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Designing new VM-165 thin wall drill pipe for uERD development

In planning for **ultra Extended Reach Wells (uERW)** wells, projected torque & drag (T&D) loads exceed the capabilities of existing high-strength drill pipe. As operators continue to evaluate uERD options, they have been forced to consider using non-steel drill pipe materials (such as aluminum, titanium, composite, or other) for reduced surface loads. While these materials have been used for some time in a variety of applications, many drilling engineers are reluctant to pursue complicated and high-value developments with what they perceive as lesser known or less understood technologies.

Following the successful development of an new high-strength steel with a SMYS of 165 ksi (**VM-165** grade) by VAM Drilling, one major operator has now selected a **specially designed high-strength thin wall drill pipe for their uERD development**. The new field is located in shallow water and due to environmental and commercial considerations will take advantage of existing infrastructure. The projected wells are significantly beyond current industry experience (outside the envelope) and are considered Ultra Extended Reach (uERD) wells.

Design process

The basic design philosophy was to keep the entire drill string as light as possible and to use higher strength tool joints and pipe where required. As the design process was highly iterative, the first-pass analysis assumed standard API dimensions and weights. Hydraulics (both pump pressures and ECDs) were the key drivers for the hole size and pipe size combination. From this point, the T&D iterations commenced.
This resulted in a drill string designed firstly for managing the tension and combined-load scenarios. From this point, the expected torque loads are then established.

This first pass review established surface equipment requirements, and pipe requirements for a standard solution. Based on this, a 5" x 5 7/8" x 6 5/8" drill string design was finally selected. This combination was an effective compromise, taking into account what drill pipe would also be used in the previous hole section. The next iterations involved making the **drill string as light as possible** (via use of smaller drill pipe) for reduced loads on the top-most pipe. By reducing the loads, this also allowed 'smaller' tool joints to be used (which in turn further reduces T&D).

Finally, the use of high-strength drill pipe was investigated, to establish benefits. The immediate benefit was **improved overpull and combined-load capacity** on the top-most pipe. A secondary benefit was the possible use of non-standard thin-walled drill pipe (**for reduced pipe weight, as well as improved hydraulics performance**). Thin walled tubes were eventually selected for both the 5" and 5 7/8" pipe after determining it was acceptable for all loading situations.

High resistance to crack propagation - Fracture toughness and Crack Tip Opening Displacements (CTOD) have been measured on various steel grades as per ASTM E399-06. The CTOD delta value gives the maximum acceptable notch size that will not initiate a crack into the material at a given temperature. The fracture toughness value gives information on the ability of the material to absorb the energy due to a sudden shock. In both of these cases, when drilling equipment is submitted to severe loads, these values are known to noticeably decrease with steel strength. The results collected in the chart below (figure 6) show that the **VM-165** is in line with usual API grades and does not demonstrate any drop of performance.

Grade	CTOD [10^-3mm]	CTOD [10^-3 inch]	Kmax [MPa.mm^0,5]	Kmax [ksi.inch^0,5]
S135	95,0	3,7	135,2	148,6
VM-150	99,0	3,9	136,1	149,6
VM-165	111,0	4,4	149,6	164,4

Fracture toughness properties of standard API S135, VM-150 and VM-165 grade

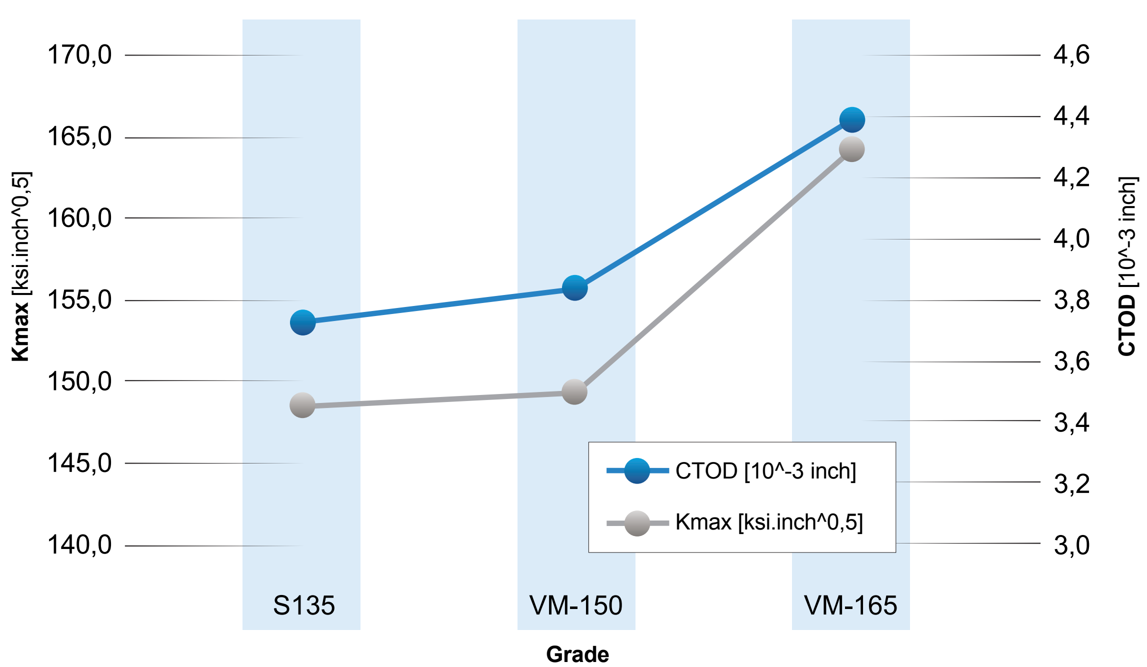

Figure 6: Fracture toughness and CTOD levels of the VM-165 compared to usual API and VM-150 grade.

Modeling strongly suggests that the uERD project is technically feasible but requires the development of the next generation in drill pipe technology. In every well design case, **the VM-165 triple taper design - 6-5/8" x 5-7/8" x 5"- with the HSTJ (high strengths tool joints) satisfies the torque, tensile and hydraulic performance requirements** with sufficient safety margins. The 135k tool joints along with broadening connection performance make up envelop will definitely add value. This means that having a connection with a wider make and break window will reduce fatigue of tool joints and surface running equipment. **The leap from 150 to 165 is monumental in terms of improving the ability to reached more extended**, longer reach targets but in actuality with respect to chemistry and connection design these are simply enhancements to existing technology.

To date, five sizes of **VM-165** have been successfully manufactured and both lab and field tests have been conducted internally and externally to verify properties. All small scale test results either met or exceeded a strenuous purchase specification. An extensive field validation program was used to prove up the pipe before going to the operator. Following successful completion of these field trials the pipe is currently at the rig site awaiting spud which is expected in Q3 of 2010.

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Performance of the Drill Pipe

The drivers for the choice of the pipe body grade are: **resistance to high tensile loads, resistance to shock, resistance to fatigue and resistance to crack initiation & propagation**. Following multiple iterations using state of the art drilling optimization software **VM-165** grade provided the necessary strength properties with no drawbacks.

High strength steels usually become brittle under low service temperatures and it is very difficult to associate good performances in tension resistance and in shock resistance. Yet this is not the case for **VM-165** grade drill pipe. This unique steel grade, when used in drill pipe applications, associates ultra high strength performance - 165 ksi minimum yield strength - with high impact toughness - Charpy V-notch energies above 44 ft.lbs at -4°C, for a 10 x 7,5 specimen. It is this performance capability that makes **165 ksi drill pipe particularly well suited for highly demanding drilling operations**.

High tension loads - The **VM-165** grade has minimum yield strength of 165 ksi and a minimum ultimate tensile strength of 175 ksi. This gives it the **excellent ability to resist to high tension loads**. Typical values are collected in table 1 and compared to those of VM-150 grade and a standard API grade.

Grade	Tensile specimen Form	Tensile specimen Size [mm]	Rp0.2 [MPa]	Rp0.2 [ksi]	UTS - Rm [MPa]	UTS - Rm [ksi]	Elongation A% [%]
VM-165	cyl.	6,35	1220	177,0	1282	186,0	19,41
VM-150	cyl.	6,35	1138	165,1	1158	168,0	19,69
S135	cyl.	6,35	1035	150,1	1091	158,0	20,92

Table 1. VM-165 typical tensile properties.

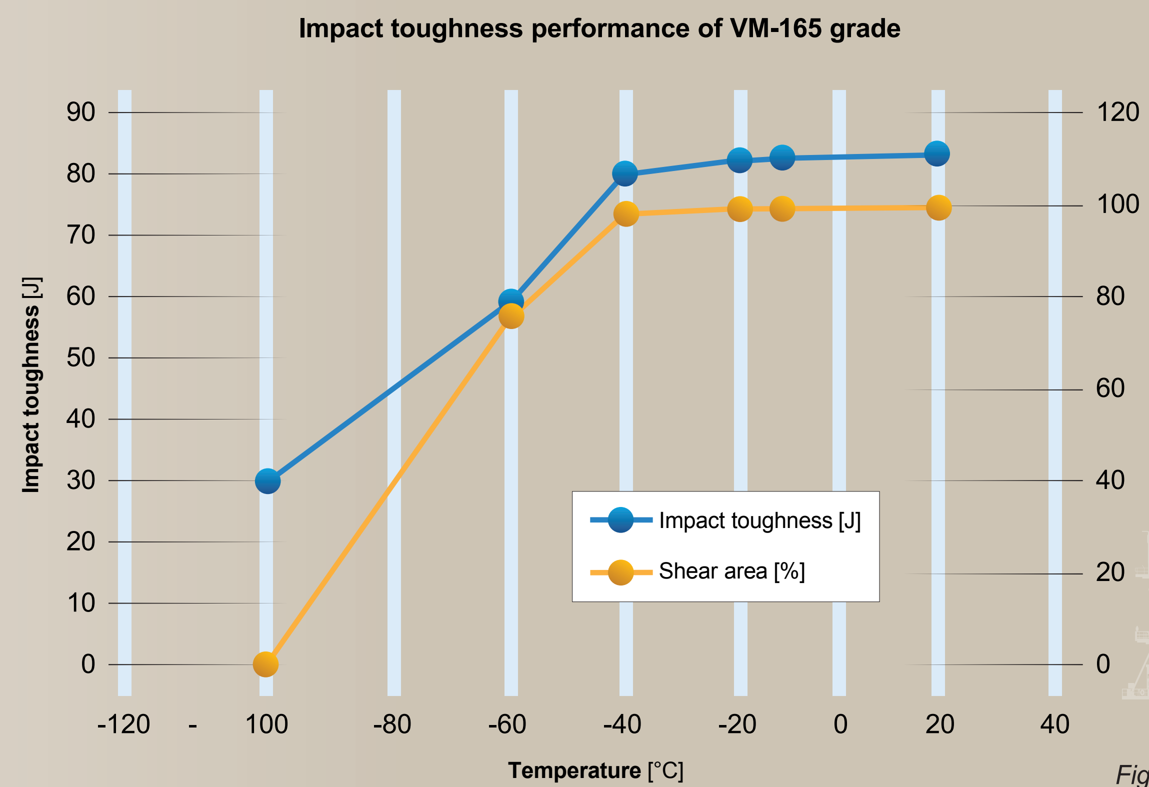

Fig. 5: Transition curve of the VM-165.

High resistance to shock - Impact toughness measurements have been conducted as per ASTM E23.
The **VM-165** grade shows high impact toughness performance, even at low temperature.Table 3 shows the performances reached with VM-165 at -4°F in the longitudinal direction,
for 10 x 7,5 mm specimens.

VM-165 still exhibits a fully ductile behaviour at temperatures as low as -35°C. The ductile to brittle transition temperature is around -60°C.

KCV Experimental results 10 x 7,5 @-4°F (-20°C / -4°F)

	Specimen 1 [J]	Specimen 2 [J]	Specimen 3 [J]	Average [J]	Average [ft.lbs]	Min [ft.lbs]	Ductility [%]
S135	85	93	93	90,3	65,9	62,0	100
VM-150	98	95	103	98,7	71,9	69,3	100
VM-165	82	82	87	83,7	61,0	59,8	100

Table 2. Charpy V-notch energies reached with VM-165, compared with S135 API and VM-150 grade.

High resistance to fatigue - Small scale fatigue tests simulate the resistance of the material when loads are applied a huge number of times, for example, when the pipe rotates while remaining within a dog leg. The fatigue limit of **VM-165** base material was evaluated, with the use of round specimens submitted to tension / compression loads (stress ratio = -1), and a post treatment as per ASTM E739. The number of cycles to run-out was set at 10 million. This data, compared to the fatigue limit of other drill pipe and OCTG casing grades, is compiled in table 3. The **VM-165** grade shows the highest fatigue limit.

Tested grade	UTS [ksi]	R=-1		
		Fatigue limit @ 10^7 cycles [ksi]	Fatigue limit @ 10^6 cycles [ksi]	Amplitude/UTS @ 10^6 cycles
P110	128	69,1	70,8	0,55
S135	160	84,3	87,2	0,54
VM-165	186	—	103,5	0,56

Table 3: comparison of fatigue limits of various High Strength Low Alloy (HSLA) steels.