Comparison of Totally Enclosed Motor Coolers For Severe Environment Service in the COG Industry

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Abstract – **As the size of motors being manufactured increases, the issue of motor cooling becomes more and more critical. The high ambient temperature and the severe corrosive environment of many locations in the Chemical, Oil & Gas (COG) industry, in addition to the scarcity of pure water, make this selection a complex one. This paper evaluates the differences between the two most common Totally Enclosed motor constructions, the Air-to-Air and Air-to-Water. A comparison between the two in terms of size, weight, efficiency and cost are analyzed in an effort to assist in selecting the most appropriate construction for future installations.**

Index Terms – **Air-to-air, (TEAAC), Air-to-Water, (TEWAC), Totally enclosed, Coolers.**

I. INTRODUCTION

Motors, the drive-horse of modern industry, are one of the most critical pieces of equipment in the facility. With improvements in technology in addition to process demands and requirements, electric motors are becoming larger and larger. One such motor is a 55 MW, built in 2002 for an oil facility in South Africa.

As the size of these motors increase, the method of cooling the internal active parts becomes more critical. Currently, both IEC 60034-6 and NEMA MG 1 have adopted the same International Cooling method designation (IC Code) identifying the motor cooling arrangement. The IC code letters and numbers specify the primary and secondary cooling circuit medium (coolant) and method of coolant movement[1, 2].

II. THE TYPES OF COOLERS

Motors built to the referenced IC codes could either be open, or totally enclosed. For the severe corrosive environment, commonly the case for the Oil & Gas industry, totally enclosed motors are mandated. This requirement is based on two factors, the first being that most in-plant locations are designated as classified Zone-2 locations, while the second is due to the environment conditions from humidity to dust and wind-blown sand. Heat exchangers with such totally enclosed motors are most commonly Air-to-Air (TEAAC) or Water-to-Air (TEWAC), as still portrayed in API STD 546[3].

Pipe ventilated construction is a less common solution. Such constructions are applicable to large synchronous and induction motors, where the IC Code circuit arrangement designation identifies the primary cooling medium as being closed-loop, with a heat exchanger attached to the motor.

The two common cooler constructions are:

1. Air to Air coolers: The construction of such coolers has a heat exchanger attached to the motor, where the primary coolant and the secondary coolant are both air. The internal air-flow is usually self-circulating, while the secondary air-flow can either be self-circulating (shaft-mounted fan) or by means of an independent component (electric-driven fans). The basic operation of a TEAAC construction can be shown in Fig. 1. The sketch is clear in showing how the heat exchange is performed, in which the cold (external) air is pushed through tubes across the length of the motor. The internal cooling air circulates between the motor active parts and the heat exchanger, continuously.

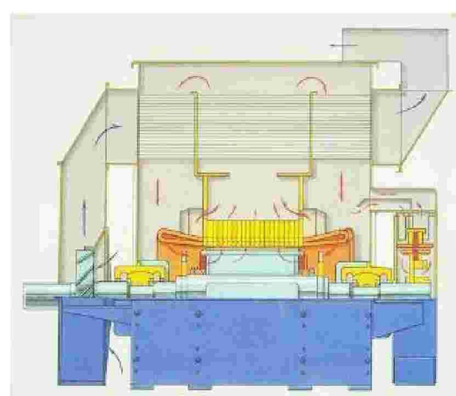


Figure 1. TEAAC operation.

2. Air to Water coolers: The construction of such coolers has a heat exchanger attached to the motor, similar to that of a TEAAC motor. In this construction, the primary coolant is air while the secondary coolant is water. The internal air-flow is also self-circulating, and the secondary water-flow will most commonly be controlled and pressurized via an independent component or system. The basic operation of a TEWAC construction is clear in Fig. 2. In this sketch, the water is circulated via a separate system not shown in this Figure, while the cooling (internal) air is circulated between the motor active parts and the heat exchanger. It is also shown that the air flows from both sides of the motor, and then rises from within the cooling openings in the core, to the exchanger. Also indicated is the path of cooling air flowing to the synchronous motor exciter.

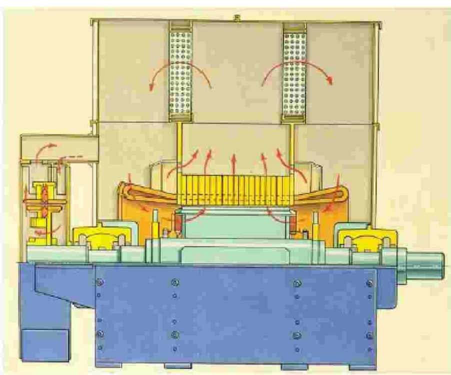


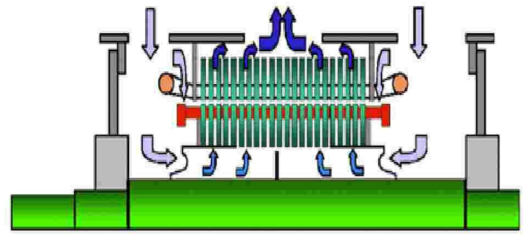
Figure 2. TEWAC operation.

Motor construction will be in such a way to allow air flow within the active parts of the motor, known as being through ventilated. This air-flow within the motor frame can either be symmetric or asymmetric. This designation identifies if the internal air circulation flows evenly from both sides of the motor and returns to the exchanger from the middle, or if it begins from one side and exits from the other end, as illustrated in Fig. 3 (a) and (b) respectively. The basic difference is the even cooling of the active parts in the symmetric cooling construction, while the asymmetric construction will result in slight temperature differences between the opposite sides of the stator and rotor.

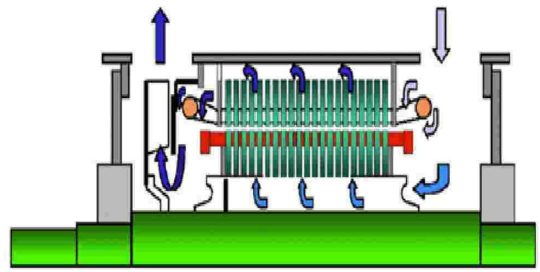
III. COOLER SPECIFICS

Cooler Construction:

The internal air-flow is very similar in both the TEAAC and TEWAC construction. The difference



a) Symmetric



b) Asymmetric

Figure 3. Through ventilated air-flow.

is in the secondary coolant. In the case of the TEAAC, the secondary air-flow can be directed either by a large shaft-mounted fan or a set of electrically driven fan motors. The choice between the two options is size dependent, where it is not feasible to use electrical fans on smaller motors, while a single large shaft-mounted fan becomes extremely inefficient on larger motors. Additionally, the shaft-mounted fans induce much more noise, which becomes difficult to attenuate using common sound dampening techniques, especially for low noise pressure requirements such as 85 dBA. Therefore, there is no clear cutoff point.

Furthermore, in multiple TEAAC motor installations, where several motors are placed side by side, it is important to insure that the inlet air to one cooler is not in the exhaust path of another. If not identified and resolved early, the motor in question would be exposed to a much higher ambient than designed for.

TEWAC motors will have a secondary circulation system, which will either be closed or open. The closed loop will consist of water circulating between the motor heat exchanger and a chiller, as the water flow and pressure will be controlled via pumps installed in between. On the other hand, an open loop construction will consume water from an endless supply, whether sweet-water from a lake, or seawater. The type of water will definitely have an effect on the cooler construction, where the following options can be taken into consideration:

- Tube material, depending on cooling-water quality, can be selected to best match the environment. The most common material used is copper or stainless steel, while titanium is used for the most severe and corrosive environments.
- In case of tube corrosion, the following water leakage solutions are possible:
    - Leakage detectors would detect water droplets and alarm, informing plant personnel of a potential failure, providing ample time to plan for the cooler repair.
    - Humidity detectors would sense smaller leeks that evaporate prior to contact with the leakage detection trays. These devices monitor the humidity inside the motor indicating a cooler leakage and highlighting a potential risk to the motor coils due to humidity.
    - Double tubes are an option for critical operation, when a motor shutdown is not possible for tube repair. The disadvantage with double-tubes is the lower efficiency in cooling associated with having a gap between the two tubes, reducing the cooling coefficient, as shown in Fig. 4.

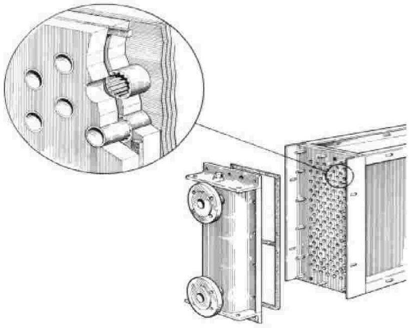


Figure 4. Sketch of a double tube (Property of Coiltech).

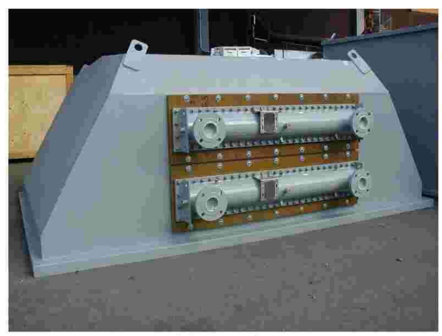
Cooler Redundancy:

Increasing the number of required tubes by 5% to 10% to allow for some tube fouling and blockage, in a TEAAC motor, is one way to extend the time required for maintenance. Actual redundancy can also be achieved by increasing the number of electric fans used in conjunction with TEAAC motors. Redundancy in such a case can be either 100%, where two motors are connected and only one is required, or 50% redundancy, where two fan motors are required while three are installed, as indicated in Fig. 5.

(a) *100% (2 fans)*

(b) *50% (3 fans)*

Figure 5. Cooler fan redundancy.



(a) *2-element*

(b) *4-element*

Figure 6. Water-cooled with 100% redundancy.

In the case of TEWAC coolers, in addition to the option of installing double tubes to increase reliability, 100% redundancy can be achieved. For relatively smaller motors, where only one water-cooling element is required, a second one can be installed, allowing the first to be withdrawn and repaired without any main motor shutdown. Similarly, when two water-cooling elements are required, such as the example of Fig. 2, then two additional elements would also be installed. Both examples are illustrated in Fig. 6.

Additionally, API specifies a Fouling Factor calculation method when designing the water cooler, which is to consider a factor of 0.35 m^2-K/kW[3].

IV. COOLING EFFICIENCY

In comparing the efficiency of the water cooled to the air cooled motor, one must observe the temperature rise of the internal cold circulating air. In the case of water cooled, based on manufacturer experience from studies and actual designs, the air temperature drop is approximately two times that of an air cooled machine, when comparing the same temperature of external air and water. This additional temperature drop allows for a better utilization of an identical machine, by increasing its output power capabilities.

As an example, the largest TEAAC motors built by ABB are the 29,000 HP motors supplied to Saudi Aramco, shown in Fig. 7. Adding to this is the fact that the ambient is considered to be 50 °C, which resulted in a huge air-to-air cooler. Normally, motors of this size would be water cooled due to the cooling water temperature and the higher efficiency of the water coolers.

Furthermore, when using TEAAC motors, as mentioned earlier, there is an option to use shaft mounted or auxiliary cooling fans. Auxiliary cooling fans moving the external cooling air use approximately 60% less energy than shaft-mounted fans, based on actual consumption evaluation, which has a major effect on overall efficiency.

V. SIZE AND COST COMPARISON

A comparison of the benefits associated with each of the two constructions would require a detailed analysis. The cooler dependence on inlet cooling air/water, as well as the heat exchanger temperature drop inside the motor, has a major effect on the cooler size and cost. Therefore, a comparison analysis makes this point clear.

(a) Complete Motor

(b) Cooler only

Figure 7. 29,000 HP TEWAAC Motor.

To conduct an accurate comparison, actual environment conditions would produce a more realistic conclusion. Therefore, the value used for the maximum ambient temperature of the Persian (Arabian) Gulf region, being 50 °C. Similarly, for the TEWAC cooler, the comparison is also based on the water quality of the Gulf. The water analysis, in which the cooler material and design will be based, is as shown in Table 1.

Table 1. Gulf Water Analysis

Item	Level
Water temp. (max)	40 °C
Bicarbonate	304 mg/L
Calcium	573 mg/L
Chloride	27,268 mg/L
Conductivity	55,010 micromhos
Magnesium	1,573 mg/L
PH	8.1
Sodium	13,213 mg/L
Sp Gravity	1.0326
Sulfate	4,220 mg/L
Dissolved solids	49,666 mg/L (TDS)

Table 2. TEAAC and TEWAC 10 MW Motors Comparison

Cooler Construction	Cost (%)		Weight (kg)	Shaft Height (mm)	Efficiency (%)
	Motor	Cooler			
Air-to-Air					
With auxilary fans	85	15	35,000	900	97.80
Air-to-Water					
Open-loop Single tubes (Titanium) 100% Redundancy	78	18	23,000	800	97.98
Open-loop Double tubes (CuNi/Cu) 100% Redundancy	78	5	23,000	800	97.98

Based on an analysis of the above water quality, it was confirmed that copper-nickel tubes may be used. Consequently, the comparison will consist of both single-tube titanium coolers, as well as a double-tube copper-nickel construction, where both are designated for critical operation motors.

Table 2 summarizes the comparison results between a TEAAC and TEWAC 10 MW motor. As indicated previously, air-cooled motors of this capacity are normally cooled via auxiliary cooling fans, thus the shaft-mounted option is not included in the comparison. Furthermore, auxiliary fans (for air-cooled), pumps (for open-loop water cooled or closed loop with an existing chiller), and motor controllers are not included in the cost analysis. This is due to the fact that all will have the same cost increment, except for a closed-loop water-cooled system, which requires a dedicated chiller. Therefore, the option of having a dedicated chiller is not feasible and will not be evaluated. On the other hand, if a sweet-water cooling system is available in the facility, then it would be advantageous to evaluate the cost reduction associated with using standard tubes in the water cooler.

VI. CONCLUSION

Table 2 summarized the comparison between the two different types of motor coolers discussed in this paper. In general, if the source of cooling water is readily available, then the following advantages will be realized for the TEWAC motors:

- A reduction in cost is achieved as a result of the reduction in motor size (shaft height) needed, as well as the size of the cooler construction. If Copper-Nickel tubes are used, the cost avoidance would be approximately 17%, while the savings are only 4% if Titanium tubes were specified.
- Higher efficiency for the water cooled machine, which would manage a 0.18% increase in the overall efficiency.
- Reduction in the total weight for the same output motor, less by 34%. This is specifically critical for offshore installations.
- The improvement in efficiency and reduction in motor frame size are associated with the improvement in cooling medium temperature. This is basically related to the cooling air inlet temperature as apposed to that of the water.

If a water supply is not available within close proximity, additional water pumps are necessary, or a dedicated closed loop system. In such a case, the comparison won't be so attractive for the water cooler assembly.

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