Experimental Analysis of Heat Transfer on the Tubular Tube Heater with a Variable of Twisted Tape Inserts and Wire Coil to Prevent the Icing Contaminated Tailplane Stall

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Abstract. An anti-icing system has the purpose of protecting the leading edge of the tailplane from contamination during aircraft flight. An anti-icing system in a turboprop aircraft employs heaters that use electrical energy as their power source or heat generated by the bleed air. Protecting the tailplane from contamination is preventing the aircraft stall from occurring that triggers dangerous flight conditions. The aluminum prototype tailplane is assembled with a variable of twisted tape insert and wire coil. The twisted tape insert comes in three different geometries with twist ratio $T_3 = 9.3$; $T_4 = 7$; and $T_5 = 5.6$, as well as a wire coil with fixed geometry. This study shows the best heat transfer rate occurs in $T_3$ with a value of 33.90 W. The consequence of this condition is an increase in pressure drop that occurs. Twisted 3 has the greatest pressure drop when compared to other geometry, with an average value of 4.72 Pa.

1. Introduction
An aircraft is a vehicle in the air that requires stability during flight. The heater on the tailplane is important for this purpose because it prevents icing formation caused by low temperature exposure. Because of the icing effect of changing the shape of the leading edge shape, an icing-forming or contaminated tailplane is dangerous. Airflow around the tailplane becomes turbulent and triggers flow separation to bring the aircraft into a stall condition. Aircraft at supercooled condition up to $-40^\circ$C induced liquid water droplet and formation of ice on leading-edge of the wing that can prevent by the electro-thermal anti-icing[1]. Another technic to prevent the formation of ice is the anti-icing system is the piccolo tube anti-icing is commonly used in commercial aircraft [2]. By adding a heater on the leading edge of the tailplane, icing formation can be prevented. Airflow around the tailplane becomes smooth and prevents separation at a low angle of attack.

The heater is operated by transferring high energy from a source to the air on the tailplane surface, especially on the leading edge of the tailplane. The heater can employ sources from bleed air, exhaust gas, or electrical device to produce heat sources. The tubular tube has a simple geometry that accommodates the purpose of a pipeline that contains fluid at a higher temperature than the surrounding environment for heaters that use bleed air. Due to easy manufacturing, the tubular tube is the best choice as a heater. The problem came from heat transfer tubular tubes have a tendency to low heat transfer. Many methods can be applied to enhance heat transfer, such as adding a flow disturber. The flow was disrupted when any shape such as a twisted insert or wire coil was added to the tubular tube.

Maradiya reported many heat transfer enhancement techniques were developed such as twisted tape insert, helical insert, winglet twisted tape, wire coil insert, perforation, fin, rib and groove, roughness,
duct shape, and nanofluid [3]. This method results in material and cost reduction using in device operational by increasing heat transfer surface or modify flow into the turbulent region. The twisted insert can be applied with one or more as reported in He’s investigation [4]. From the thermal-fluid dynamics viewpoint, more than one twisted insert applied is not favorable due to one twist has a performance efficiency coefficient larger than two twisted inserts. Patil reported that an experimental study of laminar flow inside a square duct resulted in a low heat transfer enhancement due to a change in twist ratio [5].

2. Experimental setup

A twisted plate with dimensions of 420 mm length, 15 mm width, and 0.75 mm thickness. Twist inserted into a wire coil with a diameter 2 mm, pitch 10 mm, and tubular tube with a diameter of 19 mm and 435 mm length as shown in figure 1. In previous research, Patil conducted a small twist ratio of 2.66, 3.55, and 4.01 were connected in series. The larger twist ratio with uniform ratio needed to be evaluated in this research to conduct the heat transfer characteristic at a larger twist ratio in transitional flow. The ratio between length and width (twist ratio) for each geometric is T3 = 9.3; T4 = 7; and T5 = 5.6.

![Wire coil T3 T4 T5](image)

**Figure 1.** Three twisted tape geometries with a wire coil inserted on the outside.

Figure 2 shows a schematic diagram of an apparatus with a tubular tube inserted into a prototype wing made of a 0.75 mm aluminum plate. The wing has a chord of 580 mm, 140 mm thickness, 400 mm width. To prevent leading-edge temperature drop due to cooling by water spray from the nozzle at low temperature, hot air from the heat gun is transferred to a tubular tube as a heater. Water is sprayed on the leading edge to simulate a drop in temperature caused by the wing being exposed to air during flight. Experimental results were obtained by setting the heat gun temperature within the range of 50 °C, 60 °C, 70 °C, 80 °C, 90 °C, 100 °C as inlet temperature for each twisted geometric tested.
Figure 2. Schematic diagram of test apparatus of heat transfer enhancement by using twisted tape insert and wire coil.

3. Experimental calculations

In this study, twisted tape insert and wire coil were investigated using three different twist ratios to evaluated thermal characteristic tubular heater in a turbulent flow region. Thermal characteristics of a heater are determined by Reynold number, Nusselt number, convective heat transfer, heat transfer rate, friction factor, and pressure drop using equation (1-6) below [6]. A dimensionless quality is called Reynolds number to determine the flow regime of the fluid:

\[ Re = \frac{\rho V D}{\mu} \]  \hspace{1cm} (1)

where \( \rho \) is the density, \( V \) is the velocity, \( D \) is the diameter, and \( \mu \) is dynamic viscosity. Dimensionless convection heat transfer coefficient is called Nusselt number for turbulent flow in tube from Dittus-Boelter equation with approach turbulent flow assumption:

\[ Nu = 0.23 Re^{0.8} Pr^{0.4} \]  \hspace{1cm} (2)

where \( Pr \) is Prandtl number. The convective heat transfer coefficient calculated from Nusselt number:

\[ h = \frac{Nu k}{D} \]  \hspace{1cm} (3)

where \( k \) is thermal conductivity of working fluid. Heat transfer rate must be supplied by flowing fluid:

\[ \dot{Q} = \dot{m} Cp \Delta T \]  \hspace{1cm} (4)

where \( \dot{m} \) is mass flow rate of working fluid, \( Cp \) is specific heat of working fluid, and \( \Delta T \) is temperature between different inlet and outlet. Pressure drop is calculated from friction factor below which is valid for \( 2300 < Re < 4500 \):

\[ f = 3.03 \times 10^{-12} Re^3 - 3.67 \times 10^{-8} Re^2 + 1.46 \times 10^{-4} Re - 0.151 \]  \hspace{1cm} (5)

\[ \Delta P = f \frac{L}{D} \rho \frac{V^2}{2} \]  \hspace{1cm} (6)

where \( f \) is friction factor, \( \Delta P \) is pressure drop, and \( L \) is length of tube.
4. Results and discussion

The tubular tube is a simple geometry that can be used for the heater to prevent leading edge icing. Flow inside the tubular tube has the best heat transfer performance while in a turbulent region. To accomplish this, a twisted insert and wire recoil are installed in a tubular tube and tested at various temperatures to determine the Reynolds number. The Reynolds number is an important parameter to determine flow characteristics in heat transfer. Figure 3 shows T3 has the largest Reynolds number compared to T4 and T5. It is beneficial to enhance flow to the turbulent regime by reducing the number of twists from 5 to 3, causing inertia force more dominance than viscous force. Reducing Reynold number due to adding twist number followed by reducing Nusselt number as shown in figure 4. A Nusselt number greater than one indicated that convection rather than conduction dominated flow inside the tubular tube.

![Figure 3](image1.png)

**Figure 3.** Effect twisted insert geometry to Reynolds number.

![Figure 4](image2.png)

**Figure 4.** Effect twisted insert geometry to Nusselt number.

To increase heating on the leading-edge using T3 is a better choice than the other two due to the fact T3 has large heat transfer as shown in figure 5 and follows with convective heat transfer coefficient as shown in figure 6. It is shown that the Reynolds number affects heat transfer rate. Increasing Reynolds number will increase the heat transfer rate from the heater to the leading-edge during use to prevent icing forming.

![Figure 5](image3.png)

**Figure 5.** Effect twisted insert geometry to heat transfer rate.

![Figure 6](image4.png)

**Figure 6.** Effect twisted insert geometry to convective heat transfer coefficient.

The largest friction factor is about 7.1% has a significant effect on fluid flow followed by pressure drop as shown in figure 7-8. It came from a heater that was inserted into the 400 mm wide wing.
prototype in this study. Hot air flows inside the heater for a short period due to short piping for the heater is used. This study compared a heater with and without a wire coil related to Reynolds number and convective heat transfer. Figure 9-10 shown the wire coil affects reducing Reynolds number and convective heat transfer coefficient. Reynolds number and convective heat transfer coefficient for the heater with and without a wire coil to Reynolds number have different tendencies. For the heater with a wire coil, increasing twist ratio results in increasing Reynolds number and convective heat transfer coefficient. For the heater without a wire coil, increasing twist ratio results in decreasing Reynolds number and convective heat transfer coefficient. For that reason, removing a wire coil is the best choice for increasing heat-transfer characteristics in this study.

![Figure 7](#). Effect twisted insert geometry to friction factor.

![Figure 8](#). Effect twisted insert geometry to pressure drop.

![Figure 9](#). Comparison of a heater with and without a wire coil to Reynolds number.

![Figure 10](#). Comparison of a heater with and without a wire coil to convective heat transfer coefficient.

5. Conclusions
The purpose of this study to analyze perform of wire coil as flow disturbed combine twisted insert. Applied wire coil into twisted insert leads to better performance at high twist ratio where T3 has largest Reynolds number and convective heat transfer. T3 has the greatest pressure drop when compared to other geometry, with an average value of 4.72 Pa where its related to Reynolds number of
the combination wire coil and twisted insert. Removing wire coil is more favorable due to increasing twist ratio where T4 has the largest Reynolds number and convective heat transfer in turbulent flow. In transitional flow, increasing twist ratio has pros to heat transfer characteristics, more heat transferred to leading-edge conducted to prevent the formation of ice. Future work to evaluate laminar and fully turbulent flow is needed to study the effect of the combination wire coil and twisted insert.

Nomenclature

- $C_p$: specific heat (J/kg·K)
- $D$: diameter (m)
- $f$: friction factor
- $h$: convective heat transfer coefficient (W/m$^2$·K)
- $L$: length (m)
- $k$: thermal conductivity (W/m·K)
- $Nu$: Nusselt number
- $\dot{m}$: mass flow rate (kg/s)
- $Pr$: Prandtl number
- $\dot{Q}$: heat transfer rate (W)
- $Re$: Reynolds number
- $V$: velocity (m/s)
- $\Delta P$: pressure drop (Pa)
- $\Delta T$: temperature difference (°C)
- $\mu$: dynamic viscosity (kg/m·s)
- $\rho$: density (kg/m$^3$)

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