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Cooling of Lubrication System in Aircraft Engines Using Peltier's Principle

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Abstract

The increased complexity of the aircraft engines has added to the need of better lubrication system. Jet engine require better lubrication to reduce the friction. Better lubrication demand better cooling, pumping and better grade oil. cooling is the heart of the lubrication system. Temperature is one of the parameters that largely decides the properties of the oil. The temperature of the oil increases after the lubrication of engine parts. It is very much necessary to cool the oil to maintain the properties of the oil. There is a need of better cooling system to maintain an optimum temperature. Increase in temperature would result in failure of the bearing and other components. So, the engine oil should have all the properties to meet the requirement and its property should be withstood throughout the operation. Normal conventional cooling method would not meet the increasing requirement hence there is a need for better system. This paper introduces a new and efficient way of cooling using Peltier's principle. This is done by introducing Peltier's cells in cooling system.

Keywords

Peltier effect, Peltier cell, thermoelectric cooler, seebeck's effect, oil cooler, lubrication.

1. Introduction

The need for performance and efficiency of aircraft engines in the present world has led to increase in need for better auxiliary systems. Due to the increase in the size of the engines, there is a need for better lubrication system hence better cooling system. The bearing of the turbines would get heated to very high temperature. The major lose is due to friction caused due to rubbing of mating parts. All the losses would add up to the decrease in the efficiency of the engine, therefore Friction plays a major role in reducing the efficiency. Hence it is very important to reduce the friction between the rubbing parts increasing the mechanical efficiency. The primary purpose of any lubricant is to reduce friction caused by metal-to-metal contact. This is done by lubricating oil providing a film that permits surfaces to glide over one another with less friction. Therefore, lubrication is essential to prevent wear in mechanical devices where surfaces rub together. There are many steps taken to control the loses due to friction like improving the design parameter related to bearing and other movable parts, increase in cooling, better lubrication etc.

Oil systems used in jet engines are relatively simple in design and operation, but their function is important. The principal purposes of the oil system are to provide an adequate supply of clean oil to bearings and gears at the right pressure and temperature, to remove heat from the engine, and to remove contaminants from the system and deposit them in the filters. The ability of the oil to lubricate correctly depends upon its temperature and pressure. If the oil is too hot, it will not have enough viscosity. If it is too cold, the oil will resist movement between the parts and flow too slowly for proper lubrication. If the oil pressure is too low, not enough oil will be supplied to the bearing for proper cooling. If the pressure is too high, it may cause high-speed antifriction bearings to skid and not roll properly. The cooling system should be capable of meeting the cooling requirement hence reducing the temperature of critical parts like bearing etc. The oils used for turbine engines are required to operate over a wide range of temperatures. Temperatures from minus 40°C to more than 250°C for maximum bearing temperatures are possible. It is very difficult to meet all these requirements with conventional cooling. This can be easily met by implementing thermoelectric coolers. Present cooling system of lubrication system involves cooling using flow of air and air fuel cooling.

Peltier's cooling principle is the reverse of Seebeck's affect. When voltage is applied across different metal joined together, temperature gradient is created across the junction [1]. This results in one surface getting heated and the other getting cooled. This can be used to both cool the oil and preheat the fuel.

Generally low viscosity synthetic lubricants and no mineral oils are used in turbine engines because synthetic oils retain their lubricating properties and are more resistant to oxidation at high temperatures. These oils also have better characteristics concerning thermal stability and the viscosity. Thermal Stability is an important property of the oil that effects lubrication. The term thermal stability describes the resistance of the oil to decompose into oil compounds at high temperatures. The oil molecules are made of several individual compounds. At high temperatures, these molecules can break apart and the chemical composition and the lubrication capability of the oil changes. This decomposition usually occurs at very high temperatures, well above the normal operating temperatures of the engine oil.

2. Cooling of lubrication system

Lubricating oil must cool moving parts by carrying heat away from gears and bearings. This is an important function considering the many parts located next to burners or turbine wheels, where temperatures are over 1700 degrees Fahrenheit (F). Liquid lubricants cool by pumping or spraying oil on or around bearings or gears. The oil absorbs the heat and later dissipates it through oil coolers [2,3].

The contamination of oil by engine fuel can result from a ruptured fuel-oil cooler. Because the fuel system operates at a higher pressure than the lube system, the flow will be into the oil supply. The presence of fuel in the oil will cause oil dilution. It also changes the oil properties so the oil cannot cool and lubricate the bearings properly.

3. Oil Coolers

During the lubrication process heat is transferred from the engine components to the oil. It must be subsequently removed from the oil to keep the oil temperature within the set limits. This requires an oil cooler in the system. These coolers keep the temperature of the oil within the proper range.

4. Types of Oil Cooler

4.1 Air-Oil Cooler

The air-oil type cooler is installed at the entry end of the engine as an integral part of the engine (see figure 1).

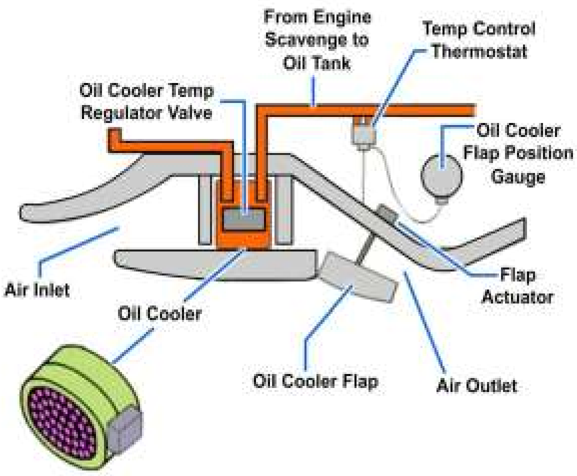


Figure 1. Air cooler.

This type of cooler is usually an aircraft part conforming to the inlet duct design of the airframe. This cooler is made of rectangular-sectioned aluminum tubing, spirally wound between two end flanges and formed, by welding, into a cylinder. Two bosses, located on the horizontal center plane, are provided for oil inlet and outlet connections. This type of cooler acts as an inlet air duct; therefore, a cooling effect occurs when the engine is operating. The cooling capacity of each of the oil cooler assemblies depends upon the amount of air allowed to pass through the cooler. Some aircraft use a controllable oil cooler door, which restricts the opening of the oil cooler exit duct to control the air intake.

4.2 Fuel-Oil Coolers

The fuel-oil cooler or heat exchanger shown in Figure 2 cools the hot oil and preheats the fuel for combustion. Fuel flow to the engine must pass through the heat exchanger. However, a thermostatic valve controls the oil flow, so the oil may bypass the cooler if no cooling is needed. The fuel-oil heat exchanger consists of a series of joined tubes with an inlet (see Figure 2) and an outlet port. The oil enters the inlet port, flows around the fuel tubes, and goes out the oil outlet port.

The heat-exchanger type of cooler has the advantage of allowing the engine to keep its small frontal area. Since the cooler is flat and mounted on the bottom side of the engine, it offers little drag. The fuel-oil heat exchanger is also effective during ground operation and need not be exposed to the airflow. The lubrication systems on some engines use additional air-cooled oil coolers to control the temperatures of oil and fuel during the operation with low fuel flows. This type of cooler is an engine part.

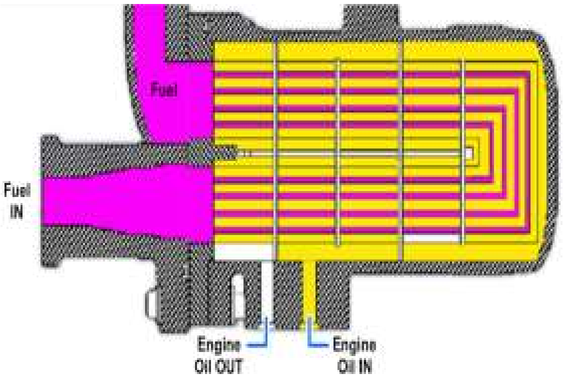


Figure 2. Fuel-oil heat-exchanger type of cooler.

5. Peltier's Effect

The reverse of Seebeck's effect is called as Peltier effect. The Peltier's effect was discovered by the scientist named Jean Charles Athanase Peltier. When potential difference is applied between the two dis-similar conductors, temperature difference is created at the junction. This is called the Peltier Effect. Peltier cells are the Thermoelectric heat pumps that will produce a temperature gradient that is proportional to an applied current. The direction of heat transfer is controlled by the polarity of the applied voltage. Thus, in principle, the same device can be used for heating as well as cooling purpose by reversing voltage polarities. A combination of the semiconductors Bismuth and Telluride is most commonly used for the thermocouples [6]. The semiconductors are heavily doped, which means that additional impurities are added to either create an excess (N-type semiconductor), or a lack (P-type semiconductor) of free electrons. Early thermocouples were metallic, but many more recently developed thermoelectric devices are made from alternating p-type and n-type semiconductor elements connected by metallic interconnects. Charge flows through the n-type element, crosses a metallic interconnect, and passes into the p-type element. If a power source is provided, the thermoelectric device will act as a cooler.

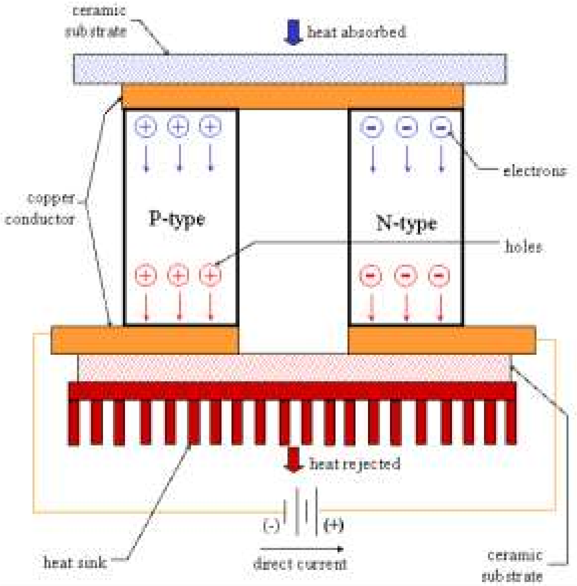


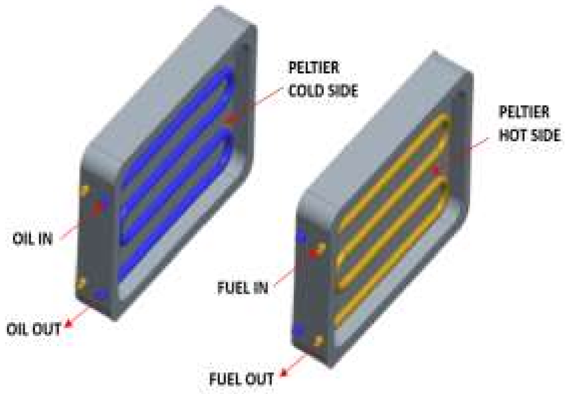
Figure 3. Thermoelectric Cooler (Peltier's module)

As shown in Fig 3. Electrons in the n-type element will move opposite the direction of current and holes in the p-type element will move in the direction of current, both removing heat from one side of the device. Thermoelectric module is also called as Peltier's module.

6. Cooling of oil using thermoelectric module.

The existing oil coolers in aircrafts are not efficient during ground operations. They need air to for the cooling of oil. Cooling of oil may be achieved even in ground operation by adapting thermoelectric oil cooler. It is very efficient since it is very compact in size, works on DC low current and this even has a surface which heats the fuel. In conventional heat-exchanger the heat of the oil is taken by the fuel by preheating the fuel. Here no additional heat or cooling is generated. Here just the heat is exchanged unlike thermoelectric module. In thermoelectric module, additional heating of fuel and cooling of oil takes place. In thermoelectric cooling the oil is cooled to a lower temperature and fuel is preheated to a higher temperature than the conventional cooling [4-5].

The working of the thermoelectric module has been illustrated through CREO design in figure 4. The cooling of oil and preheating of the fuel happens simultaneously [7]. Thermoelectric module is placed at the centre of the shell. One side of the module heats and the other side cools. The desired temperature can be set by controlling the flow of the current. Tubing is placed on both the sides of the module. One for oil and another for the fuel to pass through. Hot oil passes through the blue tubing and gets cooled as it flows through the thermoelectric module and the cooled oil is flushed out for the next cycle of the lubrication. Fuel enters the yellow tubing and gets heated to a certain temperature as it passes through the thermoelectric module and the preheated oil is flushed out of the tube. The cycle continues.



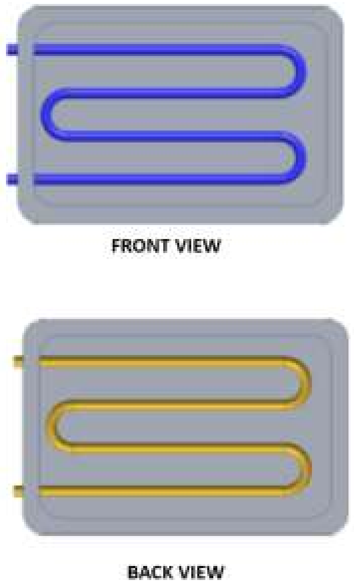


Figure 4. Design of Thermoelectric cooler for lubrication in aircraft engines.

7. Design of Thermoelectric Module

The design of thermoelectric cooling system is slightly different to the conventional cooling system involving compressor, condenser, evaporator etc. as this works completely on different principle. The design of thermoelectric cooling system is comparatively easy when compared to conventional refrigeration cooling system as lesser parts are involved in the system.

Q_{max}, ΔT_{max}, I_{max}, V_{max} are the main parameters for the selection of thermoelectric cooling module [8].

T_h= Hot side temperature

T_c= Cold side temperature

ΔT= T_h-T_c(K)

T_a=Ambient Temperature(K)

I= Current (A)

V= Voltage

Q_c= Heat absorbed at cold surface(W)

Q_p= Power input for TEC (W)

COP= Coefficient of performance Q_c / Q_p

s= Seebeck coefficient (V/K)

ρ= Resistivity (Ωm)

k= Thermal conductivity

Z= Figure of merit, $s^2 / (\rho K)$, $(K\text{-}1)$

G= Area/Length of thermoelectric element (cm)

N= Number of pair of thermoelectric element

S_M= Device Seebeck voltage, $2sN$

R_M= Device electrical resistance, $2\rho N/G$, (Ω)

K_M= Device thermal conductance $2kNG$, (W/K)

I_{max}= Input current resulting in greatest ΔT i.e. $\Delta T_{max.}$ (A)

Q_{max}= Maximum amount of heat that can be absorbed at cold face (occurs at $I=I_{max}$, ΔT=0°C) (W)

ΔT_{max}= Maximum temperature difference a TEC can achieve, occurs at $I=I_{max}$

V_{max}= voltage at $\Delta T=\Delta T_{max}$, (V)

$R_{heatsink}$ = Thermal resistance of heat sink

$(T_h-T_a)/(Q_c+Q_p)$, (K/W)

$R_{hs\text{-}max}$ = Maximum allowable heat sink thermal resistance (K/W)

$$Q_c= 2N \left[s\, I\, T_c - \frac{1}{2} I^2 \frac{\rho}{G} - k\, G\, \Delta T \right] \qquad \text{-(1)}$$

$$V=2N \left[I\frac{\rho}{G}+s\, \Delta T \right] \qquad \text{-(2)}$$

$$Q_p=VI \qquad \text{-(3)}$$

$$Z= s^2/\rho k \qquad \text{-(4)}$$

Define S_M , R_M , K_M

$$S_M = 2sN \qquad \text{-(5)}$$

$$R_M= 2\rho N/G \qquad \text{-(6)}$$

$$K_M= 2NkG \qquad \text{-(7)}$$

Substituting S_M , R_M , K_M in equations (1-4)

We get

$$Q_c= S_M\, T_c\, I - \frac{1}{2} I^2 R_M - k\, G\, \Delta T \qquad \text{-(8)}$$

$$V= S_M\, \Delta T+IR_M \qquad \text{-(9)}$$

$$Z=S^2{}_M /(R_M\, K_M) \qquad \text{-(10)}$$

The parameters s, ρ and k are fundamental physical properties of the TEC materials and S_M , R_M , K_M are the physical characteristics of the TEC as a device. The figure of merit Z is directly related with the ability of a TEC to pump heat and is a criterion to evaluate the quality of the TEC.

Equation (8) reveals that DT varies as the square of current I when Q_c is zero, as shown in equation (11)

$$\Delta T=(1/K_M)\ (S_M\, T_c\, I - \frac{1}{2} I^2 R_M) \qquad \text{-(11)}$$

Differentiating equation (11) with respect to I leads to equation (12)

$$\frac{d\Delta T}{dI}=(1/K_M)\ (S_M\ T_c - \frac{1}{2}\ I\, R_M)=0 \qquad \text{-(12)}$$

Equating equation (12) to zero and solving for I to maximize ΔT leads to equation (13)

$$I=(S_M / R_M)\ T_c \qquad \text{-(13)}$$

Equation (13) is the prerequisite to produce the maximum temperature difference ΔT_{max}, and the current is defined as the maximum current I_{max}. The voltage at this time is defined as the maximum voltage $V_{max.}$ Now, inserting the value of I_{max} from equation (13) into equation (11) results in equation (14) for ΔT_{max}

$$\Delta T_{max}= \frac{1}{2}\, ZT_C{}^2 \qquad \text{-(14)}$$

Replacing ΔT and I with ΔT_{max} and I_{max} in equation (9), an expression for V_{max} can be obtained, as shown in equation (15).

$$V_{max}=S_M\ \Delta T_{max}+I_{max}\, R_M \qquad \text{-(15)}$$

ΔT_{max}, I_{max}, V_{max}, at specific hot side temperature are the performance specification for TEC. Replacing Tc with $(T_h\text{-}\Delta T_{max})$ in equation (13) and (14), equation (16) and equation (17) are obtained.

$$I_{max} = (S_M / R_M)(T_h - \Delta T_{max}) \quad \text{-(16)}$$

$$\Delta T_{max} = \frac{1}{2} Z (T_h - \Delta T_{max})2 \quad \text{-(17)}$$

In addition, Q_{max} occurs also at specific hot side temperature when $I = I_{max}$ and $\Delta T = 0°C$.
Therefore, equation (8) can be reformed as equation (18).

$$Q_{max} = S_M T_c I_{max} - \frac{1}{2} I_{max}^2 R_M \quad \text{-(18)}$$

8. Conclusion

Thermoelectric cooler is the efficient technology to meet the increased cooling requirement in aircraft lubrication system due to their unique features like

- Compact.
- No moving parts.
- This can be used even to preheat the fuel.
- Very efficient even in ground operations.
- The coefficient of performance is independent of capacity.
- The cooling rate is easily controlled.
- Reversible operation is possible allowing heating as well as cooling.
- Vibration-free operation.
- Precise temperature control

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