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Engineered Magnet System Reveals True Quantity of Metal Contamination in Drilling Fluid

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Abstract

An engineered magnet system retrieves upwards of 100 pounds of magnetic debris during daily drilling operations, increasing tool reliability and revealing a magnetic metal presence in drilling fluids that is much larger than previously thought. Magnet systems are recognized as a best practice for debris removal, but the power and positioning of these magnet systems is often overlooked. The specially designed system was deployed on multiple drilling rigs with a surprising increase in debris removal even when installed downstream of the existing rig magnet systems. After continued use, detailed evaluation confirms substantial amounts of residual magnetic debris, including finer particles that are not retrieved by conventional ditch magnets.

The patented magnet system utilizes a special flow path with geometrically aligned neodymium magnet rods to maximize surface area and facilitate easy cleanup. The portable design facilitates installation across different rig designs. After multiple trials, X-ray fluorescence (XRF) reveals the sources and scale of metallic debris within drilling fluids alongside the weight of debris collected throughout the drilling process.

It is well-documented that magnetic debris interferes with MWD measurements, logs, and may contribute to RSS failure. The type and quantity of magnetic debris in fluid offer new opportunities to improve drilling system reliability – particularly as laterals grow longer and tool hours increase.

Introduction

Magnet systems are not new to drilling operations. There are many shapes and forms, but they are often overlooked as potentially trip-saving tools.

In most cases, a set of conventional magnets are set in the flow line, the header box before the shakers, or in the fluid ditch just past them. Most careful monitoring occurs during operations such as milling, where the quantity of swarf recovered is an important metric, particularly in a cased hole sidetrack where residual swarf can impact tools and measurements at the milled window.

Magnet performance is measured by trends. The rate of collection may act as an indicator of increasing wear or sufficient removal during an operation. In milling operations, it may be that 80% by weight of the expected swarf is recovered on magnets before proceeding.

The engineered magnet system, a flow positioned ditch magnet system (Saasen et al., 2019) features high-powered neodymium magnets arranged to account for maximum surface area and the flow dynamics of fluid passing through the system. System concepts were tested and proven offshore, but the new box apparatus provides greater adaptability to land rigs with minimal modifications. After numerous evaluations with positive results, the magnet box system has been deployed on more than 30 drilling rigs.

Hazards of Magnetic and Metal Debris

Magnetic debris impacts drilling performance by abrasion, interference with measurement tools, and jamming of magnetized tool parts.

Abrasion

Metal debris acts as a highly abrasive material that can lead to premature failures from erosion of critical parts. Abrasion is a function of several factors, including specific gravity, hardness, particle size distribution, shape, velocity, and flow regime.

Particle momentum is a function of mass and velocity. For two particles moving at the same speed and of the same size, a denser particle will have a higher impact force (change in momentum). Saasen et al (2001) also note that thinner fluids increase abrasion tendency. The high specific gravity of steel relative to other weight materials (Table 1) provides a relative comparison.

Table 1: Specific Gravity Comparison

Material	Specific Gravity
Calcium Carbonate	2.7 – 2.8
Barite	4.1 – 4.2
Hematite	4.7
Ilmenite	5.1
Carbon Steel	7.8

The hardness differential of materials is another factor for abrasion. If a harder material impacts a soft one, the soft material may erode. Barite is a preferred weight material because it is relatively soft relative to steel. The Mohs hardness scale compares scratching resistance between different minerals. (Table 2). Hardened steel from casing and drill pipe is harder and more abrasive as a fluid component than other solids in the system.

Table 2: Mohs hardness of select minerals (National Park Service, 2023)

Material	Mohs Hardness
Talc	1
Calcium Carbonate	3
Barite	2.5-3.5
Ilmenite	5-6
Hematite	5.5-6.5
Quartz	7
Hardened Steel	7-8
Tungsten Carbide	9
Diamond	10

While fine particles are less abrasive, steel will retain more abrasive properties at a small particle size distribution due to their density and hardness. Traditional magnet systems seldom remove metal particle below 100-150 microns. When a high-powered magnet system was introduced to one rig, field personnel observed the finer particles on the magnets, which appeared as a paste (Saasen 2019).

Table 3 shows particle size distribution of magnet debris recovered by the high-powered magnet system. It is likely that prior to the introduction of high-powered magnets, all of this material remained in the fluid system.

Table 3: Magnetic debris particle size distribution system from the present field study

Percentile	Diameter, microns
D_{10}	2.12
D_{50}	11.41
D_{90}	47.43

Pattarini et al (2016) suggest that most magnetic material above 40 microns is removed with conventional equipment, but this depends upon equipment and conditions.

Abrasion studies of softer drilling fluid weight material show detrimental effects at lower particle size distributions than 100-150 microns. Tehrani et al (2014) confirm the particle size distribution of material impacts abrasive properties by comparing hematite and ilmenite with a D_{95} of 25 microns versus 75 microns. In each case, the fine grind version was significantly less abrasive than the coarse sample.

Original trials of ilmenite as a weight material noted the excess abrasion, and current applications utilize micronized material to mitigate abrasion concerns (Saasen et al, 2001).

API certified barite does not have a specific particle size distribution, but no more than 3%/mass shall be greater than 75 microns in diameter and no more than 30%/mass shall be less than 6 microns in diameter (American Petroleum Institute 2019). Fine grind barite is regularly used in HPHT operations to mitigate sag and facilitate lower equivalent circulating pressures, but they have limited application onshore.

Magnetic Signal Interference

Magnetic interference is a primary concern in measurement while drilling. MWD references the earth's magnetic field via magnetometers. Magnetic particles within a drilling fluid disrupt readings, risking errors in measurement. There are a variety of techniques to address interference, but they can add time and cost to operations (Kok et al. 2023).

Magnetic particles also impact resistivity readings and induction logging tools, which depend upon conductivity for measurement. Nuclear magnetic resonance (NMR) is impacted by magnetic particles in the fluid and deposition in the filter cake (Tehrani et al. 2014).

Field experience from the offshore Ivar Aasen field in the North Sea shows that directional drilling was significantly improved when the magnetic contamination of the drilling fluid was removed using similar ditch magnet system (Saasen et al. 2019). Furthermore, the signal to noise ratio of the down hole logging tools were significantly improved. No drill strings were pulled out of the hole to replace or repair logging tools because of agglomeration of magnetic material. (Saasen et al 2021).

Tool Failure from Magnetic Debris Accumulation

General abrasion of materials was discussed, but there are additional failure modes associated with magnetic materials. Anesbug et al. (2023) provide a case history where a magnetic clutch on a MWD seized from magnetic debris attaching to the inner and outer clutch assembly.

Rotary steerable systems are highly susceptible to debris failures. Magnetic materials may attach to moving parts due to induced magnetic fields from rotating parts, such as between torquers (Alterbeh et al. 2018). As material accumulates, attached particles jam between moving parts and lead to failure. It is possible that the reason base fluid sweeps can mitigate failure risk is they are able to rinse some accumulated fine particles from parts to increase clearance. This method does add to drilling fluid costs through unplanned dilution and product required to sustain fluid properties.

RSS failures extend beyond the cost of the tool as they are required for long laterals where insufficient weight is available for sliding. An RSS failure near the end of a long lateral includes the cost of a premium tool and the cost of the trip, which may include extra time to lay down pipe that exceeds derrick capacity (Toomes and Offenbacher, 2024).

Sources of Magnetic Materials

Magnetic materials are found throughout the rigsite, but there are a few select sources for them to appear as a drilling fluid constituent.

Casing and Pipe Wear

Laboratory analysis of magnet debris demonstrates that the primary source of magnetic debris in drilling fluid is from casing and pipe wear. Because casing and pipe wear occurs while drilling, it is best to remove the debris at the rigsite as it is generated.

The degree of casing wear is subject to well trajectory (Khalili et al. 2021), rotating hours, hard-banding of pipe, drilling fluid types, formation, and other factors. In unconventional wells, the curve section features a short build section followed by a long lateral production section where pipe is forced to rotate against casing throughout the interval. As laterals continue to grow longer, the intermediate casing section will encounter longer rotating hours with greater metal loss through casing wear.

Schneider and Collins (1992) performed a detailed evaluation of casing wear on an s-curve well, using 64-arm caliper runs to monitor wear. Casing wear was about 5%, with extreme wear zones exceeding 15%. Wilson and Brooks (2001) observed a similar 5% average casing loss.

Compositional analysis of recovered magnet debris via x-ray fluorescence indicates the presence of common tubular alloys by the presence of elements including cobalt, manganese, silicon, titanium, phosphorus, chromium, and molybdenum (Table 4). Material abundance is reported as a fraction of detected sample. Elements such as carbon are abundant in steel, but they are not accounted for in reporting because their atomic mass is insufficient to be captured by the 3000 watt machine.

Table 4: Elemental analysis of recovered debris via x-ray fluorescence

Element	Abundance
Si	14.6 mass %
P	1210 ppm
Ti	1070 ppm
Cr	1660 ppm
Mn	1830 ppm
Fe	15.3 mass %
Co	93.0 ppm
Ni	193 ppm
Cu	209.0 ppm
Zn	173.0 ppm
Nb	71.3 ppm
Mo	197.0 ppm
W	412.0 ppm

Recycled Drilling Fluid

Recycled drilling fluid is not the origin of magnetic debris, but it results in greater accumulation across wells that increases risk of issues with magnetic materials. Laboratory investigation trends show that fresh fluid has less magnetic interference than used fluid (Torkildsen et al, 2004). Pattarini et al (2016) observed fresh fluid contained 0.6 lb/bbl magnetic particles to 2.6 lb/bbl after drilling for an extended period of time.

Wilson and Brooks (2001) observed that water-base drilling fluids exhibit less interference than invert emulsion drilling fluids with the assumption that invert emulsion reuse results in greater accumulation of magnetic material. Water-base drilling fluid usually requires higher dilution rates from high retention on cuttings and lower drill solids tolerance.

In environments where drilling fluid losses and dilution are limited, such as cost-sensitive unconventional drilling, fluid reuse has the potential for metal debris accumulation. In one example, a new casing program eliminated losses across a field. The increase in fluid reuse led to a sudden increase in MWD issues due to magnetic interference from the drilling fluid.

When operating in barite recovery mode, the high specific gravity of metal can lead to greater accumulation. Hadley et al. (2023) recommend a daily conventional cycle to strip metal debris. They also recommend sending recovered barite to at least one tank before the suction to increase settling time.

Drilling Fluid Additives

Drilling fluid additives, particularly naturally occurring minerals, may contain traces of iron. Other processes, such as grinding, may introduce small quantities of iron as part of the manufacturing process. Analytical methods can determine the quantity of iron present. Rigsite methods of running a magnet through a sample yield mixed results. In many cases, residual oil from handling or static electricity cause particles to stick to metal that are not actually magnetic.

Tellefsen et al (2012) noted magnetic interference from bentonite, which is known to contain iron impurities; however, synthetically-derived hectorite did not cause magnetic interference – likely due to fewer impurities.

Depending on the density, weight material is usually the largest particle constituency in the drilling fluid. Solid weight materials are primarily ground from ore, and impurities may include magnetic materials.

Iron impurities and quantities in barite vary by source (Johnson et al. 2017). Crecelius et al. (2007) published barite analysis of samples ranging between 6000 ppm from a Chinese source and 25 000 ppm from Norway. Tehrani et al observed that barite has the lowest magnetic interference when compared to ilmenite ($FeO \cdot TiO_2$) and hematite (Fe_2O_3), which are both iron-rich materials.

Pneumatic Transfer

Pneumatic transfer, particularly of weight material, eliminates manual lifting and facilitates blending. There are few detailed studies on metal incorporation from erosion during transfer, but erosion has been documented by Saasen et al (2001).

Drill Solids

Formation materials can have trace amounts of iron. Stuckman et al (2019) analyzed drilling fluid, core material, and cuttings. The drilling fluid had 1% iron while the cuttings and core material ranged as high as 4% iron.

Flow Positioned Magnet Design

The original magnet system design focused on addressing many of the shortcomings of traditional system to improve magnetic debris removal. A special box provides adaptability to the variation in rig designs with no modification required (Figure 1).

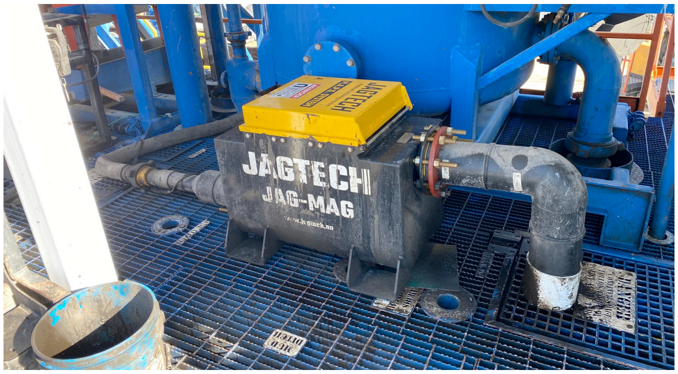

Figure 1: Installed magnet box

Optimized Magnetic Field

The magnet system utilizes a series of stacked neodymium magnet rods protected by thin titanium sleeves the provide a peak magnetic flux density of 12 000 Gauss (1.2 T) on the rod surface. Typical flux density of standard ditch magnets is in the range of 4 000 Gauss (0.4 T). Because magnetic fields deplete rapidly with distance, the magnet rods are staggered to maximize the magnetic flux across a large flow area (Figure 2). A series of 18 rod magnets provides maximum flow area that prevents bypass as the front magnet sets accumulate magnetic debris.

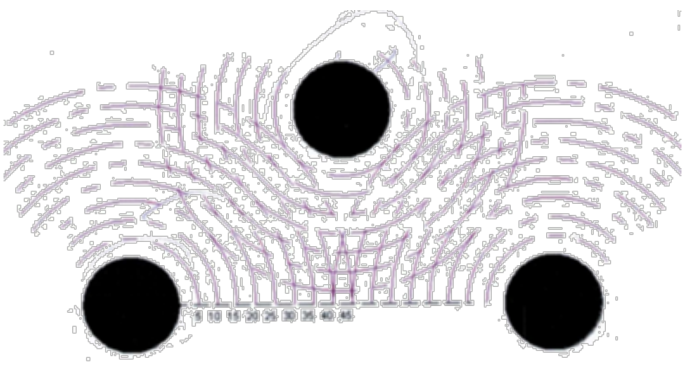
Figure 2: Magnet fluid density interference pattern to maximize debris capture

Flow Distribution

To capture fine particles, the magnetic force must exceed the hydraulic force of flowing fluid passing through the magnet system. Computational fluid dynamics revealed that unrestricted flow risked dislodging fine particles weakly attached to a magnet rod (Strømø et al, 2017). A series of 90º spoilers were added between pairs of magnets to divert fluid flow towards the next magnet (Figure 3 and Figure 4).

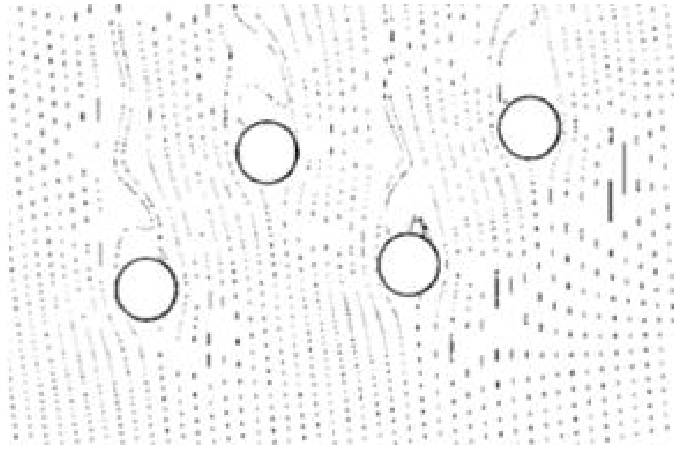
Figure 3: Flow analysis of magnet rods without flow diversion

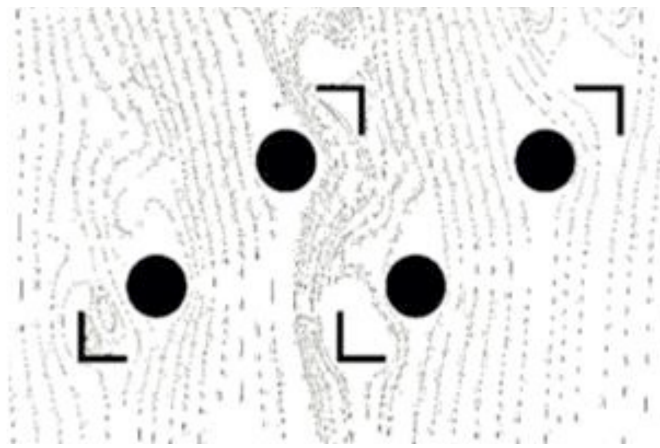
Figure 4: Flow analysis of magnet rods with flow diversion

Safe Handling and Cleaning

An essential aspect of magnet performance is regular cleaning and tracking of weighed debris. Safe, simple cleaning procedures encourage proper maintenance to maximize system performance.

The magnet system features sets of dual rods with integrated handles for safe lifting and cleaning. Each set is numbered to track placement within the magnet box. The magnet rods also feature an integrated cleaning scraper that facilitates rapid removal of material for weighing. An optional cleaning cabinet, powered by rig air, automates the cleaning process.

Rig Compatibility

The high-powered magnet system consists of a standalone feeder box containing nine high efficiency dual magnet rods with individual scraper systems to enable safe and effective removal of debris. The system can be installed at any appropriate point in the rig's active mud system and is fed by any available independent pump downstream of the shakers thus making the system easy to install in any given rig configuration.

Case Studies

The case studies are part of a broad study to evaluate magnet box performance. In both examples, the magnets were placed after the existing ditch magnet system, revealing that substantial magnetic debris remains in a drilling fluid system.

Prior to the field studies lab work was conducted on field drilling fluid from West Texas to try and determine typical quantities of debris that might be contained in an average fluid system. A 1 gallon samlpe was exposed to the magnets under lab conditions (Figure 5) with the solids removed, dried and weighed.

Table 5: Magnetic debris removed under lab conditions and results extrapolated

Sample Size	
Sample Volume, gallons	1
Metal removed by magnet, grams	10.6
Active system volume, bbl	3080
Grams per pound	453.6
Grams in the mud system	1 371,216
Calculated ultra-fine metal in the active system, pounds	**3023.0**

Figure 5: Debris removed under lab conditions

Case Study #1

A field trial of the magnet box system was performed on a rig in West Texas to evaluate the effectiveness of the system versus the current ditch magnet system already installed. The magnet box unit was installed downstream of the existing ditch magnets which remained in place and the amount of debris removed from each system was measured and recorded independently.

The test was conducted for a total of 30 circulating days and data collected and recorded for each day. The average removal rate for the existing ditch magnet system was 16 lbs. of debris per day with the average removal for the downstream magnet box system was 52 pounds of debris per day (Figure 6).

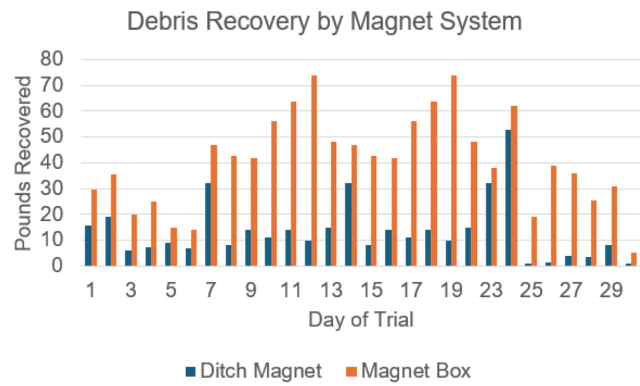

Figure 6: Debris removal rates in pounds

Over the 30-day period, the traditional magnets retrieved a total of 375.86 pounds and the magnet box retrieved 1 141.34 pounds – more than 1500 pounds total.

Sample debris was collected from the magnet box system and sent for lab analysis, the material collected was shown to have a D_{50} of 11.41µ (Table 3 and Figure 7).

Figure 7: Sample of magnet box debris

Case Study #2

A field trial of the magnet box system was carried out on a rig in the Permian Basin to evaluate the effectiveness of the system versus the current ditch magnet system already installed. The magnet box unit was installed downstream of the existing ditch magnets which remained in place. The quantity of debris removed by the magnet box system was measured and recorded over a 28 day period. At the outset of the trial a cleaning frequency was determined based on the accumulation of material on the magnets over time (Figure 8). It was determined that the magnets should be cleaned every 4 hours at a minimum.

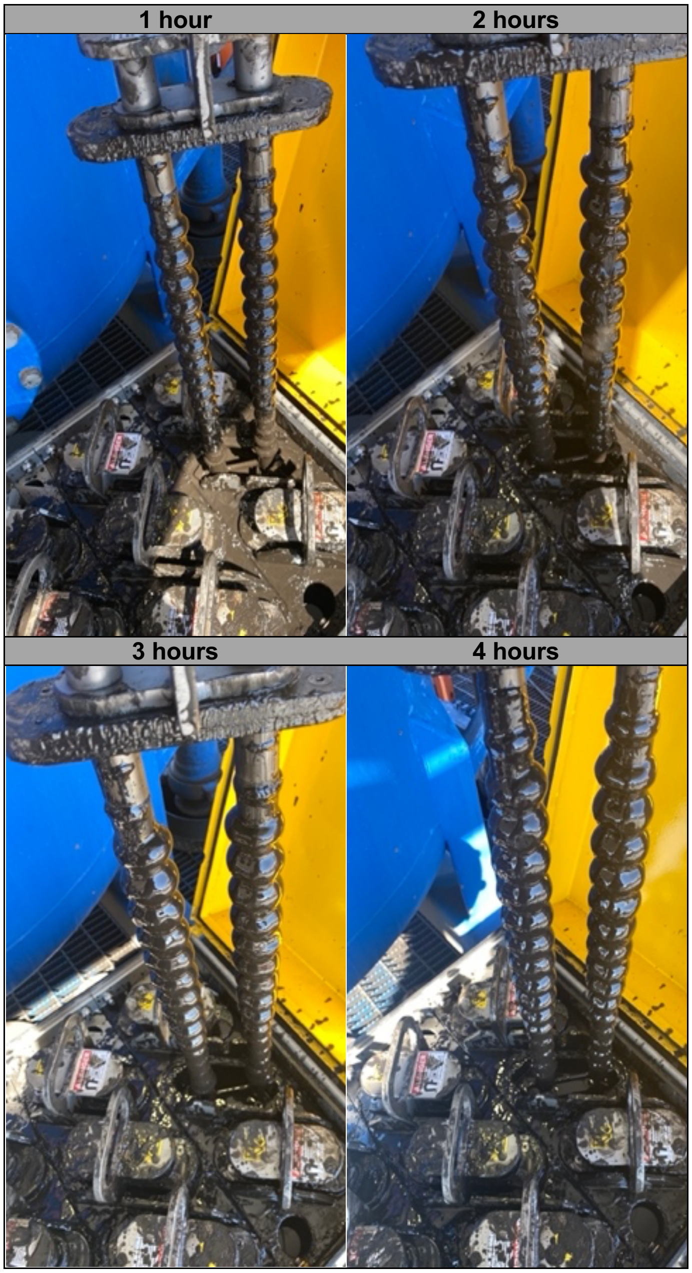

Figure 8: Debris buildup over time

The average daily removal rate of the magnet box system was 72.2 lbs. of debris per day with a cumulative removal of 2 022 lbs. of debris over the 29 day period. Figure 9 illustrates daily debris removal. Note the downward trend of recovery, with the first 15 days averaging 81 lbs. daily and the remaining 14 days averaging 59 lbs.

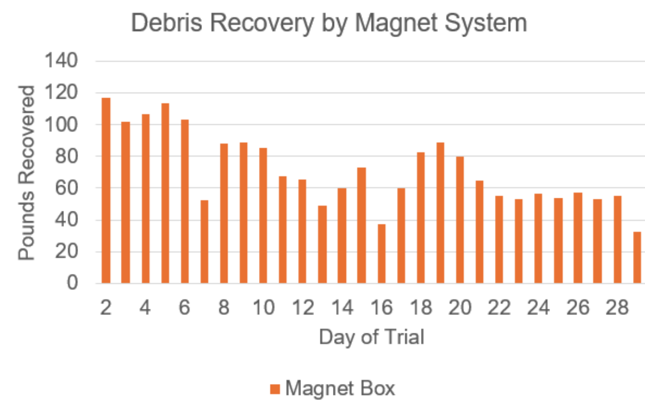

Figure 9: Daily recovered debris

Debris from the magnet box system was collected and sent for lab analysis. The material was found to be primarily ferritic with trace elements of chromium, manganese, molybdenum and tungsten. The particle size analysis was determined to have a D_{50} of 13.2µ (Table 6).

Table 6: Magnetic debris particle size distribution system from field study #2

Percentile	Diameter, microns
D_{10}	2.41
D_{50}	13.2
D_{90}	47.6

Case Study #3

A magnet box system was installed on a rig in West Texas and the debris recovery rate analyzed while drilling a 16 193 ft section of 6-3/4" hole. The gross recovery rate over this period was 1 492.84 lbs with an average daily recovery rate of 114.83 pounds per day as shown in Figure 10.

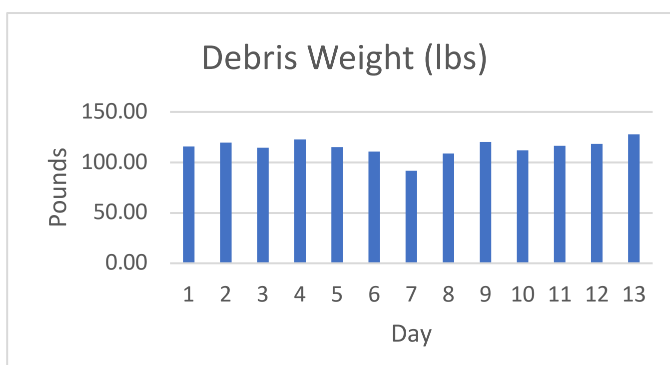

Figure 10: Daily recovered debris

Case Study #4

A magnet box system was installed on a rig in West Texas to condition an OBM drilling fluid system while drilling a 8 ¾" pilot hole in preparation for open hole logging operations. Previous open hole logging operations required a dedicated drill pipe-conveyed magnet run for a nuclear magnetic resonance logging due to magnetic interference from the particles in the fluid system. After drilling to TD, the 1 600 bbl. fluid system was deemed adequately free of magnetic debris, which permitted omitting a dedicated magnet run. The NMR tool was then run successfully across the desired open hole interval without issue.

Conclusions

Through the ditch magnet system study, the following conclusions were made:

- Magnetic debris is primarily generated through casing wear and drilling processes at the rigsite.
- Optimized, high-powered magnets extract significant amounts of debris that traditionally remained in drilling fluid
- Filtering magnetic debris from drilling fluids can improve log quality and reduce operational inefficiencies
- Removing additional metal debris has the capacity to reduce failure incidents and improve reliability for downhole drilling tools, as well as surface equipment. Analysis of these benefits is ongoing

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