INITIATION SYSTEMS FOR OIL AND GAS PERFORATING GUNS

An investigation of the effects of industry-used cleaning fluids on the A-140F perforator initiation system.

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INTRODUCTION

Fluid desensitized detonators were developed specifically for the petroleum industry, designed as an additional precaution against the occasional leakage of liquid (oil, water, and perhaps a mixture of oil and water) into the perforator carrier [1]. The alternative design[1] ensures that should any liquid enter the detonator, specifically the distance between the fuse head and base charge, desensitization will occur, and thus the perforating shape charges will not detonate. However, partial order detonation[2] has been observed regardless of the absence of a leakage; this an obvious safety concern for wireline operators. The industry speculates that the reason for this occurrence is the presence of residual perforator cleaning fluids within the assembly. Typically, perforating equipment is cleaned with water, and petroleum-based distillates: mineral spirits and diesel fuel. It is an easier, more cost effective method to clean the equipment and to use it again, instead of returning it directly to the manufacturer. Essentially, the assumption is that some residual cleaning fluid is left in the system, and is then sealed into the assembly. When the perforator is lowered into the production well, temperatures become significantly high – reaching 300 degrees Fahrenheit – and the residual liquids become vaporized within the system. Although the fluid desensitized detonators are designed not to detonate in the presence of a liquid obstruction, the chemical effects of small amounts of liquids and vaporized petroleum-based cleaning fluids have not been studied. The industry, however, has noted a significantly higher order of partial detonation of the detonators in field operations than in laboratory conditions. Undoubtedly, this is causing concern that operating procedure is, ultimately, the primary source of initiation system error. Thus, this investigation was conducted by undergraduate researchers from the Advanced Explosives Processing Research Group (AXPRO) at the Colorado School of Mines to determine the effects of cleaning fluids on the typical perforator initiation system, with experimentation designed in such a way that

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[1] Note that while there are several basic constructions for electric detonators used in wireline operations, including non-resistorized, resistorized, fluid disabled, and fluid sensitive detonators, this investigation focuses exclusively on the alternatively designed fluid desensitized detonators.

[2] Partial order detonation occurs when some components of the initiation system do not initiate or display a low order of detonation.

all conditions for partial detonation were understood, and subsequently either eliminated or acknowledged.

METHODS AND MATERIALS

Experimentation was conducted with the Austin Powder A-140F Block Type OilStar Detonator (A-140F Detonator), and Fireline 17/80 RDX Oil Field Detonating Cord. The A-140F Detonator is a fluid-desensitized detonator that is typically used by the petroleum industry, and was specifically noted by a wireline company as experiencing a higher order of field operation failures, which were speculated to be a result of the effects of residual cleaning fluids within the sealed gun assembly.

A general description of the A-140F Detonator involves a metal detonator shell, with a base charge (compressed cyclotrimethylenetrinitramine (RDX) capped with a small amount of lead azide) being positioned at one end of the shell, and protected by a mesh. Adjacent to this, but a sufficient distance away, is a fuse head (a low explosive), a donor explosive, embedded with a bridge wire, which connects the legs wires, thus forming a means of electrical ignition [2]. If a firing current is applied to the leg wires, then the bridge wire becomes incandescent, and the fuse head is initiated [1]. This initiation then has enough force to initiate the base charge and, subsequently, cause detonation of the detonating cord. If liquid fills the space between the fuse head and base charge through the fluid desensitizing holes, then the initiation of the fuse head charge should not have enough force to initiate the base charge, and therefore, detonation should not propagate to the detonating cord.

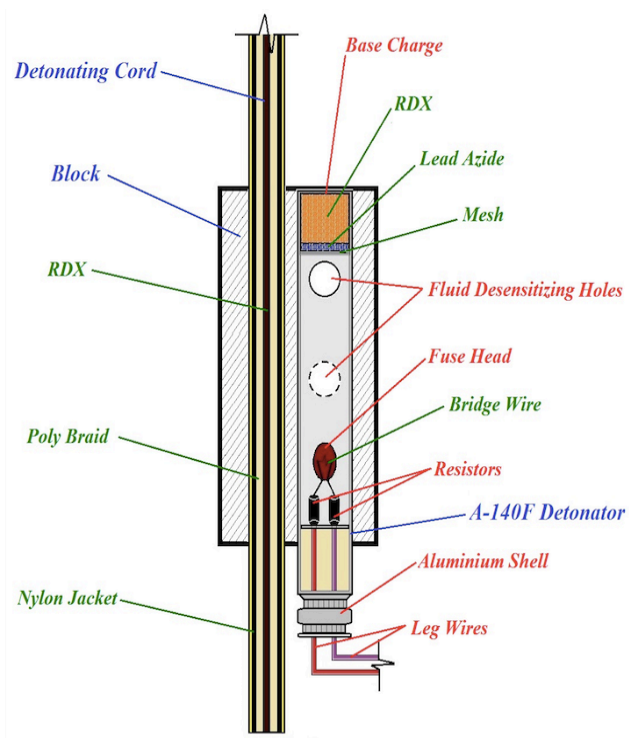

Figure 1. Diagram of initiation system components with detailed illustration of the A-140F Block Type Detonator interior design.

Initiation System Failure Study

AXPRO began experimentation with an evaluation of the various possible conditions for partial detonation of the initiation system to ensure a standard against which the cleaning fluids testing could be compared to. Incorrect operating procedure with each component of the initiation system was tested as a control to standardize established user error as conditions for partial detonation. Thus, testing investigated user initiation system assembly that was either described by the manufacturer as not following procedure, or was not a generally recommended practice [2]. Specifically, I) tape covering the fluid desensitizing holes of the detonator was not removed before use, II) the detonating cord position was varied, and not standardly positioned through the cord hole in the block, and III) the detonating cord was physically damaged so that the amount of secondary explosive within it was reduced.

AXPRO investigated the detonator's compatibility with cleaning fluids by testing varied amounts of misted mineral spirits and diesel fuel on the fuse head and the base charge, respectively. To examine the detonator's sensitivity to fluids, the initiation system was partially and completely submerged in fresh water. AXPRO also completely submerged the detonator in crude oil, as well as produced water, to observe the detonator's sensitivity to wellbore fluids. Experimentation of the initiation system at accurate wellbore temperature and pressure was not conducted at the AXPRO Research Laboratory at the Colorado School of Mines because of safety and cost concerns, and because this investigation's primary objective was to provide proof of concept.

AXPRO conducted further examination of the detonator's sensitivity to fluids to verify experimental results. The preliminary sensitivity testing indicated that the detonators were not becoming desensitized when fully submerged in fresh water, and thus further examination was needed. As noted previously, testing involved both partially and completely submerging the initiation system in fresh water.

For these studies, the detonator was oriented with the leg wires pointed downwards, and curled upwards through the block; the industry indicated that this orientation is used in standard wireline procedural practices.

Initiation system performance was evaluated using a high-speed Phantom 7.13 Light System Camera, with a frame rate of 59,027 frames per second.

Detonator Fluid-Desensitizing Function Study

Inasmuch as AXPRO continued to observe full order detonation of the A-140F Detonators, further experimentation was conducted, with recommendation from the manufacturer, to evaluate the influence of hydrostatic pressure on the detonator. The Austin Powder Company first performed the hydrostatic pressure testing, orienting the detonator in its standard position, with the leg wires pointed upwards. Fundamentally, the company concluded that at an immersion depth of 50 cm, it was clearly observed that the detonator's fluid-desensitizing (FD) function was operating correctly [4]. Thus, AXPRO performed similar experimentation, placing the detonator at immersion depths of 50 cm and 85 cm, but keeping the detonator oriented in the industry standard, with the leg wires pointed downwards.

However, as there are significant elevation differences between Golden, Colorado, United States, and Vsetín, Czech Republic, the locations where AXPRO and Austin Powder Company conducted testing, respectively, the immersion depth of detonator was adjusted by AXPRO to achieve approximately the same hydrostatic pressure where the Austin Powder Company reported having proper FD function. Accordingly, the detonator was submerged at an immersion depth of 200 cm, and placed in various orientations: I) the detonator was oriented according to industry standard II) the detonator was oriented according to manufacturer standard, III) the entire initiation system (A-140F detonator with block, and detonating cord) was submerged, with the detonator oriented according to industry standard, IV) the detonator was oriented horizontally, and tilted slightly upwards, with the fluid desensitizing holes oriented horizontally, V) the detonator was oriented horizontally, with the fluid desensitizing holes oriented vertically, and VI) the detonator was oriented horizontally, and tilted slightly downwards, with the fluid desensitizing holes oriented horizontally.

Note that initiation system performance was evaluated, using a high-speed Phantom 7.13 Light System Camera, for experimentation with the detonator at immersion depths of 50 cm and 85 cm. However, because a long steel pipe was used for subsequent testing at immersion depths of 200 cm, use of high-speed imaging for evaluation was not possible, therefore initiation system performance was assessed post-blast.

RESULTS AND IMPLICATIONS

Initiation System Failure Study

Although AXPRO's evaluation of the initiation system by failure to follow manufacturer recommendations was intended to ensure a controlled experiment, and standardize incorrect operating procedures as conditions for partial detonation, the experimental data indicates that the importance of specific procedure needs to be re-accessed by the manufacturer, as well as the industry. High-speed imaging results demonstrated that the initiation system had full order detonation despite AXPRO I) failing to remove the tape from the detonators before use, II) varying the detonating cord position from standard-position, and III) physically damaging the detonating cord so that the amount of explosive within it was reduced. Thus, while it is always important to follow the manufacturer's directions, and handle explosives and explosive devices with great caution, industry employees must consider all conditions when ensuring proper function of their explosive devices.

Partial order detonation of the detonator was observed when the petroleum-based cleaning fluids, mineral spirits and diesel fuel, were placed directly on the detonator's base charge – chemically, RDX displays decreased thermal stability when in the presence of petroleum-based cleaning products [3]. However, the fuse head was not desensitized when in the presence of the distillates, suggesting that the low explosive is not soluble to petroleum-based solutions. Thus, industry-operating procedure is indeed a cause of partial order detonation of the perforator initiation system. Although using petroleum-based distillates to clean perforating equipment is not a manufacturer recommended practice, it is not an obvious concern. Therefore, procedural changes are required to ensure effective production and safety within the industry. Wireline companies, specifically, should not use mineral spirits or diesel fuel to clean perforating equipment – it would be more suitable to use a fluid that both the fuse head and the base charge have shown no reaction to, perhaps fresh water. Otherwise, it is advisable that companies return the equipment to the manufacturer to either be professionally cleaned or replaced.

Notwithstanding AXPRO's observation of the effects of the petroleum-based cleaning fluids, full order detonation was observed when the detonator was submerged, as well as shaken, in the wellbore fluids, crude oil and produced water. Thus, it is yet unclear what components of the cleaning fluids caused the base charge to become desensitized – AXPRO is currently conducting a chemical analysis on the distillates.

Detonator Fluid-Desensitizing Function Study

Fully submerging the A-140F Detonator in fresh water when industry-oriented, demonstrated an inconsistency in the FD function, as AXPRO's high-speed imaging evaluated the detonations consistently as full order. Thus, as was previously indicated, immersion depth tests were recommended by the Austin Powder Company, with the assumption that the detonator FD function required a specific hydrostatic pressure to begin to operate properly – at the Colorado School of Mines in Golden, Colorado, United States, this approximate pressure was calculated to be at an immersion depth of 200 cm. Thus AXPRO conducted several experiments at this depth, with varying orientations. Consistent, full order detonation was observed when the detonator was oriented according to industry-standard; when the entire initiation system was submerged, with the detonator oriented in industry-standard, this detonation was powerful enough to propagate to the detonating cord. However, when the detonator was oriented according to manufacturer-standard, AXPRO observed partial order detonation, as only the fuse head detonated. Partial order detonation also occurred when the A-140F Detonator was oriented horizontally, and tilted downwards with the fluid desensitizing holes horizontal, and when the detonator was oriented horizontally, with the fluid desensitizing holes vertical. When the detonator was oriented horizontally, and tilted upwards with the fluid desensitizing holes horizontal, AXPRO observed full order detonation. These discrepancies in detonation order, can indeed, be explained by the varying orientations, as specific orientations create distinct air bubble locations. When the detonator is oriented according to industry-standards, or oriented horizontally, and tilted upwards with fluid desensitizing holes horizontal, an air bubble is trapped directly beneath the base charge and mesh. When a firing current is applied to the leg wires, the bridge wire becomes incandescent, and the fuse head is initiated. This detonation creates a shockwave travels through the high density water as a compression wave, eventually reaching the low density air, which causes spalling, in these circumstances, high velocity water droplets that impact the mesh and subsequently have enough force to initiate the very sensitive lead azide primary explosive, and therefore the RDX [4]. When the detonator is oriented according to manufacturer-standards, or oriented in the other positions that displayed partial order detonations, the air bubble is trapped below the fuse head. Thus, when the fuse head is initiated, there is indeed a detonation shockwave that moves from the low-density air to the high-density water, but no direct physical force to initiate the base charge.

Thus, while the A-140F Detonators are certainly quite durable, and their block design functions exceptionally well in allowing detonation to propagate to the detonating cord, they act in a distinctive way depending upon their orientation, at least on a surface level, and certainly the industry should be aware of these characteristics.

LIMITATIONS AND RECOMMENDATIOBS

Because testing the failure to follow the manufacturer's recommendations proved relatively inconclusive, AXPRO would like to conduct more experimentation involving explicitly not removing the manufacturer's tape on the detonator, and placing the initiation system at an immersion depth of 200 cm, with the detonator oriented according to manufacturer-standards. It is expected that the tape, which covers the detonator's fluid-desensitizing holes, would provide enough of a seal to ensure no leakage of water into the detonator, thus allowing for full order detonation of the initiation system.

Although experimentation was not conducted at accurate wellbore temperature and pressure, because of safety, as well as cost concerns, it would certainly be significant for AXPRO to understand the effects of vaporized fluids, in combination with significantly high pressures, on the A-140F Detonator. Thus it is recommended that further testing be conducted with the petroleum-based cleaning fluids, mineral spirits and diesel fuel, and the initiation system in accurate simulations of the wellbore environment. The detonator's FD function, with varying orientation, should also be examined in this environment. Note that while accurate wellbore conditions include a lengthy immersion time (in cleaning fluids, wellbore fluids, or fresh water), AXPRO expects little variation in the results of the FD function studies with this variable, as the FD function is designed to operate immediately in the presence of a liquid obstruction.

As a university-affiliated group, AXPRO conducts experimentation with an objective perspective. The petroleum industry, and specifically wireline companies, must be aware of the operation characteristics of their detonators. Fundamentally, AXPRO believes that it would be exceptionally beneficial to assist the industry, and specifically wireline companies, to achieve a greater understanding of their perforator initiation systems; AXPRO's Research Laboratory certainly has the capability to allow for thorough examination of the advantages and limitations of the various production well detonators.

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