Improving efficiency of mobile hydraulic systems

New technology is improving energy efficiency in mobile hydraulic fluids with the use of displacement-controlled actuators.

Increases in energy costs are prompting the hydraulic industry to pursue improvements in the energy efficiency of mobile machines. A key example is excavators, which are designed for digging in construction, mining and other applications.

In an excavator, the operator is located in a cabin that can swivel in a 360-degree fashion. The cabin is placed on tracks that can propel the vehicle over virtually any kind of terrain. Three hydraulic actuators (cylinders) control the movement of a toothed bucket to lift, dig, push and generally move material. A typical compact excavator is shown in Figure 1.

Chris Williamson, a doctorate student in the department of agricultural and biological engineering at Purdue University, says, “The trouble with mobile hydraulic systems is that they are controlled with valves. Valves act as fluid resistances, adapting the supply pressure to the load pressure by restricting the flow and converting fluid power to heat. These ‘throttling losses’ are the greatest contributor to system inefficiency for a multiactuator system in an excavator or similar machine.

“The most common hydraulic circuit design in mobile equipment today is a load-sensing (LS) system. In this configuration, a single hydraulic pump supplies fluid to several actuators. The pump is constantly adjusted to the highest pressure required by any of the actuators. Once an actuator needs higher pressure, it provides feedback through a hydraulic line to the pump to increase pump power. Unfortunately, the pump pressure must be reduced by a valve to the lower pressure level required by the other actuators. Essentially, there is a mismatch between power supply and power consumption, and the difference is wasted.”

To explain, Williamson makes an analogy to electrical technology. “Years ago, variable speed electric motors operated with direct current and were controlled with resistors. Now variable speed motors are usually frequency controlled with alternating current. It’s an inherently more efficient approach. Hydraulic systems are still controlled with resistances, and we’re now at a point where we need more...
efficient flow-control technologies.”

An alternative mobile hydraulic system that could offer improved efficiency utilizes displacement-controlled (DC) actuators. Williamson explains, “DC actuation involves the direct control of an individual actuator with a single hydraulic pump. Through this technology, the hydraulic pump can consistently provide the actuator with the optimal amount of fluid power needed. Valves are no longer used to control the actuator power.”

The prospect of realizing efficiency improvement in mobile hydraulic fluids with DC actuators has not been determined until now.

**DISPLACEMENT-CONTROLLED ACTUATORS**

Previous work by the researchers on wheel loaders and skid-steer loaders showed that DC hydraulic systems display fuels savings between 10% and 20% compared to existing systems. In current work, DC and LS hydraulic systems are compared by mathematical modeling in a simulation study using a Bobcat 435 compact excavator (Figure 1).

Williamson says, “We chose a five-ton miniexcavator because while it has the same load-sensing hydraulics found in larger excavators it is small enough to be evaluated in the laboratory.” Smaller excavators are more versatile than the larger machines used for mining and heavy construction, as they have additional actuator functions and can be operated with other attachments besides a bucket for digging.

The simulation study measured dynamic and steady-state processes that each hydraulic system would use in controlling the excavator. An example of the former is how the excavator responds to an applied force. In the latter, how efficiently the hydraulic systems are using energy is evaluated. Steady-state characteristics were based on experimental measurements of the hydraulic components.

The energy consumed by the excavator in a 60-second digging cycle was measured using both hydraulic systems. Five power distributed categories were evaluated including actuator work, valve losses, pump losses, frictional losses (in the hoses and actuator seals) and other losses for charge and drive pumps and a cooling fan. Williamson says, “We found that the largest difference in energy loss was due to the hydraulic valves. In fact, for the LS hydraulic system, valve losses represent 43% of the total energy consumed.”

In contrast, the DC hydraulic system does not rely on valves for actuator control, which means there is minimal energy loss. Overall, if DC technology is used, the excavator would realize an energy savings of 39%.

The biggest challenge in using DC hydraulics is not the added weight of additional pumps but space and cost. Williamson says, “The additional pumps weigh a few hundred pounds, which is negligible when the excavator weighs five tons. But finding a way to fit more pumps in an already compact machine was not a trivial problem. Also, equipment manufacturers like Bobcat are very sensitive to cost increases. Our argument is that customers are willing to pay a little more up front for much lower operating costs. It’s the same phenomenon that we see with hybrid passenger cars.”

This simulation work was carried out with an ISO VG46, mineral oil-based hydraulic fluid. Williamson believes there is a need to evaluate other fluids in order to determine if more energy savings can be realized. He says, “More pumps in a DC hydraulic system means their characteristics and performance are a dominant factor. Any lubricant that can help to improve lubrication and pump performance would increase energy efficiency.”

Future work will involve the actual installation of a DC hydraulic system in a prototype excavator. Once the machine is complete, system performance will be further improved with new control algorithms for optimizing the operation of the diesel engine and hydraulic system.

Additional information can be obtained from a presentation made by Williamson at a recent conference.1 He can also be contacted at williaca@purdue.edu. The research is funded by the Center for Compact and Efficient Fluid Power (CCEFP) and the National Fluid Power Association (NFPA).

**REFERENCE**

Those of us who work in laboratory environments often prepare a large number of blends as part of a product development project or a specific quality control (QC) procedure. In doing this work, we are faced with conducting very repetitive tasks.

Often, in my past, I have needed to line up at least 20 beakers on a bench top. Addition of the required raw materials on a balance then occurs followed by using a magnetic stirrer to prepare the mixture. This can be a very tedious and time-consuming task.

Problems with handling powders or highly viscous raw materials also can increase the difficulty in preparing mixtures. Time also can be a factor, particularly in QC where production personnel always are asking when the testing is done and a specific batch can be approved. The sales department also is concerned because the customer will be upset if the batch is not approved and shipped in a timely fashion.

As we are all multitasking to greater and greater degrees in the current business climate, any technology that can be used to accelerate the process without reducing the precision and accuracy of preparing blends would be welcomed.

A new automated workbench can perform multiple samples in the lab and blend them into uniform, homogeneous mixtures.

Figure 2
This two-meter long automated blending unit can prepare 160 blends in a 24-hour period. Each blend contains nine raw materials. [Courtesy of Zinsser North America, Inc.]
HIGH THROUGHPUT BLENDING

Zinsser Analytic has developed an automated product that can prepare multiple samples by accurately weighing raw materials and then blending them into uniform, homogeneous mixtures. Their product is known as BLENDA.

Jim Schools, director of marketing for Zinsser North America in Northridge, Calif., says, “Our technology expedites the preparation of multiple formulations for the user to evaluate down the line. Blending is done on an automated workbench that contains balances for weighing, heating elements and magnetic stirrers. The capability is also present to do overhead, mechanical stirring.”

In certain cases, heating is required to facilitate the preparation of a homogeneous mixture because one of the components is very viscous and another might be a solid. Schools says, “The workbench has the capability of heating up vessels to 250 C.”

A representative two-meter long unit is shown in Figure 2. This unit has a depth of 700 millimeters and a height of 550 millimeters. Schools indicates that units as small as one-meter in length are available.

Robotic arms are used to secure the appropriate glassware from storage and transport it to the balances. After being tared, raw materials are metered into the blending vessel. Schools says, “Bulk reagents used in the preparation of mixtures are stored in five large volume containers underneath the workbench. High-precision rotating pumps are used to transport these reagents to the blending vessel. Other reagents are stored on the workbench and can be added to the blending vessel using the appropriate cartridge to dispense the liquid raw material.”

One of the strengths of this technology is its ability to handle viscous raw materials. The lubricant industry has its share of thick additive components such as polybutenes that are used as synthetic basestocks. School says, “We know that our technology can easily work with reagents with viscosities up to at least 3,000 cSt at 50 C.”

Equally challenging can be the introduction of powders into a lubricant formulation. This needs to be done to produce oil and water dispersions such as those made with molybdenum disulfide. Schools adds, “We have developed tools and modules to work with powders developed in collaboration with the pharmaceutical and fine chemical industries. Our dispensing equipment can handle a range of solids that may be sticky or fluffy.”

The workbench does real-time weighing by dispensing either liquids or solids into a blending vessel gravimetrically. The vessel sits on a balance that can have four to five decimal places. Schools says, “The specific weighing process has an accuracy and a precision of less than +/- 1%.”

The two-meter workbench shown in Figure 2 can prepare 160 blends with a volume between 40 and 50 milliliters each in 24 hours. Each of the blends contains at least nine raw materials.

The workbench also has the capability of using different techniques to agitate mixtures. Schools says, “Besides using a magnetic stirrer or mechanical stirring, shaking and sonication are other options available to the user.”

This technology also can be used to measure the pH of a mixture, which could be of importance in a water-based metalworking fluid or an aqueous hydraulic fluid. Schools says, “Our technology contains a pH probe that can measure the pH of a mixture. Acids and bases can then be automatically added to adjust the pH to the desired value. Most acids and bases are compatible with the workbench except for those that attack metal.” Schools also notes that the accuracy and precision of pH measurement is +/- 0.025 pH units.

Other tools that the workbench can offer to the user are centrifugation, drying, evaporation and filtration. Schools indicates that the xyz robot platform has been in use for 20 years and is extremely durable. It is used extensively by the pharmaceutical industry. Several lubricant manufacturers also have successfully utilized this technology over the past two years.

Maintenance is relatively easy for the user. Schools says, “The user needs to keep the raw material containers filled and properly labeled. The unit will automatically flush vessels that need to be cleaned. We visit a user once or twice a year to do routine maintenance depending upon the client’s requirements.”

Further information on the workbench can be obtained by contacting Schools at jimschools@zinsserna.com or by visiting www.zinsserna.com/blending.
henolic biocides have been used in metalworking fluids since the 1940s. Prior to 1980 they were utilized to control microbial growth in water dilutable metalworking fluids. But the EPA banned the discharge of all phenolics in wastewater in the early 1980s, which significantly discouraged their use.

STLE-member Peter Hug, principal for Recombinant Innovation, LLC, in Toledo, Ohio, says, “Phenolic biocides have been restricted in a number of local municipalities to discharge levels not exceeding 1 ppm. The challenge in using phenolics in this case is that these biocides are used in metalworking fluids systems at levels between 2,000 and 2,500 ppm.”

The other option for dealing with phenolics is to have the entire fluid hauled away. But the cost of this process can be prohibitive.

Over the past decade, phenolic biocides have made a comeback in metalworking fluids as several large end-users have reapproved their use. An additional benefit is that phenolic biocides are effective against a specific type of bacteria known as mycobacteria. One of the most widely used biocides in this series is the chlorinated phenolic, parachlorometacresol (PCMC).

Hug adds, “Phenolic biocides have a well-known toxicity profile, and their use is well understood. This factor enables their use at specific levels that will not cause harm to users, yet still control bacterial growth in metalworking fluids.”

With the increased interest in their use, any approach that could be used to facilitate the waste treatment of chlorinated phenolic biocides would be welcome. Such a technology has not been available until now.

**F**E-TAML® **O**XIDATIVE **C**ATALYST

Hug, in collaboration with researchers at Carnegie Mellon University, has been evaluating the efficacy of a catalyst known as Fe-TAML [Iron (III) tetraamido-macrocyclic ligand]. Work done shows that Fe-TAML works to potentiate the well-known oxidizing agent, hydrogen peroxide, to degrade chlorinated phenolics very effectively at ambient temperature and pressure.

The researchers found that chlorinated phenolic pollutants, such as pentachlorophenol (PCP) and 2,4,6-trichlorophenol (TCP), are destroyed in only a matter of minutes.1 Hug says, “The decomposition products are two- and three-carbon chain fragments such as salts of acetates and propionates. Most important, the reaction...
is effective at the alkaline pH operating range (8.5 to 9.5) of metalworking fluids.

Hug indicates that TAML is a cyclic adduct that forces the iron atom to be in an undesirable oxidation state. He adds, “Hydrogen peroxide oxidizes iron, which then opens up the aromatic phenolic ring.” This process also can occur in some systems without the need for hydrogen peroxide. In those cases, atmospheric oxygen is suitable, according to Hug.

Hug found that the Fe-TAML catalyst, in combination with hydrogen peroxide, very efficiently degrades PCMC in water dilutable metalworking fluid systems. He explains, “Addition of hydrogen peroxide at concentrations of 10 millimolar, in combination with 1 micromolar Fe-TAML, rapidly degrades PCMC. After one addition of hydrogen peroxide and Fe-TAML, the level of PCMC drops from its initial concentration of 2,000 ppm to 1,500 ppm. This figure drops to zero after a second addition of hydrogen peroxide.”

The most effective way to use this technology is to first add the Fe-TAML catalyst at a concentration of 1 micromolar to the metalworking fluid system and ensure it is uniformly dispersed. Hydrogen peroxide is then added to the metalworking fluid system and then the process is repeated after 15 minutes.

Hug says, “The half life of the hydrogen peroxide-activated catalyst is 15 minutes. Typically, degradation of 80% of the PCMC present is seen during this time frame. Additional increments of hydrogen peroxide must be added to further reduce the PCMC concentrations down to zero.”

Two analytical techniques are used to determine the PCMC concentration in the metalworking fluid. The 4-aminoantipyrine (4-AAP) method is a spectrophotometric method that takes advantage of the reaction between phenolic compounds and 4-AAP in the presence of potassium ferricyanide at a pH of 10. The concentration of the resulting reddish-brown colored dye can be determined as a function of PCMC concentration.

Figure 3 shows the actual color intensity of a series of used metalworking fluid samples that have been subjected to three hydrogen peroxide treatments. It is clearly evident that the concentration of PCMC is declining after each successive hydrogen peroxide addition.

Hug says, “We can correlate these results with HPLC data, which indicates that the original sample contained 2,072 ppm PCMC. This concentration drops to 205 ppm after the first addition and then to 32 ppm PCMC after the second addition. No PCMC was detected after the third addition.” The 4-AAP technique is portable and can be used to measure PCMC concentration while the degradation process is being conducted in the manufacturing plant.

Two impurities that can affect this process are copper and manganese. Both metals can be present in a metalworking fluid system if they are contained within the alloy being machined. Hug says, “Copper and manganese will slow down the degradation of PCMC. We have found that more additions of hydrogen peroxide are required to eliminate the PCMC but that the process still works well, even in the presence of high concentrations of copper and manganese.”

Hug has evaluated metalworking fluids present in sumps and totes. He has not yet evaluated larger central systems. Hug adds, “We do not envision mixing the catalyst in a larger central system to be a problem. The kinetics of the process should also not be affected.”

Twelve different soluble oil and semisynthetic metalworking fluid products have been evaluated from different suppliers without any problems. Hug indicates that the technology has been licensed for commercialization from Green Ox Catalysts, Inc.

Future work will involve activating the Fe-TAML catalyst with just atmospheric oxygen and not hydrogen peroxide.

Hug says, “This approach is being examined because a hydrogen peroxide-free process will be significantly simpler and also somewhat cheaper. At present, the hydrogen peroxide-based process is effective and straightforward.”

Background information on how this catalyst system can destroy chlorinated phenols can be found in an article published in 2002. Further details about its use in a metalworking fluid system can be obtained by contacting Hug at peter.hug@rinucleus.com.

**REFERENCE**


Neil Canter heads his own consulting company, Chemical Solutions, in Willow Grove, Pa. Ideas for Tech Beat items can be sent to him at neilcanter@comcast.net.