium, aluminum, tin, zinc, beryllium, barium, manganese, or any combination thereof. Preferred metals include magnesium, calcium, and aluminum.

Examples of suitable metal alloys for the reactive metal include, but are not limited to, alloys of magnesium, calcium, aluminum, tin, zinc, beryllium, barium, manganese, or any combination thereof. Preferred metal alloys include alloys of magnesium-zinc, magnesium-
30 aluminum, calcium-magnesium, or aluminum-copper. In some examples, the metal alloys may comprise alloyed elements that are not metallic. Examples of these non-metallic elements include, but are not limited to, graphite, carbon, silicon, boron nitride, and the like. In some examples, the metal is alloyed to increase reactivity and/or to control the formation of oxides.

In some examples, the metal alloy is also alloyed with a dopant metal that promotes
35 corrosion or inhibits passivation and thus increases hydroxide formation. Examples of dopant

metals include, but are not limited to, nickel, iron, copper, carbon, titanium, gallium, mercury, cobalt, iridium, gold, palladium, or any combination thereof.

In some examples, the reactive metal comprises an oxide. As an example, calcium oxide reacts with water in an energetic reaction to produce calcium hydroxide. One mole of calcium oxide occupies 9.5 cm³ whereas one mole of calcium hydroxide occupies 34.4 cm³. This is a 260% volumetric expansion of the mole of calcium oxide relative to the mole of calcium hydroxide. Examples of metal oxides suitable for the reactive metal may include, but are not limited to, oxides of any metals disclosed herein, including magnesium, calcium, aluminum, iron, nickel, copper, chromium, tin, zinc, lead, beryllium, barium, gallium, indium, bismuth, titanium, manganese, cobalt, or any combination thereof.

It is to be understood that the selected reactive metal is chosen such that the formed reaction product does not dissolve or otherwise degrade in the reaction-inducing fluid in a manner that prevents its solidification in a void space. As such, the use of metals or metal alloys for the reactive metal that form relatively insoluble reaction products in the reaction-inducing fluid may be preferred. As an example, the magnesium hydroxide and calcium hydroxide reaction products have very low solubility in water. As an alternative or an addition, the reactive metal element may be positioned and configured in a way that constrains the degradation of the reactive metal element in the reaction-inducing fluid due to the geometry of the area in which the reactive metal element is disposed. This may result in reduced exposure of the reactive metal element to the reaction-inducing fluid, but may also reduce degradation of the reaction product of the reactive metal element, thereby prolonging the life of the reaction product in the void space. As an example, the volume of the area in which the reactive metal element is disposed may be less than the potential expansion volume of the volume of reactive metal disposed in said area. In some examples, this volume of area may be less than as much as 50% of the expansion volume of reactive metal. Alternatively, this volume of area may be less than 90% of the expansion volume of reactive metal. As another alternative, this volume of area may be less than 80% of the expansion volume of reactive metal. As another alternative, this volume of area may be less than 70% of the expansion volume of reactive metal. As another alternative, this volume of area may be less than 60% of the expansion volume of reactive metal. In a specific example, a portion of the reactive metal element may be disposed in a recess within the conduit to restrict the exposure area to only the surface portion of the reactive metal element that is not disposed in the recess.

In some examples, the formed reaction products of the reactive metal reaction may be dehydrated under sufficient pressure. For example, if a metal hydroxide is under sufficient contact pressure and resists further movement induced by additional hydroxide formation, the elevated pressure may induce dehydration of the metal hydroxide to form the metal oxide. As an example,

magnesium hydroxide may be dehydrated under sufficient pressure to form magnesium oxide and water. As another example, calcium hydroxide may be dehydrated under sufficient pressure to form calcium oxide and water. As yet another example, aluminum hydroxide may be dehydrated under sufficient pressure to form aluminum oxide and water.

5 The reactive metal elements may be formed in a solid solution process, a powder metallurgy process, or through any other method as would be apparent to one of ordinary skill in the art. Regardless of the method of manufacture, the reactive metal elements may be slipped over the conduit and held in place via any sufficient method. The reactive metal elements may be placed over the conduit in one solid piece or in multiple discrete pieces. Once in place, the reactive metal element may be held in position with end rings, stamped rings, retaining rings, fasteners, adhesives, set screws, swedging, or any other such method for retaining the reactive metal element in position. In some alternative examples, the reactive metal element may not be held in position and may slide freely on the exterior of the tubular. As discussed above, the reactive metal elements may be formed and shaped to fit over existing conduits and may not require modification of the outer diameter or profile of the liner hanger in some examples. Alternatively, the conduit may be manufactured to comprise a recess in which the reactive metal element may be disposed. The recess may be of sufficient dimensions and geometry to retain the reactive metal elements in the recess. In alternative examples, the reactive metal element may be cast onto the conduit. In some alternative examples, the diameter of the reactive metal element may be reduced (e.g., by swaging) when disposed on the conduit. In some examples, the reactive metal elements may be disposed over the length of the conduit (e.g., the singular conduit joint of the conduit string that is threaded or coupled to other conduit joints to form a conduit string). In alternative examples, the reactive metal element may be placed on only a portion of the conduit joint. In some examples, the reactive metal elements may be placed on all conduit joints to form continuous covering of the conduit string. In other examples, the reactive metal elements may be placed on only some of the conduit joints of the conduit string (e.g., at locations where cement assurance issues may occur).

 In some optional examples, the reactive metal element may be shaped such as to increase the available surface area for reaction. Such shapes may comprise pieces, pellets, latices, and the like. FIG. 1 is an illustration of a lattice-shaped reactive metal element. In some optional examples, a foam may be used as the lattice. In further optional embodiments, a non-reactive material such as non-reactive fluid or non-reactive solid may be dispersed within the shaped reactive metal element to delay contact with the reaction-inducing fluid. For example, the voids within the lattice and the exterior of the lattice may be covered with a non-reactive material. In other example, the exterior and interstitial spaces between pieces or pellets of the reactive metal

element may be filled with the non-reactive material. Examples of the non-reactive material may include non-reactive fluids including, but not limited to, air, nitrogen, carbon dioxide, liquid hydrocarbons, liquid waxes, oleaginous fluids, distilled water, glycerin, alcohol, or any combination. The non-reactive fluid may be displaced via fluid pressure from the reaction-inducing fluid upon contact and/or fluid pressure from the hydrogen gas produced by the reaction of the reactive metal and the reaction-inducing fluid as the reaction process begins on a portion of the reactive metal element. Examples of the non-reactive material may include non-reactive solids including, but not limited to, polylactic acid, polyglycolic acid, plastics, solid waxes, or any combination. The non-reactive solid material may be degraded via time and/or increasing wellbore temperature. The degraded remnants may then be displaced by fluid pressure from the reaction-inducing fluid upon contact and/or fluid pressure from the hydrogen gas produced by the reaction of the reactive metal and the reaction-inducing fluid as the reaction process begins on a portion of the reactive metal element. Upon displacement of the non-reactive material, the reactive metal of the reactive metal element may contact the reaction-inducing fluid and may react to perform the desired wellbore operation.

In some optional examples, the reactive metal element may include a removable barrier coating. The removable barrier coating may be used to cover the exterior surfaces of the reactive metal element and prevent contact of the reactive metal with the reaction-inducing fluid. The removable barrier coating may be removed after other wellbore operations are completed. The removable barrier coating may be used to delay reaction and/or prevent premature expansion with the reactive metal element. Examples of the removable barrier coating include, but are not limited to, any species of plastic shell, organic shell, paint, dissolvable coatings (e.g., solid magnesium compounds or an aliphatic polyester), a meltable material (e.g., with a melting temperature less than 550° F), or any combination thereof. When desired, the removable barrier coating may be removed from the reactive metal element with any sufficient method. For example, the removable barrier coating may be removed through dissolution, a phase change induced by changing temperature, corrosion, hydrolysis, melting, or the removable barrier coating may be time-delayed and degrade after a desired time under specific wellbore conditions.

In some optional examples, a removable casing may cover the exterior surfaces of the reactive metal element and prevent contact of the reactive metal with the reaction-inducing fluid. The removable casing may be removed after other wellbore operations are completed. The removable casing may be used to delay reaction and/or prevent premature expansion of the reactive metal element. Examples of the removable casing include, but are not limited to, frangible casings that are easily broken, degraded, destroyed, melted, shattered, etc. The frangible casing may be removed through forces such as torque, tension, puncturing, impacting, degradation from

fluid contact and/or wellbore conditions such as pressure and/or temperature, or a combination of forces. For example, the frangible casing may rip under strain from a sufficient applied axial force. The frangible casing may comprise any frangible material sufficient for breaking, ripping, shattering, degrading, melting, etc. Examples of the frangible material include, but are not limited to, sufficiently thin metals; sufficiently brittle polymers such as acrylic, polystyrene, etc.; cellulosic materials such as paper and waxed paper; ceramic materials; and the like. The degree of thinness and/or brittleness of the frangible material will be determined by the species of material chosen and the potential force available to break the frangible casing. One of ordinary skill in the art will be readily able to determine the potential force available and thus the potential material properties necessary to remove the frangible casing upon application of said force. In some additional optional examples, the frangible casing may be stressed during manufacture through the inclusion of stress risers such as cracks, grooves, etc. The stress risers may allow for a relatively lower applied force to break the frangible casing and may also allow for frangible casing to break in a consistent pattern. Upon removal, the reactive metal of the reactive metal element may contact the reaction-inducing fluid and may react to perform the desired wellbore operation.

In some optional examples, the reactive metal element may include an additive which may be added to the reactive metal element during manufacture as a part of the composition, or the additive may be coated onto the reactive metal element after manufacturing. The additive may alter one or more properties of the reactive metal element. For example, the additive may improve expansion, add texturing, improve bonding, improve gripping, etc. Examples of the additive include, but are not limited to, any species of ceramic, elastomer, glass, non-reacting metal, the like, or any combination thereof.

The reactive metal element may be used to expand into any void spaces that are proximate to the reactive metal elements. Without limitation, the reactive metal elements may be used to fill any voids in adjacent space, which may include annular spaces adjacent to a conduit, as well as defects in cement sheaths such as cracks within a cement sheath, channels formed from gas channeling through a cement sheath, microannuli formed between the cement sheath and the conduit which may be formed from temperature cycling, stress load cycling, conduit shrinkage, etc.

As described above, the reactive metal elements comprise reactive metals and as such, they are non-elastomeric materials. As non-elastomeric materials, the reactive metal elements do not possess elasticity, and therefore, they may irreversibly expand when contacted with a reaction-inducing fluid. The reactive metal elements may not return to their original size or shape even after the reaction-inducing fluid is removed from contact.

Generally, the reaction-inducing fluid induces a reaction in the reactive metal to form a reaction product that occupies more space than the unreacted reactive metal. Examples of the reaction-inducing fluid include, but are not limited to, saltwater (e.g., water containing one or more salts dissolved therein), brine (e.g., saturated saltwater, which may be produced from subterranean formations), seawater, or any combination thereof. Generally, the reaction-inducing fluid may be from any source provided that the fluid does not contain an excess of compounds that may undesirably affect other components in the sealing element. In the case of saltwater, brines, and seawater, the reaction-inducing fluid may comprise a monovalent salt or a divalent salt. Suitable monovalent salts may include, for example, sodium chloride salt, sodium bromide salt, potassium chloride salt, potassium bromide salt, and the like. Suitable divalent salt can include, for example, magnesium chloride salt, calcium chloride salt, calcium bromide salt, and the like. In some examples, the salinity of the reaction-inducing fluid may exceed 10%. Advantageously, the reactive metal elements of the present disclosure may not be impacted by contact with high-salinity fluids. One of ordinary skill in the art, with the benefit of this disclosure, should be readily able to select a reaction-inducing fluid for inducing a reaction with the reactive metal elements.

The reactive metal elements may be used in high-temperature formations (e.g., in formations with zones having temperatures equal to or exceeding 350° F). Advantageously, the use of the reactive metal elements of the present disclosure may not be impacted in high-temperature formations. In some examples, the reactive metal elements may be used in both high-temperature formations and with high-salinity fluids. In a specific example, a reactive metal element may be positioned on a conduit and used to fill a void in a cement sheath after contact with a brine having a salinity of 10% or greater while also being disposed in a wellbore zone having a temperature equal to or exceeding 350° F.

FIG. 2 is a cross-section of an example downhole device, generally 5. In this specific example, the downhole device 5 may be a sealing system such as a packer. The downhole device 5 comprises a reactive metal element 10 disposed within a void space 15. The void space 15 may be carved into the downhole device 5, or the downhole device 5 may be manufactured to comprise a suitable void space 15. The geometry of the void space 15 is designed such that an opening 20 is presented to the exterior of the downhole device 5. The downhole device 5 may be deployed and run in hole until the opening 20 is adjacent an annular space into which the reactive metal element 10 is to be deployed upon reaction. Covering at least a portion of the reactive metal element 10 is a frangible casing 25. The frangible casing 25 may cover the portion of the reactive metal element 10 exposed to the opening 20 or may cover more of the reactive metal element 10, including covering of the entirety of the reactive metal element 10. The reactive metal element

10 may be deployed in a desired shape such as a lattice, pellets, or pieces within the void space 15. In some optional examples, a non-reactive material may be deployed in the void space 15 and interspersed within the reactive metal element 10 to assist in preventing premature reaction. A sliding piston 30, or other such actuating component, may be disposed adjacent to the void space 5 15 containing the reactive metal element 10. Translation of the sliding piston 30 is prevented by a body lock ring 35. The body lock ring 35 is exemplary in nature and may be substituted for any other such locking mechanism so as to prevent undesired translation of the sliding piston 30.

FIG. 3 is a cross-section of the example downhole device 5 of FIG. 1 after the frangible casing 25 has been broken. When desired for use, the body lock ring 35 may be disengaged to 10 allow for translation of the sliding piston 30. Translation of the sliding piston 30 may occur as a result of increasing localized fluid pressure in the wellbore, or may be actuated by hydraulic, mechanical, pneumatic or other such mechanisms as would be readily apparent to one of ordinary skill in the art. The sliding piston 30 applies axial pressure to the void space 15 so as to compress the frangible casing 25 and the reactive metal element 10 disposed within. The frangible casing 15 25 is broken into pieces thereby allowing portions of the reactive metal element 10 to be exposed to the exterior annular space adjacent the opening 20. In some examples, the compression may push the pieces, pellets, and/or lattice structure of the reactive metal element 10 into the annular space. The exposed reactive metal of the reactive metal element 10 may now be in a position to contact a circulating reaction-inducing fluid. Upon contact with the reaction-inducing fluid, the 20 reactive metal within the reactive metal element 10 will react to form the reaction product, thereby providing a filling expansion into any adjacent space contactable by the reaction product to perform a sealing, filling, or anchoring operation as desired.

FIG. 4 is a cross-section of the example downhole device 5, of FIGs. 2 and 3 with modification. In this specific example, the downhole device 5 may be a sealing system such as a 25 packer. The downhole device 5 comprises a reactive metal element 10 disposed within a void space 15. The void space 15 may be carved into the downhole device 5 or the downhole device 5 may be manufactured to comprise a suitable void space 15. The geometry of the void space 15 is designed such that an opening 20 is presented to the exterior of the downhole device 5. The downhole device 5 may be deployed and run in hole until the opening 20 is adjacent an annular 30 space into which the reactive metal element 10 is to be deployed upon reaction. Covering at least a portion of the reactive metal element 10 is a frangible casing 25. The frangible casing 25 may cover the portion of the reactive metal element 10 exposed to the opening 20 or may cover more of the reactive metal element 10, including covering of the entirety of the reactive metal element 10. The reactive metal element 10 may be deployed in a desired shape such as a lattice, pellets, 35 or pieces within the void space 15. In some optional examples, a non-reactive material may be

deployed in the void space 15 and interspersed within the reactive metal element 10 to assist in preventing premature reaction. A sliding piston 30, or other such actuating component, may be disposed adjacent to the void space 15 containing the reactive metal element 10. Translation of the sliding piston 30 is prevented by a body lock ring 35. The body lock ring 35 is exemplary in nature and may be substituted for any other such locking mechanism so as to prevent undesired translation of the sliding piston 30. The interior diameter of the downhole device 5 comprises openings 40 that extend starting from a flowpath 45 within the interior of the downhole 5 through the body of the downhole device 5 and into the void space 15. A sliding component 50 (e.g., a sleeve, piston, or other translatable member) is disposed within the flowpath 45. The sliding component 50 blocks fluid flow within flowpath 40 and seals flowpath 45 with sealing elements 55. When the downhole device 5 is positioned as desired, the sliding component 50 may be removed allowing for a reaction inducing fluid to enter into openings 40 to allow for expansion and sealing of the reactive metal element 10 within the flowpath 45 as the reactive metal reacts and expands within the flowpath 45. Additionally, the sliding piston 30 may be compressed in some examples to allow sealing, anchoring, etc. as described in FIG. 3 above.

FIG. 5 is a cross-section of an example downhole device, generally 100. In this specific example, the downhole device 100 may be a sealing system such as a packer. The downhole device 100 comprises a reactive metal element 105 disposed within a void space 110. In the illustrated example, the void space 110 exists between two end rings 115 disposed on the exterior surface of the body 120 of the downhole device 100. The geometry of the void space 110 is designed such that an opening 125 is presented to the exterior of the downhole device 100. The downhole device 100 may be deployed and run in hole until the opening 125 is adjacent an annular space into which the reactive metal element 105 is to be deployed upon reaction. Covering at least a portion of the reactive metal element 105 is a frangible casing 130. The frangible casing 130 may cover the portion of the reactive metal element 105 exposed to the opening 125 or may cover more of the reactive metal element 105, including covering of the entirety of the reactive metal element 105. This specific reactive metal element 105 is illustrated as a solid piece and is not a lattice, pellet, or discrete pieces. Adjacent to the reactive metal element 105 is a non-reactive material 140 such as a non-reactive fluid.

FIG. 6 is a cross-section of the example downhole device 100 of FIG. 5 after the frangible casing 130 has been broken. When desired for use, axial force may be applied to one or both of the end rings 115 resulting in translation of at least one of the end rings 115 towards the reactive metal element 105. Translation of the end rings 115 may occur as a result of increasing localized fluid pressure in the wellbore, or may be actuated by hydraulic, mechanical, pneumatic or other such mechanisms as would be readily apparent to one of ordinary skill in the art. The end rings

115 apply axial pressure to the void space 110 so as to compress the frangible casing 130. The frangible casing 130 is broken into pieces thereby allowing portions of the reactive metal element 105 to be exposed to the exterior annular space adjacent the opening 125. The exposed reactive metal of the reactive metal element 105 may now be in a position to contact a circulating reaction-inducing fluid. Upon contact with the reaction-inducing fluid, the reactive metal within the reactive metal element 105 will react to form the reaction product, thereby providing a filling expansion into any adjacent space contactable by the reaction product to perform a sealing, filling, or anchoring operation as desired.

FIG. 7 is a cross-section of an example downhole device, generally 200. In this specific example, the downhole device 200 is a setting tool. The downhole device 200 comprises a reactive metal element 205 disposed on the exterior of the downhole device 200. In the illustrated example, the reactive metal element 205 is wedge shaped and moves along its slope as a part of the operation of the downhole device 200. Covering at least a portion of the downhole device 200 is a frangible casing 210. The frangible casing 210 covers the portion of the downhole device 200 containing the reactive metal element 205. This specific reactive metal element 205 is illustrated as a solid piece and is not a lattice, pellet, or discrete pieces. A sliding piston 215 or other translatable member is disposed within the center throughbore of the downhole device 200.

FIG. 8 is a cross-section of the example downhole device 200 of FIG. 7 after the frangible casing 210 has been broken. When desired for use, axial force may be applied the sliding piston 215 resulting in translation of the sliding piston 215. Translation of the sliding piston 215 may occur as a result of increasing localized fluid pressure in the wellbore, or may be actuated by hydraulic, mechanical, pneumatic or other such mechanisms as would be readily apparent to one of ordinary skill in the art. The sliding piston 215 applies axial pressure via a flanged or wedged structure 225 which is further translated to the wedge-shaped reactive metal element 205. The reactive metal element 205 is then shunted outward radially into the frangible casing 210 which is then broken into pieces thereby allowing portions of the reactive metal element 205 to be exposed to any exterior annular space. The exposed reactive metal of the reactive metal element 205 may now be in a position to contact a circulating reaction-inducing fluid. Upon contact with the reaction-inducing fluid, the reactive metal within the reactive metal element 205 will react to form the reaction product, thereby providing a filling expansion into any adjacent space contactable by the reaction product to perform a sealing, filling, or anchoring operation as desired.

It should be clearly understood that the examples illustrated by FIGs. 1-8 are merely general applications of the principles of this disclosure in practice, and a wide variety of other examples are possible. Therefore, the scope of this disclosure is not limited in any manner to the details of any of the FIGURES described herein.

It is also to be recognized that the disclosed reactive metal elements may also directly or indirectly affect the various downhole equipment and tools that may come into contact with the reactive metal elements during operation. Such equipment and tools may include, but are not limited to: wellbore casing, wellbore liner, completion string, insert strings, drill string, coiled tubing, slickline, wireline, drill pipe, drill collars, mud motors, downhole motors and/or pumps, surface-mounted motors and/or pumps, centralizers, turbolizers, scratchers, floats (e.g., shoes, collars, valves, etc.), logging tools and related telemetry equipment, actuators (e.g., electromechanical devices, hydromechanical devices, etc.), sliding sleeves, production sleeves, plugs, screens, filters, flow control devices (e.g., inflow control devices, autonomous inflow control devices, outflow control devices, etc.), couplings (e.g., electro-hydraulic wet connect, dry connect, inductive coupler, etc.), control lines (e.g., electrical, fiber optic, hydraulic, etc.), surveillance lines, drill bits and reamers, sensors or distributed sensors, downhole heat exchangers, valves and corresponding actuation devices, tool seals, packers, cement plugs, bridge plugs, and other wellbore isolation devices, or components, and the like. Any of these components may be included in the systems generally described above and depicted in any of the FIGURES.

Provided are methods for initiating the reaction of a reactive metal element of a downhole device. An example method comprises introducing the downhole device into a wellbore; wherein the downhole device comprises the reactive metal element; wherein the reactive metal element has a first volume; and wherein the reactive metal element is separated from a reaction-inducing fluid by a frangible casing. The method further comprises removing the frangible casing and contacting the reactive metal element with the reaction-inducing fluid to produce a reaction product having a second volume greater than the first volume.

Additionally or alternatively, the method may include one or more of the following features individually or in combination. The reactive metal element may be in the shape of a lattice. The reactive metal element may be comprised of discrete pieces. The reactive metal element may be disposed within a void space of the downhole device and a non-reactive material may be interspersed within the reactive metal element while the reactive metal element is disposed within the void space. The non-reactive material may be selected from the group consisting of air, nitrogen, carbon dioxide, liquid hydrocarbon, liquid wax, oleaginous fluid, distilled water, polylactic acid, polyglycolic acid, plastic, solid wax, glycerin, alcohol, and any combination thereof. The frangible casing may comprise a material selected from the group consisting of metal, polymer, cellulosic material, ceramic material, and any combination thereof. The reactive metal element may comprise a metal selected from the group consisting of magnesium, calcium, aluminum, tin, zinc, beryllium, barium, manganese, and any combination thereof. The reactive

metal element may comprise a metal alloy selected from the group consisting of magnesium-zinc, magnesium-aluminum, calcium-magnesium, aluminum-copper, and any combination thereof.

5 Provided are downhole devices comprising reactive metal elements. An example downhole device comprises a reactive metal element, and a frangible casing covering at least a portion of the reactive metal element.

10 Additionally or alternatively, the downhole device may include one or more of the following features individually or in combination. The reactive metal element may be in the shape of a lattice. The reactive metal element may be comprised of discrete pieces. The reactive metal element may be disposed within a void space of the downhole device and a non-reactive material may be interspersed within the reactive metal element while the reactive metal element is disposed within the void space. The non-reactive material may be selected from the group consisting of air, nitrogen, carbon dioxide, liquid hydrocarbon, liquid wax, oleaginous fluid, distilled water, polylactic acid, polyglycolic acid, plastic, solid wax, glycerin, alcohol, and any combination thereof. The frangible casing may comprise a material selected from the group consisting of metal, 15 polymer, cellulosic material, ceramic material, and any combination thereof. The reactive metal element may comprise a metal selected from the group consisting of magnesium, calcium, aluminum, tin, zinc, beryllium, barium, manganese, and any combination thereof. The reactive metal element may comprise a metal alloy selected from the group consisting of magnesium-zinc, magnesium-aluminum, calcium-magnesium, aluminum-copper, and any combination thereof.

20 Provided are systems for initiating the reaction of a reactive metal element of a downhole device. An example system comprises a reactive metal element, a frangible casing covering at least a portion of the reactive metal element, and a reaction-inducing fluid capable of reacting with the reactive metal element to produce a reaction product having a second volume that is greater than the first volume.

25 Additionally or alternatively, the system may include one or more of the following features individually or in combination. The reactive metal element may be in the shape of a lattice. The reactive metal element may be comprised of discrete pieces. The reactive metal element may be disposed within a void space of the downhole device and a non-reactive material may be interspersed within the reactive metal element while the reactive metal element is disposed within the void space. The non-reactive material may be selected from the group consisting of air, nitrogen, carbon dioxide, liquid hydrocarbon, liquid wax, oleaginous fluid, distilled water, polylactic acid, polyglycolic acid, plastic, solid wax, glycerin, alcohol, and any combination thereof. The frangible casing may comprise a material selected from the group consisting of metal, 30 polymer, cellulosic material, ceramic material, and any combination thereof. The reactive metal element may comprise a metal selected from the group consisting of magnesium, calcium, 35

aluminum, tin, zinc, beryllium, barium, manganese, and any combination thereof. The reactive metal element may comprise a metal alloy selected from the group consisting of magnesium-zinc, magnesium-aluminum, calcium-magnesium, aluminum-copper, and any combination thereof.

5 The preceding description provides various examples of the apparatus, systems, and methods of use disclosed herein which may contain different method steps and alternative combinations of components. It should be understood that, although individual examples may be discussed herein, the present disclosure covers all combinations of the disclosed examples, including, without limitation, the different component combinations, method step combinations, and properties of the system. It should be understood that the compositions and methods are
10 described in terms of “comprising,” “containing,” or “including” various components or steps. The systems and methods can also “consist essentially of” or “consist of the various components and steps.” Moreover, the indefinite articles “a” or “an,” as used in the claims, are defined herein to mean one or more than one of the element that it introduces.

For the sake of brevity, only certain ranges are explicitly disclosed herein. However,
15 ranges from any lower limit may be combined with any upper limit to recite a range not explicitly recited, as well as ranges from any lower limit may be combined with any other lower limit to recite a range not explicitly recited. In the same way, ranges from any upper limit may be combined with any other upper limit to recite a range not explicitly recited. Additionally, whenever a numerical range with a lower limit and an upper limit is disclosed, any number and
20 any included range falling within the range are specifically disclosed. In particular, every range of values (of the form, “from about a to about b,” or, equivalently, “from approximately a to b,” or, equivalently, “from approximately a-b”) disclosed herein is to be understood to set forth every number and range encompassed within the broader range of values even if not explicitly recited. Thus, every point or individual value may serve as its own lower or upper limit combined with
25 any other point or individual value or any other lower or upper limit, to recite a range not explicitly recited.

One or more illustrative examples incorporating the examples disclosed herein are presented. Not all features of a physical implementation are described or shown in this application for the sake of clarity. Therefore, the disclosed systems and methods are well adapted to attain
30 the ends and advantages mentioned, as well as those that are inherent therein. The particular examples disclosed above are illustrative only, as the teachings of the present disclosure may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown other than as described in the claims below. It is therefore
35 evident that the particular illustrative examples disclosed above may be altered, combined, or

modified, and all such variations are considered within the scope of the present disclosure. The systems and methods illustratively disclosed herein may suitably be practiced in the absence of any element that is not specifically disclosed herein and/or any optional element disclosed herein.

- Although the present disclosure and its advantages have been described in detail, it should
- 5 be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the following claims.

WHAT IS CLAIMED IS:

1. A method for initiating the reaction of a reactive metal element of a downhole device comprising:
 - 5 introducing the downhole device into a wellbore; wherein the downhole device comprises the reactive metal element; wherein the reactive metal element has a first volume; wherein the reactive metal element is separated from a reaction-inducing fluid by a frangible casing;
removing the frangible casing; and
contacting the reactive metal element with the reaction-inducing fluid to produce a
10 reaction product having a second volume greater than the first volume.
2. The method of claim 1, wherein the reactive metal element is in the shape of a lattice.
3. The method of claim 1, wherein the reactive metal element is comprised of discrete pieces.
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4. The method of claim 1, wherein the reactive metal element is disposed within a void space of the downhole device and wherein a non-reactive material is interspersed within the reactive metal element while the reactive metal element is disposed within the void space.
- 20 5. The method of claim 4, wherein the non-reactive material is selected from the group consisting of air, nitrogen, carbon dioxide, liquid hydrocarbon, liquid wax, oleaginous fluid, distilled water, polylactic acid, polyglycolic acid, plastic, solid wax, glycerin, alcohol, and any combination thereof.
- 25 6. The method of claim 1, wherein the frangible casing comprises a material selected from the group consisting of metal, polymer, cellulosic material, ceramic material, and any combination thereof.
7. The method of claim 1, wherein the reactive metal element comprises a metal selected
30 from the group consisting of magnesium, calcium, aluminum, tin, zinc, beryllium, barium, manganese, and any combination thereof.
8. The method of claim 1, wherein the reactive metal element comprises a metal alloy selected from the group consisting of magnesium-zinc, magnesium-aluminum, calcium-magnesium, aluminum-copper, and any combination thereof.
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9. A downhole device comprising:
a reactive metal element, and
a frangible casing covering at least a portion of the reactive metal element.
- 5
10. The downhole device of claim 9, wherein the reactive metal element is in the shape of a lattice.
11. The downhole device of claim 9, wherein the reactive metal element is comprised of
10 discrete pieces.
12. The downhole device of claim 9, wherein the reactive metal element is disposed within a void space of the downhole device and wherein a non-reactive material is interspersed within the reactive metal element while the reactive metal element is disposed within the void space.
- 15
13. The downhole device of claim 12, wherein the non-reactive material is selected from the group consisting of air, nitrogen, carbon dioxide, liquid hydrocarbon, liquid wax, oleaginous fluid, distilled water, polylactic acid, polyglycolic acid, plastic, solid wax, glycerin, alcohol, and any combination thereof.
- 20
14. The downhole device of claim 9, wherein the frangible casing comprises a material selected from the group consisting of metal, polymer, cellulosic material, ceramic material, and any combination thereof.
- 25
15. The downhole device of claim 9, wherein the reactive metal element comprises a metal selected from the group consisting of magnesium, calcium, aluminum, tin, zinc, beryllium, barium, manganese, and any combination thereof.
16. The downhole device of claim 9, wherein the reactive metal element comprises a metal
30 alloy selected from the group consisting of magnesium-zinc, magnesium-aluminum, calcium-magnesium, aluminum-copper, and any combination thereof.
17. A downhole device comprising:
a reactive metal element,
35 a frangible casing covering at least a portion of the reactive metal element, and

a reaction-inducing fluid capable of reacting with the reactive metal element to produce a reaction product having a second volume that is greater than the first volume.

18. The system of claim 17, wherein the reactive metal element is in the shape of a lattice.
- 5
19. The system of claim 17, wherein the reactive metal element is comprised of discrete pieces.
20. The system of claim 17, wherein the reactive metal element is disposed within a void
- 10 space of the downhole device and wherein a non-reactive material is interspersed within the reactive metal element while the reactive metal element is disposed within the void space.

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