Evaluating the Governor's Lifeblood: Weighing Governor Performance and Environmental Hazards

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Abstract

Minimizing the environmental impact of hydroelectric power generating facility is a key component in many organizations' environmental policy. One of the largest concerns in a hydroelectric plant is the risk for potential water contamination through leaking oil, especially in the turbine pit. This paper will consider why traditional oil is preferred by operators and manufacturers rather than modern environmentally-friendly biodegradable oil. This paper will also evaluate the importance of oil commonality within an organization. Several experts in governor manufacturing and maintenance were consulted for their input as to the techniques that should be used to ensure the maximum performance and longevity of a governor system as well as mitigate environmental contamination.

Introduction

Using the proper oil type is an essential component to maintaining a well-functioning governor system. By using the oil type recommended by the manufacturer, operators will minimize wear and tear over the course of a unit's lifetime. There are other factors that an organization may consider when choosing what type of oil to use in their governor system. Oil commonality can reduce the risk of operator error by utilizing the same oil for the governor as is used for the turbine. The potential environmental impacts in the event of an oil spill may be considered, especially in ecologically sensitive waterways or recreational areas. The main goal of most organizations is to extend the lifetime of their current systems by using the most cost efficient methods available. Through proper system maintenance, system upgrades, and spill mitigation techniques, a governor unit can operate efficiently and effectively for years to come.

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A Background on Governor Oil

In the early days of hydroelectricity, governor and turbine systems were solely mechanical and did not require large quantities of oil to operate. For bearings, the wood from lignum vitae trees was used because of its inherent lubricating properties, supplemented with small quantities of oil when needed. Today's hydroelectric facilities operate using International Organization for Standardization (ISO) approved turbine and hydraulic oil, as well as dashpot oil (T-10 transformer oil) in lesser quantities. These oils are graded by their kinematic viscosity[3] at 40°C (104°F). The viscosity range of tolerance is no more than 10% on either side of the nominal value, resulting in 20 viscosity grades ranging from kerosene to cylinder oils (Table 1). The most common ISO viscosity grades found in hydro plants are ISO 32, ISO 46 and ISO 68. These oils are alkane (paraffinic) in nature and are sourced through crude oil and natural gas extraction.

Table 1. ISO Viscosity Classification

ISO Viscosity Grade	Midpoint Kinematic Viscosity (mm^2/s at 40°C)	Min. Kinematic Viscosity Limit (mm^2/s at 40°C)	Max. Kinematic Viscosity Limit (mm^2/s at 40°C)
ISO 2	2.2	1.98	2.42
ISO 3	3.2	2.88	3.52
ISO 5	4.6	4.14	5.06
ISO 7	6.8	6.12	7.46
ISO 10	10	9.00	11.0
ISO 15	15	13.5	16.5
ISO 22	22	19.8	24.2
ISO 32	32	29.8	35.2
ISO 46	46	41.4	50.6
ISO 68	68	61.2	74.8
ISO 100	100	90.0	110
ISO 150	150	135	165
ISO 220	220	198	242
ISO 320	320	288	352
ISO 460	460	414	506
ISO 680	680	612	748
ISO 1000	1000	900	1100
ISO 1500	1500	1350	1650
ISO 2200	2200	1980	2420
ISO 3200	3200	2880	3520

Group I and Group II Oils

Group I and Group II refer to the base oil groups developed by the American Petroleum Institute for the purpose of creating guidelines for interchanging base stocks when blending licensed oils (Mang, 2007). Group I oils are typically solvent refined, contain high levels of sulfur and aromatics, and are typically less expensive. Group II oils are refined using a hydrocracking process which results in a lighter color, lower volatility, and better oxidation stability. When Group II oils were first released on the market, there were issues when mixed with as little as 2% of a Group I oil. It was discovered that while the base oils were compatible, the additives used in each were

[3] Kinematic viscosity is obtained by dividing the absolute viscosity of a fluid with its mass density. $v=\mu/\rho$

not, resulting in additive drop out and sludge buildup. The US Army Corps of Engineers Engineering and Construction Bulletin 2003-17 notes the potential performance problems by mixing these types of oils:

> "Three Corps powerhouses (total of 40 generating units) recently replaced Group-1 turbine oil with the new Group-2 oil. Shortly after the replacement, all showed excessive foaming with an increased amount of entrained air in the oil. Approximately six months later operational difficulties were experienced due to sticking of governor proportional valves and plugging of governor in-line filters. The disruptions of the operation in one powerhouse were so extensive that all units had to be disassembled to physically clean accumulated sludge" (Basham, 2003).

When Group II oils were initially released, there was no way to differentiate them from Group I oils other than to have them tested. The result is that many facilities may not know whether the current oil in use or in storage is a Group I or Group II oil. Once the incompatibility was discovered, manufacturers reformulated the additives to be chemically binding in Group II oils to prevent dropout if mixed. Additive dropout and sludge buildup can still occur if mixing products from different manufacturers. It is recommended that each facility saves a clearly marked sample of the oil(s) being used for both future reference and testing.

Biodegradable Oils

Biodegradable oils have the ability to break down relatively quickly and safely by biological means and reabsorb back into the environment. Biodegradable hydraulic oils for industrial use should meet the same performance characteristics as traditional oils including lubricity, flow at hot and cold temperatures, viscosity, oxidative stability, and anti-corrosive properties. Natural and synthetic biodegradable oils have inherently good lubricity and high viscosity indexes[4]. They are polar in nature, requiring reduced quantities of toxic anti-wear agents compared to conventional oils. Natural vegetable oils however have low oxidative stability and can become acidic over time, attacking the metal components in the system (Aitken, 2007). Synthetic biodegradable esters have a higher viscosity index, excellent oxidation, and thermal stability. The higher price for synthetic biodegradable oils can be attributed to more expensive raw materials, but this is offset by being more reliable and having a longer service life.

The biodegradability of oil is tested by inoculating it with bacterial and monitoring it under controlled conditions for 28 days. The percentage of oxygen consumption is then calculated to determine the degree of biodegradability. Most vegetable oils biodegrade 70% or more during this timeframe while traditional oils biodegrade 15-35% (Pickle, 2012). For an oil to be considered

[4] The viscosity index is used to characterize viscosity changes with relation to temperature, where $V=100(L-U)/(L-H)$ V indicating the viscosity index, U the kinematic viscosity at 40ºC, and L & H values based on the kinematic viscosity at 100ºC available in ASTM D2270 (ASTM International, 2014)

biodegradable, it must biodegrade more than 60% in 28 days. Because of this quality, biodegradable oils do not have the longevity of conventional oil and can degrade rapidly in the event of sustained air entrainment or water contamination. If an organization does decide to use biodegradable oils, it should closely monitor the oil and send samples for testing to ensure it is maintaining chemical stability and functioning as intended.

Oil Cleanliness and Maintenance

The performance of the governor system can be dramatically influenced by the quality of oil used. If the oil has water or other contaminants in it, the functionality of the governor can become compromised. In mechanical governors, contaminated oil can cause wear of its mechanical parts, causing slop (backlash) and leading to hunting. In analog systems the pilot control assembly can become sluggish. Dirty oil in digital governors can clog small orifices resulting in incorrect operation or the sticking of valve spools.

There are several ways to determine when it may be time to change oil: a change of appearance (color, clarity); a difference in odor from new oil; water intrusion (oil will have a white, milky color); a change in viscosity (increase or decrease); or accelerated or excessive parts wear is detected. Ideally, the oil within a governor system is changed completely every 15 years, or sooner if needed. Samples should be collected periodically from the bottom of the sump and sent for testing, along with a sample of the oil that has not been used. When changing the governor oil, new oil should be first filtered to ensure no debris has accumulated during transfers or transport. It is also important to note that turbine oil and hydraulic oils cannot be mixed. A contamination of 2% of either oil could cause coagulation. This includes contamination from using the same hoses, funnels, or storage containers.

At the Tennessee Valley Authority (TVA), the turbine oil is tested quarterly to verify that the oil is still in good condition. If unusual amounts of particulates are found in the oil, they can be analyzed and the root problem addressed early, before a minor problem becomes a major one. For example, excessive metal shavings can be an indication the governor oil pump bearings are wearing out. If repairs are performed before the bearings fail and the pump seizes, a significant amount of money can be saved. Contrast this proactive approach (a one-day outage, scheduled at a convenient time) with the “Run to Failure” approach. The Run to Failure approach results in a much-longer forced outage, usually when generation is most valuable.

Almost all problems within the governor can be sourced back to dirty oil. Additional filtering of governor oil and routine testing will help to keep oil cleaner and extend its longevity. These steps will also serve as a an early warning to any issues that may plague your unit before they become costly problems.

Figures 1-4 are of dashpot plungers. The plunger in Fig. 1 has extreme pitting caused by water contamination compared to the new plunger in Fig. 2.

Fig.1

Fig. 2

Banded wear due to friction is seen in Fig. 3, where Fig. 4 shows a smooth, polished surface.

Fig. 3

Fig. 4

The dashpot is essentially a tunable shock absorber for the governor. If the dashpot plunger is scored or pitted from water or dirt, the reset time will diminish taking the governor longer to sync and losing stability. Only dashpot oil should be used in the dashpot and to oil linkages in order to avoid accidental contamination.

The dashpot and its parts are easy to replace and refurbish when necessary. Other components, however, are much more inaccessable and costly to replace. The following exemplifies the damage that can occur from contaminated oil:

Fig. 5 Distributing Valve; MOD II Governor

This distributing valve came from a MOD II Governor that had a series of unfortunate events occur. In this unit, the piston rings in the main servo motor came apart contaminating the oil with metal shavings. This in turn caused gouges in the piston, allowing oil to bypass and leak. The pumps began cycling continuously causing the oil to overheat and eventually caused the servos to go bad. The servos then needed to be bored out and replaced.

There were several points at which this could have been avoided. The continuously cycling pumps were a sign that all was not well with this system. However, the main damage to the system occurred from the disintegration of the piston rings. The metal wore away at key components over time and eventually caused their failure. The presence of a kidney loop filtration system would have removed these contaminants and facilitated closer monitoring of the governor oil. The total price tag for the facility to remove and replace the damaged servos was extreme, and resulted in a unit being out of service for months.

Kidney Loop Filtration Systems

In legacy mechanical governors as well as partial retrofits of digital governors, only the oil going to the pilot valve gets filtered. The large volume of oil used by the distributing valve and pumped into the pressure tank is strained for contaminants larger than 40 micron (µm). Using a kidney loop filtration system ensures that the governor and every hydraulic circuit within it have clean oil. These systems operate independently of the governor and can be run continuously. The kidney loop filtration system works by pulling oil from the bottom corner of the sump and pumping it through a filter. The filtered oil is then deposited in the opposite top corner of the sump. This creates circulation and over time will result in the entire volume of oil within the sump to be filtered. An advantage of the Kidney Loop Filtration System is that the high volume-low pressure filters used in the Kidney Loop System are less expensive than the low volume-high pressure filters that are used in the governor.

Fig. 6 Kidney Loop Filtration System

The system filters normally at a rate of 10% of the total sump volume per hour, resulting in complete filtration of the sump oil twice a day. The kidney loop filtration system also has an adjustable flow restriction valve. By adjusting the valve, one can essentially adjust the temperature of the oil, maintaining a desirable temperature. This prohibits moisture accumulation due to temperature differentials. Warmer oil also lessens the oil viscosity, which enables entrained air to escape. Both moisture accumulation and entrained air will shorten the lifespan of governor oil, as well as the governor's components.

Oil Commonality

Organizations may take several approaches to ensure that governor oil and turbine oil are not mistakenly used in the wrong system. Mixing even a small quantity can cause coagulation and force outage until the contaminated oil can be removed, the system flushed, and new oil filtered and replaced. One approach is through maintaining oil commonality, either within a specific plant or throughout the entire organization. This will eliminate the possibility in accidental mixing due to errors or improper labeling. When an organization chooses an oil to use exclusively it is usually to the requirements of the turbine. This is because the turbine requires a higher oil viscosity for operation. The higher viscosity oil is compatible to work in the governor system without causing harm to the more sensitive components. However, the oil will have to be continuously heated to achieve a lower viscosity and improve flow. The oil will also require more force to pass through the filters, allowing larger sized particles to pass through. Moisture and air entrainment are also more common with higher viscosity oil that is maintained at 40ºC.

Environmental Controls

An Oil Spill Kit should be readily available near any power plant hydraulic system to mitigate oil spills. In terms of the governor oil system, a leak can occur anywhere: the distributing valve gasket; the piping and flanged fittings; or the servomotor seals, as described above. Oil pressures vary of course, but at TVA the nominal governor oil pressure is 300 pounds per square inch (psi). An oil leak under pressure must be repaired quickly in order to minimize oil loss, leading to environmental hazards and potentially the loss of unit availability and concomitant loss of generation. Leaks in high pressure oil systems (defined as 1,500psi and above) can also cause injury to humans.

The Oil Spill Kit should contain oil absorbing materials such as pads or pillows, safety gear such as oil resistant coveralls and gloves, and appropriate eye wear for the technicians involved in the clean-up. As the oil is absorbed from the spill, the oil absorbent materials should be placed in a proper container and disposed of in accordance with environmental requirements. If possible, oil can be reclaimed, filtered, and reused to prevent as much waste as possible.

In most hydro plants, there are floor drains inside the plant that drain to the Station Sump. In the case of a major spill, the oil flows to the drains and ends up in the station sump, which more commonly contains just leakage water. When a spill is discovered, personnel should endeavor to prevent the oil from entering the Station Sump. If the oil does reach the Station Sump, the automatic sump pumps that routinely evacuate the water, usually, must be turned off and the Station Sump thoroughly cleaned before the sump pumps can be placed back into operation.

Oil spills should be kept as localized as possible, and knowing where all drains are and where they lead, is critical. In very old plants, floor drains usually led to the river. If oil *is* ever released into the environment, your containment and mitigation plan must be immediately activated. A well-stocked Spill Response equipment inventory will contain a generous number of river booms and large oil absorbent pads. Just as important, power plant personnel must be well-trained and trained regularly in their proper deployment and use.

Oil is generally stored in what is referred to as containment. Containment can be temporary or permanent, depending on the circumstances. In general, an oil room in a hydro plant would have permanent containment, and oil drums in transport would be in temporary containment. Containment is designed to hold relatively small spills, and not necessarily all oil in storage. Many operational areas have containment around them.

Conclusion

Plant personnel must be well-trained in oil spill mitigation, but good containment is much preferred to expert spill clean-up. Containment helps keep oil spills or leaks localized for less environmental incidents and easier recovery and reuse of oil.

Most plants use a common type of oil in as many applications as possible to avoid costly accidental mixing of oils. Each type of oil should have its own storage and piping requirements. Additionally, purchasing a large quantity of one type of oil is less expensive than several smaller purchases. Historically, mixing even similar oils can be costly when the oils or additives are incompatible.

Biodegradable oils can be utile and desirable in certain applications, but great care must be taken when they are used. The biodegradable oils must have the same properties and performance metrics as traditional oils when chosen. More frequent monitoring is required as biodegradable oils can become acidic over time. Additionally, using biodegradable oils does not release the user from required environmental reporting.

Simply stated, clean oil leads to less downtime. Periodic oil testing allows plant maintenance technicians to be proactive instead of reactive leading to less downtime, fewer forced outages, and less loss of generation, which is ideal for the bottom line of any utility. A kidney loop oil filtration system is an excellent way of ensuring clean oil and, once installed, can be operated at a very low cost for many years.

As we have seen, oil is an important and overlooked component of a governor system. With rare exception, all hydro governors are dependent on oil. Clean, well-maintained, filtered, contained oil is a governor’s lifeblood.

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