FOLIA 204

Annales Universitatis Paedagogicae Cracoviensis

Studia Technica IX (2016)

ISSN 2081-5468

Krzysztof Pytel, Stanisław Fortuna

Conformity assessment of a radial fan flow characteristics investigated experimentally and modeled by the mathematical equations for transformation of an ideal gas

Introduction

Fans are rotary machines used to create flow within a gas or a liquid, as well as to pump vapors and gases. Modern fan is a response to specific user requirements. It can work both as a device for exhaust or blast, as well as suction and discharge. Medium flow direction is perpendicular to the axis of the rotor in centrifugal fans, whereas it is parallel to the axis of the rotor in axial fans. A wide range of fans produced nowadays with axial and radial flow direction is widely used in air conditioning systems, industrial ventilation systems, fume extraction systems, as well as dust extraction systems. Standard and custom prepared fans are used in steel mills, coal mines, power and thermal power plants, as well as in ships, vehicles and households. Fans are devices which use mechanical energy of the rotor to form flow of air and increase in total pressure. There are two main groups of impellers, that is the propeller (axial flow) fan and the centrifugal (radial flow) fan. Among the most common types of fans, the flow of the medium is essentially radial in the centrifugal fans, while the flow of the medium is implemented in parallel with the rotating shaft in the axial flow fans (Fig. 1) (http://www.engineeringtoolbox.com).

Centrifugal impellers eject air away from the tips of the blades, which are mounted in the housing and could be grouped according to blade configuration as forward curve, straight blade and backward inclined. Forward curve blades in fans are applicable if the materials are transported by air, as in the high concentration of dust. Backward inclined blades are generally more efficient. Radial fans are used for high-speed medium flow and high static pressure (Fortuna, Pytel 2016).

Axial impellers are composed of a rotor as well as the drive unit. There are different types of axial flow fans and they may be assigned to one of three categories: tubeaxial fans, vaneaxial fans and propeller fans. Tubeaxial fans are suitable for use in ducts. Vaneaxial fans mounted in the front or rear of the rotor have blades directing the air flow in the predetermined direction. Propeller fans with a driving engine are mounted in a flat bed chase and are installed in any kind of housing or directly on the walls (Fortuna, Kowalski, Zabrzeski 2015; Fortuna, Pytel 2015).

Rotating machinery belongs to fluid flow machines, which are essential mechanical devices in power engineering. Their function is to transfer energy by suitably shaped rotor blades to the medium surrounding them. The fans and blowers could be grouped based on their practical application. They could be used for nuclear and thermal power application, in road tunnels, in wind tunnel investigations, in steel industry and refining processes, in ceramics industry, water treatment, mining and chemicals applications and much more. Exemplary types of fans and some of their properties are presented in Fortuna, Pytel (2016)

Fan blades are constructed of different materials which are adapted to different operating conditions, rotational speed and operating temperature. Materials performing the assigned tasks must be properly adjusted and tested (Prauzner, Ptak 2014; Prauzner 2015; Śmiga, Garbarz-Glos, Piekarczyk, Noga, Sitko, Karpierz, Livinsh 2016; Garbarz-Glos, Bąk, Noga, Antonova, Kalvane, Śmiga 2016).

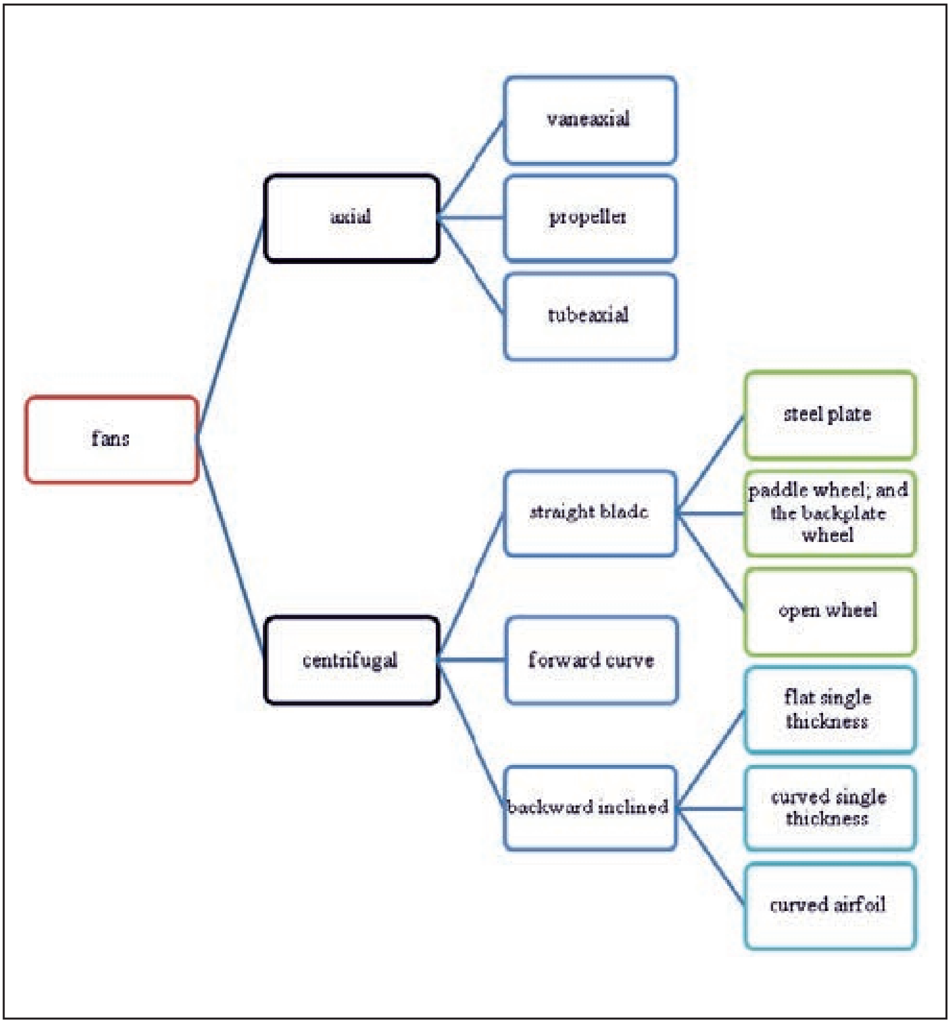

Fig. 1. Basic classification of fans (http://www.tcf.com)

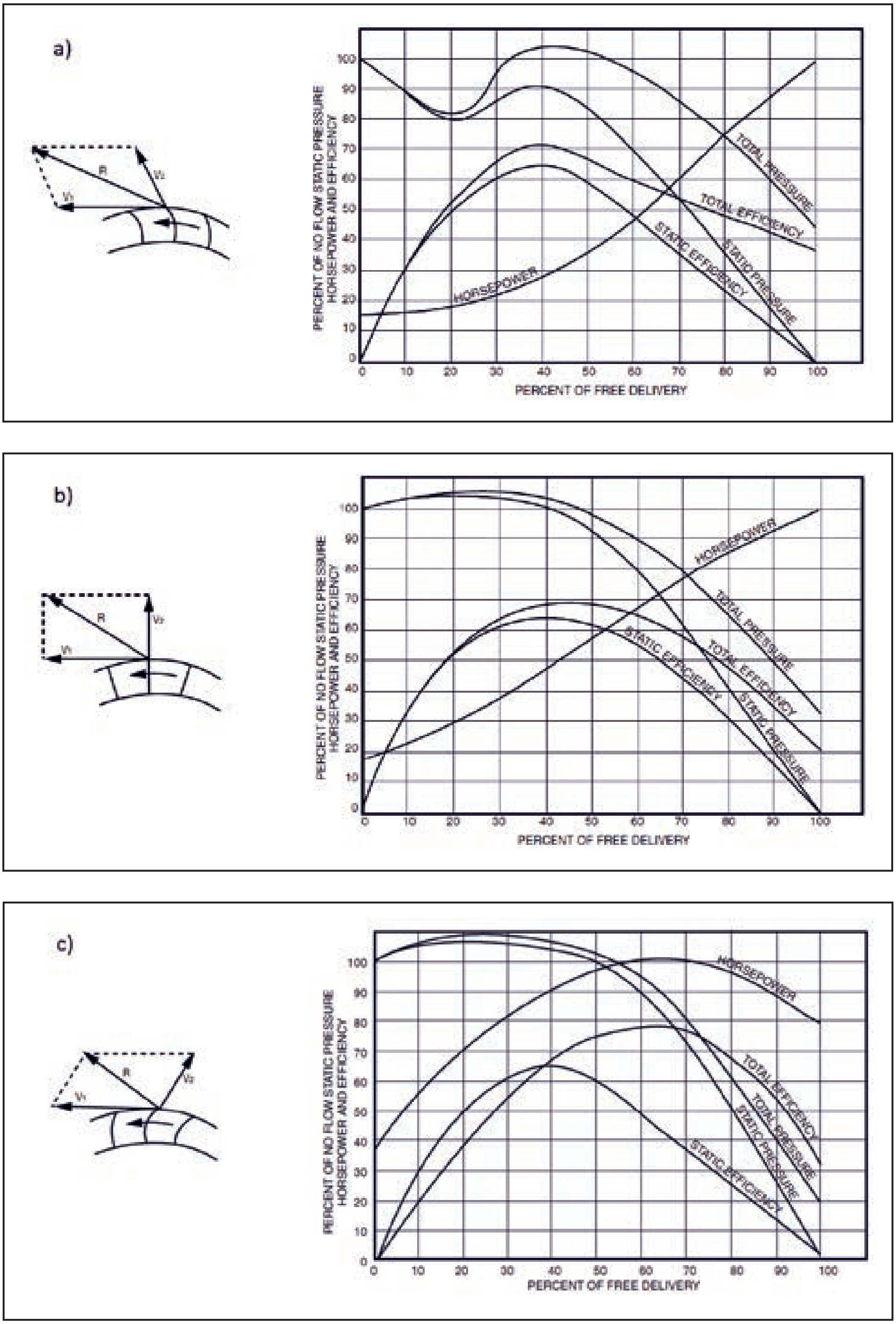

Fig. 2. Characteristics of radial fans: a) forward curve; b) straight blade; c) backward inclined (Fortuna, Pytel 2016)

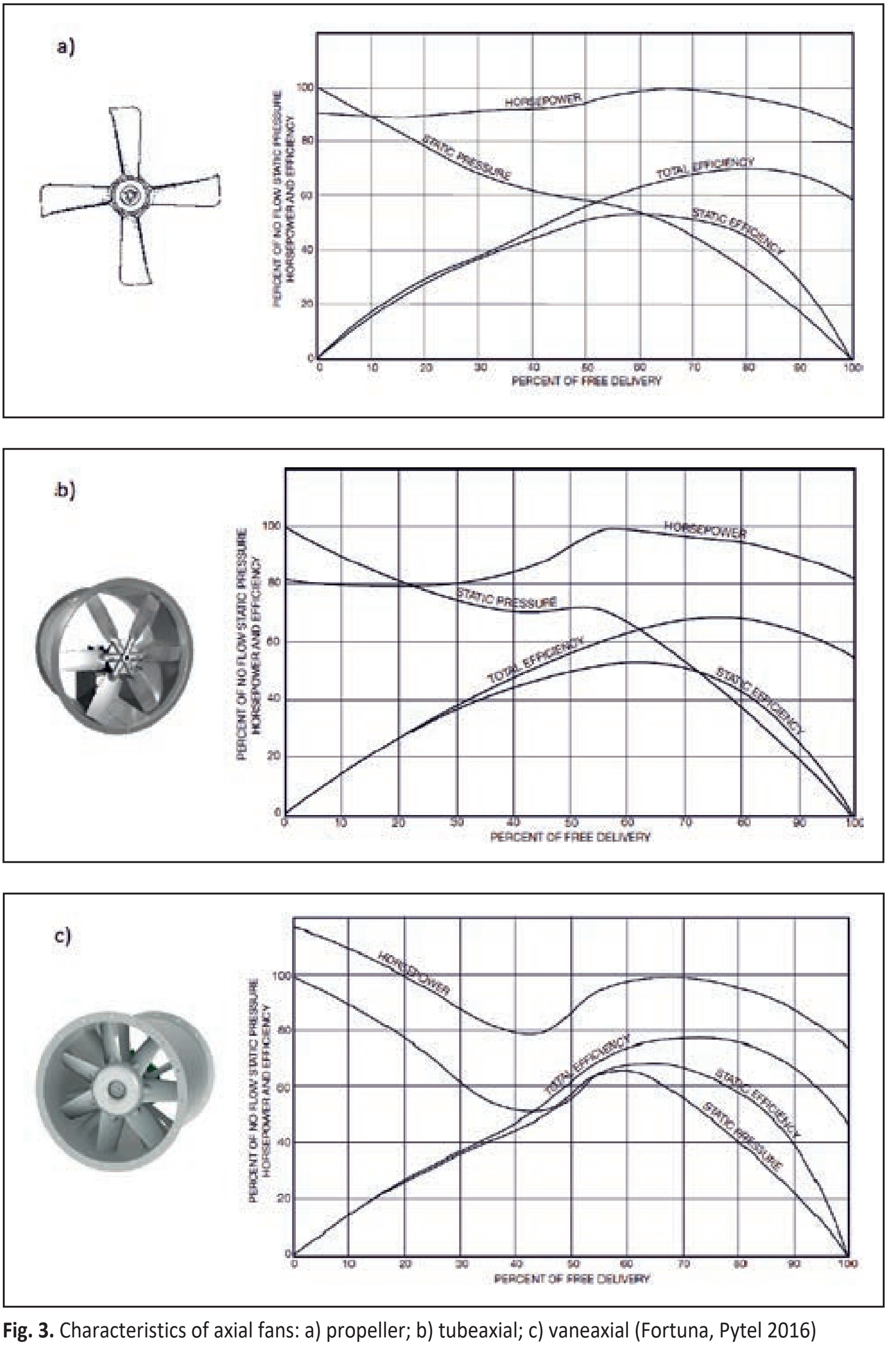

Fig. 3. Characteristics of axial fans: a) propeller; b) tubeaxial; c) vaneaxial (Fortuna, Pytel 2016)

Flow characteristics of fans

Fan operation task is to increase the pressure and to stamp the medium. It is held by the energy supplied from the outside, for example by an electric motor. As a result of the rotation of the driven rotor, the flowing medium is moved in axial (axial construction) or radial (radial construction) direction with respect to the impeller shaft. Vacuum produced in the interscapular space forces the flow of new portions of medium, that the kinetic energy as well as static pressure increases during movement. Energy supplied to rotor ought to provide complete work, that is to overcome the flow resistance as well as increase in pressure and speed rate. There are two main groups of fans which determine the way in which air passes through the rotor: propeller or axial flow, and centrifugal or radial flow.

Centrifugal fans could be constructed as machinery with blades forward curved, straight and backward inclined taking into account the necessary parameters. Each fan type has its own scope of application and limitations. Centrifugal fans are used for high pressure (Fig. 2). Axial fans are used for large volume flow and small pressure (Fig. 3) (Fortuna, Pytel 2015).

Fans are machines that are used for compression and pumping of gases as well as gas mixtures and dust. They can work together in series or in parallel. It is necessary to connect fans in series, when static pressure obtained by one fan is insufficient to overcome resistance in the pipes or in order to avoid too high circumferential speed. Increase in efficiency of the fan cannot be achieved by increase in speed. A parallel cooperation of fans allows for greater efficiency in those cases where there is no fan of the required high performance (Fig. 4).

The flow of the medium in the fan is a non-stationary and results from the flow structure. Research on fans is focused on finding optimal working conditions, by which the machine is characterized by a stable flow characteristics in the working range between 75% and 100% of the maximum efficiency.

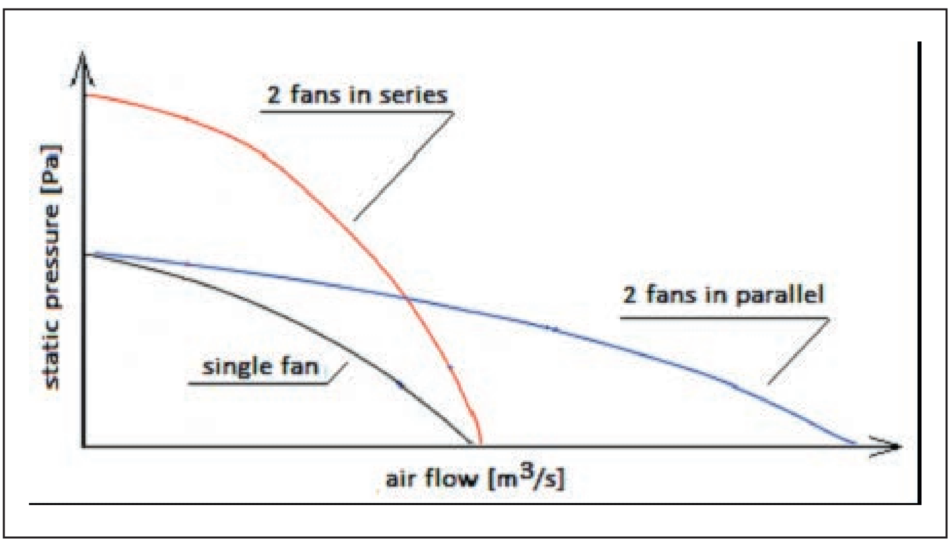

Fig. 4. Cooperation of fans

Execution of flow characteristics of the radial fan

Basic characteristics of the fan were determined experimentally. The diagram and description of the research position was presented in Fortuna, Kowalski, Zabrzeski (2015). Results were plotted in Fig. 5. The results of theoretical transformations for ideal gases were compared to those from measurements. Polytropy was described by the equation:

$$pV^n = p_1V_1^{\,n} = p_2V_2^{\,n} = \text{const.}$$

where:
p – pressure [Pa]
V – volume [m^3]
n – polytropic exponent, equal:

$$n = \frac{c - c_p}{c - c_v}$$

where:
c_p – heat capacity for constant pressure
c_v – heat capacity for constant volume
c – the heat capacity for the desired thermodynamic conversion.

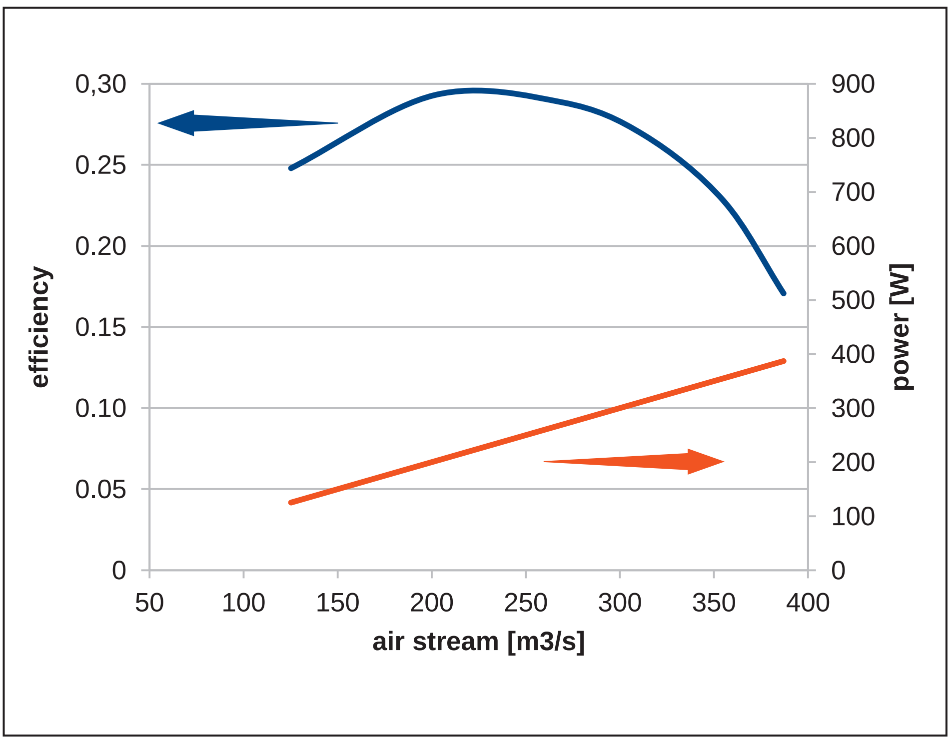

Fig. 5. Efficiency and the power of the examined radial fan.

Transformation of gas treated as an ideal gas, can be analyzed as a solution to the equation of polytropy for specific polytropic exponent value (Fortuna 2011). A polytropic transformation could occur at a constant pressure or a constant volume, constant temperature or constant entropy. The polytropic exponent, receiving a constant value for a particular polytropic process, simultaneously receives the chosen values in the range of minus infinity to plus infinity for another polytropic transformation. Particular cases of polytropic transformations are:

- isobaric transformation, for n=0, $c=c_p$;
- isothermal transformation, for n=1, $c=\infty$;
- adiabatic heat development, for $n=c_p/c_v$, c=0;
- isochoric transformation, for $n=\infty$, $c=c_v$.

A work in the transformation of real gas can be calculated (Tab. 1). The simulations carried out for the transformation of an isobaric isochoric isothermal and adiabatic and the results were compared with the results obtained for the transformation from polytropy. Analyses were performed for the equations of the characteristic transformation of ideal gas for the absolute and technical work. Results are shown in a graph describing the dependence of power as a function of the performance of the fan in the contractual conditions (Figs 6, 8).

Tab. 1. Tab. 1. The equations of characteristic transformation of an ideal gas

Transformation	Absolute work, $L_{1\text{-}2}$	Technical work, $L_{t1\text{-}2}$
isobaric	$L_{1\text{-}2} = p(V_2 - V_1)$	$L_{t1\text{-}2} = 0$
isochoric	$L_{1\text{-}2} = 0$	$L_{t1\text{-}2} = V(p_2 - p_1)$
isothermal	$L_{1\text{-}2} = p_2 V_2 ln\frac{p_1}{p_2} = p_1 V_1 ln\frac{V_2}{V_1}$	$L_{t1\text{-}2} = L_{1\text{-}2}$
adiabatic	$L_{1\text{-}2} = \frac{p_1 V_1}{\kappa-1}\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}}\right]$ dla κ= 1,4	$L_{t1\text{-}2} = \kappa L_{1\text{-}2}$
polytropy	$L_{1\text{-}2} = \frac{1}{n-1}(p_1 V_1 - p_2 V_2)$	$L_{t1\text{-}2} = n L_{1\text{-}2}$

Losses in the system for the analyzed transformation were defined as:

$$\eta_{ip} = 1 - \frac{\eta_p}{\eta_i}$$

$$\eta_{it} = 1 - \frac{\eta_t}{\eta_i}$$

$$\eta_{is} = 1 - \frac{\eta_s}{\eta_i}$$

Losses are defined as a deviation from the results obtained from the experience. The results are shown in a graph describing the dependence of the losses in the system as a function of fan efficiency in the contractual conditions (Figs. 7, 9). When comparing dependency on absolute work of conversion with obtained results it was noted, that at the point of maximum efficiency of the machine, at which a tested centrifugal fan works most optimally, the loss with respect to the isobaric process is approximately 2.5%, for isothermal transformation is equal to approximately 1.5%, while for adiabatic transformation reaches about 35%.

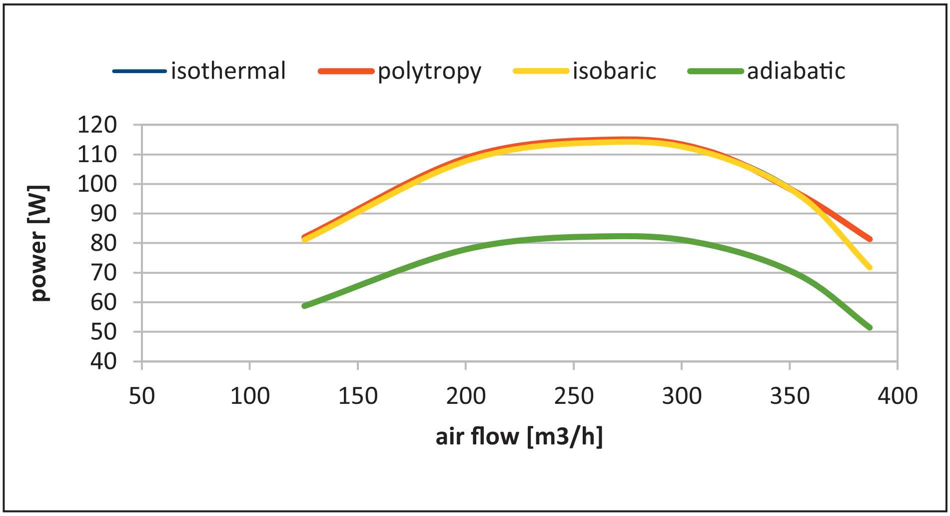

Fig. 6. Comparison of power output for polytropy transformation and transformation for ideal gases (absolute work)

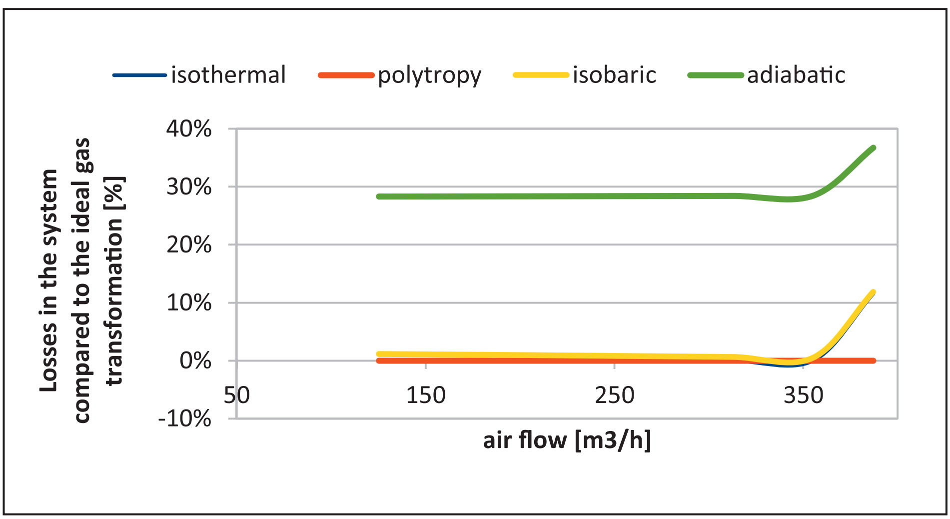

Fig. 7. Comparison of losses in the system for polytropy transformation and transformation for ideal gases (absolute work)

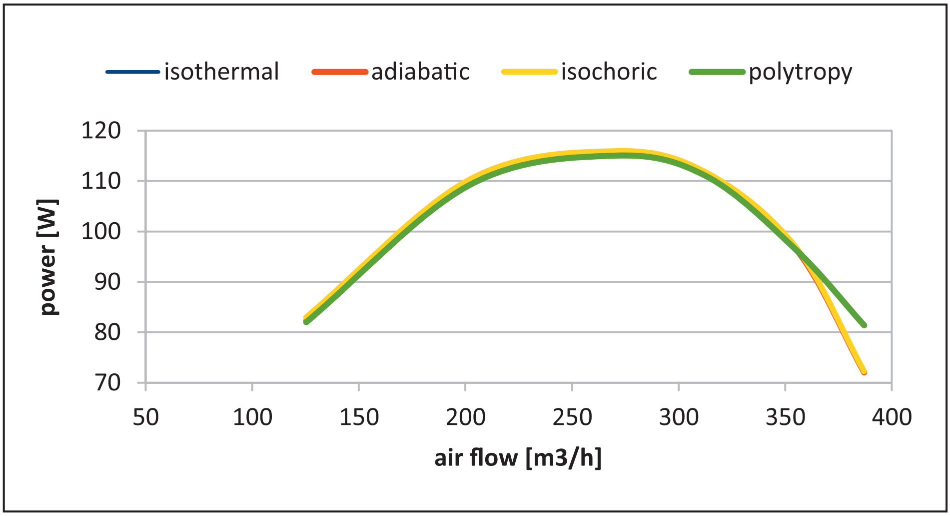

Fig. 8. Comparison of power output for polytropy transformation and transformation for ideal gases (technical work)

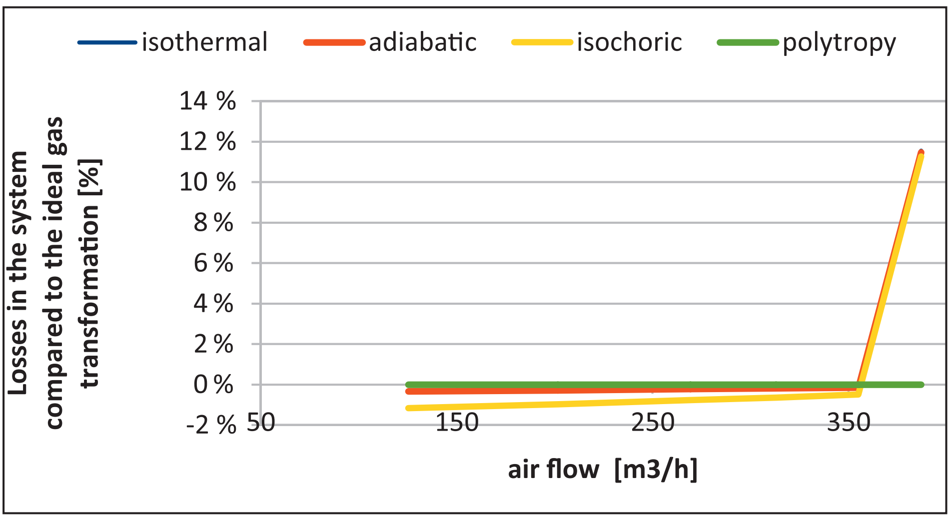

Fig. 9. Comparison of losses in the system for polytropy transformation and transformation for ideal gases (technical work)

Losses related to isothermal and isobaric transformation do not exceed 8% for operation range of the characteristic. When comparing the dependence on the technical work of transformation with results obtained, it is noted that maximum deviations of counted values using the equations of transformation of ideal gas does not exceed 12% at the point of maximum efficiency of the machine, at which a tested centrifugal fan worked most optimally, losses in relation to the analyzed transformation is less than 1%, the isothermal transformation is equal to approximately 0%.

Summary and conclusions

The researches of fans, pumps and power machines are aimed at finding the optimal working conditions of the machine. The analysis shows the dependence of the increase of the total pressure on performance. High pressure is associated with low air stream and high performance is associated with the presence of low pressure.

Analyzing the results of capacity, measured and modeled using the ideal gas transformation it was noted that the nearest approach obtain when compared to the isothermal transformation of an ideal gas, taking into account the dependence on technical work, whereby loss determined as exceptions on the result calculated by the equations of the selected transformation, changing with the change of performance (from 0% to 11% for the analyzed range of air stream).

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Abstract

This work is devoted to the analysis of an installation with radial and centrifugal fans. Knowledge of the scope and parameters of each operation is necessary for the proper selection of the installation. The analysis was performed in order to minimize the number of measurements. The analysis was based on determining the relationship between the experimental data and the results of analytical methods. The experimental results are compared with the results obtained for an ideal gas equation. High concordance between the results of experimental and theoretical analyzes was obtained.

Key words: axial and radial fans, fan performance prediction, stream flow, fan flow, ideal gas

Krzysztof Pytel

Pedagogical University of Cracow
Institute of Technology
ul. Podchorążych 2
30–084 Kraków, Poland

Stanisław Fortuna
Akademia Górniczo-Hutnicza
Wydział Inżynierii Mechanicznej i Robotyki
Katedra Systemów Energetycznych i Urządzeń Ochrony Środowiska
Al. Mickiewicza 30
30–059 Kraków