

LABORATORY SIMULATIONS OF AIR JET DYNAMICS ENCOUNTERED IN FORCED-AIR WARMING SYSTEMS

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INTRODUCTION

Bair Hugger® warming therapy is used on surgical patients to minimize physiologic complications due to inadvertent hypothermia. It has been reported that anesthetic-induced vasodilatation brings about a drop in the patient's body core temperature during surgery and is responsible for metabolic stresses during the recovery period [1]. Bair Hugger® warming therapy utilizes both convective and radiative modes of heat transfer to transport heat energy from a warming cover to the patient's cutaneous layer. In order to quantify the convective component of this heat transfer, a calorimetric heat flux gauge was designed and fabricated. This was accomplished by inputting the measured timewise varying gauge temperature into a data reduction program and calculating the desired convection heat transfer coefficient.

METHODS

The calorimetric heat flux gauge used a highly polished conductive metal disk that reflected more than 95 percent of all incident radiation. The convective heating was accomplished using nine impinging air jets similar in nature to the jets emerging from the Bair Hugger® cover. Each jet, with an initial diameter of 1 mm, impinges onto the gauge at a flow rate equal to 7.0 cm³/sec. A guard heater was used to eliminate spurious heat loss errors. The timewise temperature variations of the metal disk given by an embedded thermocouple were recorded for two separate experiments. The first experiment involved vertical impinging jets normal to the gauge, while the second experiment implemented horizontal impinging jets normal to the gauge.

With the measured timewise disk and ambient temperatures, the total heat transfer coefficient \bar{h}_{total} for simultaneously occurring forced convection, natural convection and radiation was deduced from the following formula.

$$P = \rho c V \frac{dT}{dt} + \bar{h}_{total} A (T - T_{\infty}) \quad \text{Eq. 1}$$

Equation 1 represents an energy conservation equation with the following defined variables: P, power inflow to the calorimeter from the heater; ρ , disk density; c, disk specific heat; V, disk volume; T, disk temperature; T_{∞} , ambient air temperature; A, disk surface area; t, time. In words, Equation 1 states that the power inflow to the calorimeter disk from the embedded heater equals the sum of the timewise rise in the internal energy of the calorimeter disk and the power convected and radiated from the disk's surface.

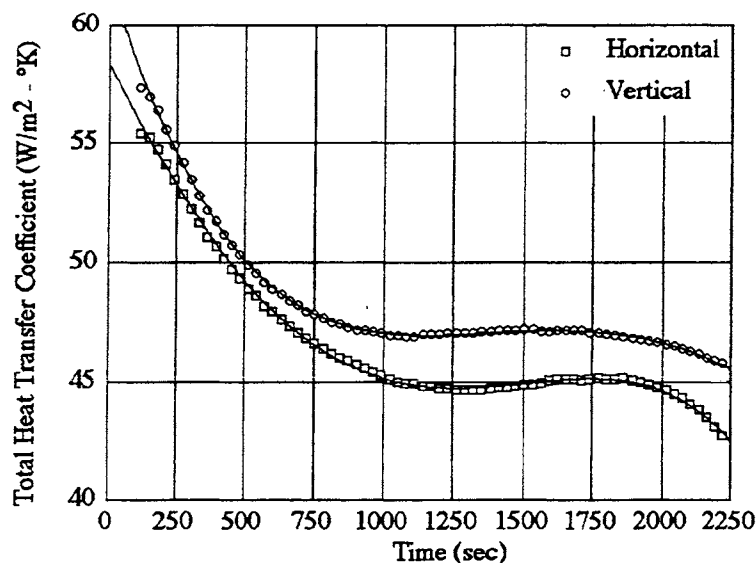


Fig. 1 Heat Transfer Coefficient vs. Time for Normal Horizontal and Normal Vertical Jet Impingement Obtained Using Curve Fitted Temperatures

RESULTS

The magnitudes of the timewise variation of the heat transfer coefficients for both jet orientations were determined from Equation 1 and plotted in Figure 1. For the numerical evaluation of Equation 1, the needed values of the calorimeter and ambient temperatures were imputed by means of curve fits. These temperatures were curve-fitted to minimize errors produced by ambient temperature fluctuations. For the vertical and horizontal impinging jet scenarios, the total quasi-steady-state convective heat transfer coefficients were determined from Figure 1 to be $46.8 \text{ W/m}^2\text{-}^\circ\text{K}$ and $44.8 \text{ W/m}^2\text{-}^\circ\text{K}$ respectively. When the slopes of the curves in Figure 1 approach a value of zero, quasi-steady-state conditions are achieved. This condition occurs as an equilibrium is attained between the conductive heat transfer across the metal disk and the convective heat transfer from the disk's surface.

As previously described, natural convection heat transfer coefficients were calculated for both jet orientations [2]. For the vertical jet orientation the natural convection coefficient equaled $6.86 \text{ W/m}^2\text{-}^\circ\text{K}$, and for the horizontal jet orientation the coefficient equaled $5.13 \text{ W/m}^2\text{-}^\circ\text{K}$. With the aid of an analytical model, the radiation heat transfer coefficients were determined for both orientations. For a gray body model of the polished metal disk, the radiant heat transfer coefficient was calculated to equal $0.30 \text{ W/m}^2\text{-}^\circ\text{K}$. All heat transfer coefficients are summarized in Table 1.

Heat Transfer Coefficient	Vertical Jet	Horizontal Jet
Total	$46.8 \text{ W/m}^2\text{-}^\circ\text{K}$	$44.8 \text{ W/m}^2\text{-}^\circ\text{K}$
Natural Convection	$6.86 \text{ W/m}^2\text{-}^\circ\text{K}$	$5.13 \text{ W/m}^2\text{-}^\circ\text{K}$
Forced Convection	$46.6 \text{ W/m}^2\text{-}^\circ\text{K}$	$44.5 \text{ W/m}^2\text{-}^\circ\text{K}$
Radiation	$0.30 \text{ W/m}^2\text{-}^\circ\text{K}$	$0.30 \text{ W/m}^2\text{-}^\circ\text{K}$

Table 1 Summary of Heat Transfer Coefficients

CONCLUSIONS

The calorimetric heat flux gauge provided a means to measure the convective heat transfer coefficients for both vertical and horizontal jet impingement orientations. In comparing the magnitudes of the forced and natural convective components of the total heat transfer coefficient for the polished gauge, the results show that the Bair Hugger® warming therapy is dominated by forced convection heat transfer. Both the natural convection and radiation heat transfer effects were considered to be negligible.

REFERENCES

1. Seessel, D. I., and A. Moyer 1990, Skin-Surface warming: Heat Flux and Central Temperature, *Anesthesiology* 73(2).
2. Sparrow, E. M., and R. B. Hussar 1969, Free Convection From a Plane Vertical Surface with a Non-Horizontal Leading Edge, *Int. J. of Heat and Mass Transfer*, Vol. 12, 365-369.