Pump ED 101

AIR VS OIL FILLED SEWAGE PUMP MOTORS

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Why would anyone want to fill a perfectly good electric motor with oil? If you to ask the manufacturer's of oil filled submersible pump motors this question, they will give a number of good reasons. On the other hand, the manufacturer's of air filled units will provide just as many good reasons why one should not!

This short paper will explore this question in depth and investigate the pros and cons of each design. I will also try to expose any myths that each group of advocates may have inflicted upon the other. Although we may not decide upon a single clear choice for all applications, we should gain a better understanding of the capabilities of each.[1]

MOTOR ENCLOSURES

Let us start with a short review of non-submersible motors and then compare their characteristics to those of submersible motors. I will also use these comparisons as we debate the pros and cons of each design.

The vast majority of electric motors are not filled with oil. A couple of notable exceptions include sealed refrigeration units and certain hydraulic systems that use oil for bearing lubrication and cooling. These oil filled applications are analogous to water filled circulating and submersible turbine pump motors that also use water for bearing lubrication and cooling. The rest, however, have nothing but air within the motor housing. They may use oil as a bearing lubricant, as is the case with vertical hollow shaft motors, but that oil is isolated from the stator housing.

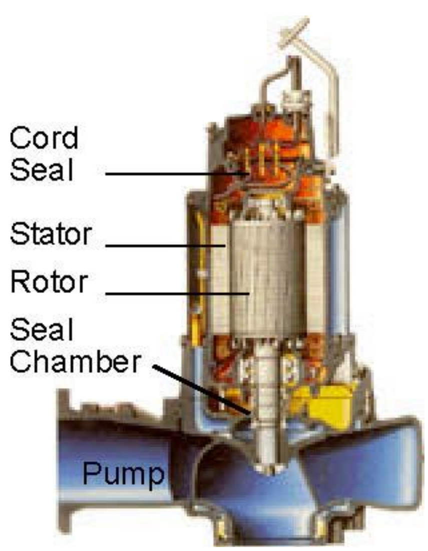
[1] For a general introduction to electric motors check out the tutorials on single and three phase motors at http://www.pumped101.com

The two most common enclosures found in NEMA frame motor construction are the open drip proof (ODP) and totally enclosed fan cooled (TEFC) designs. The ODP motor is open to atmosphere and uses an internal fan to force outside air through the motor housing. Because outside air is always moving through the motor housing, cooling is simple and efficient. There are times, however, when contaminants within the air can damage the motor windings and the ODP enclosure is not the best choice.

The TEFC enclosure is closed to atmosphere and relies on an external fan to force air around the outside of the motor housing. Cooling is not as efficient as the ODP enclosure and often, one finds that the motor service factor is reduced when these enclosures are employed (check out the "Puzzler" for more about service factor). A variant of the TEFC enclosure is known as totally enclosed non ventilated (TENV). These enclosures are normally used in direct drive fan applications and rely on the air moved by the driven machine for their cooling. In non-fan applications, they may be fitted with a water jacket (heat exchanger) for cooling.

The submersible sewage pump motor also uses a TENV enclosure that has been modified in such a way as to prohibit water from entering the motor housing. Instead of a fan, the surrounding water is used to transfer heat from the motor housing. In unsubmerged applications, a water jacket may also be employed.

TO OIL OR NOT TO OIL



So far so good. We now know that the submersible sewage pump motor is just an under water version of its TENV cousin. With this in mind, let the arguments begin. The figure to the left is a cross section of a typical submersible sewage pump. Although designs vary by manufacturer, each have a motor housing and rotor that are close coupled to a non-clog pump end. Higher end pumps will incorporate a dual shaft seals with an oil filled chamber between. Some manufacturers will install a seal leak sensor in this chamber to detect outer seal leakage before water has the opportunity to enter the motor housing. Some will also use a multiple sealing arrangement at the cord entry that includes epoxy potting of the individual motor leads. This step eliminates the "wicking" of water into the motor housing if the cord insulation is damaged. Sealing is a very important topic and probably has a greater impact on pump life than the motor fill. But our discussion today centers around why some manufacturers fill these motor housings with oil while others do not.

THE PROS & CONS

Unfortunately the stated pluses and minuses of oil and air filled motors are not always objective. If you check the literature you probably will not find an objective comparison by a knowledgeable, independent author. Most of our own prejudices are influenced by the manufacturer's themselves. And, why should we blame them? After all, their objective is to sell their own products, not those of their competitors. Lets see if we can remedy this situation by taking an unbiased look at each point of contention and either sustain it or cast it aside. And, by the way, I will let you make the final judgment.

The tables below list some of the common pros and cons that are tossed about by the competing manufacturer's. You will notice that the pros of one are, more often than not, the cons of the other

Air Filled Motors

Pros: Higher motor efficiency
Better bearing lubrication
Longer life
Easier maintenance
Cons: Poor heat transfer
More frequent maintenance

Oil Filled Motors

Pros: Better heat transfer
Better bearing lubrication
Longer life
Permanent Lubrication

Cons: Lower efficiency
Environmental hazard
More difficult to maintain

Efficiency

The efficiency of a three phase induction motor is dependent upon the quality of its materials, how well they are assembled, and the design of the rotor / stator assembly. If we were to look at the published efficiencies of three phase, horizontal T-Frame motors produced by various main stream manufacturers, we would find that they vary by no more than a few tenths of a percent. Also, we would find that larger motors are more efficient that smaller ones. Typical efficiencies for T-Frame motors range from about 84% - 90% for motors under 10HP and increase to 96% as horsepower approaches 200. Single phase motors are much less efficient and tend to lag three phase units by 7% - 15%.

Submersible sewage pump motors are similar in design to T-Frame motors but tend to utilize a more elongated stator in order to reduce the motor's overall diameter. This design trade off results in a lower maximum efficiency when compared with a T-Frame motor of the same horsepower and speed. This efficiency reduction is especially evident in submersible turbine pump motors where their diameter must be greatly reduced in order to allow installation in a narrow well casing.

Oil filled motors are often accused of being less efficient because of a purported increase in the clearance between the stator and rotor. This increase, which is presumably required to accommodate the oil, is said to reduce the stator's ability to induce a charge on the rotor. Although this may be the case in some models, all of the oil filled motors, with which I am familiar, utilize the same rotor / stator clearance as air filled models. What does reduce an oil filled motor's efficiency is the energy loss due to oil circulation within the stator housing. As a rule of thumb, this circulation requirement reduces efficiency by about 1.5% when compared to an air filled motor.

Although 1.5% may sound significant, we have to remember that motor efficiency is not our only concern. Pump efficiency is an equally important factor and, typically, pumps are not nearly as efficient as motors. In fact the efficiency of the total machine (pump and motor), known as *wire to water efficiency*, is the product of the two individual efficiencies. For example, when a pump with a hydraulic efficiency of 70% is connected to a motor that is 90% efficient, the efficiency of the entire machine is only 63%. If motor efficiency is reduced to 88.5% the total efficiency drops just 1% to 62% - - so efficiency does not appear to be a major issue.

Heat Transfer

In an ODP motor, heat transfer is accomplished through conduction. Although some conduction occurs via direct contact of the stator laminations with the stator housing, the majority is due to air flowing around and through the stator. Normally we think of convection as the heat transfer agent when a fluid such as air is involved but, if that fluid is flowing the physics changes and the result, although complex, is a combination of both conduction and convection.

In a TENV motor, the spinning rotor causes air movement within the stator housing and both conduction and convection are involved. In this case most of the conduction occurs through stator / housing contact, but some is also due to moving air contacting the motor housing. The major difference, as compared to the ODP motor, is that there is a finite amount of air within the motor and therefore, its ability to transfer heat to the housing is limited.[2] Once heat is transferred to the motor housing, it is removed by forced air or a water jacket.

Air filled submersible pump motors cool themselves in exactly the same way as the TENV motor. They do have a distinct advantage in that water is in direct contact with the motor housing and conducts heat more rapidly than does the air provided by a fan or even an external water jacket. But, if it is operating unsubmerged that advantage disappears.

The oil filled motor also cools itself primarily through stator / housing conduction, however, it does have an additional advantage. The circulating oil

[2] This limited air volume can also contribute to hot spots in the stator windings of the TENV motor that can reduce stator life.

with its greater heat capacity and thermal conductivity transfers more heat, more quickly to the motor housing than does air.[3] For this reason, oil filled motors tend to operate at somewhat lower temperature than do air filled models. Oil filled motors also reduce the possibility of winding hot spots by providing a more even heat distribution. This is a particular advantage when Class B winding insulation is employed. For example, even a small increase in operating temperature from 100°C to 110°C reduces the projected life of Class B insulation from 140,000 to 80,000 hours.[4] With Class H insulation this advantage is less significant at operating temperatures below 120°C.

Another factor that affects operating temperature is the stator mounting method. If the stator is pressed into the motor housing the metal to metal surface area contact becomes greater when compared to a non-pressed (bolted) stator. The result is better conductive heat transfer and, this is the reason non-submersible, T-Frame motors utilize pressed in stators. But, there is also a significant advantage to the bolted stator - - it is easier to remove and replace and therefore reduces the cost of maintenance. When a submersible motor is filled with oil, the conductive differences between the two stator installation methods becomes moot because the oil's greater thermal conductivity increases the heat transfer between the stator and the housing.

Both oil and air filled motors can operate in an unsubmerged environment. Although oil filled motors transfer heat more rapidly to the motor housing than do air filled models, how long either can operate depends more upon the mass of the motor than it does with the fill fluid. After all, one could easily design a TENV motor of almost any horsepower that can cool itself without outside intervention if the size of the motor and its cost were not a concern. For example, if one were to construct a 2 HP submersible motor on a 10 HP frame, it could run unsubmerged indefinitely. Its sheer mass and surface area would provide the necessary cooling. Unfortunately, one does not often have that luxury when designing a submersible sewage pump. Therefore supplemental cooling is usually required. In some instances diversion of a portion of the pumpage so that it flows over the motor body is sufficient. In other cases, a cooling jacket and an external liquid source is required.

[3] Conductivity @ 200°F Air k=0.0181 Shellflex 210 Oil k= 0.0741 [4] Per IEEE 117 & 101

Lubrication

Depending upon the application, a motor's bearings must support both axial (back & forth) and radial (sideways) forces. For example, when a T-Frame motor is flex coupled to a base mounted centrifugal pump, the motor's bearings will see radial forces generated by the spinning rotor and the torque generated by the pump. They experience very little, if any, axial loading. That same motor in a belt drive application would undergo an additional radial force generated by the tension on the belt.

In the case of close coupled pump motors, where the impeller is attached directly to the motor shaft, these same radial forces exist but are joined by axial forces. The axial forces are either backward or forward loads that are generated by the pump and its application environment. Vertical close coupled pumps, like the submersible sewage pump, see an additional axial force in the form of the *hanging* weight of the rotor/impeller assembly.[5]

Roller and ball bearings belong to a somewhat *misnamed* family known as antifriction bearings.[6] These bearings reduce friction and wear by utilizing a thin film of oil or grease to separate the balls or rollers from their inner and outer races. The sole purpose of this lubricating film is to reduce metal to metal contact. Theoretically, this film could be only a single molecule thick and still meet its objective.

Although there are ongoing debates over which form of lubrication, oil or grease, provides superior protection, it appears that both perform equally well in most applications. Under conditions of extremely high heat grease is preferred, while oil is the choice in unusually high thrust applications. Since the submersible sewage pump motor typically sees neither of these extremes, either should suffice.

The air filled motor's bearings are usually grease lubricated. An exception is the high thrust vertical hollowshaft motor where the lower bearing resides

[5] An extreme example of an axial force due to hanging weight is the lineshaft turbine. Its motor bearings not only carry the weight of the rotor and impeller(s) but also the weight of hundreds of feet of shafting.

[6] Antifriction is usually defined as *without friction* which we know cannot be true. From the physics viewpoint, antifriction is defined as *against or opposed* to friction. Since friction is a true force, antifriction implies that the bearing must produce some force to oppose and neutralize it. This is also an improbability at best!

in an oil chamber. Smaller air filled motors usually incorporate *sealed* bearings. This type of bearing is greased for *life*, where life is defined as a certain number of hours under certain conditions. Medium and larger motors use regreaseable bearings. Oil filled motors, on the other hand, rely upon their dielectric oil for lubrication. As long as the proper grade of lubricant is used and the manufacturer's instructions are followed, both lubrication methods will perform satisfactorily.

One precaution, however, is advised. Over greasing of the bearings of air filled motors, especially those with external grease fittings, must be avoided. Grease can damage the stator winding insulation and create hot spots by limiting heat transfer.

Maintenance and Serviceability

Most of the normal maintenance a submersible sewage pump receives tends to be the same regardless of its fluid fill. Replacement of the power cord, control cords, impeller, wear ring, and seals are very similar regardless of the design. One area that can differ is relubrication. The oil filled motor does not require relubrication as long as an inspection of the oil verifies that it is has not been contaminated by water or degraded by excessive heating. The air filled motor does require regreasing, but if is fitted with external grease fittings this can usually be accomplished during normal maintenance inspections. If external fittings are not supplied, the motor must be disassembled for regreasing.

Although bearings are more reliable than ever and Class H insulation is prolonging stator life, there will come a time when a motor must be disassembled. With the oil filled motor, an extra step is required. The oil must be drained and disposed of properly. If it was not damaged by excessive heat (motor overload etc) it can be filtered and reused in seal chambers or other *white* oil applications. Once the oil is removed; stator, rotor, and bearing replacement proceed in the same manner as air filled motors.

Pressed in stators, whether they reside in air or oil filled motors, require that the stator housing be heated for removal and replacement. For this reason, manufacturers of pressed stator motors offer replacement stators preinstalled in the stator housing. Although the stator can be rewound, the cost is often a wash. For this reason they are often replaced. Bolted stators are less costly to rewind due to the reduced labor required for removal and reinstallation.

Environmental Concerns

Finally, one of the concerns that is sometimes raised about oil filled motors is the potential for the oil to enter the environment. Although modern dielectric oils do not contain environmentally hazardous chemicals and are not considered hazardous waste by the EPA, they are not readily biodegradable.[7] Therefore, it is important to minimize the introduction of any lubricant into our wastewater systems.

Catastrophic failures involving loss of oil from oil filled, double sealed pumps are rare in monitored pump stations. Because of the very different operating environments of the inner and outer seals, it is statistically improbable that the inner seal will fail before the outer one. The vast majority of the oil resides within the stator housing. The amount that resides in the seal chamber is small and, in the event of an outer seal failure, a seal leak probe located in the seal chamber detects the presence of water and produces an alarm condition. This allows replacement of the outer seal long before the possibility of an inner seal failure.

Most air filled motors also utilize a leak probe in the seal chamber to detect an outer seal failure. Some, however, locate the probe in the motor chamber - - a design that can compromise the stator windings if both the outer and inner seals fail.

SUMMARY

Well, there you have it -- a comparison of the pros and cons and, in a format I believe to be reasonably accurate and unbiased. There are, without question, several differences but are these differences really advantages or disadvantages? Below is a summary of each.

[7] The same dielectric oil used in submersible sewage pumps is also used in oil filled submersible turbine pump motors in the domestic water industry.

1) There is a small difference in air and oil filled motor efficiency but it has little effect on the overall efficiency of the system.

2) The oil filled motor does run cooler and distributes heat more evenly, but class H insulation may make heat transfer less important at temperatures under 120°C. In bolted stator designs oil also increases conductive heat transfer.

3) Oil filled motors may also have an advantage in unsubmerged applications where a water jacket is not used but it disappears when one is installed.

4) Bearing lubrication does not seem to be an issue if the manufacturer's instructions are followed, but care must be exercised when regreasing air filled motors via external grease fittings. Oil filled motors usually do not require relubrication.

5) Although oil must be drained from an oil filled motor prior to its disassembly, most of the normal maintenance procedures are similar for both designs. One disadvantage is found in air filled motors without external grease fittings. They must be disassembled for regreasing.

6) Although dielectric oil is not a hazardous material, it is not readily biodegradable and should not be introduced into the environment. Dual seals with a internal leak sensor located in the seal chamber will prevent oil leakage from the motor housing.