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Oil Viscosity Effects on Hydraulic Systems for Gates

TADS – Bureau of Reclamation Resources Newly Available Online

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This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Bureau of Reclamation personnel and water user groups in operating and maintaining project facilities.

The *Water Operation and Maintenance Bulletin* and subject index may be accessed on the Internet at: <**http://www.usbr.gov/pmts/infrastructure/inspection/waterbulletin**>.

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***Cover photographs** – Photos depicting oil viscosity.*

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Oil Viscosity Effects on Hydraulic Systems for Gates

Introduction

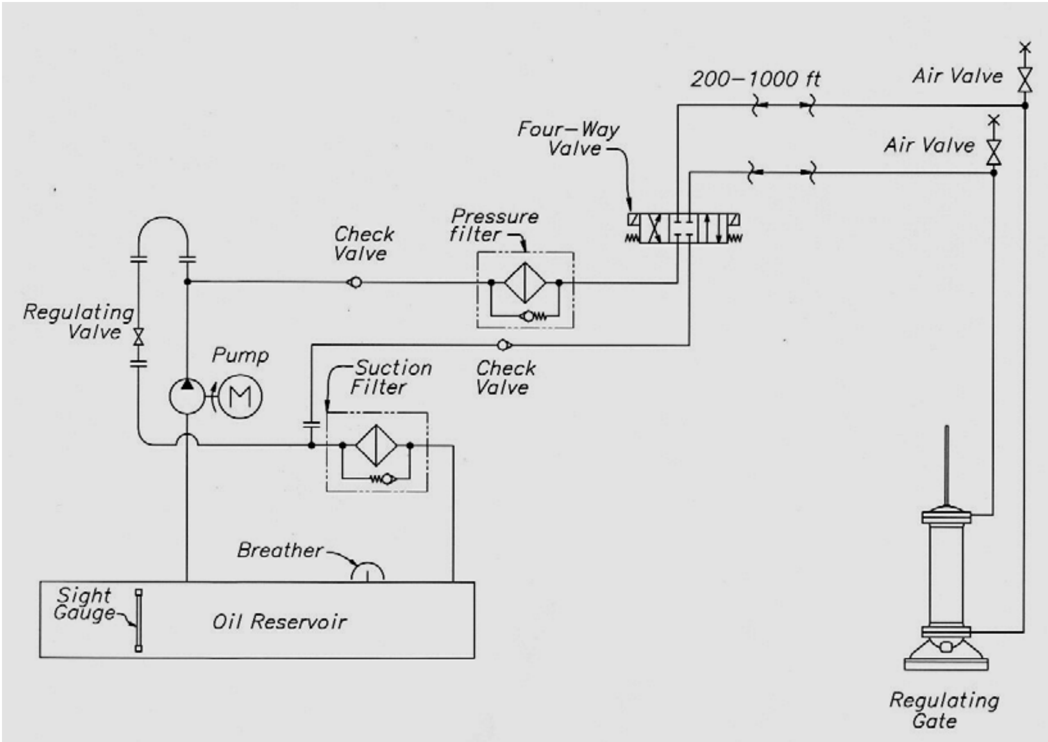
A problem has been observed at several dams where the hydraulically operated slide gates either operate slowly or don't operate at all. The available pressure seems to be inadequate to open the gates during colder temperatures. Some field "work-a-rounds" include increasing the pressure relief valve setting or using only one pump on a two-pump hydraulic power unit (HPU). The problem is caused by an excessive pressure drop in the piping between the HPU and the gate. In this document, five possible solutions were examined in order to alleviate the problem:

1. Change the oil to synthetic oil
2. Decrease pump flow
3. Install pipes of a larger diameter
4. Install heaters
5. Adjust the pressure relief valve

Depending on the system and available funding, different solutions can be used.

Schematic Diagram

Currently, about 20 dams specify hydraulic oil for valve operating systems with viscosities of 150 Seconds Saybolt Universal (SSU) at 100 degrees Fahrenheit (°F) with a viscosity index of 106. About 12 of those dams are in regions of colder temperatures, at times averaging 50 °F (inside the dam tunnel). Another five dams specify hydraulic oil with viscosities of 190–220 SSU at 130 °F with a viscosity index of 70.



Definitions

Viscosity is a liquid's resistance to flow. Viscosity is a result of the internal friction of the material's molecules. Materials with a high viscosity do not flow readily. The unit of viscosity is the SSU – Seconds Saybolt Universal. It refers to the time required for a liquid to flow from a filled container of specified dimensions through a small orifice in the bottom of the container.

Viscosity Index (VI) indicates the change of viscosity with a given change in temperature. The greater the value of the viscosity index, the smaller the change in viscosity for a given change in temperature. It is an arbitrary unitless scale used to show the magnitude of viscosity changes in lubricating oils with changes in temperature. Oils with low VI number such as VI = 0 ("zero") have high change in viscosity with a given change in temperature. They thicken quickly with decreasing temperature and thin out quickly with increasing temperature. Oils with a high VI number, such as VI = 200, will still thicken with decreasing temperature (but not as rapidly) and will also thin out with increasing temperature, but again, not as much as oil with a low VI number. Tables found in ASTM Method D 2270 are widely used to determine VI number. However, the VI number does not tell the whole story; it only reflects the viscosity/temperature relationship between temperatures of 40 degrees Celsius (°C) (about 100 °F) and 100 °C (about 210 °F). Two lubricants or base oils with the same VI number may perform dramatically different at temperatures below 32 °F.

Hydraulic System Design

One facility uses a 2.2-gallon-per-minute pump to move the hydraulic oil through a 1/2-inch-diameter schedule 40 pipe approximately 300 feet to the gate. The gate opens 6 inches per minute at an operating pressure between 500 and 600 pounds per square inch (lb/in^2). The hydraulic oil in the system is specified at 150 SSU at 100 °F with brands such as Texaco Regal Type O&A (MIL-L-17672 grade 2110 TH), Shell Tellus 32, or American Petroleum Institute Antiwear Type API. The relief valve is set to return the oil back into the sump (from the pump discharge) when the pressure reaches 750 lb/in^2. Using the equation below (taken from the design criteria), the system should work perfectly at 100 °F.

Total pressure loss =

(2 * v * V * L) / (C * D4) + HPU losses (due to filters, valves, etc.)

Where:

V = Oil flow in gallons per minute (gpm)
v = Viscosity in SSU
D = Inner diameter of pipe in inches
L = Length of pipe (one way) in feet
C = conversion factor = 18,300

As Designed

Gate operating speed	6 inches / minimum
Oil flow rate	2.2 gpm
Number of gates operated	1
Fluid liner inner diameter	0.622 inch (1/2-inch-diameter pipe)
Temperature	100 °F
Viscosity – SSU	150
Maximum distance HPU to gate	300 feet (one way)
Pressure loss per foot	0.12 lb/in^2/ft
HPU losses	
Suction filter	5 lb/in^2
Pressure filter	1 lb/in^2
Pilot op. check valve	10 lb/in^2
Counterbalance valve	10 lb/in^2
4-way valve	10 lb/in^2
Manifold and int. lines	1 lb/in^2
Total pressure losses	**109 lb/in^2**

The total pressure loss for the system is only about 110 lb/in^2, which allows the system to work as designed. The relief valve works at 750 lb/in^2, and the gate operates around 500 to 600 lb/in^2 plus 110 lb/in^2 loss, which equals 610 to 710 lb/in^2; therefore, the relief valve doesn't return the oil to the tank, and the system works as designed.

Current System

At some of the dams, the current system does not work as planned because the hydraulic lines that are located in a tunnel through the dam do not operate at 100 °F; the actual temperature is much lower (50 °F). When the temperature decreases, the oil viscosity increases, causing the oil to flow less readily and thus increasing the pressure loss of the system.

Gate operating speed	6 inches / minimum
Oil flow rate	2.2 gpm
Number of gates operated	1
Fluid liner inner diameter	0.622 inch (1/2-inch-diameter pipe)
Temperature	50 °F
Viscosity – SSU	744
Maximum distance HPU to gate	300 feet (one way)
Pressure loss per foot	0.598 lb/in^2/ft
HPU losses	
Suction filter	7 lb/in^2
Pressure filter	2 lb/in^2
Pilot op. check valve	15 lb/in^2
Counterbalance valve	15 lb/in^2
4-way valve	15 lb/in^2
Manifold and int. lines	2 lb/in^2
Total pressure losses	**415 lb/in^2**

The total pressure loss for the system is about 415 lb/in^2, plus the required operating pressure at the gate of around 500 to 600 lb/in^2, which equals a total required pressure of 915 to 1,015 lb/in^2. The relief valve is set at 750 lb/in^2; therefore, the relief valve opens and the gate does not operate.

Possible Solutions

Synthetic Oil

Changing the oil from a conventional blend to a synthetic blend will lower the viscosity and increase the viscosity index. Synthetic oils will work with

current pumps, valves, and seals, but it is usually best to stay with the same oil manufacturer. There is no need for special flushing or cleaning in order to change over to synthetic oils. Synthetic oil works over a larger temperature range than conventional blends so it's better for lower temperatures. Synthetic also has an excellent anti-wear performance. Synthetic oil has about double the life span of conventional oil, and the cost is about 3 times more than conventional oil. The Shell HD synthetic grade 32 costs about $26 per gallon, and the Shell Tellus 32 is $7 a gallon. Using synthetic oil only decreases line pressure losses by 70 lb/in^2, which isn't enough for this system to work as designed. Changing to synthetic oil doesn't seem to make a great difference at temperatures below 60 °F.

Synthetic Oil Grade 32

Gate operating speed	6 inches / minimum
Oil flow rate	2.2 gpm
Number of gates operated	1
Fluid liner inner diameter	0.622 inch (1/2-inch-diameter pipe)
Temperature	50 °F
Viscosity – SSU	601
Maximum distance HPU to gate	300 feet (one way)
Pressure loss per foot	0.482 lb/in^2/ft
HPU losses	
Suction filter	5 lb/in^2
Pressure filter	1 lb/in^2
Pilot op. check valve	10 lb/in^2
Counterbalance valve	10 lb/in^2
4-way valve	10 lb/in^2
Manifold and int. lines	1 lb/in^2
Total pressure losses	**327 lb/in^2**

Decreased Pump Flow

Decreasing the pump flow will cause the gates to open at a slower speed but will decrease the oil velocity through the piping, thus decreasing the pressure losses. Decreasing the pump flow will require a new pump or replacement parts inside the pump (if available) to reduce the volumetric capacity. Some sites have two pumps that open the gates and we have found that if they only use one pump, the gate will open at half of the design speed.

Gate operating speed	12 inches / minimum
Oil flow rate	1 gpm
Number of gates operated	1
Fluid liner inner diameter	0.622 inch (1/2-inch-diameter pipe)
Temperature	50 °F
Viscosity – SSU	744
Maximum distance HPU to gate	300 feet (one way)
Pressure loss per foot	0.272 lb/in^2/ft
HPU losses	
Suction filter	3 lb/in^2
Pressure filter	1 lb/in^2
Pilot op. check valve	7 lb/in^2
Counterbalance valve	7 lb/in^2
4-way valve	7 lb/in^2
Manifold and int. lines	1 lb/in^2
Total pressure losses	**190 lb/in^2**

The total pressure loss for the system is about 190 lb/in^2, plus the required operating pressure at the gate of around 500 to 600 lb/in^2, which equals a total required pressure of 690 to 790 lb/in^2. The relief valve is set at 750 lb/in^2; therefore, the relief valve probably stays closed and the gate opens.

Increased Pipe Size

Increasing the pipe size from 1/2 inch to 3/4 inch decreases the pipe pressure losses and keeps the same gate timing. Increasing the pipe size for 600 feet would be about $7 a foot for the 3/4-inch-diameter pipe and about $2.50 a foot for removal of the old pipe, which totals $6,000.

New Pipe Diameter of 3/4 Inch

Gate operating speed	6 inches / minimum
Oil flow rate	2.2 gpm
Number of gates operated	1
Fluid liner inner diameter	0.824 inch (3/4-inch-diameter pipe)
Temperature	50 °F
Viscosity – SSU	744 – use current oil grade 32
Maximum distance HPU to gate	300 feet (one way)
Pressure loss per foot	0.194 lb/in^2/ft
HPU losses	
Suction filter	5 lb/in^2
Pressure filter	1 lb/in^2
Pilot op. check valve	10 lb/in^2
Counterbalance valve	10 lb/in^2
4-way valve	10 lb/in^2
Manifold and int. lines	1 lb/in^2
Total pressure losses	**154 lb/in^2**

The total pressure loss for the system is about 154 lb/in^2, plus the required operating pressure at the gate of around 500 to 600 lb/in^2, which equals a total required pressure of 654 to 754 lb/in^2. The relief valve is set at 750 lb/in^2; therefore, the relief valve stays closed and the gate opens.

Heating the Oil

The oil would need to be heated at the tank and in the pipes. Chromalox makes rope heating elements that can run the length of the pipe with a temperature regulating thermostat and an emersion heater for the reservoir tank. Costs are approximately $6.20 per foot for the cable heating elements, $150 for the thermostat, $200 for the emersion heater, and $40 for miscellaneous costs. For this system, the total cost (not including labor) would be about $4,110. The heating system needs about 8 watts per foot of cable, so that would be about 4,800 watts. The system would only run when the temperature of the oil was below 65 °F. This option uses the current oil, allows the gate to open at design speed, and allows the system to operate, as designed, in safe conditions, but requires energy and extra maintenance.

Adjusting the Relief Valve

Adjusting the relief valve to operate at a higher pressure works at low temperatures, but can cause safety issues when the temperature rises. If the temperature rises and the viscosity of the oil decreases, then the fluid flows as designed. If the relief valve is set at a high pressure, then the gate could be subjected to the higher relief valve setting and would put unnecessary loads on the gate. For the current system, the relief valve would need to be set at a pressure of 950 lb/in^2. Another concern with a higher relief valve setting is if the control system is able to handle this higher pressure. The 1/2-inch-diameter schedule 40 pipe can handle up to 1,300 lb/in^2 safely, but can the other valves and connections handle the increased pressure? Each component would have to be analyzed to see if it could handle the pressure increase. It would also not be best to adjust the relief valve constantly for each change in season in order to work for the current temperature.

Conclusion

Depending on the system and problems the dam is experiencing, there are different options that work best for different systems and the money available. If the low operating temperature is not at a critical low, then changing to synthetic oil will help the system operate within the designed oil pressure. In order to maintain the current speed of the gate and to operate within the allowable pressure of the hydraulic lines, it is best to install larger steel piping. If the gate speed isn't critical, then changing the pump to a lower flow will reduce line losses at the expense of gate speed. Changing the pump parts is a low-cost fix, as is replacing a pump with a lower flow pump. Temperature at a site is a large factor that influences how a hydraulic system will operate; designing for the worst case will ensure proper operations at all times.

TADS – Bureau of Reclamation Resources Newly Available Online

"Training Aids for Dam Safety" (TADS) is a Federal/State-developed training program designed to train individuals involved with or having responsibility for the safety of dams. There are nine VHS videos in the original TADS program. All nine of the videos have been digitized and posted on the U.S. Army Corps of Engineers' (USACE) Web-Based Learning Network. All nine of the videos can be played from the following USACE Web site:

http://usaceln.org/technical/TADSLN/TADSII/

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The purpose of this bulletin is to serve as a medium of exchanging operation and maintenance information. Its success depends upon your help in obtaining and submitting new and useful operation and maintenance ideas.

Advertise your district's or project's resourcefulness by having an article published in the bulletin—let us hear from you soon!

Prospective articles should be submitted to one of the Bureau of Reclamation contacts listed below:

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