Temperature in an air jet

Questions should be of general interest and be about temperature measurement techniques and/or heat transfer.

QUESTIONS? ANSWERS!

QUESTION: In one of our test rigs we release hot air into the environment via a long and well-insulated pipe with an inner diameter of 100 mm. We use a ø 2 mm sheathed thermocouple to measure the air temperature at the centre of the the pipe. On one occasion I used the same type of thermocouple to measure the temperature at the centre of the air flow and approximately 20 cm outside the mouth of the pipe. The temperature inside the pipe was 220 °C and in the air jet it was approximately 10 °C lower. What can cause this discrepancy? When I took the readings the flow meter displayed 360 m^3/h?

Jesper A

ANSWER: The thermocouple inside the pipe is only marginally affected by the radiation exchange with the pipe wall. This is because the pipe's good insulation means that the pipe wall adopts a temperature that is close to the air temperature.

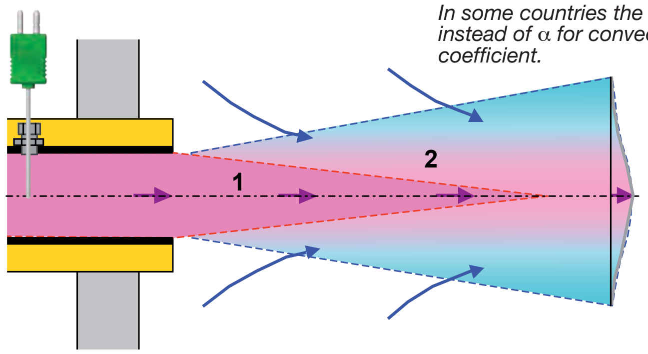
In contrast, the reading taken in the air flow outside the mouth of the pipe is affected by the radiation exchange between the thermocouple and the significantly colder external environment. The heat flow via radiation from the thermocouple to the surroundings, $\dot{Q}_{radiation}$, lowers the sensor temperature below the air jet temperature. A heat flow, $\dot{Q}_{conv}$, is then added to the thermocouple from the air jet via convection. Under stationary conditions $\dot{Q}_{conv} = \dot{Q}_{radiation}$ and from this equation we can now estimate the temperature that is being measured by the thermocouple.

The convective heat flow to the thermocouple is determined by the relationship emissivity $\dot{Q}_{conv} = \alpha A\,(T_{air} - T)$, where α is the heat transfer coefficient in W/(m^2K), A is the heat transferring area in m^2, T_{air} is the air flow temperature in K and T is the thermocouple temperature in K. The heat flow via radiation can be calculated from the relationship $\dot{Q}_{radiation} = \varepsilon A\sigma(T^4 - T_{surroundings}^4)$, where ε is the thermocouple's emissivity, σ is Stefan-Boltzmann's constant ($5.67 \cdot 10^{-8}$ W/(m^2 K^4)) and $T_{surroundings}$ is the ambient temperature in K. The solution requires determining of α and assumptions about ε and $T_{surroundings}$.

An air flow of 360 m^3/h gives an average velocity in the pipe of 12.7 m/s. The air flow in the pipe is turbulent and we can therefore estimate the speed at the centre to be 12.7/0.82 = 15.5 m/s. If we regard the thermocouple as being a long cylinder with airflow normal to the cylinder , we can calculate the heat transfer coefficient to be 280 W/(m^2 K) [Ref 1]. We can assume the surrounding temperature to be 10 °C (283 K) and assume that $\varepsilon = 0.95$ is a reasonable value for the thermocouple's emissivity. Based on these assumptions, the thermocouple temperature is then 484 K (211 °C), i.e. approximately 10 °C lower than the temperature inside the pipe.

In this case, the radiation to the surroundings is the primary reason why the measured value is too low. Because the calculation is based on a number of assumptions, the result should be used with caution. This particular measurement was taken 20 cm (2 pipe diameters) downstream from the pipe mouth and in the core flow, in which the velocity is the same as that inside the pipe. If we take the measurement downstream from the core jet or outside the outer edge of the core jet, the air velocity will be lower and the measurement error will therefore increase. We will discuss temperature measurement in jets more in a future article.

In some countries the character h is used instead of α for convective heat transfer coefficient.



1 = the core jet and 2 = the mixed flow area where the core flow combines with the ambient air outside the outer edge of the jet.

See www.pentronic.se > Kundtidningen > arkiv:
[Ref 1] StoPextra 1998-6, p 4 (in Swedish)

If you have comments or questions, contact Professor Dan Loyd at the Institute of Technology at Linköping University: dan.loyd@liu.se