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LOW-POWER FANS AS A SOURCE OF ENERGY IN PIPELINE TRANSPORTATION

This paper presents results of experimental tests conducted in the Chair of Thermal Engineering of Poznan University of Technology dedicated to determination of efficiency of low-power barrel fans. Operation parameters of fans produced for industry were checked with respect to the requirements of Directive 2009/125/EC of the European Parliament. Experimental tests allow determining the efficiency of fans and comparing them to values determined according to the European Directive. Test results are presented on graphs as functions of air volume flow. Those characteristics comprise distributions of total pressure, electric power absorbed by the motor and fan's efficiency. Obtained results indicate that there is a need to develop new guidelines. They should concern those efficiencies of low-power fans which are not covered by Directive 2009/125/EC of the European Parliament.

Keywords:fans, fan's efficiency, pipeline transportation

1. INTRODUCTION

This article presents results of tests on low-power barrel fans being a source of energy in pipeline transportation. Thirteen fans produced in an enterprise with along history from Wielkopolska Province being delivered to pipeline installations and energy producers were analyzed. The purpose of the this article is to compare the results of tests with the Resolution of the Minister of Economy of 11 March

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2014 implementing the changes in the performance of Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW. To check the application of Directive's requirements to the fans driven by motors with an electric input power below 125 W, twelve fans of power ranging from 10 W to 125 W were tested.

2.DESCRIPTION OF DIRECTIVE 2009/125/EC OF THE EUROPEAN PARLIAMENT

Directive 2009/125/EC of the European Parliament and of the Council [9] was implemented to reduce electric energy consumption as a result of technology development and improvement of the design, raising the energy efficiency of fans used for gas transportation. This Directive concerns fans driven by motors of an electric input power between 125 W and 500 kW. Such fans are devices dedicated to transport gases for relatively short distances when resistances to motion are not lower than several dozen or a few hundred Pascals. Fans of similar power serve as devices supporting medium transportation in pipeline systems. For the European market, energy consumption of fans described above is 344 TWh per year. If current Union market trends persist, in 2020 it will raise to 560 TWh. With regard to the project being implemented by the European Union, requirements for fans were established. In its main part, the Directive presents information on how to calculate the minimum energy efficiency of a fan.

First, the division according to the methodology of tests on fans was made. Four measurement categories defining the arrangement of measurements and the inlet and outlet conditions of the fan were distinguished:

– 'measurement category A' – the fan is measured with free inlet and outlet conditions,

– 'measurement category B' – the fan is measured with free inlet and with a duct fitted to its outlet,

– 'measurement category C' – the fan is measured with a duct fitted to its inlet and with free outlet conditions,

–'measurement category D' – the fan is measured with a duct fitted to its inlet and outlet.

Furthermore, the Directive differentiates fans with regard to their construction; it sets apart axial fans, centrifugal forward curved fans, centrifugal radial bladed fans, centrifugal backward curved fans without housing, centrifugal backward curved fans with housing, mixed flow fans, and barrel fans. The last division is made with regard to the fan's efficiency:

–static (determining based on static pressure increase),

–total (determining based on the total pressure increase).

Based on the construction classification, methodology of tests and efficiency categories, minimum energy efficiency requirements for a fan are determined.

3. TEST METHOD

Figure 1 presents a scheme of a measurement stand designed to test low-power fans.

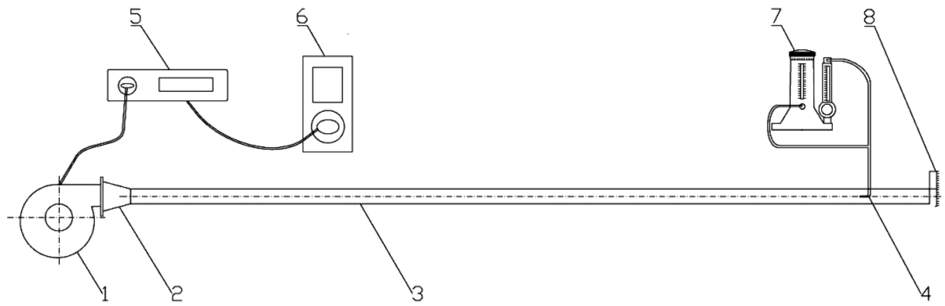

Fig. 1. Scheme of a measurement stand: 1– fan, 2 – confusor, 3 – measuring channel, 4 – Prandtl probe, 5 – fan's operation regulator, 6 – wattmeter, 7 – compensation micro-manometer, 8 – flap valve [6]

Barrel forward curved fans [1, 2, 8, 9] were the subject of tests. Those fans were tested using the arrangement where the fan is measured with free inlet and with a duct fitted to its outlet [3, 4, 5, 6]. To the outlet port of the fan a confusor serving as aconnector between the fan and the measuring discharge channel was installed. Inclination angle of the confusor walls was 15°. The inner diameter of the measuring channel was 75 mm. At the distance of 3.7 m from the start of the measuring channel the Prandtl probe was installed. An advantage of using the Prandtl pipe is its low sensitivity to inaccurate levelling of the medium stream flowing through it. The pipe deflection of the flow direction below 6°brings low measurement error. With the deflection of 15° this error is not higher than 2.5% [7]. A compensation micro-manometer was used to measure the total and dynamic pressure. Due to a high accuracy of readings, being of ±0.02 mm, the compensation micro-manometer is used to calibrate and check other measuring manometers. At the outlet of the measuring channel a flap valve was installed to reduce the flow area of the channel, i.e. to change the air volume flow. As a chocking device, the gate valve moving perpendicular to the axis of the channel was used. An inverter was used to control motor speed. To measure the input power, a wattmeter measuring momentary energy consumption was used.

Conducted tests allowed to measure and calculate the following quantities describing fans under tests: Δp_c – total pressure increase, P – electric power consumed bythe fan, η – total efficiency of the fan, $\dot{V}$ – volume flow of the air flowing through the fan.

The formula (1) from Directive 2009/125/EC used to determine the minimum required energy efficiency that should be obtained by a fan is presented below:

$$\eta_d = 2{,}74 \cdot \ln(P) - 6{,}33 + N \tag{1}$$

where: η_d – energy efficiency, P – input power of the fan, N – energy efficiency grade (depending on the test methodology, type of fan and the efficiency).

4. TEST RESULTS

Figures from 2 to 13 present characteristics of total pressure increase, efficiency and power varying in a function of air volume flow for fans of electric power lower than 125 W, obtained based on tests made on the measuring stand in the Chair of Thermal Engineering of Poznan University of Technology. Fans under tests were produced by well-known manufacturer of flow devices from western Wielkopolska. Graphs show the increase in the input electric power and the decrease in pressure increase with the volume flow increase. Measurements were made for maximum motor speeds n .

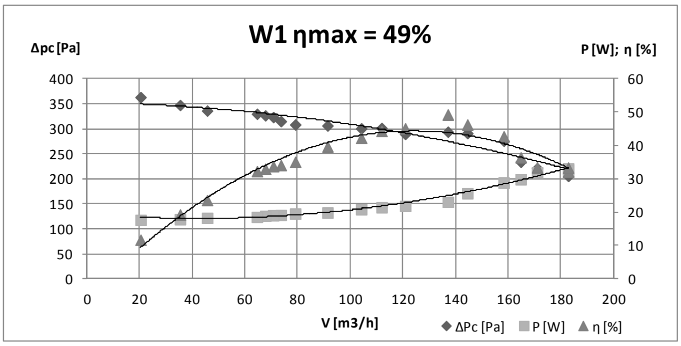

Fig. 2. Characteristics of fan W1

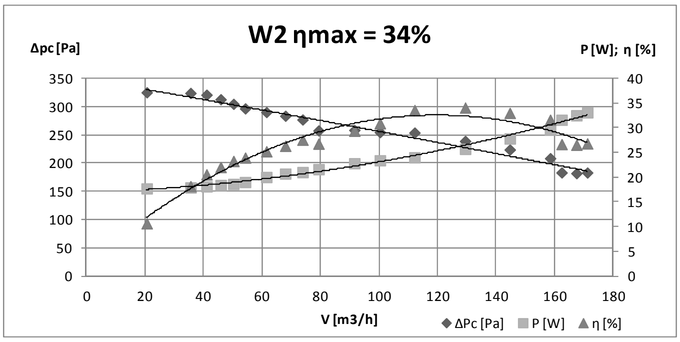

Fig. 3. Characteristics of fan W2

Figure 2 presents the characteristics of fan W1. The air volume flow ranges from 20 m^3/h to 183 m^3/h. With the increase of the volume flow, the pressure decreases from 325 Pa to 183 Pa, and the electric power increases from 18 W to 33 W. Efficiency characteristics has the shape of parabola. Efficiency increases from 12 % to 49 % and for the volume flow equal to 137 m^3/h, it breaks and starts to decrease to 32 %. Figure 3 presents the characteristics of fan W2. With the increase of the volume flow from 20 m^3/h to 171 m^3/h, a decrease of pressure from 364 Pa to 206 Pa and the increase of consumed power from 18 W to 33 W were observed. Efficiency characteristics also has the shape of parabola. The efficiency grows from 11 % to 34 % and for the volume flow equal to 129 m^3/h, it breaks and starts to decrease to 27 %.

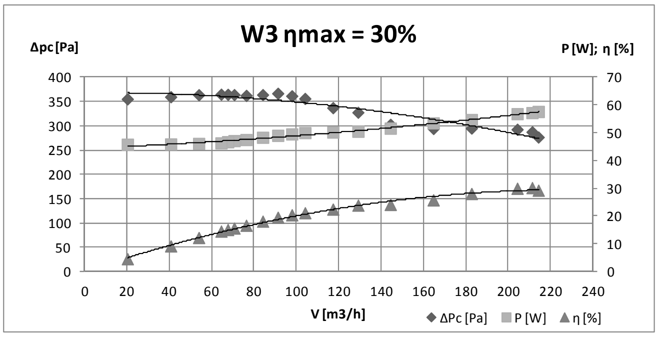

Fig. 4. Characteristics of fan W3

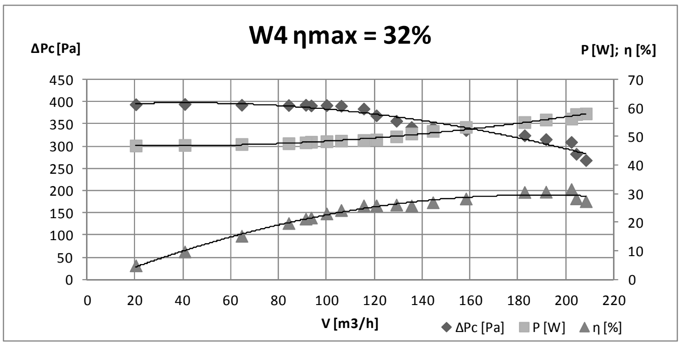

Fig. 5. Characteristics of fan W4

Figure 4 presents the characteristics of fan W3. The volume flow ranges from 20 m^3/h to 214m^3/h. With its increase, the pressure decreases from 354 Pa to 276 Pa and the power consumption increases from 46 W to 58 W. With the increase of volume flow, the efficiency increases from 4 % to 30% and for the volume flow equal to 204 m^3/h it starts to decrease to 29 %. Figure 5 presents the characteristics of fan W4. The volume flow ranges from 20 m^3/h to 208m^3/h. With its increase, the pressure decreases from 394 Pa to 268 Pa and the power consumption increases from 47 W to 58 W. With the increase of volume flow, the efficiency increases from 5 % to 32% and for the volume flow equal to 202 m^3/h it starts to decrease to 27 %. Figure 6 shows the characteristics of fan W5. The volume flow ranges from 35 m^3/h to 289 m^3/h. With its increase, the pressure decreases from 583 Pa to 431 Pa, and the power consumption increases from 85 W to 110 W. With the increase of volume flow, the efficiency increases from 7 % to 32 %. Figure 7 presents the characteristics of fan W6. The volume flow ranges from 35 m^3/h to 224 m^3/h. With its increase, the pressure decreases from 271 Pa to 368 Pa, and the power consumption increases from 48 W to 62 W. With the increase of volume flow, the efficiency increases from 8 % to 31 % and for the volume flow equal to 183 m^3/h it starts to decrease to 27 %.Figure 8 presents the characteristics of fan W7. The volume flow ranges from 35 m^3/h to 224 m^3/h. With its increase, the pressure decreases from 368 Pa to 299 Pa and the power consumption increases from 44 W to 56 W. With the increase of volume flow, the efficiency increases from 8 % to 35 % and for the volume flow equal to 183 m^3/h it starts to decrease to 34 %.

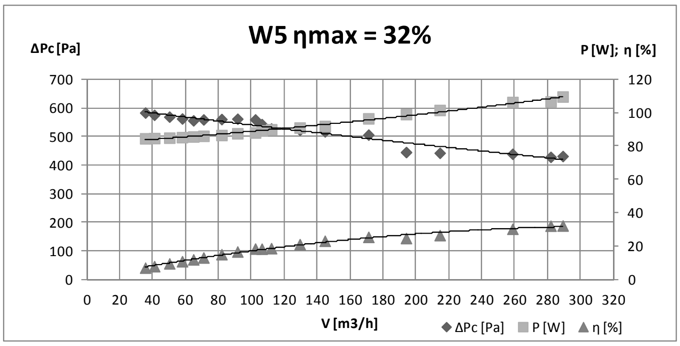

Fig. 6. Characteristics of fan W5

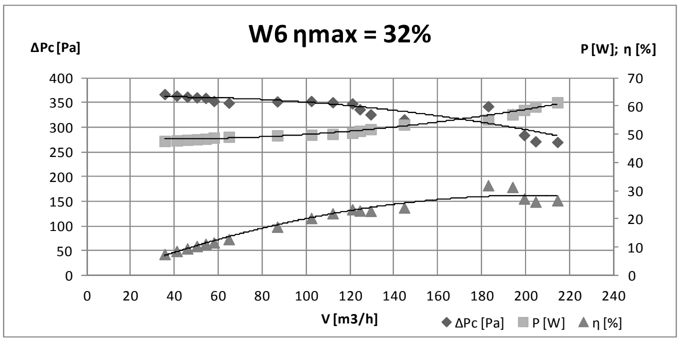

Fig. 7. Characteristics of fan W6

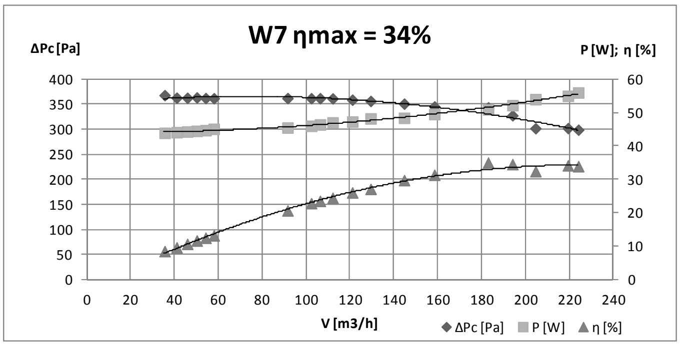

Fig. 8. Characteristics of fan W7

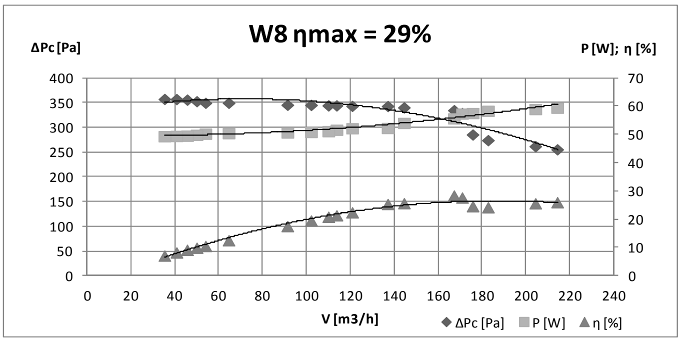

Fig. 9. Characteristics of fan W8

Figure 9 presents the characteristics of fan W8. The volume flow ranges from 35 m^3/h to 214 m^3/h. With its increase, the pressure decreases from 358 Pa to 256 Pa and the power consumption increases from 50 W to 60 W. With the increase of volume flow, the efficiency increases from 7 % to 29 % and for the volume flow equal to 167 m^3/h it starts to decrease to 26 %.

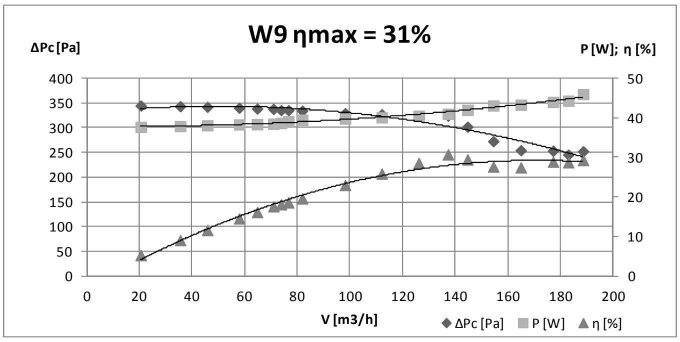

Fig. 10. Characteristics of fan W9

Figure 10 presents the characteristics of fan W9. The volume flow ranges from 20 m^3/h to 188 m^3/h. With its increase, the pressure decreases from 345 Pa to 252 Pa and the power consumption increases from 8 W to 45 W. With the increase of volume flow, the efficiency increases from 5 % to 31 % and for the volume flow equal to 137 m^3/h it starts to decrease to 29 %.

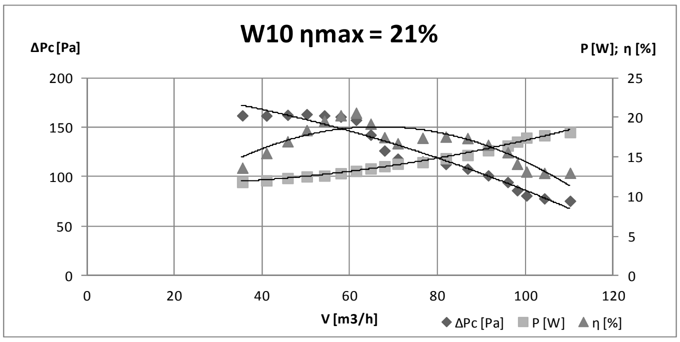

Fig. 11. Characteristics of fan W10

Figure 11 presents the characteristics of fan W10. The volume flow ranges from 35 m^3/h to 110 m^3/h. With its increase, the pressure decreases from 162 Pa to 76 Pa and the power consumption increases from 12 W to 18 W. With the increase of volume flow, the efficiency increases from 14 % to 21 % and for the volume flow equal to 61 m^3/h it starts to decrease to 13 %.

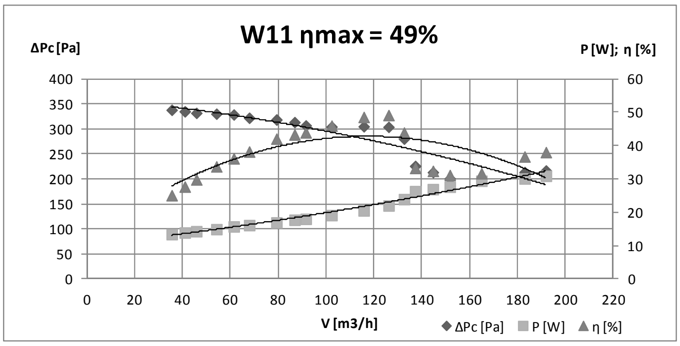

Fig. 12. Characteristics of fan W11

Figure 12 presents the characteristics of fan W11. The volume flow ranges from 35 m^3/h to 192 m^3/h. With its increase, the pressure decreases from 339 Pa to 217 Pa and the power consumption increases from 14 W to 31 W. With the increase of volume flow, the efficiency increases from 25 % to 49 % and for the volume flow equal to 126 m^3/h it starts to decrease to 31 %.

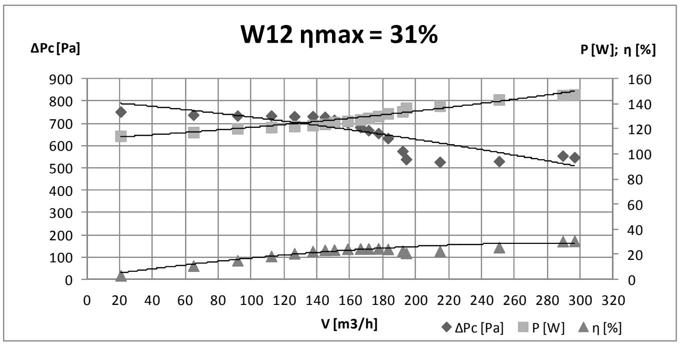

Fig. 13. Characteristics of fan W12

Figure 13 presents the characteristics of fan W12. The volume flow ranges from 20 m^3/h to 296 m^3/h. With its increase, the pressure decreases from 756 Pa to 551 Pa and the power consumption increases from 14 W to 31 W. With the increase of volume flow, the efficiency increases from 4 % to 31 %.

Figures from 14 to 16 present characteristics of relative quantities compared with the volume flow for fan W13 with electric input power higher than 125 W. Measurements were made for different values of motor speed *n*, 100 %, 86 %, 72 %, 58 %, 44 %, and 31 % of the maximum speed, respectively. The volume flow for speeds under test was as follows:

–for n = 100 %, the volume flow increases from 65 m^3/h to 296 m^3/h,
–for n = 86 %, the pressure decreases from 68 m^3/h to 303 m^3/h,
– for n = 72 %, the pressure decreases from 65 m^3/h to 289 m^3/h,
– for n = 58 %, the pressure decreases from 65 m^3/h to 274 m^3/h,
– for n = 44 %, the pressure decreases from 65 m^3/h to 267 m^3/h,
–for n = 31 %, the pressure decreases from 65 m^3/h to 229 m^3/h.

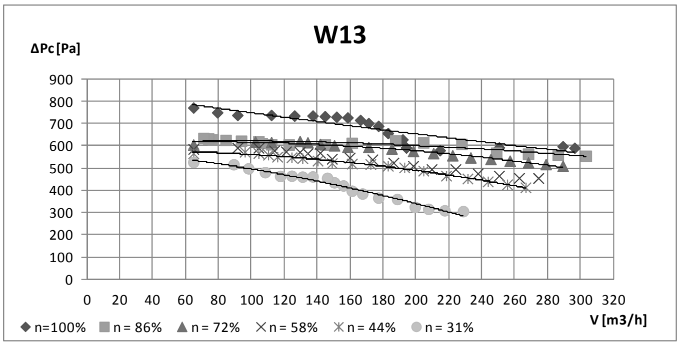

Fig. 14. Characteristics ΔPc for fan W13

In figure 14 we may notice the decrease of pressure with the increase of air volume flow. This dependence repeats for all motor speeds. For subsequent motor speeds, the pressure decrease was as follows:

–for n = 100 % the pressure decreased from 771 Pa to 590 Pa,
–for n = 86 % the pressure decreased from 636 Pa to 554 Pa,
–for n = 72 % the pressure decreased from 605 Pa to 509 Pa,
–for n = 58 % the pressure decreased from 585 Pa to 455 Pa,
–for n = 44 % the pressure decreased from 566 Pa to 413 Pa,
–for n = 31 % the pressure decreased from 526 Pa to 305 Pa.

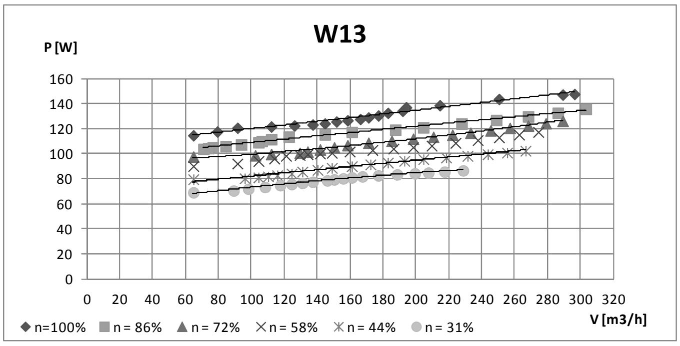

Fig. 15. Characteristics P for fan W13

In figure 15 we may notice the increase of consumed electric power with the increase of air volume flow. This dependence repeats for all motor speeds. For subsequent motor speeds, the pressure increase was as follows:

–for n = 100 %, the electric power increased from 115 W to 148 W,
–for n = 86 %, the electric power increased from 103 W to 136 W,
– for n = 72 %, the electric power increased from 98 W to 127 W,
– for n = 58 %, the electric power increased from 91 W to 118 W,
– for n = 44 %, the electric power increased from 80 W to 103 W,
– for n = 31 %, the electric power increased from 70 W to 87 W.

Figure 16 presents efficiencies characteristics. Efficiency characteristics for motor speed n = 31 % has the shape of parabola. Efficiency increases with the volume flow from 14 % to 24 % and for the volume flow equal to 146 m^3/h, it starts todecrease to 22 %.In case of other motor speeds:

–for n = 100 %, the efficiency increased from 12 % to 33 %,
–for n = 86 %, the efficiency increased from 12 % to 35 %,
– for n = 72 %, the efficiency increased from 11 % to 33 %,
– for n = 58%, the efficiency increased from 12 % to 30 %,
– for n = 44 %, the efficiency increased from 13 % to 30 %.

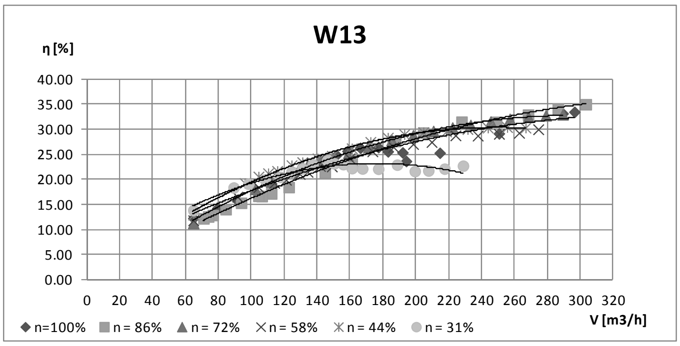

Fig. 16. Characteristics η for fan W13

Table 1 presents a comparison of efficiencies obtained as a result of test measurements and efficiencies calculated based on the Directive.

Table 1

Comparison of results for fans' efficiencies

Fan symbol	Electric power P [W]	Efficiency obtained in tests η[%]	Efficiency calculated based on the Directive η_d[%]
W1	33	**49**	45
W2	33	34	45
W3	58	30	47
W4	58	32	47
W5	110	32	49
W6	62	32	47
W7	56	34	47
W8	60	29	47
W9	45	31	46
W10	18	21	44
W11	31	**49**	45
W12	54	29	47
W13	148	35	49

5. CONCLUSIONS

The purpose of this article was to compare results of tests of 13 barrel fans with regard to obtained efficiencies and the requirements of the Resolution of the Minister of Economy of 11 March 2014 implementing the changes in the performance of

Directive 2009/125/EC of the European Parliament and of the Council [9] with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW. Having tested twelve fans (W1÷W12) in respect of electric power consumption ranging from 10 W to 125 W, we may observe that more than 80 % of them would not meet requirements concerning the minimum energy efficiency described by the Directive. With regard to the above, appropriate resolution comprising requirements for fans from this class, based on the results of tests on already-existing fans should be drawn up. Fan W13, driven by an electric motor of power higher than 125 W, which means that it was a subject of the Directive, was tested as thirteen one. This fan also did not meet the requirements defined in the Directive. Its efficiency was lower by 14 % than the efficiency calculated based on the Directive. With regard to that it is justified to formulate a motion to Polish Committee for Standardization to verify the above-mentioned resolution.

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[5] PN-81/M-42366Pomiary przepływu płynu. Pomiary strumienia objętości metodami całkowania bryły prędkości.
[6] PN-81/M-42367 Pomiary przepływu płynu. Pomiary prędkości przepływu za pomocą rurek spiętrzających.
[7] PN-ISO 5221 Rozprowadzanie i rozdział powietrza. Metody pomiaru przepływu strumienia powietrza w przewodzie.
[8] PN-M-43011Wentylatory, Podział i terminologia.
[9] Rozporządzenie Komisji (UE) nr 327/2011 z dnia 30 marca 2011 r. w sprawie wykonania dyrektywy Parlamentu Europejskiego i Rady 2009/125/WE w odniesieniu do wymogów dotyczących ekoprojektu dla wentylatorów napędzanych silnikiem elektrycznym o poborze mocy od 125 W do 500 kW.
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ZASTOSOWANIE DMUCHAW W TRANSPORCIE RUROCIĄGOWYM

Streszczenie

W artykule przedstawiono wyniki badań eksperymentalnych, prowadzonych w Katedrze Techniki Cieplnej Politechniki Poznańskiej, mających na celu wyznaczenie sprawności wentylatorów bębnowych małej mocy. Zgodnie z dyrektywą Parlamentu Europejskiego numer 2009/125/WE, sprawdzono parametry pracy wentylatorów produkowanych na potrzeby przemysłu. Badania eksperymentalne pozwoliły określić sprawność maszyn i porównać ją z wartościami wyznaczonymi zgodnie z dyrektywą unijną. Wyniki badań przedstawiono na wykresach w funkcji strumienia objętości przepływającego powietrza. Charakterystyki obejmują rozkłady ciśnienia całkowitego, mocy elektrycznej pobieranej przez napęd oraz sprawności wentylatora. Uzyskane wyniki wskazują na konieczność opracowania nowych wytycznych uwzględniających sprawność osiąganą przez wentylatory małej mocy, nieujęte w rozporządzeniu Parlamentu Europejskiego numer 2009/125/WE.