United States Patent Application Publication	20250264007
Kind Code	A1
Publication Date	August 21, 2025
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KINETIC ENERGY PERFORATING ROUND ASSEMBLY AND METHODS OF USE

Abstract

An assembly suitable for use in downhole operations including frac'ing. The assembly includes a sabot that includes an ignition stack, and a projectile partially received within the sabot, and the projectile includes an electrical contact in electrical communication with the ignition stack. The assembly may be received in a dispensing device that includes a propellant chamber and a barrel, and the assembly may be positioned in the dispensing device so that the ignition stack extends partway into the propellant chamber.

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Family ID: **1000008448842**

Appl. No.: **19/051985**

Filed: **February 12, 2025**

Related U.S. Application Data

us-provisional-application US 63554055 20240215

Publication Classification

Int. Cl.: **E21B43/11** (20060101); **F42B14/06** (20060101)

U.S. Cl.:

CPC **E21B43/11** (20130101); **F42B14/06** (20130101);

Background/Summary

TECHNOLOGICAL FIELD OF THE DISCLOSURE

[0001] One or more example embodiments disclosed herein are directed to projectiles and associated components such as may be employed in downhole perforation operations. More specifically, example embodiments comprise a projectile comprising a kinetic energy perforating round assembly, and methods for using the same.

BACKGROUND

[0002] Perforating is a process used to create holes in a well casing disposed in a wellbore. Typically, the holes, or perforations, are created using a perforation gun that fires a projectile of some kind. While conventional projectiles are effective in creating perforations, the size, quality, and shape, of the perforations are inconsistent and can vary widely from one perforation to another, even when the same type of projectile is used to create the various perforations. Such variations can cause problems, such as by inhibiting the free flow of hydrocarbons into a well bore. As another example, some processes, such as hydraulic fracturing, or frac'ing, may require the use of symmetric and uniform holes for optimal performance. However, conventional projectiles often create holes that are asymmetric.

ASPECTS OF AN EXAMPLE EMBODIMENT

[0003] One or more example embodiments disclosed herein are directed to assemblies that include a projectile and sabot, such as may be employed in downhole perforation operations. More specifically, example embodiments comprise an assembly that includes a projectile comprising a kinetic energy perforating round and a non-discarding sabot connected to the projectile, and methods for using the same.

[0004] One example embodiment is directed to an assembly that comprises a sabot, and further comprises a projectile that may, or may not, be connected to the sabot. The projectile may be configured to control a flow of target material as the projectile enters, and passes through, the target. The sabot may be a non-discarding sabot that includes an ignition stack partly received within the target. The ignition stack may include an ignitor in communication with propellant in a propellant chamber. Example embodiments of a projectile are disclosed in U.S. patent application, atty. docket 22464.26.1, entitled KINETIC ENERGY PERFORATING ROUND AND METHODS OF USE, filed the same day herewith, and incorporated herein in its entirety by this reference. Example embodiments of a sabot are disclosed in U.S. patent application, atty. docket 22464.25.1, entitled GROUNDING SABOT AND METHODS OF USE, filed the same day herewith, and incorporated herein in its entirety by this reference.

[0005] As will be apparent from this disclosure, example embodiments may be advantageous in various respects. For example, an embodiment may create symmetric and uniform perforations in a target material. As another example, an embodiment of an assembly that comprises a projectile and a sabot may comprise one or more reusable components. Various other advantages of one or more embodiments will be apparent from this disclosure.

[0006] It should be noted that nothing herein should be construed as constituting an essential or indispensable element of any embodiment. Rather, and as the person of ordinary skill in the art will readily appreciate, various aspects of the disclosed embodiments may be combined in a variety of ways so as to define yet further embodiments. Such further embodiments are considered as being within the scope of this disclosure. As well, none of the embodiments embraced within the scope of this disclosure should be construed as resolving, or being limited to the resolution of, any particular problem(s). Nor should such embodiments be construed to implement, or be limited to implementation of, any particular effect(s).

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The appended drawings contain figures of various example embodiments to further illustrate and clarify the above and other aspects of example embodiments. It will be appreciated that these drawings depict only example embodiments and are not intended to limit the scope of this disclosure or of any claims. Example embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings.

[0008] FIG. **1** is a top perspective view of an assembly, according to one embodiment, that comprises a sabot and a projectile.

[0009] FIG. **2** is a side view of an example assembly, according to one embodiment.

[0010] FIG. **3** is a top view of the example assembly, according to one embodiment.

[0011] FIG. **4** is side cross-sectional view of an example assembly, according to one embodiment, in which the assembly has been loaded into a perf gun.

[0012] FIG. **5** is a side cross-sectional view of an example assembly, according to one embodiment, in which the assembly has been fired, and the projectile has traveled partway along a barrel of a perf gun, or a barrel of a penetrating charge dispenser (PCD) that is loaded/loadable into a perf gun.

[0013] FIG. **6** is a side cross-sectional view of an example assembly, according to one embodiment, in which the assembly has been fired, and the projectile is at the point of impact with one or more target materials.

[0014] FIG. **7** is a side cross-sectional view of an example assembly, according to one embodiment, in which the assembly has been fired, and the projectile has passed through one target material, and become embedded in another target material.

[0015] FIG. **8** discloses an embodiment of a height adjustment mechanism, comprising a spring, for a projectile.

[0016] FIG. **9** discloses an embodiment of a height adjustment mechanism, comprising a height adjustment ring, for a projectile.

[0017] FIG. **10** discloses an embodiment of a height adjustment mechanism, comprising a PCB, for a projectile.

[0018] FIG. **11** discloses an embodiment of a height adjustment mechanism, comprising one or more shims, for a projectile.

DETAILED DESCRIPTION OF SOME EXAMPLE EMBODIMENTS

[0019] With attention now to the examples of FIGS. **1** through **7**, details are provided concerning an example assembly, generally referred to in the Figures at **200**, that includes a sabot, and also includes a projectile, one example embodiment of which is a kinetic energy perforating round (KEPR). Details are provided herein as well concerning some example methods of use of the example assembly **200**.

A. Assembly

A.1 Introduction

[0020] An assembly **200** according to one embodiment may provide short-range penetration through confined targets in confined spaces, such as by perforating an oil and gas well, and, particularly, target materials such as well casing, cement, and geological formations. In an embodiment, the assembly **200** is configured to ensure that maximum energy is contained within and behind the projectile. The assembly **200** may comprise two primary components, namely, a non-discarding sabot, and a projectile. The assembly **200** may be configured for use in short-barrel applications, with an emphasis on rapid penetration through confined targets, such as well casing in an oil and gas wellbore. Barrel travel of the assembly may be less than 3.00″ and a distance to target, that is, a stand-off distance, may be less than 1.00″ from the muzzle of the barrel. Thus, in one embodiment, the travel distance of the assembly **200** may be up to 4.00″ and, in most cases, less than 4.00″.

A.2 Overview of Aspects of an Example Assembly

[0021] As shown in the Figures, an assembly **200** may comprise a projectile **201**, such as a KEPR for example, and a sabot **202** in which a portion of the projectile **201** may be received, and attached. The assembly **200** may further comprise a power contact **203** which may comprise an electrically conductive element configured and arranged to receive, and pass, an electrical current. Additionally, or alternatively, the power contact **203** may serve to carry communication signals and data. As shown in FIG. **2**, the assembly **200** may comprise an ignition stack **204**. The ignition stack **204**, which may comprise an ignitor **205**, may be in electrical communication with the power contact **203** so as to enable the ignitor **205** to receive an electrical current for initiating ignition of a propellant. The ignitor **205** may be connected to a ground wire **206** to enable grounding of an electrical current received by the ignition stack **204**.

[0022] As shown in FIG. **4**, the assembly **200** may comprise a penetrating charge dispenser (PCD) ignition jack **207**. In an embodiment, the PCD ignition jack **207** may comprise an opening or inlet on a PCD that enables electrical power, comms, and data signals, to be passed to the assembly **200**, such as by way of the power contact **203**, when the assembly **200** is positioned in a barrel **208** of a PCD, or other device.

[0023] Finally, and as further indicated in FIG. **4**, the barrel **208** may communicate with a propellant chamber **209**, which may be defined in a PCD or other device. The barrel **208** may terminate in a muzzle **211**. The propellant chamber **209** may hold one or more propellants. As well, and shown in FIG. **4**, part of the assembly **200** may be received in the propellant chamber **209**.

B. Example Components and Aspects of an Embodiment of an Assembly

[0024] Example components of the assembly **200** are discussed in detail below. Where a component is not listed, information concerning that component may be found in the Appendices A and/or B.

B.1 Target Penetration Mechanism

[0025] The confined target, in one example use case, is a steel wall pipe such as well casing that may be surrounded by cement and rock formation, as in the example of an oil and gas well. The projectile **201** may be configured to withstand the initial impact forces resulting from impact of the projectile **201** on the target, and then efficiently perforate both the steel wall and the cement. The high kinetic energy and density of the projectile **201** ensure effective material penetration, while its structural integrity is maintained.

B.2 Impact Distance Considerations

[0026] Given that, in one use case, the target may be less than 1 inch away from the muzzle of the barrel **208**, the overall shape and geometry of the projectile **201**, in combination with the components and features of the example sabot **202**, may ensure the projectile **201** effectively perforates the target without damaging the penetrating charge dispenser barrel **208** and penetrates through the casing, cement, and rock formation leaving a precise, uniformly shaped, perforation. This result may be achieved repeatedly with additional assemblies **200** fired from respective penetrating charge dispensers.

B.3 KEPR or Other Projectile

[0027] The projectile **201** is the component that perforates the target(s). In an embodiment, the projectile **201** may comprise a high-density material, or a dense metal alloy such as depleted uranium, tungsten, tool steel, NC310YW, and Aermet **100** among other alloys that have similar properties including material hardness, density, toughness, yield, and tensile strengths. The material may be chosen for its kinetic energy retention properties. The projectile **201** may be shaped to optimize its perforating capabilities as it transitions through targets such as, but not limited to, steel casing, cement, and rock formations. The projectile **201** that may be utilized in the assembly **200** may be equipped with different features, come in multiple calibers, different shapes such as elliptical, octagonal, or circular, come in different lengths, and or have external components around the bearing surface of the projectile or have a smooth bearing surface.

[0028] Regarding its interface with the sabot **202**, the projectile **201** may have a specific section or surface **201***a*, which may be annular about the projectile **201**, that interfaces with the sabot **202**. This section might include features such as grooves, ridges, or other elements that can engage with corresponding components on the sabot projectile interface. The section **201***a* that interfaces with the sabot **202** may include elements that can be adjusted in length. This adjustment may be achieved through telescoping sections, threads, or other mechanisms that allow the projectile **201** to extend or retract within the sabot **202**. Similarly, the section **201**a may also include features for adjusting the height of the projectile within the sabot.

B.4 Sabot

[0029] The sabot **202**, which may comprise a discarding sabot or a non-discarding sabot, may be configured to amplify the energy transfer from the ignition of the propellant in the propellant chamber **209** into the projectile **201**, as well as to guide the projectile **201** through the barrel **208**. Unlike conventional sabots that discard, that is, separate from the projectile **201**, upon exiting the muzzle, a non-discarding sabot **202**, according to one embodiment, remains integral, and connected to the projectile **201**, throughout the trajectory of the projectile **201**. In operation, the sabot **202** may minimize air resistance, manage gas expansion, and reduce friction, all of which functions may individually and collectively enable optimal velocity retention of the assembly **200** in a short barrel, such as the barrel **208** of a PCD for example. As discussed below, an example sabot **202** may comprise various features relating to its interface with the projectile **201**. Such features may be made of any suitable material(s), including metals.

B.4.1 Sabot Bore Diameter

[0030] The sabot **202** interface may comprise a bore that defines an annular surface **202***a*, that may be adjusted in various ways, to accommodate variations in the diameter or caliber of the projectile **201**. This adjustment may ensure optimal contact between the sabot **202** and the projectile **201**. For example, a sleeve or other structure may be provided in the bore, such as between the projectile **201** and the sabot **202**, to reduce the diameter of the bore.

B.**4**.2 Telescoping/Sliding Mechanism

[0031] The sabot **202** interface **202***a* may include a telescoping or sliding mechanism, such as a sleeve for example, that enables adjustment of the vertical position of the projectile **201** in the sabot **202**. This element may be controlled through external mechanisms or may respond to dynamic conditions when fired or upon impact. With reference to FIG. **8**, one example mechanism for adjusting the position of the projectile **201** is shown at **202***b*. The example mechanism **202***b* may comprise a spring **202***b***-1**, supporting cylinder **202***b***-2**, and sliding disk **202***b***-3**. The sliding disk **202***b***-3** may have a shape that conforms with the shape of the underside of the projectile **201**. A force exerted by the spring **202***b***-1** may be transferred to the projectile **201** by the sliding disk **202***b***-3**, thus adjusting the position of the projectile **201**. The supporting cylinder **202***b***-2** may receive the spring **202***b***-1** and provide lateral and axial support to the spring **202***b***-1** to ensure that the spring **202***b***-1** remains in position.

B.4.3 Height Adjustment Mechanism

[0032] To adjust the vertical position of the projectile **201** within the sabot **202**, the sabot **202** interface **202***a* may incorporate a mechanism that may have the ability to raise or lower the projectile **201**. This specific mechanism may comprise shimming elements, actuators, or other mechanisms that respond to external inputs or conditions. One example of this approach is disclosed in FIG. **9** which shows a height adjustment ring **202***c*. As shown, the height adjustment ring **202***c* may have an upper surface configured to fit with the shape of the underside of the projectile **201**. The thickness of the height adjustment ring **202***c* may be selected to provide the desired vertical position of the projectile **201**.

B.4.4 Dynamic Adjustment Sensors

[0033] As shown in FIG. **10**, sensors, which may be carried by a PCB (printed circuit board) **202***d*, may be integrated into the sabot **202** interface **202***a* may measure environmental conditions, target properties, or other relevant factors such as pressure, temperature, and stand-off distance to target. The information gathered by these sensors may be used to dynamically adjust the projectile **201** position within the sabot **202** for optimal performance. In an embodiment, the PCB **202***d* may be combined with a height adjustment ring **202***c*, as shown in the example of FIG. **9**.

B.4.5 Shimming Components

[0034] Shimming elements within the sabot **202** interface **202***a* provide a mechanism to fine-tune the fit and alignment of the projectile **201**. For example, and as shown in FIG. **11**, one or more shims **202***e* may be placed to adjust the height and ensure proper positioning for enhanced penetration power and perforation efficiency of the projectile **201**.

B.4.6 Variable Weight Distribution

[0035] The sabot **202** interface may include provisions for adjusting the weight distribution of the projectile **201**. This may be achieved, for example, by incorporating removable or adjustable weights within the sabot **202**, enabling customization based on the desired penetration capacity, flight characteristics, and perforation efficiency.

B.4.7 Control System

[0036] The sabot **202** interface may be integrated into a control system that manages the dynamic adjustments based on pre-programmed parameters or real-time data. This may involve electronic controls, actuators, and feedback loops to ensure precise and timely adjustments. These adjustments and parameters may be received and transferred through the power contact **203** of the assembly **200**.

B.4.8 Penetration Enhancement Features

[0037] The sabot **202** interface may incorporate features that enhance penetration capability. For example, dynamic adjustments may be made to optimize the angle of perforation, or the interface might include special coatings or materials to increase penetration upon impact with the casing wall, cement, and rock formation.

B.5 Power Contact

[0038] In an embodiment, the power contact **203** may comprise a specific area or element within an electrical connector or device that is configured and arranged to handle the transmission of electrical power. The power contact **203** may serve as an interface through which electrical power is delivered or received. In addition to transmitting power, the power contact **203** may also carry communication signals, and handle data transfer.

[0039] The power contact **203** may be made of conductive materials such as copper or other metals that allow the efficient flow of electrical current. The power contact **203** may also be an insulated contact. The surface of the power contact **203** may be configured to establish a secure connection with its corresponding counterpart. Below are some example embodiments of a power contact **203**.

[0040] A power contact **203** may comprise a magnetic contact that may utilize magnets to establish a connection between the assembly **200** and power with, or without, direct physical contact. The contact surface, in the case of direct physical contact, involves magnetic elements that attract and hold the components together, creating a magnetic circuit for power, communication, and or data transfer.

[0041] A power contact **203** may comprise a pin-and-socket configuration that comprises metal pins or blades for contact surfaces. These pins or blades provide a direct physical connection between the male and female parts of the power contact and the assembly **200**.

[0042] A power contact **203** may comprise a spring-loaded contact, which may be a mechanism where a metal spring ensures constant pressure between mating surfaces. This will compensate for multiple variations in tolerances and provide a reliable connection even in the presence of minor misalignments between the power contact and power.

[0043] In an embodiment, the power contact **203** may comprise a single conductive pathway, or have an additional conductive pathway or additional elements within the same connector, so as to constitute a multifunctional interface that may be able to convey, for example, power, data, and control signals. The multifunctional interface may comprise a single wire interface and example interfaces may implement, and operate using, various functionalities, examples of which are discussed hereafter.

[0044] One example functionality of such a multifunctional interface is a modulation technique, such as Amplitude Modulation (AM) or Frequency Modulation (FM): The data or communication signals can be modulated onto the carrier signal by varying the amplitude (AM) or frequency (FM) of the carrier wave. This enables the transmission of information alongside the power signal.

[0045] Another example functionality is Time-Division Multiplexing (TDM) which may involve dividing the time into slots, and each function (power, data, communication) is allocated a specific time slot during which it can transmit or receive signals. This may enable a single wire to cycle though different functions rapidly, allowing for the integration of multiple functions over the same single wire.

[0046] A multifunctional interface may perform, or at least be compatible with, Frequency-Division Multiplexing (FDM). FDM may involve dividing the available frequency spectrum into different frequency bands, and each function may be allocated to a specific frequency band for transmission. This may be accomplished by transmitting different frequencies. Filtering may be established between the assembly **200** and power that may separate and extract specific signals that may consist of signals such as Safe Mode, Arm, and Fire.

[0047] Another example functionality is Pulse Width Modulation (PWM), which may involve varying the width of pulses in a digital signal. The width of the pulses can represent different data values or functions. Power may be delivered to the assembly **200** continuously with the width of the pulses being modulated to transmit communication and data. These pulse widths may be interpreted to extract information, or commands.

[0048] A further example functionality is bi-directional communication. By incorporating bidirectional communication protocols between the assembly **200** and power, the single wire can be used for two-way communication. This allows for data transmission in both directions over the same wire. Some communication protocols that may be utilized are I2C or SPI, which both enable devices to send and receive data over a shared single wire.

[0049] A final example functionality of a multifunctional interface is smart switching or multiplexing circuits. Switching circuits or multiplexers may be used to route the signals on the single wire to different components or functions, within the assembly **200**, based on control signals. On one single wire, this may allow the system to switch between power delivery, data transmission, and communication on the same wire.

B.6 Penetrating Charge Dispenser (PCD) Ignition Jack

[0050] The PCD ignition jack **207** comprise an opening or inlet on the PCD that enables access for electrical power, comms, and data transfer to enter the barrel on a cable, or single wire. The PCD ignition jack **207** may enable the power cable to be directly inserted into the barrel **208** of the PCD without the need for an additional connector. The power cable may be threaded through the PCD ignition jack **207**, thus serving as a direct link for delivering electrical power to the assembly **200**. Note that an embodiment of a penetrating charge dispenser is denoted 'PCD' in FIG. **4**.

B.7 Propellant Chamber

[0051] With particular reference now to the example of FIG. **5**, details are provided concerning some example operations of the assembly **200**. These are provided only by way of example, and not limitation.

B.7.1 Gas Expansion Propelling Projectile

[0052] With reference to the propellant gas expansion **210***a* in FIG. **5**, propellant ignition may begins with the ignition of the propellant. This may be solid propellant in the form of grains or pellets that burn rapidly and produce a large volume of hot gases.

[0053] As the propellant burns, it undergoes a chemical reaction that releases a significant amount of energy in the form of hot gases. The specific chemical composition of the propellant may determine the type and or amount of gases produced.

[0054] The rapid combustion of the propellant may generate high-pressure gases within the propellant chamber **209**. The confined space of the propellant chamber **209** leads to a rapid increase in pressure as the gases are produced. This pressure buildup may propel the projectile **201** out of the barrel **208**.

[0055] As the pressure of the propellant gas(es) builds up, one or more components of the sabot **202** may expand as a result of the heat and pressure from the gas ignition and portions of those components may thus be forced against the barrel **208** walls, ensuring that most of the generated energy is transferred to the projectile **201**. For example, the pressure exerted on the sabot **202** is transmitted to the projectile **201**, which is connected to the sabot **202**. The projectile **201** accelerates down the barrel **208** due to the high-pressure gas behind it. The short barrel length which may be less than 2 inches, may require a rapid acceleration to achieve the desired assembly **200** velocity.

B.7.2 Gas Expansion Deflector Actuating Gas Valve

[0056] The deflector (see Appendices A and B) may be a ring-shaped component located at the bottom of the sabot **202**. with the deflector may possess flexibility to expand and make contact with the inner wall of the barrel **208** during the propellant ignition and gas expansion process **210***b*. The deflector may comprise an inner hollow core or cavity, creating an area where gas can expand. This cavity is configured to create a pressure differential that activates the gas valve.

[0057] As the propellant ignites, hot gases created by the propellant ignition rapidly expand, creating high pressure within the propellant chamber **209**. As shown at **210***b*, pressure is transferred to the interior of the deflector through passages or openings that connect the propellant chamber **209** to the inner hollow core of the deflector, as shown in Detail A of FIG. **5**. As the deflector possesses a degree of flexibility, that is, elastic deformability, responds to this pressure by expanding outward toward the inner wall of the barrel **208**. This expansion creates a seal between the deflector and the barrel **208**, reducing gas blow-by and directing more pressure toward the projectile **201**.

[0058] The outer diameter of the sabot **202** may be equipped with a gas valve mechanism. This valve serves to control the release of gases from the propellant chamber **209** to the atmosphere. The expansion of the deflector, driven by the pressure buildup within its inner hollow core, actuates the gas valve. The pressure applied to the outer wall of the deflector triggers the gas valve to open, or close, allowing a controlled release of gas into the compensator. Further, the gas valve manages the pressure within the propellant chamber **209** and prevents excessive pressure that could lead to damage or instability. By regulating the gas flow, the gas valve ensures that the projectile **201** is accelerated optimally while maintaining control over the entire propulsion process.

[0059] As well, the deflector, by expanding towards the inner wall of the barrel **208** and actuating the gas valve, helps minimize gas blow-by. Gas blow-by refers to the escape of propellant gases around the projectile **201**, which can reduce the efficiency of the perforation that is intended to be made in the casing, cement, and rock formation. The deflector operates to channel the majority of the expanding gases behind the projectile **201**, driving the projectile **201** forward while preventing unnecessary loss of energy.

B.7.3 Gas Expansion Gas Valve Controlling Gas Flow into Compensator

[0060] The gas valve (see Appendices A and B) is a component situated around the outer diameter of the sabot **202** and serves as a control mechanism for the release of gases from the propellant chamber into compensator. The gas valve is actuated by the expansion of the deflector. As the deflector expands against the inner wall of the barrel, it applies pressure to the outer wall of the gas valve, causing it to open, or close. This controlled opening allows gas to flow over the conducive angle and into the compensator, as shown at **210***c*.

[0061] Above the gas valve, as viewed in FIG. **5**, there is a conducive angle designed to facilitate a smooth transition of gas from the propellant chamber **209** into the compensator. This conducive angle minimizes turbulence and ensures that the gas flows efficiently into the next stage of the system. The conducive angle may be designed to optimize the gas flow, avoiding sharp turns or obstacles that could disrupt the flow dynamics. A smooth gas transition maintains the consistency in the energy and velocity of the gas as it moves toward the compensator.

[0062] The compensator may comprise a groove or channel that encircles the outer diameter of the sabot **202**. One function of the compensator is to enhance energy transfer to the projectile **201** by trapping and containing the gas that has been managed by the gas valve. As the gas flows into the compensator, the groove is configured to capture and channel the gas in a way that maximizes the pressure exerted by the gas on the projectile **201**. The compensator acts as a reservoir, temporarily holding the pressurized gas and allowing it to exert force on the projectile **201** over a longer duration of time than if the compensator were not present.

[0063] The shape, size, and orientation of the compensator may be configured to optimize the transfer of energy to the projectile. This may involve considerations such as the gas expansion rate, the projectile **201** dynamics, and the desired velocity of the projectile **201**. The gas, now contained within the compensator, exerts pressure on the projectile **201**. The shape and design of the compensator may ensure that the pressure is applied in a controlled and directed manner. The trapped gas provides continuous propulsive force to the projectile **201** as the projectile moves down the barrel **208**. In this way, an embodiment may achieve maximum velocity, energy, and work on the projectile **201**, optimizing its ability to perforate the casing, cement, and rock formation.

B.8 Muzzle

[0064] The muzzle **211** refers to the end of the barrel **208**. This is shown in FIG. **6**.

B.9 Casing

[0065] The well casing **212**, shown in FIG. **6**, is a component used in the construction and operation of oil wells and/or gas wells. The casing **212** is used to provide structural support to the wellbore and prevent its collapse. Casing **212** may also serve as in isolator between the different geological formations and fluids.

[0066] In more detail, the casing **212** is inserted into the wellbore during the drilling process to prevent the collapse of the hole walls. The casing **212** helps isolate various geological formations to prevent the mixing of fluids and to protect the well from external contaminants. It also helps control the flow of fluids within the well. As well, the casing **212** may play a role in preventing blowouts, which are uncontrolled releases of oil or gas. The casing **212** may provide a barrier to contain the pressure within the well. Once the casing **212** is installed, it is typically cemented in place to further enhance the structural integrity of the well and the cement serves to fill the annular space between the casing **212** and the wellbore.

[0067] The casing **212** may be provided in various sizes and may be selected based on the specific requirements of the well and the geological conditions. The sizes are typically specified by the outside diameter (OD). Some common casing **212** sizes include 4.5″, 5.5″, 6″, 7″, 9 5/8″, and 13 3/8″, among others. The wall thickness and material hardness of the casing **212** may be considered when configuring an assembly **200**. Casing **212** is often made of steel with varying levels of hardness to withstand the downhole conditions. The hardness may range from 30 HRC to 40 HRC and is usually measured in units such as Rockwell hardness. Higher hardness values indicate greater resistance to wear and deformation. These material parameters require that the assembly **200** contain and retain as much of the kinetic energy as possible when required to perforate downhole oil and gas wells. In addition to the casing **212** material being the first material to perforate as part of a fracturing process, the casing **212** is also confined by cement and rock formation. This extra material, the confinement of the casing **212**, and the short stand- off distance to the casing **212**, may require the projectile **201** to be a specific shape and the assembly **200** to maintain a specific weight and length. The full assembly **200** weight may range between 190 grains and 400 grains and a length range of 0.800″ to 1.400″ from the base of the assembly **200** to the tip of the projectile **201**.

B.10 Cement

[0068] One purpose of cement **213** is to provide zonal isolation by sealing the annular space between the casing **212** and the wellbore, thereby preventing the migration of fluids between different geological formations **214** and ensuring the integrity of the well. Following are some example aspects of well cementing.

[0069] Cementing may provide zonal isolation. Particularly, the annular space between the casing **212** and the wellbore is filled with cement **213** to create a barrier that isolates different formations. This helps prevent the mixing of fluids and the migration of gas or other contaminants, enhancing the safety and efficiency of the well. Cementing provides additional structural support to the casing **212**, anchoring it in place and reinforcing the wellbore. This maintains the stability of the well. Finally, the cement **213** not only seals the annular space but also bonds with both the casing **212** and the formation **214**. This bond may prevent fluid migration and ensures the overall integrity of the well.

B.11 Formation

[0070] As shown in FIG. **6**, a formation **214**, which may comprise various types and combinations of rock, may comprise naturally occurring rock with characteristics that may vary widely based on the geological history and composition. The formation **214**, in some cases, may contain oil, gas, and or water.

B.12 Perforation

[0071] With attention now to FIG. **7**, details are provided concerning a perforation such as may be achieved with an embodiment of the assembly **200**. In general, FIG. **7** discloses a case where an assembly **200** has passed through the casing **212**, cement **213**, and entered the formation **214**, thus creating a perforation **215** that extends through those elements.

[0072] The uniform hole that comprises the perforation **215** may be achieved through controlled perforation techniques using the assembly **200**. The precision in creating a uniform hole and making that same uniform hole consistent throughout the wellbore with repeated perforations with the assembly **200** may maintain consistent flow characteristics from perforation to perforation.

[0073] The jet nozzle **215**a may be formed of extruded material from the casing **212** that extends outward into the cement **213** and formation **214**. This extrusion is a result of the perforation **215** created by the assembly **200** that penetrated through the casing **212**. The interior surface of the perforation **215**, including the extruded jet nozzle **215***a*, may feature a smooth bore. This smooth surface, created by the assembly **200**, may serve to minimize frictional losses during fluid flow, promoting efficient movement of the fracturing fluid through the perforation **215**. As well, the perforation **215** created by the assembly **200** may be tailored to either enhance turbulent or laminar flow, depending on the specific requirements of the fracturing operation.

[0074] In an embodiment, turbulent flow is beneficial for mixing and carrying proppant, while laminar flow may be preferred for maintaining consistent fluid placement. The choice of laminar or turbulent flow, that is created by the assembly **200**, may depend on the desired outcomes of the hydraulic fracturing process.

[0075] In an embodiment, an objective of the perforation configuration, created by the assembly **200**, may be to reduce friction and subsequently minimize pressure when pumping the frac fluid through the nozzle. By optimizing flow characteristics, this may ensure that the hydraulic fracturing fluid can be delivered at the required pressure and rate to effectively create fractures in the reservoir rock.

[0076] The jet nozzle **215***a*, formed as a result of the perforation created by the assembly **200**, may have a smaller inner diameter compared to the entry hole **216** of the perforation **215**.

[0077] This reduction in diameter may control the flow rate (Q=v×A, where Q is flow rate, v is velocity, and A is the cross sectional area ((η×d.sup.2)/4)) of the opening) through the jet nozzle **215***a*, providing a degree of flow restriction that optimizes fluid velocity and distribution. In an embodiment, the perforation **215** may serve to optimize flow rates and ensure an even distribution of water and proppant throughout all the perforations **215** in a given stage of a fracturing, or frac'ing, operation.

B.13 Entry Hole

[0078] As shown in the example of FIG. **7**, an entry hole **216** is the initial perforation **215** made in the steel casing **212** or pipe by the assembly **200**. The entry hole **216** may have a larger inner diameter compared to the inside diameter of the jet nozzle **215***a*. This difference in respective diameters may help in optimizing flow dynamics during a hydraulic fracturing process

[0079] The assembly **200** used to create the entry hole **216** can introduce features or irregularities into the surrounding steel casing **212**. These features may control the way the perforation erodes when proppant, such as sand for example, and water are pumped through the entry hole **216** during a fracturing process. These features may include grooves, indentations, or other geometrical characteristics that influence the erosion pattern and help direct the flow of fluids.

[0080] As proppant-laden fluid is pumped through the perforation **215**, the erosion control features in the entry hole **216** influence how the surrounding material erodes. This controlled erosion may ensure that the perforation **215** maintains its structural integrity while facilitating the desired fluid flow into the formation. The larger inner diameter of the entry hole **216** enhances flow characteristics during hydraulic fracturing. This configuration, created by the assembly **200**, enables increased fluid velocity and reduced pressure, enabling efficient transportation of proppant and fluid through the perforation **215** and into the formation.

[0081] The controlled erosion features introduced during the perforation process work in conjunction with the larger entry hole diameter to optimize the flow path, preventing excessive damage to the casing or formation and promoting uniform distribution of the fracturing fluid. The combination of a larger entry hole **216** diameter and erosion control features assists in optimizing the transport of proppant through the perforation **215**. The controlled erosion ensures that proppant is effectively carried into the created fractures.

B.14 Jet Nozzle

[0082] The inner walls of the perforation **215** and the jet nozzle **215***a* may be created to match the outer geometry of the assembly **200** used to perforate the casing **212**. This matching geometry may ensure the precision in the creation of the perforation **215** and jet nozzle **215***a*. As shown in FIG. **7**, a lower portion **217** of the perforation **215** may comprise an inlet portion.

[0083] The inner walls of the perforation **215** and the jet nozzle **215***a* may feature a smooth surface, possibly having the characteristics of a machined surface. This smooth surface may minimize frictional losses during fluid flow, reducing turbulence and pressure drops. A smooth surface may maintain laminar flow which may ensure controlled and consistent fluid placement. As well, the smooth inner walls of the inlet portion **217** of the jet nozzle **215***a* contribute to efficient fluid flow through the perforation **215**. This characteristic may minimize friction and pressure losses, ensuring that the fracturing fluid reaches the formation with the desired force and distribution. As fluid and proppant move through the perforation **215**, the smooth inner walls may facilitate a seamless transition from the entry hole **216** through the mid-section and out of the extruded nozzle. The transition may maintain a uniform flow profile, preventing turbulence that could impede the effective distribution of proppant and fluid throughout the perforation.

[0084] Alternatively, the inner walls may take a different geometric shape based on the desired flow characteristics. For instance, if turbulent flow is preferred for effective proppant mixing and transport, the inner walls might be designed with features that promote controlled turbulence. The transition of fluid and proppant through the perforation, guided by the inner walls, impacts the distribution of proppant within the fractures. The geometry may ensure that proppant is evenly dispersed, which may optimize the effectiveness of the hydraulic fracturing process. The extruded nozzle, with its inner geometry, further contributes to maintaining a controlled flow path and distributing proppant evenly across the perforation.

B.15 Exit Nozzle

[0085] As shown in FIG. **7**, the exit nozzle **218** is the endpoint of the perforation **215**, where fluid and proppant flow from the casing **212** into the cement **213** and formation **214**. The exit nozzle **218** may take the form of a round nozzle, providing a smooth and continuous flow path. Alternatively, the shape an size of the exit nozzle **218** may mimic the geometry of the assembly **200**, which may ensure a smooth transition from the jet nozzle **215**a to the surrounding formation **214**.

[0086] The exit nozzle **218** may comprise a smooth inner surface or have a serrated configuration. The particular configured employed may depend on the desired impact of the exit nozzle **218** geometry on fluid and proppant flow. An exit nozzle **218** with relatively smooth interior surfaces may be utilized to create controlled laminar flow. It may minimize turbulence, reduce pressure drops, and ensure that the fluid and proppant exit the casing **212** with a consistent and predictable velocity.

[0087] A serrated or textured exit nozzle **218** may introduce controlled turbulence, promoting enhanced mixing of the proppant and fluid. This configuration may be employed where improved proppant dispersion and distribution are required for effective fracture creation. For example, a smooth surface in the exit nozzle **218** will induce laminar flow. If the tunnel walls are not smooth, and have some rugosity or features to the interior wall, the tunnel walls will induce turbulence to the fluid passing through.

[0088] The exit nozzle **218** geometry and surface characteristics may dictate the flow characteristics of the fluid and proppant as they leave the casing **212**. Thus, the exit nozzle **218** may influence the velocity, dispersion, and distribution of the fracturing fluid in the surrounding formation. The exit nozzle **218** configuration may contribute to controlled fracture initiation in the formation **214**. Whether smooth or serrated, the exit nozzle **218** may ensure that the fracturing fluid is released in a manner that optimally interacts with the geological features of the reservoir rock. The specific characteristics of the exit nozzle **218** may optimize proppant placement within the fractures. This may achieve uniform and effective distribution of proppant throughout the targeted reservoir zones. As the last point in the casing **212** before the fluid reaches the cement **213** and formation **214**, the exit nozzle **218** may help to ensure that the hydraulic fracturing process is completed with precision and efficiency.

C. Further Example Embodiments

[0089] Following are some further example embodiments. These are presented only by way

[0090] of example and are not intended to limit the scope of this disclosure, or of the claims, in any way.

[0091] Embodiment 1. An assembly suitable for use in downhole operations including frac'ing, comprising: a sabot comprising an ignition stack; and a projectile partially received within the sabot, and the projectile comprising an electrical contact in electrical communication with the ignition stack.

[0092] Embodiment 2. The assembly as recited in any preceding embodiment, wherein after firing of the projectile, a portion of the sabot is reusable for firing of another projectile.

[0093] Embodiment 3. The assembly as recited in any preceding embodiment, wherein the sabot comprises an annular interface surface that conforms to a shape of a portion of the projectile.

[0094] Embodiment 4. The assembly as recited in any preceding embodiment, wherein the projectile comprises a crown configuration disposed about a circumference of the projectile.

[0095] Embodiment 5. The assembly as recited in any preceding embodiment, wherein the ignition stack is electrically grounded to a terminal of the sabot.

[0096] Embodiment 6. The assembly as recited in any preceding embodiment, wherein the projectile comprises a kinetic energy perforating round (KEPR).

[0097] Embodiment 7. The assembly as recited in any preceding embodiment, further comprising a carrier in which the sabot and the projectile are configured to be received.

[0098] Embodiment 8. The assembly as recited in embodiment 7, wherein the carrier comprises a

propellant chamber configured to receive a portion of the sabot so that an ignitor of the ignition stack extends into the propellant chamber.
[0099] Embodiment 9. The assembly as recited in embodiment 7, wherein the carrier comprises a barrel in which the projectile and sabot are configured to be partly received.
[0100] Embodiment 10. A method for performing a perforation operation in a downhole environment, comprising: positioning an assembly in a downhole environment, and the assembly comprises a sabot and a projectile that contacts the sabot; using an ignition stack of the sabot to ignite a propellant carried by the assembly; and propelling the projectile through a target, using a propellant gas generated by ignition of the propellant, so that the projectile creates a perforation in the target.
[0101] Embodiment 11. The method as recited in claim **10**, wherein when a fluid passes through the perforation, a structure of the perforation induces, in the fluid, any one or more of: laminar flow; turbulent flow; and/or transition flow.
[0102] Embodiment 12. The method as recited in claim **10**, wherein the target comprises a well casing.
[0103] Embodiment 13. The method as recited in any of embodiments 11-12, wherein the projectile passes partway into one or more other materials beyond the target, and the one or more other materials comprises one or both of cement, and a formation.
[0104] Embodiment 14. The method as recited in any of embodiments 11-13, wherein the target exhibits a crown and valley configuration adjacent to the perforation.
[0105] Embodiment 15. The method as recited in any of embodiments 11-14, wherein the sabot is reused to fire another projectile.
[0106] Embodiment 16. The method as recited in any of embodiments 11-15, wherein the perforation has a uniform depth in the target.
[0107] Embodiment 17. The method as recited in any of embodiments 11-16, wherein the ignition stack ignites the propellant in response to an electrical current applied to a contact point of the projectile that is in electrical communication with the ignition stack.
[0108] Embodiment 18. The method as recited in any of embodiments 11-17, wherein the sabot and projectile remain connected to each other after the projectile has been fired.
[0109] Embodiment 19. The method as recited in any of embodiments 11-18, wherein a portion of the sabot is positioned in the perforation after the projectile has been fired.
[0110] Embodiment 20. The method as recited in any of embodiments 11-19, wherein the projectile creates a jet nozzle in the target as the projectile passes through the target.
[0111] The described embodiments are to be considered in all respects only as illustrative and not restrictive. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

Claims

1. An assembly suitable for use in downhole operations including hydraulic fracture stimulations, comprising: a sabot comprising an ignition stack; and a projectile partially received within the sabot, and the projectile comprising an electrical contact in electrical communication with the ignition stack.
2. The assembly as recited in claim 1, wherein after firing of the projectile, a portion of the sabot is reusable for firing of another projectile.
3. The assembly as recited in claim 1, wherein the sabot comprises an annular interface surface that conforms to a shape of a portion of the projectile.
4. The assembly as recited in claim 1, wherein the projectile comprises a crown configuration disposed about a circumference of the projectile.
5. The assembly as recited in claim 1, wherein the ignition stack is electrically grounded to a

terminal of the sabot.
6. The assembly as recited in claim 1, wherein the projectile comprises a kinetic energy perforating round (KEPR).
7. The assembly as recited in claim 1, further comprising a carrier in which the sabot and the projectile are configured to be received.
8. The assembly as recited in claim 7, wherein the carrier comprises a propellant chamber configured to receive a portion of the sabot so that an ignitor of the ignition stack extends into the propellant chamber.
9. The assembly as recited in claim 7, wherein the carrier comprises a barrel in which the projectile and sabot are configured to be partly received.
10. A method for performing a perforation operation in a downhole environment, comprising: positioning an assembly in a downhole environment, and the assembly comprises a sabot and a projectile that contacts the sabot; using an ignition stack of the sabot to ignite a propellant carried by the assembly; and propelling the projectile through a target, using a propellant gas generated by ignition of the propellant, so that the projectile creates a perforation in the target.
11. The method as recited in claim 10, wherein when a fluid passes through the perforation, a structure of the perforation induces, in the fluid, any one or more of: laminar flow; turbulent flow; and/or transition flow.
12. The method as recited in claim 10, wherein the target comprises a well casing.
13. The method as recited in claim 10, wherein the projectile passes partway into one or more other materials beyond the target, and the one or more other materials comprises one or both of cement, and a formation.
14. The method as recited in claim 10, wherein the target exhibits a crown and valley configuration adjacent to the perforation.
15. The method as recited in claim 10, wherein the sabot is reused to fire another projectile.
16. The method as recited in claim 10, wherein the perforation has a uniform depth in the target.
17. The method as recited in claim 10, wherein the ignition stack ignites the propellant in response to an electrical current applied to a contact point of the projectile that is in electrical communication with the ignition stack.
18. The method as recited in claim 10, wherein the sabot and projectile remain connected to each other after the projectile has been fired.
19. The method as recited in claim 10, wherein a portion of the sabot is positioned in the perforation after the projectile has been fired.
20. The method as recited in claim 10, wherein the projectile creates a jet nozzle in the target as the projectile passes through the target.