Open Access Journal

Journal of Power Technologies 97 (1) (2017) 69–74

journal homepage:papers.itc.pw.edu.pl

Characteristics of fans used in low-power boilers

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Abstract

This paper presents the results of tests conducted in the Chair of Thermal Engineering of Poznan University of Technology dedicated to determining the efficiency of low-power barrel fans, which are used in low-power boilers. Operation parameters of fans produced for industry were checked with respect to the requirements of Directive 2009/125/EC of the European Parliament. The tests were used to determine the efficiency of fans and to compare them against values determined according to the European Directive. The 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 efficiency. The 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 efficiency; pipeline transportation; low-power fans; low-power boiler

1. Introduction

This article presents results of tests on low-power barrel fans, which are a source of energy in pipeline transportation. Thirteen fans produced by a long-established enterprise in Wielkopolska Province, Poland for supply to pipeline installations and energy producers were analyzed. The purpose of this article is to compare the results of the tests with 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 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 the Directive's requirements to the fans driven by motors with an electric input power below 125 W, twelve fans ranging in power from 10 W to 125 W were tested. Earlier areas of interest of the authors included research energy boilers [1] and aerodynamic analysis of gas flow by recirculating [2] including the combustion chamber.

2. Description of Directive 2009/125/EC of the European Parliament

Directive 2009/125/EC [3] was implemented to reduce electric energy consumption through development of technology and improved design, raising the energy efficiency of fans used for gas transportation. The Directive concerns fans driven by motors with an electric input power of between 125 W and 500 kW. Fans of this type are used to transport gases over relatively short distances, when resistance to motion is not lower than several dozen or a few hundred Pascals. Fans of similar power serve as devices supporting medium level transportation in pipeline systems. For the European market, the energy consumption of the fans described above is 344 TWh per year. If current EU market trends persist, in 2020 it will raise to 560 TWh. Requirements for fans were established with regard to the project being implemented by the EU. In its main part, the Directive presents information on how to calculate the minimum energy efficiency of a fan.

First, a 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.

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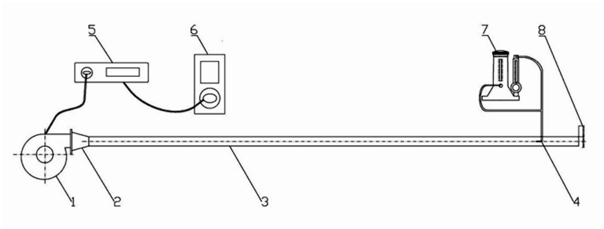

Figure 1: Schematic diagram of the measurement stand: 1—fan, 2—confusor, 3—measuring channel, 4—Prandtl probe, 5—fan operation regulator, 6—wattmeter, 7—compensation micro-manometer, 8—flap valve [4]

The Directive differentiates fans with regard to their construction. It deals separately with 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 total pressure increase).

Minimum energy efficiency requirements for fans are determined based on the construction classification, methodology of tests and efficiency categories.

3. Test method

Barrel forward curved fans [3, 5–7] were subject to testing. The fans were tested using the arrangement (Fig. 1) where the fan is measured with free inlet and with a duct fitted to its outlet [4, 8–10]. A confusor serving as a connector between the fan and the measuring discharge channel was installed on the outlet port of the fan. The inclination angle of the confusor walls was 15°.

The inner diameter of the measuring channel was 75 mm. The Prandtl probe was installed at a distance of 3.7 m from the start of the measuring channel. One 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° achieves low measurement error. With deflection of 15° this error is not higher than 2.5% [11]. A compensation micro-manometer was used to measure total and dynamic pressure. Due to the high accuracy of readings, ±0.02 mm, a 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. A gate valve moving perpendicular to the axis of the channel was used as a chocking device. An inverter was used to control motor speed. To measure input power, a wattmeter measuring momentary energy consumption was used. The tests were used to measure and calculate the following quantities describing the fans: Δp_c—total pressure increase, P—electric power consumed by the fan, η—total efficiency of the fan, V—volume flow of the air flowing through the fan.

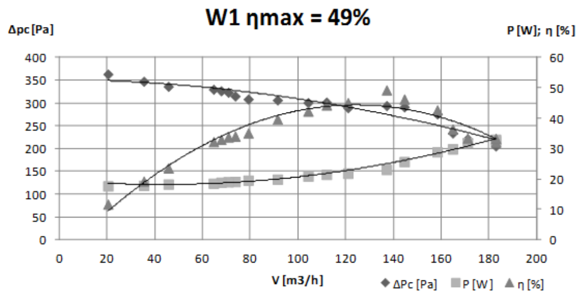

Figure 2: Characteristics of fan W1

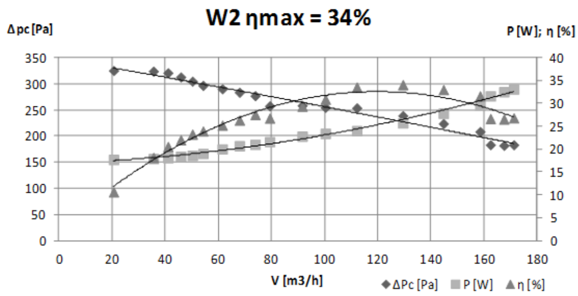

Figure 3: Characteristics of fan W2

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:

$$\eta_d = 2.74 \cdot \ln(P) - 6.33 + N \quad (1)$$

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

4. Results and discussion

Figures from 2 to 13 present the characteristics of total pressure increase, efficiency and power varying as 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. The fans subject to testing were produced by a well-known manufacturer of flow devices. The graphs show an increase in input electric power and a decrease in pressure increase with the volume flow increase. Measurements were made for maximum motor speeds n.

Fig. 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 in volume flow, the pressure decreases from 325 Pa to 183 Pa, and the electric power increases from 18 W to 33 W. The efficiency characteristics are parabolic in shape. Efficiency increases from 12% to 49% and for volume flow of 137 m^3/h, it breaks and starts to decrease to 32%. Fig. 3 presents the characteristics of fan W2. With the increase in volume flow from 20 m^3/h to 171 m^3/h, a decrease in pressure from 364 Pa to 206 Pa and an increase in consumed power from

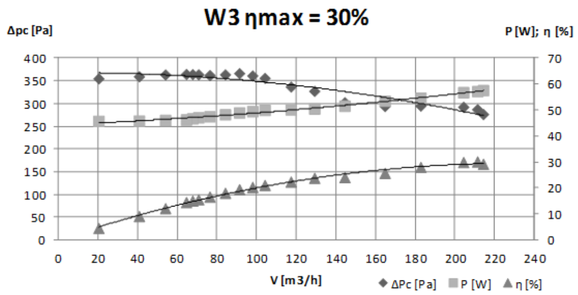

Figure 4: Characteristics of fan W3

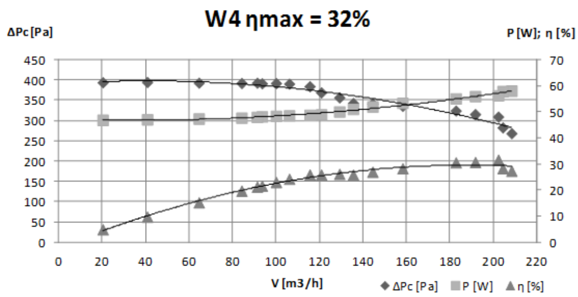

Figure 5: Characteristics of fan W4

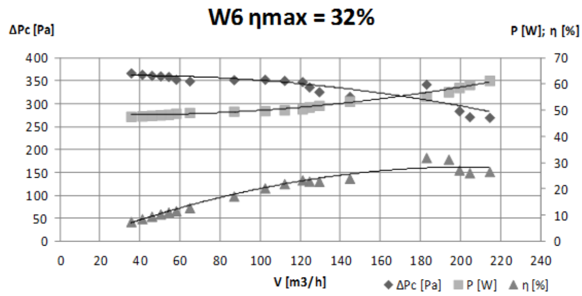

Figure 7: Characteristics of fan W6

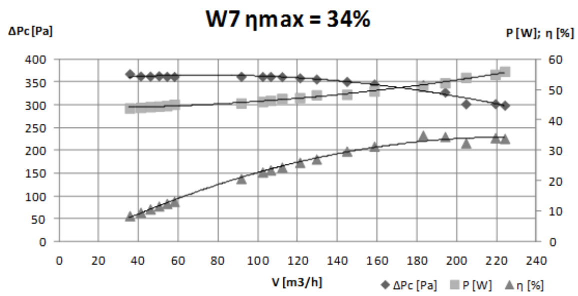

Figure 8: Characteristics of fan W7

18 W to 33 W were observed. The efficiency characteristics are parabolic in shape. Efficiency rises from 11% to 34% and for volume flow of 129 m^3/h, it breaks and starts to decrease to 27%.

Fig. 4 presents the characteristics of fan W3. The volume flow ranges from 20 m^3/h to 214 m^3/h. With the increase in volume flow, the pressure decreases from 354 Pa to 276 Pa and the power consumption increases from 46 W to 58 W. With the increase in volume flow, efficiency increases from 4% to 30% and for volume flow of 204 m^3/h it starts to decrease to 29%. Fig. 5 presents the characteristics of fan W4. The volume flow ranges from 20 m^3/h to 208 m^3/h. With the increase in volume flow, the pressure decreases from 394 Pa to 268 Pa and the power consumption increases from 47 W to 58 W. With the increase in volume flow, efficiency increases from 5% to 32% and for volume flow of 202 m^3/h it starts to decrease to 27%. Fig. 6 shows the characteristics of fan W5. The volume flow ranges from 35 m^3/h to 289 m^3/h. With the increase in volume flow, the pressure decreases from 583 Pa to 431 Pa, and the power consumption increases from 85 W to 110 W. With the increase in volume flow, efficiency increases from 7% to 32%.

Fig. 7 presents the characteristics of fan W6. The volume flow ranges from 35 m^3/h to 224 m^3/h. With the increase in volume flow, the pressure decreases from 271 Pa to 368 Pa, and the power consumption increases from 48 W to 62 W. With the increase in volume flow, efficiency increases from 8% to 31% and for volume flow of 183 m^3/h it starts to decrease to 27%. Fig. 8 presents the characteristics of fan W7. The volume flow ranges from 35 m^3/h to 224 m^3/h. With the increase in volume flow, the pressure decreases from 368 Pa to 299 Pa and the power consumption increases from 44 W to 56 W. With the increase in volume flow, efficiency increases from 8% to 35% and for volume flow of 183 m^3/h it starts to decrease to 34%.

Fig. 9 presents the characteristics of fan W8. The volume flow ranges from 35 m^3/h to 214 m^3/h. With the increase in volume flow, the pressure decreases from 358 Pa to 256 Pa

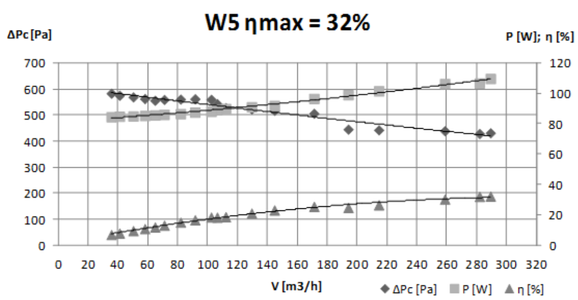

Figure 6: Characteristics of fan W5

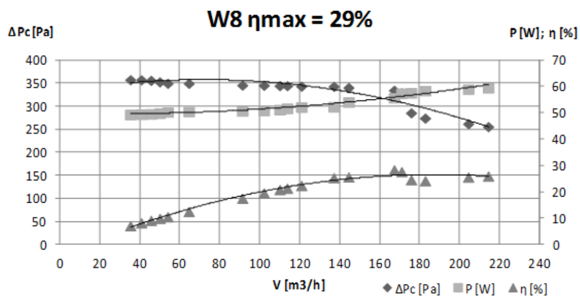

Figure 9: Characteristics of fan W8

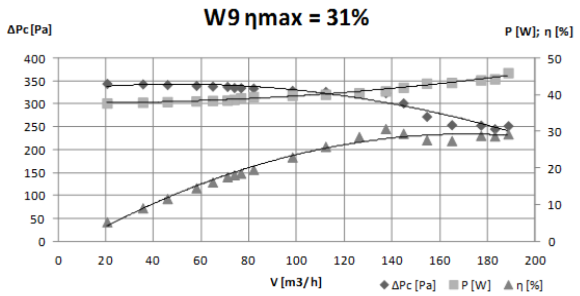

Figure 10: Characteristics of fan W9

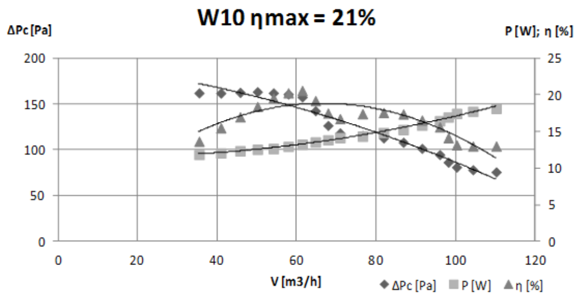

Figure 11: Characteristics of fan W10

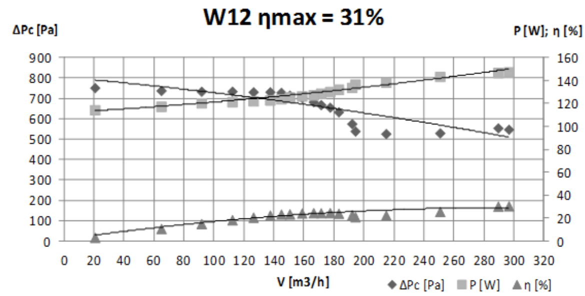

Figure 13: Characteristics of fan W12

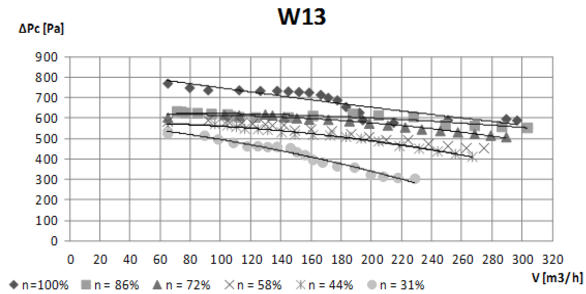

Figure 14: Characteristics of ΔPc for fan W13

and the power consumption increases from 50 W to 60 W. With the increase in volume flow, the efficiency increases from 7% to 29% and for volume flow of 167 m^3/h it starts to decrease to 26%. Fig. 10 presents the characteristics of fan W9. The volume flow ranges from 20 m^3/h to 188 m^3/h. With the increase in volume flow, the pressure decreases from 345 Pa to 252 Pa and the power consumption increases from 8 W to 45 W. With the increase in volume flow, efficiency increases from 5% to 31% and for volume flow of 137 m^3/h it starts to decrease to 29%.

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

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

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

Figures from 14 to 16 present the characteristics of relative quantities compared with 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 subject to testing was as follows:

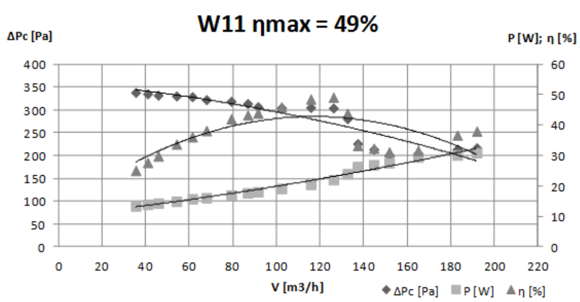

Figure 12: Characteristics of fan W11

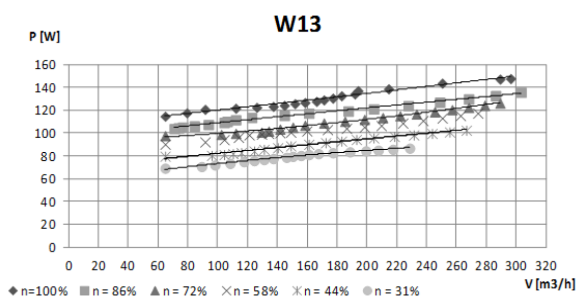

Figure 15: Characteristics of P for fan W13

- 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 shows a decrease in pressure as air volume flow increases. 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 shows an increase in consumed electric power as air volume flow increases. 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.

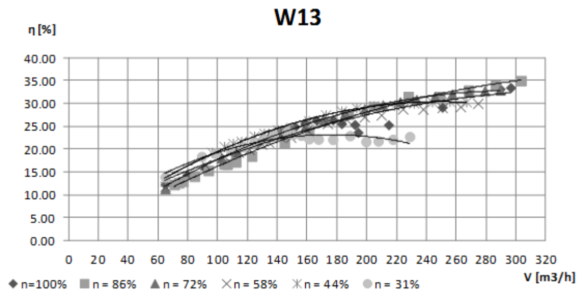

Figure 16: Characteristics of η for fan W13

Table 1: Comparison of results for fan efficiency

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

Fig. 16 presents efficiency characteristics. Efficiency characteristics for motor speed n = 31% is parabolic in shape. Efficiency increases with the volume flow from 14% to 24% and for the volume flow of 146 m^3/h, it starts to decrease to 22%. In the case of other motor speeds:

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

5. Conclusions

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

The purpose of this article was to compare the results of tests on 13 barrel fans with regard to obtained efficiencies and the requirements of the Resolution of the Minister of Economy of 11 March 2014 implementing changes in performance of Directive 2009/125/EC of the European Parliament and of the Council [3] with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW. Having tested thirteen fans, more than 80% of them would not meet requirements concerning minimum energy efficiency described by the Directive. With regard to the above, an appropriate resolution comprising requirements for fans of this class, based on the results of tests on already-existing fans, should be drawn up and it is justified to formulate a motion to the Polish Committee for Standardization to verify the aforementioned resolution.

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