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ANALYSIS OF PRESSURE LOSSES IN THE CROSS FLOW FAN HEAT EXCHANGER AT VARIOUS THERMAL AND FLOW CONDITIONS

ANALIZA STRAT CIŚNIENIA W WENTYLATOROWYM WYMIENNIKU CIEPŁA DLA RÓŻNYCH WARUNKÓW CIEPLNYCH I PRZEPŁYWOWYCH

A b s t r a c t

In this paper the analysis of performance characteristics of a cross flow fan working as an element of the unit incorporating heat exchanger as well as performance characteristics of the unit are presented. These experimental results were basic for consideration of pressure losses arising as an effect of direct connection of a cross flow fan and a heat exchanger located in the charging zone of the fan as a resistance. Analysis of an influence of rotational speed variation as well as a medium temperature on aerodynamic characteristics of heat exchanger let to propose a method for the local pressure loss estimation.

Keywords: cross flow fan heat exchanger, performance characteristics, local pressure losses

S t r e s z c z e n i e

W artykule przedstawiono analizę charakterystyk pracy wentylatora poprzecznego jako elementu układu z wymiennikiem ciepła oraz charakterystyk układu. Wyniki eksperymentalne stanowiły podstawę do przeprowadzenia analizy strat ciśnienia spowodowanych bezpośrednim połączeniem wentylatora poprzecznego z wymiennikiem ciepła umieszczonym w jego strefie tłoczenia. W wyniku analizy wpływu zmiany prędkości obrotów wirnika wentylatora jak i temperatury medium w wymienniku ciepła na charakterystyki aerodynamiczne wymiennika, zaproponowano metodę oceny lokalnej straty ciśnienia.

Słowa kluczowe: wentylatorowy wymiennik ciepła, charakterystyki pracy, lokalne straty ciśnienia

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1. Introduction

Cross flow fan cooperation with a heat exchanger seems to be more useful solution than the use of axial or radial fans due to the relatively low noise and a uniform velocity distribution at its inlet and outlet cross sections. The dimension of rectangular inlet or outlet cross section of the fan is adapted to rectangular inlet cross section of the heat exchanger reducing the local pressure losses. Fig. 1 shows an example of direct connection of both elements of the unit, where the cross flow fan (1) is directly connected to the heat exchanger (2) mounted at the fan suction zone [1].

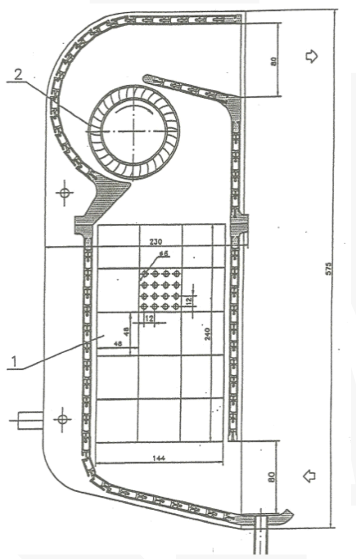

Fig. 1. Cross flow fan heat exchanger

Cross flow fan heat exchanger as the air curtain or as an element of air conditioning system forming perpendicular laminar air stream is applied for example in hospital operating rooms for separating the places which require special conditions of clean air free from microorganisms.

Lengthening of the impeller (limited by strength of material) gives a possibility to increase the volumetric flow rate and adapt to the requirements of particular application. Its rectangular cross sections in the suction and discharging zones enabling the direct connection with the heat exchanger are an advantage in local losses reducing.

Among whole literature one can find only a few studies taking into account a heat exchanger application in the air conditioning unit. An effect of heat exchanger as a suction resistance on internal flow in a room air conditioner was investigated and presented in [2]. The total pressure was stable inside the both suction and discharging zones when the cross flow fan worked without a heat exchanger. The size and magnitude of vortex depended on the setting of heat exchanger as an element of the unit which created the turbulence. In [3] the authors considered three different casing designs of a unit containing the same cross flow fan and heat exchanger indicating an influence of the design of a cross flow fan parameters on the air conditioning unit performance. The study has been carried out numerically and experimentally for the heat exchanger located at the suction zone of the cross flow fan.

2. Some experimental results of cross flow fan heat exchanger investigations

As mentioned above a heat exchanger usually is mounted at the suction zone of the cross flow fan. Experiments carried out for the cross flow fan model (L/D = 180/60) with throttling at inlet and outlet cross section indicated higher values of the dimensionless pressure coefficient and efficiency for the case of throttling realized at the discharging zone [4].

The aim of investigations presented in this paper is an evaluation of local loss aroused on connection of the cross flow fan WPU 450/100 constructed at the Cracow University of Technology and the mass-produced heat exchanger GP6/7 forming together a unit. The quantitative estimation of the flow structure effect was based on the analysis of aerodynamics and efficiency curves obtained for different flow and thermal conditions comparing the performances made for a cross flow fan operating separately and as an element of the unit with the built-in heat exchanger. Some selected experimental results showing the influence of the rotational speed on the unit performances were presented in [5]. An increase of the rotational speed from n = 5 1/s to n = 20 1/s caused the increase of dimensionless static and total coefficients of the unit about 97 % for ψ_s^u and 58% for ψ_t^u as well as efficiency which reached η_t^u = 40 % for the flow coefficient φ = 0.85.

In Fig. 2 the scheme of measurements of the static pressure (p_1, p_2, p_3) averaged at the cross sections (A_1, A_2, A_3) is shown.

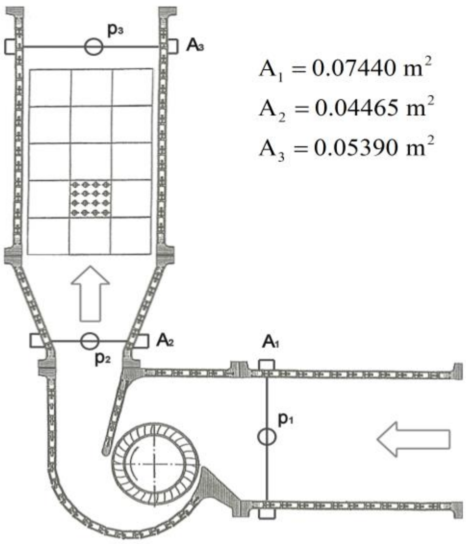

Fig. 2. Scheme of static pressure measurements for a unit: the cross flow fan – the heat exchanger

Relation between the total pressure coefficient and the flow coefficient in the form of curves: $\psi_t = f(\varphi)$ - for the cross flow fan working separately, it means that the air is discharged straight to the atmosphere so static pressure at the outlet is assumed to be zero – and $\psi_t^* = f(\varphi)$ as an element of a unit containing a heat exchanger, measured at the two rotational speeds: $n = 15\ s^{-1}$ and $n = 20\ s^{-1}$ – are shown in Fig. 3.

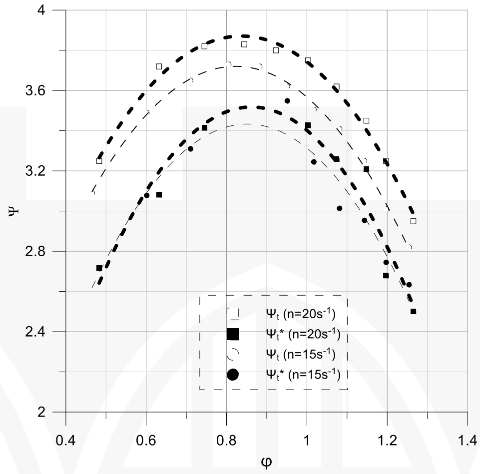

Fig. 3. Changes of the total pressure coefficient for the cross flow fan working separately ψ_t and as an element of a unit ψ_t^* at different rotational speeds: $n = 20\ s^{-1}$ and $n = 15\ s^{-1}$

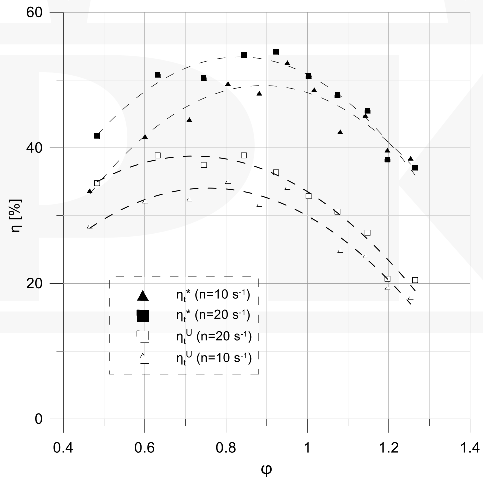

Fig. 4. Total efficiency vs. flow coefficient at rotational speed $n = 20\ s^{-1}$ and $n = 10\ s^{-1}$

The experimental results have confirmed two expected phenomena: one that the higher values of the total pressure coefficient were obtained at higher rotational speed and the second that the lower values of the total pressure coefficient were obtained for the cross flow fan working as an element of a unit ψ_t^* for both rotational speeds. The difference of the total pressure coefficient varying in the range between 8% and 10% should be treated as the consequence of the heat exchanger resistance.

Total efficiency of the cross flow fan working as an element of a unit η* and efficiency of the unit η^u (dotted lines) in function of the flow coefficient for two rotational speeds: $n = 20\ s^{-1}$ and $n = 10\ s^{-1}$ is shown in Fig.4. Reduction of total efficiency of the unit in comparison with efficiency of the cross flow fan in unit from 7% to 18% may be treated as a heat exchanger "negative efficiency" located at the outlet part of the cross flow fan in considered range of φ.

Curves of dynamic pressure obtained for varied volumetric flow rate $\dot{V}$ at three rotational speeds: $n = 10\ s^{-1}$, $15\ s^{-1}$ and $20\ s^{-1}$ for the cross flow fan working as the element of a unit p_d* and for the unit p_d^u are presented in Fig. 5.

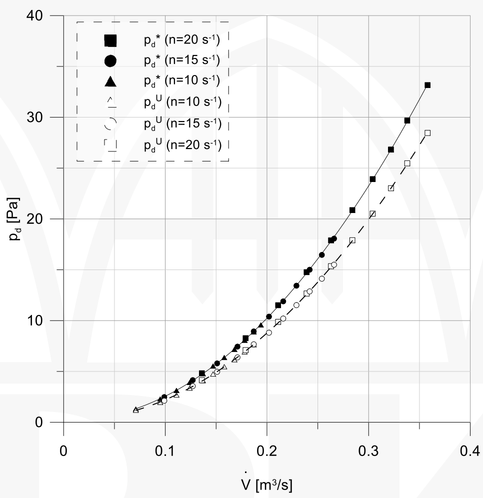

Fig. 5. Dynamic pressure versus volumetric flow rate for different rotational speeds

These results can be approximated by following functions, respectively:

$$p_d^* = 266.80 \cdot \dot{V}^2 - 3.28 \cdot \dot{V} + 0.22 \tag{1}$$

$$p_d^u = 230.39 \cdot \dot{V}^2 - 3.49 \cdot \dot{V} + 0.26 \tag{2}$$

and using them gives a possibility to estimate a total pressure rise Δp_t for the arbitrary value of Δp_s,

$$\Delta p_t^* = \Delta p_s^* + p_d^* \quad \text{and} \quad \Delta p_t^u = \Delta p_s^u + p_d^u \tag{3}$$

independently of the rotational speed of the cross flow fan impeller in determined range of the volumetric flow rate.

3. A quantitative effect of the heat exchanger as a discharge resistance

The heat exchanger has been mounted at the outlet part of the cross flow fan and connected with it by a short rectangular duct used to adapt the cross sections of these two elements. Measurements of pressure allow estimating the difference in values of static and total pressure for each element and for the whole unit. Some selected results are presented in the form of characteristics indicating the influence of the heat exchanger as a discharge resistance in the air flow as well as an effect of variable temperature of medium flowing inside the heat exchanger pipes on aerodynamic performances. Some selected experimental results of measurements presented in [6] have been used for the considerations and calculations in this part of publication.

3.1. An influence of impeller rotational speed on aerodynamic characteristics of the heat exchanger

Static pressure drop on a heat exchanger Δp_s^h was estimated as difference between averaged static pressure measured at the cross section for the unit and for the cross flow fan as an element of the unit (Fig. 2). The curves $\Delta p_s^h = f(\dot{V})$ obtained at different rotational speeds indicate a significant influence of cross flow fan acting. The aerodynamic drag of the heat exchanger increases with the increase of the air velocity but the curve runs differ from typical second degree curves with more intensive tendency at a higher rotational speed. Superposition of cross flow fan performances and resistance curves of the heat exchanger create characteristics shown in Fig. 6 changing their runs in dependence of the air velocity.

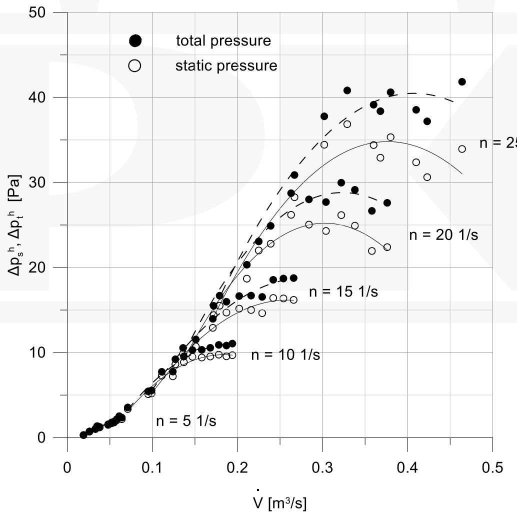

Fig. 6. Flow characteristics of heat exchanger $\Delta p_s^h = f(\dot{V})$ and $\Delta p_t^h = f(\dot{V})$ for different rotational speed

At lower values of volumetric flow rate ($\dot{V}$ < 0.125 m^3/s) the influence of dynamic pressure on the heat exchanger performance is not visible so for different rotational speeds at studied range the results are similar and the curves run identically.

3.2. An influence of medium temperature on aerodynamic characteristics of the heat exchanger

In Fig. 7. selected flow characteristics of heat exchanger: $\Delta p_s^h = f(\dot{V})$ and $\Delta p_t^h = f(\dot{V})$ measured at three different temperatures of medium: 20°C, 35°C and 50°C at constant rotational speed n = 15 s^{-1} are presented. It is worth to notice that in this case the influence of aerodynamic performances of cross flow fan on the heat exchanger characteristics is much more visible than the temperature effect in the determined range of volumetric flow rate.

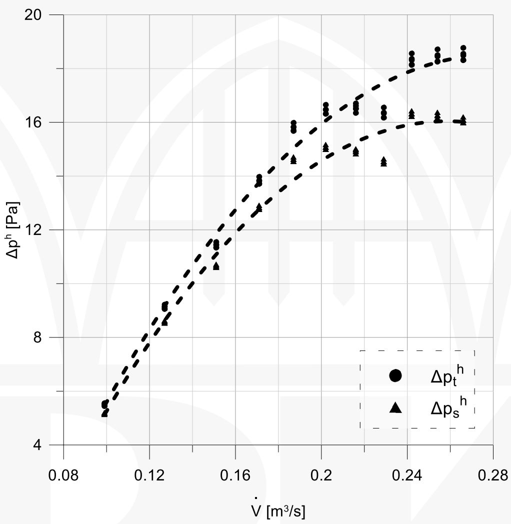

Fig. 7. Flow characteristics of the heat exchanger for various medium temperatures

The run of curves indicates a limited value of volumetric flow rate at which static and total pressure differences reach the highest values and then Δp_t^h and Δp_s^h decrease because of the stronger effect of the cross flow fan acting.

Dynamic pressure obtained as the difference between total pressure drop and static pressure drop measured for heat exchanger $\Delta p_{d\,(m)}^{h}$ (measured) was compared with dynamic pressures calculated as the difference between total and static pressures for a cross flow fan in the unit and the unit $\Delta p_{d\,(c)}^{h}$ (calculated) in the range of volumetric flow $\dot{V}$ = 0.08 ÷ 0.28 m^3/s for various medium temperatures (Fig. 8). Both calculated and measured results have been approximated using the following formula, respectively:

calculated: $$p_{d\,(c)}^{h} = 33.041 \cdot \dot{V}^2 - 0.059 \cdot \dot{V} - 0.005 \quad (4)$$

measured: $$p_{d\ (m)}^{\ h} = 34.451 \cdot \dot{V}^2 - 0.083 \cdot \dot{V} - 0.005 \qquad (5)$$

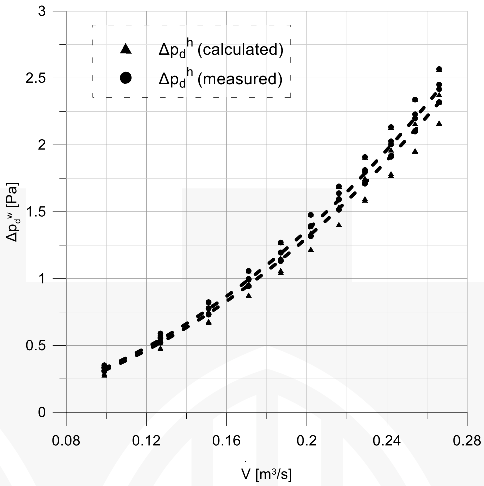

Fig. 8. Dynamic pressure vs. volumetric flow rate for different medium temperatures

Comparison of approximated results obtained from measurement and calculation show rather good agreement although calculated values lie below measured results. Differences between calculated and measured values of Δp_d^h are in the range of 0.16 Pa, more visible at higher volumetric flow rate.

4. Quantitative evaluation of pressure loss

Analyzing the results of dynamic pressure obtained as a difference between total and static pressure at the cross section before (A_2) and behind (A_3) the heat exchanger evaluated from measurements for the unit and cross flow fan as well as calculated using a simplified formula [7]:

$$p_d^{\ h} = \frac{1}{2} \cdot \rho^2 \cdot V^2 \cdot \left[\frac{1}{\rho_3 \cdot A_3^{\ 2}} - \frac{1}{\rho_2 \cdot A_2^{\ 2}} \right] \qquad (6)$$

for medium temperatures: 20°C, 35°C , 40°C , 45°C and 50°C, some differences have been indicated. The ratio of dynamic pressure measured and calculated determined as “dimensionless coefficient of dynamic pressure” ξ_d plotted versus volumetric flow rate is shown in Fig. 9.

Independence of ξ_d from the medium temperature in the investigated range (20°C ÷ 50°C) and almost constant value of the ratio equal to 2.63 indicate the local dynamic pressure loss as an effect of the heat exchanger resistance.

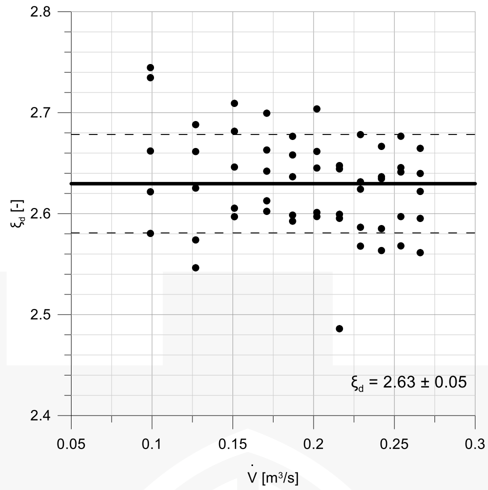

Fig. 9. Dimensionless coefficient ξ_d vs. volumetric flow rate for different medium temperatures

5. Conclusions

The runs of performance presented in this paper showed the different influence of rotational speed of the cross flow fan impeller as well as the temperature of working medium in the heat exchanger. The comparison of dimensionless curves $\psi = f(\varphi)$ obtained for the cross flow fan working alone and as an element of a unit incorporating heat exchanger indicated the effect of throttling . The similar effect has been seen comparing the efficiency $\eta = f(\varphi)$ obtained for the cross flow fan working as an element of a unit with the efficiency for the whole unit. The analysis allowed identifying an influence of cross flow fan rotational speed and temperature of working medium in a heat exchanger on its aerodynamic performances.

Nomenclature

A – area cross section, [m^2];
D_2 – outer diameter of impeller, [m];
L – length of impeller, [m];
u_2 – tangential velocity at outer diameter, [m s^{-1}];
n – rotational speed, [s^{-1}];
p – pressure, [Pa];
P – power, [W];
$\dot{V}$ – volumetric flow rate, [m^3 s^{-1}];
ξ_d – dimensionless coefficient of dynamic pressure;
ρ – density, [kg m^{-3}];

$\eta = \frac{\Delta p \cdot \dot{V}}{P}$ – efficiency;

$\varphi = \frac{\dot{V}}{D_2 \cdot L \cdot u_2}$ – flow coefficient;

$\psi = \frac{2 \cdot \Delta p}{\rho \cdot u_2^2}$ – pressure coefficient;

Subscribes

s – static;
t – total;
d – dynamic;

Superscripts

* – cross flow fan;
h – heat exchanger;
u – unit.

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