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Applied Thermal Engineering 26 (2006) 200–208

Applied Thermal Engineering

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Numerical investigation into the effect of cross-flow on the performance of axial flow fans in forced draught air-cooled heat exchangers

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Received 3 November 2004; accepted 20 May 2005
Available online 2 August 2005

Abstract

Air-cooled heat exchangers (ACHEs) which utilise large arrays of axial fans, commonly suffer from inlet flow losses related to off-axis flow into the fans. This investigation aims to extend current knowledge on the effect of off-axis inflow on the performance of axial fans in this type of installation. An actuator disk fan-model was developed for the Computational Fluid Dynamics (CFD) code, FLUENT™, and validated against experimental data for off-axis inflow angles up to 45°. Agreement between numerical and experimental pressure rise was good, although fan power consumption and fan static efficiency were under and over-predicted respectively. Experimentally observed trends were confirmed numerically: fan static pressure rise and efficiency were adversely affected, while fan power consumption was not significantly affected by the presence of cross-flow into the fan. The investigation revealed that while the torque characteristics over the outer portion of the fan blades are fundamental in determining the global fan power requirements, the net effect of cross-flow in this region is very small. Local variations of blade torque at diametrically opposed orientations more or less cancel each other out, explaining the independence of fan power consumption to cross-flow conditions. The adverse effect of off-axis inflow on fan static pressure rise was attributed to two factors: increased kinetic energy per unit volume at the fan exit, and greater dissipation through the fan itself. Off-axis inflow was found to affect fan-blade loading characteristics, with implications for blade fatigue.

Keywords: Actuator disk; Axial flow fan; Distorted flow; Off-axis inflow; Cross-flow; Fan performance

1. Introduction

Air-cooled heat exchangers (ACHEs) are used extensively in the petro-chemical, process and power industries. These installations typically utilise large numbers of vertically aligned axial flow fans, drawing in air from below, and forcing it upwards through heat exchanger bundles mounted above the fans. It is common for multiple fan-banks to be used adjacently, each bank consisting of any number of axially aligned fan pairs. An example of this type of installation, using two fan-banks, is shown in Fig. 1.

It may be noted that in ACHEs where many banks of fans are used, flow will not ordinarily cross symmetry-planes between identical fans, such as planes 1 and 2 represented in Fig. 1. Consequently, fans along the periphery of the array may have only one "open" side, while the inner fans must operate with none at all, necessarily drawing in air across the inlets of fans closer to the perimeter, shown again in Fig. 1. The resulting

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1359-4311/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2005.05.012

Nomenclature

A	fan exit area, m^2	α	kinetic energy correction coefficient
C_l	lift coefficient	γ	effective angle of attack, deg
$\dot{m}$	mass flow rate, kg/s	η	efficiency
$\bar{n}$	unit normal vector	ρ	density, kg/m^3
P_R	fan power consumption, W	ω	fan rotational speed, rad/s
Q	fan torque, N m		
R	fan outer radius, m	*Subscripts*	
r	radial location, m	ave	average
T	fan thrust, N	axl	axial (fan axis)
U	velocity magnitude, m/s	e	fan exit
$\overline{U}$	velocity vector, m/s	s	static
V	volume flow rate, m^3/s	Fs	fan static
v_c	cross-flow velocity component, m/s	Ft	fan total
Δp	pressure rise, N/m^2	i	fan inlet

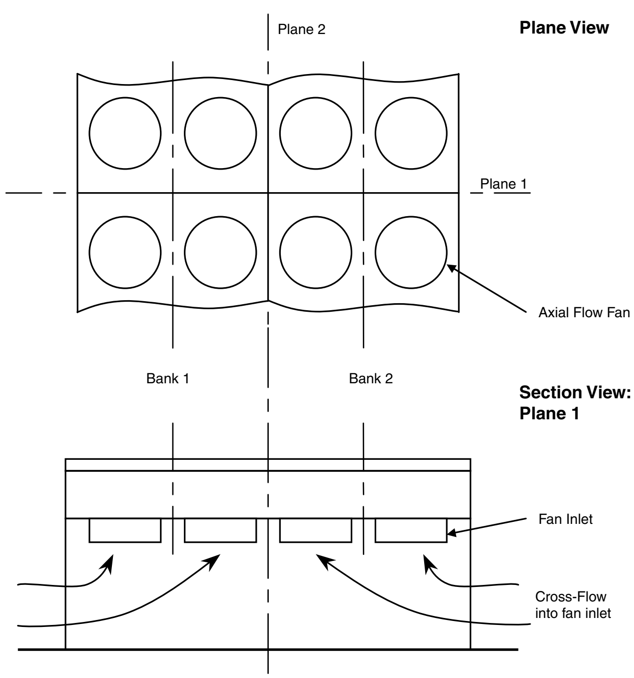

Fig. 1. Diagram representing part of an array of ACHEs consisting of two identical banks, and showing the induced cross-flow at the fan inlets.

maldistribution of flow at the fan inlets has been shown to have an adverse effect on fan performance, and ultimately the effectiveness of the cooling installation [1–6].

Monroe [1] described this type of fan inlet loss, advocating the use of a bell-shaped inlet section, and restriction of the cross-flow velocity component at the fan inlet to less than half the average velocity through the fan throat. The work of Speirs [2] indicated that installations comprising multiple fans are more sensitive than single fan units to reduction of the distance between ground level and fan inlet. A reduction in ground clearance would decrease the flow inlet area around the perimeter of the installation, increasing the cross-flow component at the fan inlets.

In general, such inlet flow losses in ACHEs have been attributed to two sources. The first, flow separation in the region of the fan inlet lip, is described by Russell and Peachey [3], Salta and Kröger [4] and Duvenhage et al. [5]. Fans on the perimeter of the array typically experience higher cross-flow velocities, with flow being drawn towards the interior by the inner fans, and are more likely to experience this type of flow-separation inlet loss.

Off-axis inflow, the second type of fan inlet condition associated with losses in ACHE arrays, was investigated by Stinnes and von Backström [6]. This condition is typically associated with fans in the interior of a large ACHE fan-cluster, for which the inlet flow velocities are not as large as those near the edges. Losses are primarily due to acute off-axis flow into the fan, rather than flow separation. Stinnes and von Backström [6] used a series of inlet duct sections to control the degree of cross-flow into an axial flow fan, illustrated in Fig. 2. This configuration allowed them to isolate the effects of off-axis inflow on the performance of axial flow fans, with results reported for inflow angles of up to 45°. Stinnes and von Backström [6] concluded that the fan power consumption is not adversely affected by cross-flow conditions, while the reduction in fan static pressure characteristics may be represented by the dynamic pressure based on the cross-flow velocity component.

The primary aim of the current investigation is to advance understanding of inflow losses related to the off-axis inflow conditions investigated by Stinnes and von Backström [6]. This is accomplished through the use of numerical techniques to generate detailed flow data in