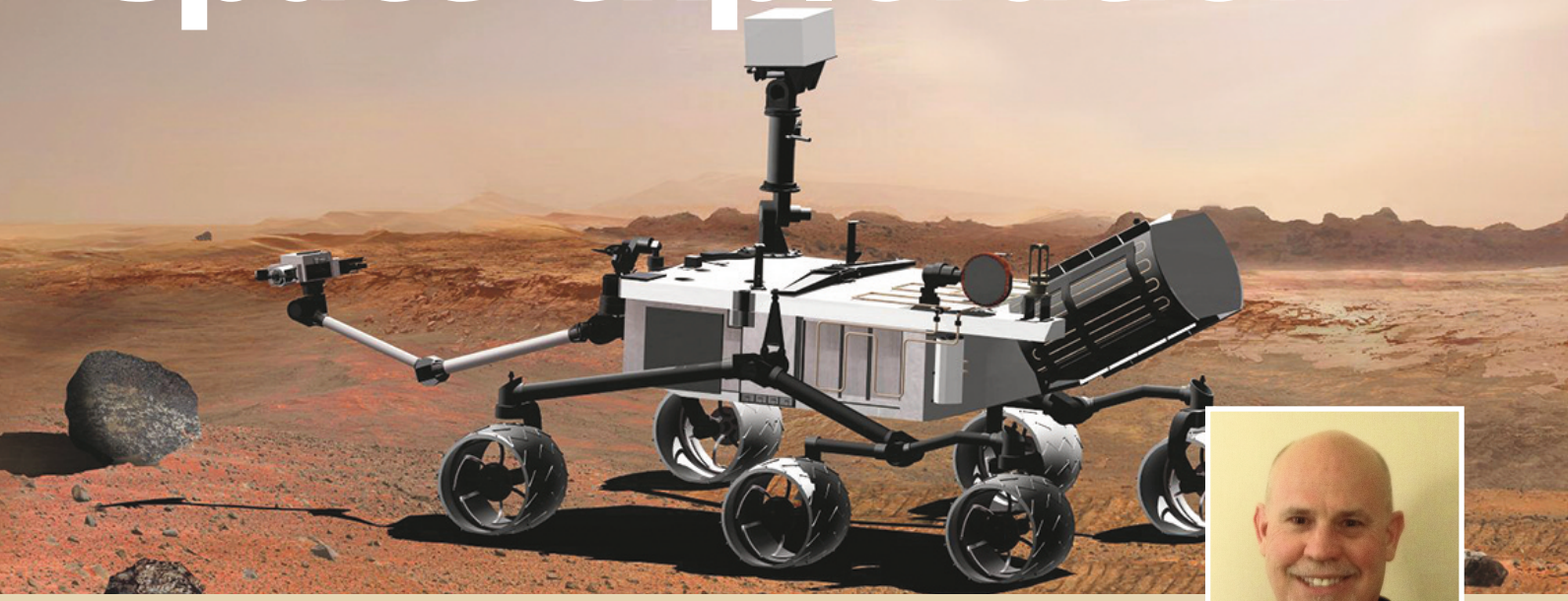
Lubricating space exploration



Keith Campbell

Castrol Industrial has a long history of developing greases for space missions, having worked with NASA since the 1960s, and although it's perhaps not the most physically apparent element of a space operation, lubricant is mission critical.

Castrol has provided the necessary lubricant for both Mars rovers, most recently Curiosity which arrived on the red planet on 6 August 2012. An innovative Castrol lubricant, Braycote 601 EF, was used on many parts of the car-sized Curiosity and affects almost all of the rover's operations, from navigation to identification of hazards and communicating with NASA. The lubricant is used on most of Curiosity's moving parts including the robotic arm, mast deploy actuator and pivot mechanism, six wheel drive actuators, four wheel steering actuators, drill mechanisms, science instruments on the turret and the dust removal tool.

Challenging environmental extremes

Lubricants face numerous severe challenges in space. One major challenge is that maintenance is usually not possible so lubricant applications are 'fill for life'. The lubricant must therefore continuously withstand a large number of environmental challenges over a long period of time for it to do its job and ensure the smooth running of the rover. Space is a vacuum which plays a big role in selecting a lubricant as it literally pulls the base oils out of the grease, leading to outgassing, or the evaporative loss of the grease itself; NASA measures outgassing at 124°C.

There are two issues with outgassing. The first is that because the oil is the most volatile part of the grease, the vacuum can theoretically deplete it completely, leading to mechanical failure of the grease and therefore the component it is protecting. Solids are not volatile so remain within the grease structure.

The second issue is that the material that outgasses can condense in other areas of the spacecraft such as the optic. These contaminants can become a major pollutant on instrumentation and can cause components to fail or operate erratically.

Another major challenge is friction. Friction causes wear, and if moving parts wear down they stop operating correctly and movement will grind to a halt. Friction must be eliminated, or at least reduced, so this wear does not take place - this is where lubricants come in.

Lubricants for space also need to be able to cope with dramatic swings in temperature without outgassing. It may seem that since space is so cold, concerns about higher temperatures are unfounded but exposure to the sun as well as equipment operation can warm the components sufficiently to reach potential outgassing temperatures. In addition, spacecraft can be exposed to elevated temperatures during lift-off.

According to NASA, Mars' temperature ranges from 20°C at the equator during summer to minus 153°C at the poles. A lubricant that works well at such a cold temperatures is generally a low-viscosity, low-molecular weight fluid that resists chemical or physical change at low temperatures. However, the lubricant also needs to be able to operate normally when brought back up to temperatures within the normal operating range. Viscosity will be extremely low at higher temperatures and outgassing can increase dramatically. It takes careful formulation to operate at the low temperatures, yet resist outgassing at the warmer temperatures.

Castrol Braycote 601 EF can perform in temperatures ranging from minus 80°C to 204°C, with no adverse effects. The Curiosity rover can also be exposed to a number of other conditions that affect operation on Mars itself. For instance, Mars experiences frequent dust storms that include a wide variety and size of dust particles. Even though the joints on Curiosity are generally sealed well enough to resist dust, the lubricant still has to resist dust ingestion as a second line of defence.

NASA at one time looked at putting a manned station on the moon and asked Castrol about the effects of moon dust on Braycote 601 EF and whether they had any testing methodology that could be used. Castrol looked at the results of tests that had been completed for the effects of mining operations on lubricants, which NASA incorporated with their findings from tests using ground volcano dust, apparently very similar to moon dust. Castrol were told that the dust did not cause a problem to the lubricant or any moving part.

Designing a lubricant for use in space
As with any application on the ground, the characteristics of lubricants used in space have to meet strict standards. The testing of lubricants to approve them for space use is carried out by space agencies, often in conjunction with the lubricant manufacturers. NASA measures outgassing in the ASTM E 595 test, which evaluates the changes in mass of a test specimen exposed to 10 -7 torr vacuum at 125°C. It also measures the mass of product that leaves the specimen and condenses on a collector at a temperature of 25°C.

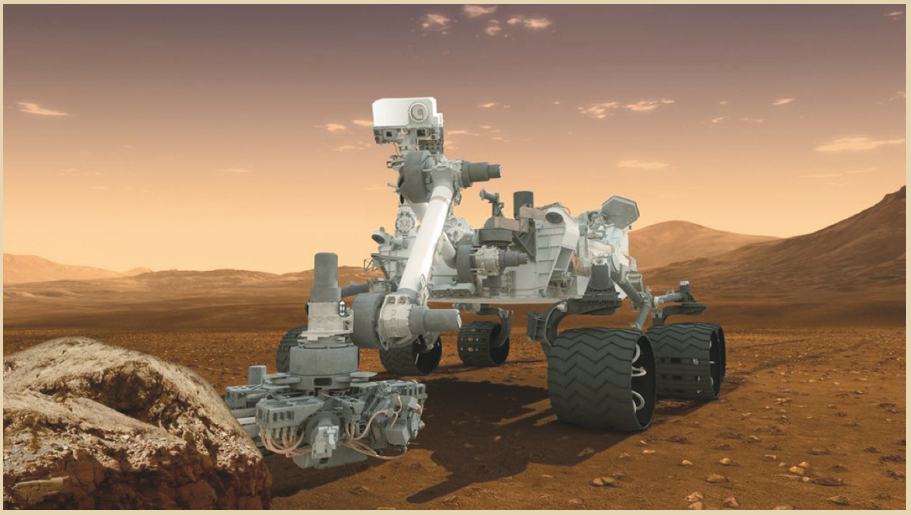
The simulation of the vacuum in space in this test method does not require that the pressure be as low as that encountered in interplanetary flight (10-12 Pascals or 10-14 torr). It is sufficient that the pressure be low enough that the mean free path of gas molecules is long, compared to chamber dimensions.

Two parameters are measured in the test: total mass loss (TML) and collected volatile condensable materials (CVCM). The amount of water vapour regained can also be measured after completing the exposures and measurements required for TML and CVCM of 0.10 per cent.

Success in space lubrication
Lubricants based on perfluoropolyether (PFPE) chemistry have proven in space agency tests to be the best cold temperature and low outgassing lubricants.

The Castrol Braycote line, which includes sister products 600 EF, 602 EF and 815 Z, has been used frequently by NASA since the start of space exploration in the 1960s. Volumes used by the space sector are small but there are a lot of things that make the Castrol Braycote product very special. It performs in a vacuum, it is non-toxic and non-reactive with oxygen and other compounds, it has low outgassing and it keeps working for years – vital for long haul missions where maintenance is almost impossible.

To get the combination of viscosity over a wide temperature range and low



outgassing, Castrol Braycote 601 EF is formulated from PFPE oil thickened with polytetrafluoroethylene (PTFE) powder. The PFPE has a viscosity index of 350, which provides the wide temperature range required for this environment.

The grease, which has a paste-like consistency, is not 'cooked' like conventional greases. The grease is manufactured by mechanical mixing to distribute the PTFE particles into the oil, as PTFE is not soluble in PFPE.

The grease also contains a corrosion inhibitor to protect components in the time before launch or during storage, where it can be exposed to high humidity. It is inert to acids, bases and oxidizers as well as rocket propellants and in addition, the non-toxic, non-flammable lubricant does not use any chlorofluorocarbons during manufacturing.

What's next?
Although mission life requirements were just minutes or hours at the beginning of space exploration, then rising to months and now to several years in the case of the space station, the characteristics of the lubricants have barely changed. Other space missions where Braycote products have lubricated the moving parts include the Apollo moon missions, the Hubble space telescope, numerous satellites, the International Space Station (ISS) and past rovers.

The products have also been used on many spacesuits worn by astronauts, including that worn by record-breaking Austrian space jumper Felix Baumgartner in October 2012. In 2007, after attempts with pure gold had failed, astronauts used Castrol Braycote 601 EF to fix a lubrication problem on the ISS solar power mechanism. A small amount of grease prevented what an investigation into the issue said threatened to be an 'unrecoverable stall of the mechanism'.

Castrol Braycote 601 EF should also be considered where there are any hostile chemicals or extreme environmental conditions that would preclude the use of other lubricants, such as the chemical industry and air processing and handling. Companies with manufacturing processes that require a vacuum such as the production of semi-conductors, micro-chips, flat panel display and hard disk drives will also benefit from using this type of lubricant. Typical applications in these areas include ball and roller bearings, gears and as an assembly lubricant for O-rings and elastomers.

As the space industry develops, including the rise of private sector space programmes and space tourism, and developments by other space organisations such as the European Space Programme take place, the customer base for these high-performance products is expected to widen.

According to NASA, the limiting factor in terms of spacecraft mechanism life and allowable operating temperature range is the lubricant. Lubricant stress limits, such as the 100,000 psi contact pressure limits for Castrol Braycote, are important design drivers that determine the physical size and weight of space mechanisms.

Castrol continues to work closely with NASA and other agencies to develop other lubricants to meet the ever-increasing challenges of space exploration. Much of this is as yet unknown territory, but what is known is that space presents environments far more hostile than those currently encountered on Mars by the Curiosity rover and Castrol's Braycote.

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