Heat Transfer from Impinging Slot Jets of Air
Part 1: Aerodynamic Characteristics of Free Jets

D. G. Arganbright, H. Resch and J. R. Olson
University of California, Forest Products Laboratory, Richmond, California

Abstract. Aerodynamic data on the axial velocity and turbulence development of free slot jets is presented. Jets varying from 0.0635 to 0.375 inches (1.59 to 9.53 mm) in width and with air velocities between 2,000 and 10,000 ft/min (10.2 to 50.8 m/sec) were examined. This study was the first phase of a research program aimed at developing empirical data describing impinging slot jet heat transfer commonly used in veneer drying.

Introduction

The use of impinging air jets for heating and cooling surfaces has steadily increased over the past two and one-half decades. The relatively high heat transfer rates and uniformity of heat delivery, compared with nonimpinging techniques, are largely responsible for the popularity of this heat transfer method.

Impinging air jets are used for a wide variety of applications, ranging from the tempering of glass sheets to the cooling of gas turbine blades. Impingement drying systems are quite common to the forest products industry, being used in the drying of veneer and paper. Although they are more efficient than parallel air flow systems, there is still need for improved and more efficient design and operation of this type of drier. This is due to ever-increasing fuel costs, desires for greater drier throughput in shorter times, and the rather large capital investment costs involved.

Adequate information to predict heat transfer under various operating conditions such as with multiple slot jets at low jet exit to surface distances is not presently available. Relatively few studies have been made for multiple slot jets with nozzle to surface distances less than 10 slot widths. In one [Schuh, Pettersson 1966], measurements were made at a single distance from the jet exit. Kerscher et al. [1968] give predictive equations for multiple slot jets over a wide range of vertical distances, but the equations for distances less than 5 slot widths are based on only 58 measurements. In light of the large number of feasible slot widths, exit velocities, and vertical distances, this number of measurements appears much too small.
Purpose

The purpose of this study was to investigate the heat transfer produced by arrays of normally impinging two-dimensional air jets and the functional relationships of a number of different design and operating parameters. The desired end goal was to develop empirically derived predictive equations describing this form of heat transfer, which could be used for the design and operation of driers at optimum efficiency.

The study was divided into the following two main problem areas:
1. Aerodynamic characterization of two-dimensional jets

Only the first of these problem areas is discussed in the present paper, the other is considered separately in a second part. In regard to jet aerodynamics, data were collected for each of four jet widths, in order to determine whether jets of different sizes differ aerodynamically. In addition to centerline velocity decay, information on jet turbulence levels was desired in order to explain variations in heat transfer.

Background information

No attempt has been made here to review the current literature pertinent to such a study, as a general review is already available [Arganbright, Resch 1971]. It seems desirable, however, to make a few brief comments on the nature of air jets for those not directly working in the field and to clarify the terminology used.

Two-dimensional jets are commonly referred to as slot jets. Jets can be classified on the basis of their proximity to a surface. A free jet occurs when the jet fluid discharges from the jet orifice into a large open space without any surrounding surface impeding its flow. If a jet strikes a surface at some distance from the jet exit it is termed an impinging jet. Further, if the jet travels in such a fashion that a plane drawn through its centerline strikes a plane surface exactly at right angles, it is known as a normally impinging jet.

A normally impinging slot jet of air is depicted in Fig. 1, and lines representing lateral spread and velocity distributions at various distances from the jet exit are shown.

Immediately upon leaving the jet orifice, the outermost edges of the emerging jet begin to entrain air from the surrounding environment. This has two effects, one that the jet increases in size laterally, and secondly the entrained air diffuses toward the centerline of the jet slowly decreasing the velocity of the disturbed portion of the jet. At a distance of from 3 to 5 slot widths away from the jet exit, the entrained air finally reaches the centerline of the jet and the entire jet has a lower velocity than it did upon initially emerging. This reduction in jet velocity is exceedingly important as the heat transfer capabilities of impinging jets are strongly dependent upon the jet velocity.

Once the jet strikes the surface below it (i.e., the exchange surface), the jet divides and begins to flow roughly parallel to the surface. The point on the surface...