Temperature rise study on fluid in tube subjected to oil burner

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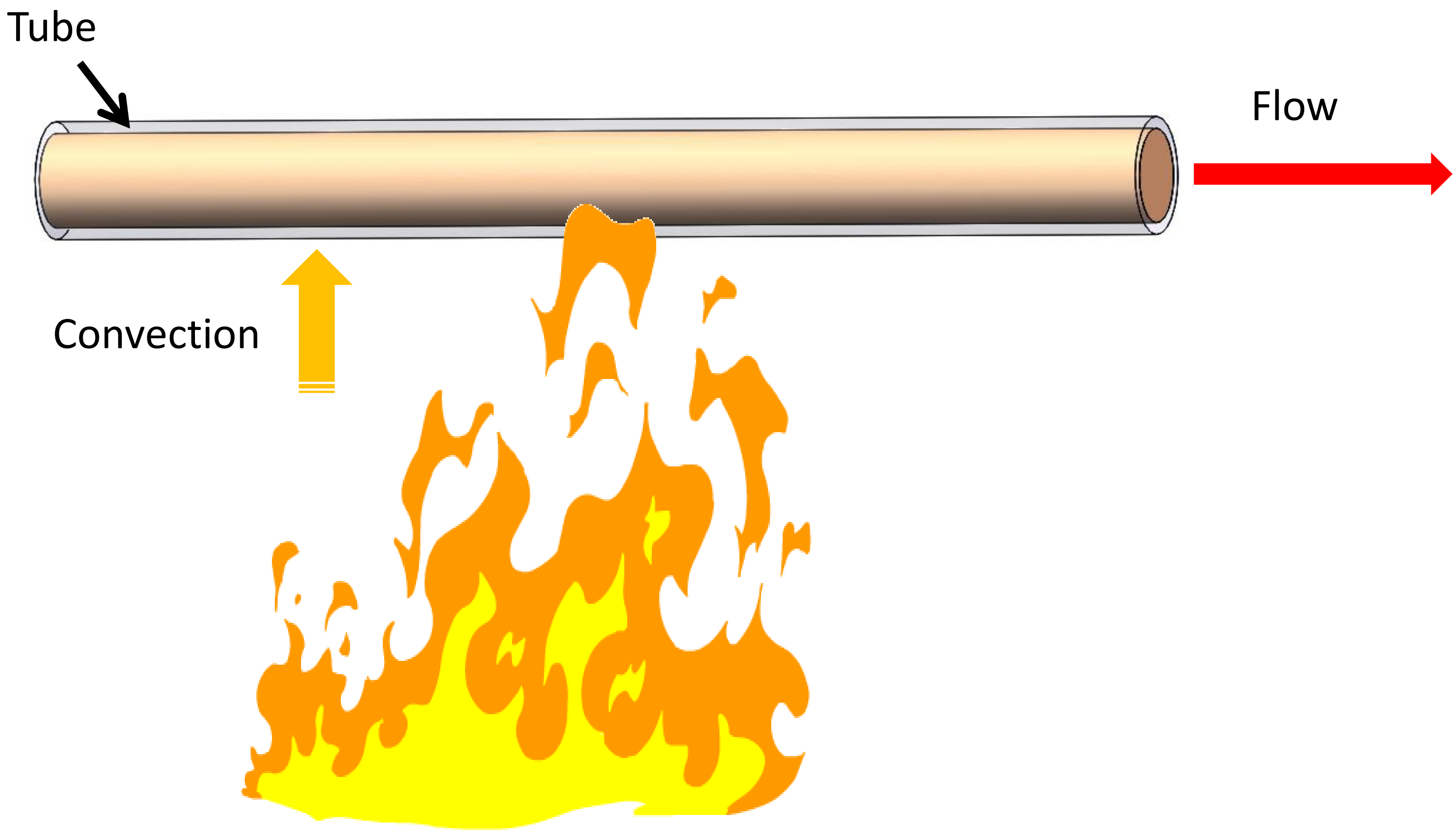
Introduction

- ◆ Tubes & hose assemblies in engine nacelle of an aircraft
- ◆ Distributing fuel, hydraulic oil & lubricant
- ◆ Tested by oil burner

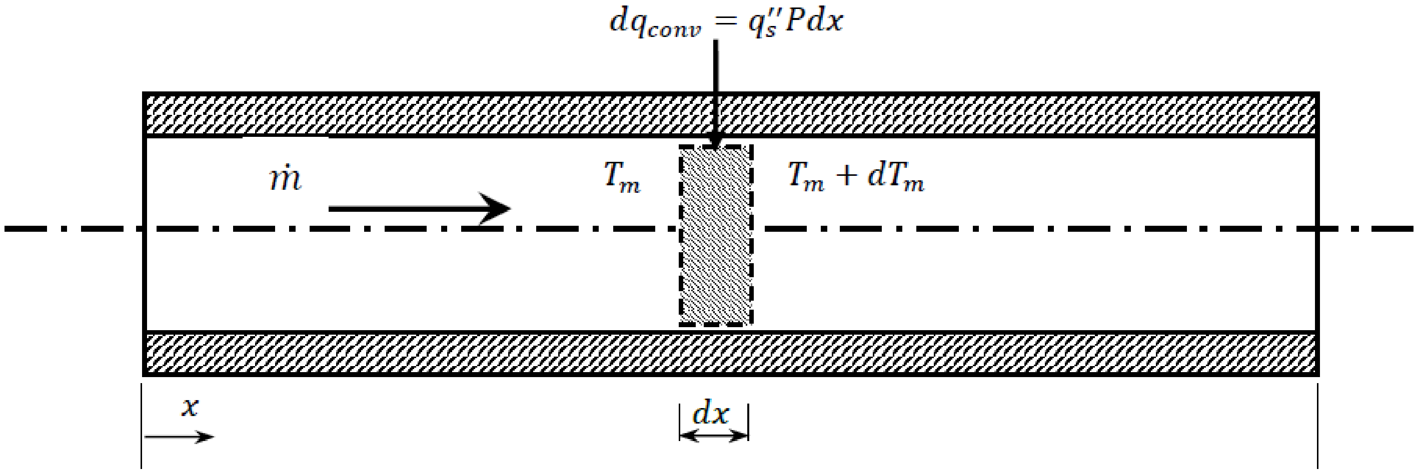
ISO 2685-1998

Aircraft Materials Fire Test Handbook

Heat transfer process



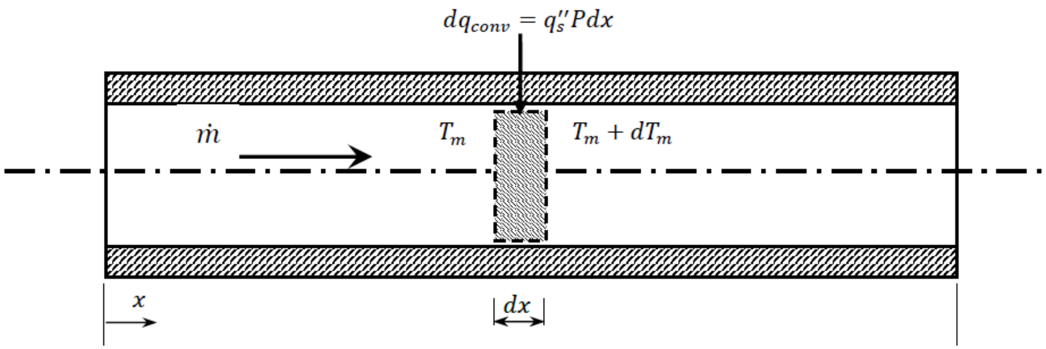
Heat transfer process



$$dq_{conv} = \dot{m}C_p[(T_m + dT_m) - T_m] = q_s'' P dx = q_s'' \pi D dx$$

Assumptions

- The temperature of position x can be represented by average temperature of this cross section, ignoring the radial temperature gradient
- As metallic tube has a relatively low heat capacity and a relatively high heat conductivity, the conventional heat absorbed by oil is approximately equal to total heat transfer of the outer surface, the flame.



$$dT_m = \frac{q_s'' \pi D dx}{\dot{m} C_p}$$

$$\boxed{T_o - T_i = \frac{q_s'' L \pi D}{\dot{m} C_p}}$$

Experiment configuration

- **Hose assembly**

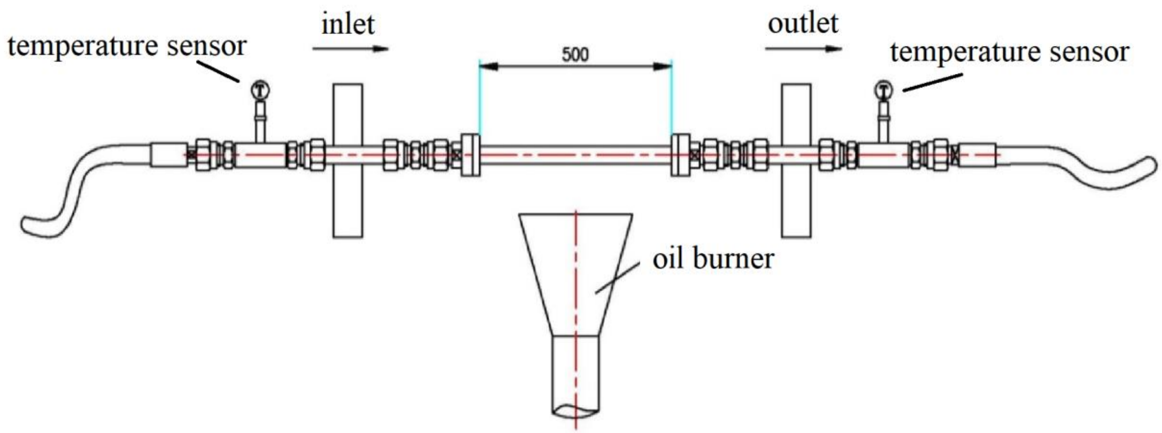
Fuel & lubricant, 12mm I.D., 500mm long stainless steel tube, 50 to 200 L/hr

- **BTU Heat Transfer Device**

Water, 12mm I.D., 380mm long cooper tube, 2.6 to 3.8L/min(156 to 228 L/hr)

Hose assembly

- No.3 Jet Fuel(Jet A-1) and RIPP 4050 are utilized
- Carlin CRD200 burner
- Air velocity: 2300 FPM
- Fuel flow rate: 2.1GPH



Hose assembly

- The flame of the burner is not evenly distributed
- Temperature rise has a linear relationship with heat flux density $\Rightarrow$ $q_s'' \approx \overline{q_s''}$
- Heat flux density of 11 horizontal points with the same distance from the burner tip is measured by Garden Gauge

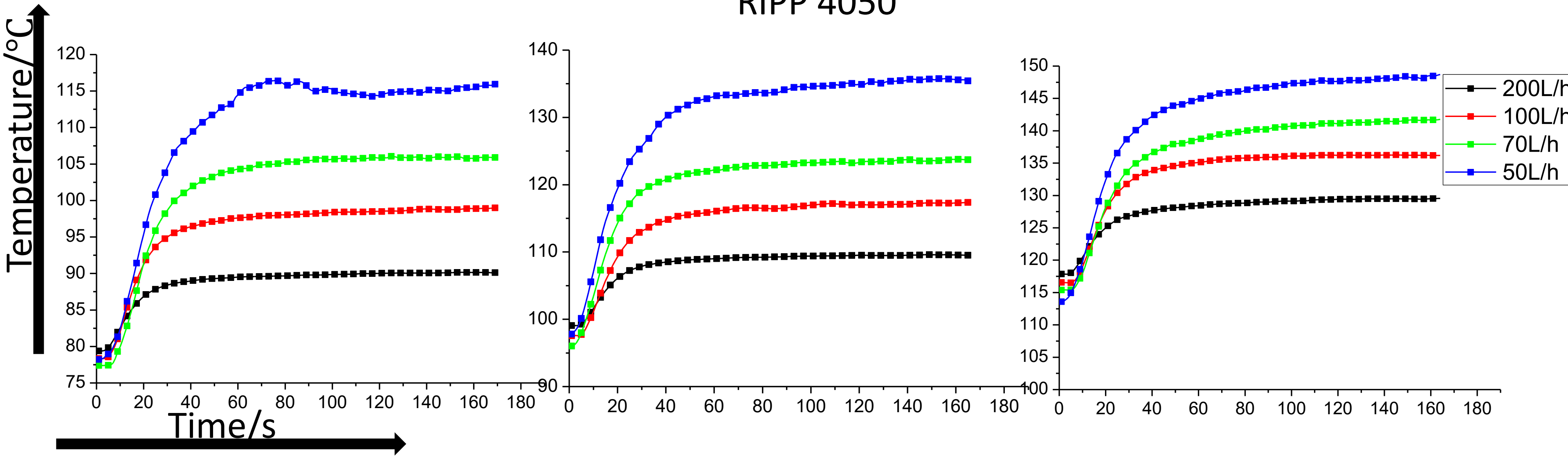
Hose assembly tests

Position[mm]	0	50	100	150	200	250	300	350	400	450	500
Heat flux Density [W/cm²]	2.8	4.7	7.4	8.0	12.0	12.2	10.8	6.0	5.3	2.9	1.7

- The position presents distance from the inlet of the tube.
- The average value $\overline{q_s''}$ is 6.445 W/cm^2.

Test Results

RIPP 4050



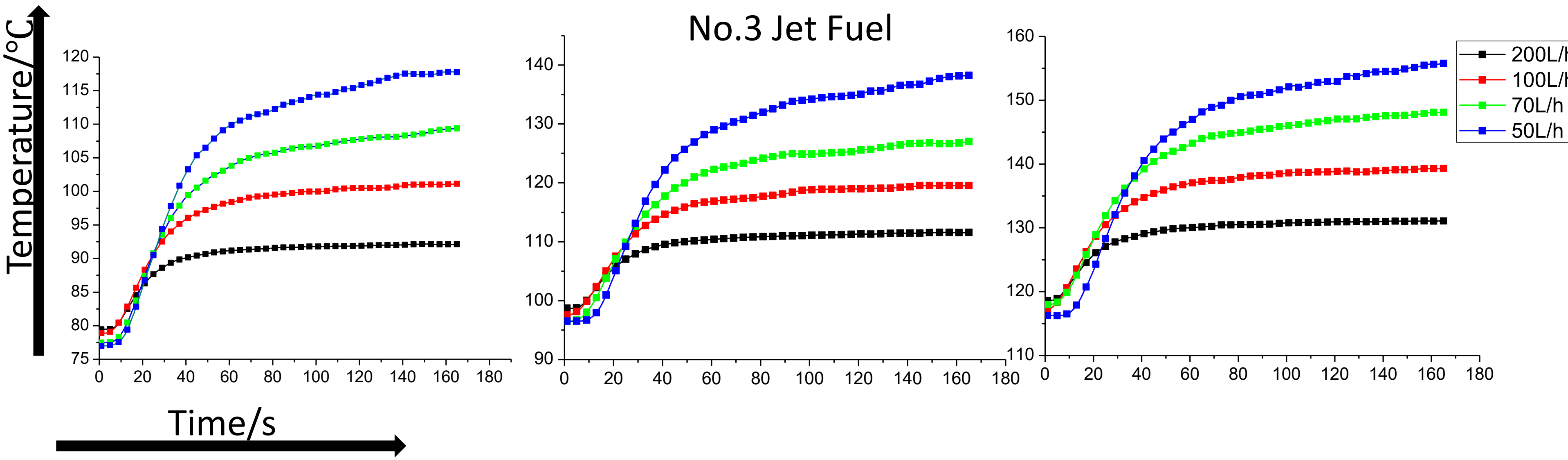
Initial Temperature：80°C

100°C

120°C

Higher fluid flow rate refers to smaller temperature rise

Test Results



Initial Temperature： 80°C　　　100°C　　　120°C

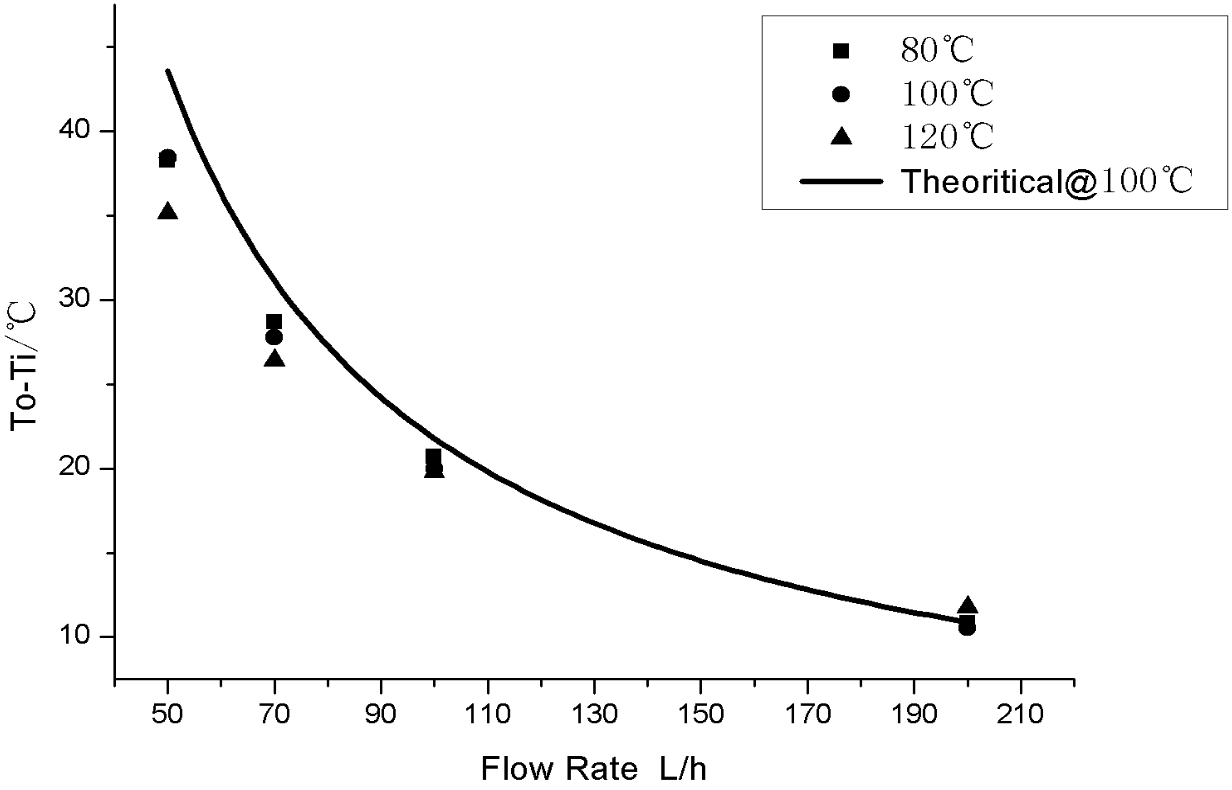
Higher fluid flow rate refers to smaller temperature rise

Hose assembly tests

- The density of RIPP 4050 is 0.9687kg/L@100°C Considered to be constant to simplify the calculation
- Heat capacity C_p=2.07kj/kg·K, L=0.5m， D=0.012m

$$T_o - T_i = \frac{q_s'' L\pi D}{\dot{m} C_p} \Rightarrow \left(\dot{V}\Delta T\right)_{Lubricant} = 2180\,,$$

Hose assembly tests

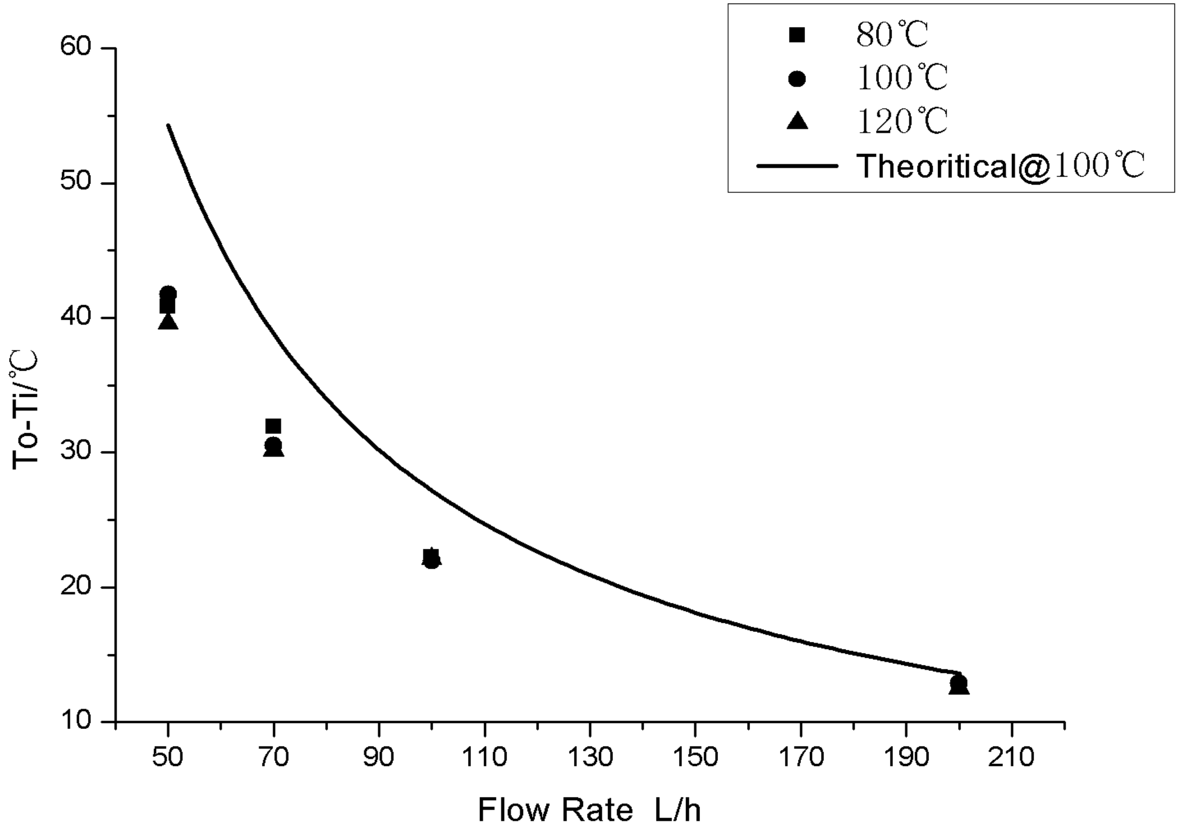


Hose assembly tests

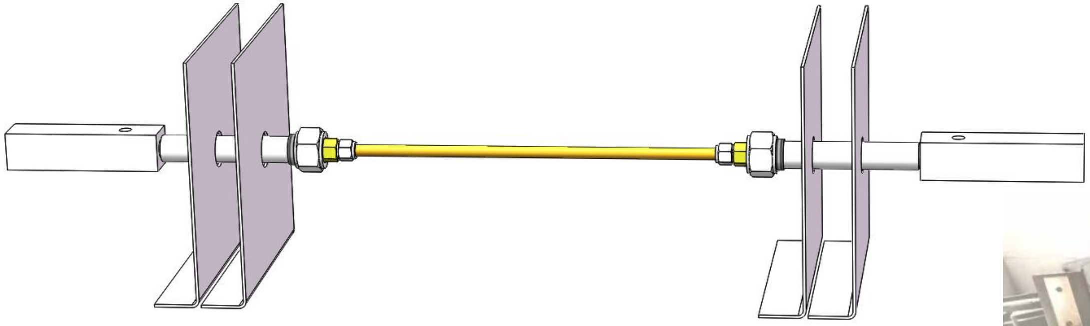
- The density of No.3 Jet Fuel is 0.73kg/L@100℃
  Considered to be constant to simplify the calculation
- Heat capacity C_p=2.35kj/kg·K, L=0.5m， D=0.012m

$$T_o - T_i = \frac{q_s'' L \pi D}{\dot{m} C_p} \Rightarrow \left(\dot{V} \Delta T\right)_{Fuel} = 2716,$$

Hose assembly tests



BTU Heat Transfer Device



BTU Heat Transfer Device

Position[mm]	0	50	100	150	200	250	300	350	400	450	500
Heat flux Density [W/cm²]	2.8	4.7	7.4	8.0	12.0	12.2	10.8	6.0	5.3	2.9	1.7

The average value $\overline{q_s''}$ within 400mm range is 8.66 W/cm^2.

BTU Heat Transfer Device

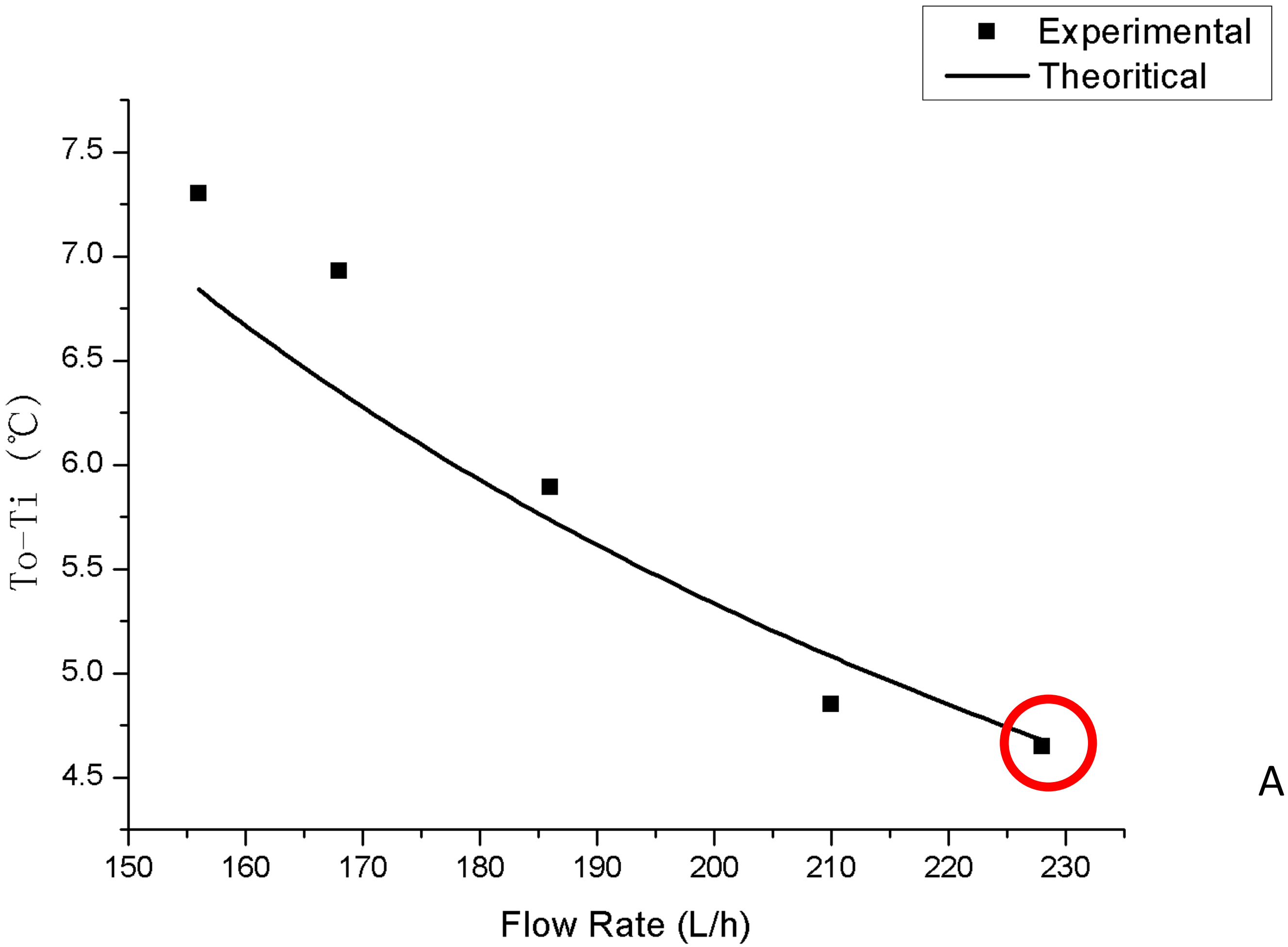
- The density of water is 1.0kg/L@25℃
- Heat capacity C_p=4.185kj/kg·K, L=0.380m， D=0.012m
- The temperature of inlet water is 21℃

$$T_o - T_i = \frac{q_s'' L\pi D}{\dot{m}C_p} \Rightarrow \left(\dot{V}\Delta T\right)_{\text{water}} = 1067,$$

BTU Heat Transfer Device

Flow Rate L/h	156	168	186	210	228
Delta Temp. Measured ℃	7.3	6.93	5.89	4.85	4.65
Delta Temp. Calculated ℃	6.84	6.35	5.74	5.08	4.68

BTU Heat Transfer Device



A little lower?

BTU Heat Transfer Device

Aircraft Materials Fire Test Handbook Chapter 11 P11 & Chapter 12 P4

12.6.5.2.3 After the warmup period, record the inlet and outlet temperatures every 30 seconds for a 3-minute period. Determine the rate of Btu increase of the water as follows:

$$1314\text{W} = \overset{263}{\cancel{146}} \times 5^\circ\text{C} \text{ watts (for Celsius)}$$

$$4500 \text{ Btu/hr} = 500 \times 9^\circ\text{F} \text{ Btu/hr (for Fahrenheit)}$$

where: To = temperature (°C or °F) at outlet

Ti = temperature (°C or °F) at inlet

12.6.5.2.4 The heat transfer rate output, as determined by the equation shown in section 12.6.5.2.3, will be a minimum of 4,500 Btu/hr (1,314 W). If the heat output from the burner is not above the minimum, make adjustments to the burner and repeat sections 12.6.1 through 12.6.5.2.3.

Conclusions

- For tube carrying fluid and subjected to oil burner, relationship between flow rate and temperature rise was studied and can be expressed as $T_o - T_i = \frac{q_s'' L\pi D}{\dot{m} C_p}$
- Experimental corresponds with the theoretical calculations very well.
- For Btu heat transfer device, the delta temperature seems to be a little lower than requirement in handbook, in both ways. Does it denote that the flame calibrated by Garden Gauge may not meet the requirement of Btu heat transfer device?

QUESTIONS？

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