ZIEHL-ABEGG SE

Guide vane for agricultural applications

Plume rise

DLG Test Report 5642F

Description

- Component for installation in an exhaust stack with a diameter of 650 mm
- Designed to increase plume height
- Guide vanes are intended to reduce swirl in the flow and thereby to increase the exhaust flow velocity in the axial direction
- Fitted in the exhaust stack approx. 20 mm downstream of the fan installed in the pipe
- Bolted to the exhaust stack pipe in four places
- Designed as circular component with 13 curved guide vanes
- Made of plastic

Main technical data

No. 00701710

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>87 mm</td>
</tr>
<tr>
<td>Diameter</td>
<td>645 mm</td>
</tr>
<tr>
<td>Mass</td>
<td>1.43 kg</td>
</tr>
</tbody>
</table>
Assessment – Brief Summary

Using the guide vane for agricultural applications increases axial flow concentration by reducing swirl at the air outlet of the exhaust stack. The core flow area is significantly more pronounced and more stable. Especially when there is no wind or at low wind speeds, this leads to an increase in plume rise. At the nominal power (100% speed) or at only slightly reduced fan speed, and at wind speeds of up to 10 m/s, the determined plume rises were between approx. 2 and 4 m higher than without a guide vane. Further reductions in fan speed lead to significantly lower plume rises and, accordingly, a smaller difference in the achieved plume rise.

Assessment

<table>
<thead>
<tr>
<th>Test criterion</th>
<th>Test result</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plume rise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Distance increase</td>
<td>2 to 4 m</td>
<td>+</td>
</tr>
<tr>
<td>– Speed increase</td>
<td>1.5 to 1.8 m/s at a distance of 4 m from outlet</td>
<td>+</td>
</tr>
<tr>
<td>– Spec. power consumption</td>
<td>Approx. 2 W/1000 m³/h additional consumption</td>
<td>+</td>
</tr>
</tbody>
</table>

Evaluation range: ++ / + / ○ / - / -- (○ = standard)

The following evaluation scheme is applied in the DLG Focus Test "Plume rise":

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Distance increase (m)</th>
<th>Speed increase (m/s)</th>
<th>Spec. additional power consumption (W/1000 m³/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>++</td>
<td>&gt; 6</td>
<td>&gt; 3</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>+</td>
<td>&gt; 3</td>
<td>&gt; 1.5</td>
<td>&lt; 2.5</td>
</tr>
<tr>
<td>○</td>
<td>&gt; 1</td>
<td>&gt; 0.5</td>
<td>&lt; 5.0</td>
</tr>
</tbody>
</table>

* At nominal voltage and with the voltage reduced by approx. 20%, wind speed < 4.5 m/s, and 10 Pa resistance of the assumed ventilation system
Test Conditions and Execution

The DLG Focus Test “Plume rise” was conducted as a laboratory test and in practical use. All measurements were taken as comparative measurements on an exhaust stack system with and without a guide vane installed.

Using numeric flow simulation, plume rises were calculated under various conditions by the Institute of Technology and Biosystems Engineering of the Federal Agricultural Research Centre (FAL Braunschweig). Calculations were performed using the CFD flow simulation program COMET, which can be used to calculate flows through and around buildings.

In the laboratory test, measurements were taken using the DLG test chamber for fans to determine the flow profile at various fan voltage levels. For this purpose, the airflow velocity was determined with a hot-wire anemometer at the following set of measuring points:

- a horizontal measuring plane at the central axis of the air flow;
- at 1 m intervals starting from the air outlet on the diffuser, up to a distance of 10 m;
- at right angles to the central axis on both sides at distances of: 0, 25, 50, 75 and 100 cm.

In practical use, comparative flue-gas analyses were carried out on a stable (pig fattening house with a total of 875 places, compartment size: 175 places). In the course of this, the discharge behaviour of the coloured plume was observed under identical conditions.

The test was conducted using a Big Dutchman CL-600 exhaust stack system with an internal stack diameter of 650 mm and a total length of approx. 4,100 mm. This consists of the following elements:

- inlet nozzle (200 mm long);
- 1st pipe section*) with axial-flow fan (manufacturer: Ziehl-Abegg AG, type: FC063-6ET.41.3, single-phase, adjustable voltage, 0.6 kW, 890 rpm);
- five further pipe sections*), top ring (400 mm long) and diffuser*.

The guide vane was installed in the second pipe section directly following the axial-flow fan.

Figure 1: Installation position of the guide vane in the exhaust stack system (example cross-sectional representation; the total length shown here is shorter than in the test unit as there are fewer pipe sections)

*) Each 500 mm long
Test Results

I. Laboratory test

The characteristic values of the exhaust stack system differ depending on whether or not the guide vane is installed. Figure 2 shows the air flow-rate measurement results for the tested configuration. Table 1 contains an overview of the key characteristic values from the comparative measurements with and without the guide vane. With the guide vane installed, the air volume flow is reduced by 2.5 to 7% at the same operating voltage; the lower the voltage, the greater the percentage difference. At the same volume flow rate, the pressure loss with the guide vane is ~ 6 Pa (Figure 4) at nominal voltage and at an assumed resistance of 10 Pa of the assumed ventilation system. This result is reflected in the values for the specific electrical power. With the guide vane installed, the system consumes an additional ~ 2 W, or ~ 6% more electrical energy, per 1,000 m³/h of exhaust volume flow.

Figures 3, 4 and 5 show the results for the flow profile after the exhaust air is discharged from the exhaust stack system at nominal voltage. It can be seen that, as a result of the guide vane’s swirl-reducing effect, the velocity profile fans out less in the radial direction and that a significantly more pronounced core flow area with a higher overall speed level develops in the axial direction. For example, with the guide vane, a speed of 4 m/s is still achieved in the core flow after a distance of ~ 7 m. In contrast, without the guide vane, the speed already drops below this value after ~ 3 m. These tendencies also persist in normal operation, i.e. with reduced voltages (Table 2). The speed differs by 1 to 2 m/s, with the higher values primarily occurring in the 2–4 m distance range.

Table 1:
Characteristic values with and without guide vane at 10 Pa constant resistance of an assumed ventilation system

<table>
<thead>
<tr>
<th>Electrical voltage V</th>
<th>With</th>
<th>Without</th>
<th>Volume flow rate difference</th>
<th>Specific electrical power</th>
<th>With</th>
<th>Without</th>
<th>Specific electrical power difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>230</td>
<td>12890</td>
<td>13220</td>
<td>-330</td>
<td>-2.5</td>
<td>37.9</td>
<td>35.9</td>
<td>2.0</td>
</tr>
<tr>
<td>180</td>
<td>11500</td>
<td>11990</td>
<td>-490</td>
<td>-4.1</td>
<td>34.7</td>
<td>32.7</td>
<td>2.0</td>
</tr>
<tr>
<td>160</td>
<td>10210</td>
<td>10690</td>
<td>-480</td>
<td>-4.5</td>
<td>35.1</td>
<td>33.0</td>
<td>2.1</td>
</tr>
<tr>
<td>140</td>
<td>8150</td>
<td>8500</td>
<td>-350</td>
<td>-4.1</td>
<td>36.4</td>
<td>34.4</td>
<td>2.0</td>
</tr>
<tr>
<td>120</td>
<td>6200</td>
<td>6510</td>
<td>-310</td>
<td>-4.8</td>
<td>37.3</td>
<td>35.0</td>
<td>2.3</td>
</tr>
<tr>
<td>100</td>
<td>4160</td>
<td>4450</td>
<td>-290</td>
<td>-6.5</td>
<td>39.2</td>
<td>36.9</td>
<td>2.3</td>
</tr>
<tr>
<td>80 *)</td>
<td>3770</td>
<td>4060</td>
<td>-290</td>
<td>-7.1</td>
<td>27.9</td>
<td>26.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*) Measured values at 5 Pa; a pressure increase of 10 Pa was not achieved.

II. Practical use

The discharge behaviour was observed visually in practical use via the shape and direction of the coloured plume under identical conditions with regard to the stable, meteorology and topography. At all settings, there was a clear difference between the plumes from the exhaust stack with and without the guide vane. For the stack with the guide vane installed, the plume...
had a more compact and concentrated shape and reached a higher vertical source height (Figure 6 and 7).

III. Calculations and simulation

Because of the specific emissions situation for agricultural livestock-farming facilities, e.g. with relatively low building heights, calculations and simulations are made of plume-rise figures for odour and ammonia dispersion in the course of approval and monitoring procedures. This is based on TA Luft and standards derived from it, e.g. VDI 3782 “Dispersion of air pollutants in the atmosphere; determination of plume rise”.

Furthermore, the VDI Standards 3471 and 3472 “Emission control; livestock management” are available to the agricultural sector. Among other things, these state that in particular times of low airflow speed and an absence of wind near the ground are critical for dispersion (Figure 8). In addition, the wind speed rises with increasing altitude; for example, the proportion of windless conditions at a height of 5 m can be twice as high as at 10 m.

According to [1], the formulas for plume rise frequently do not take account of so-called downwash effects, i.e. turbulence and lowering of the plume on the lee side of the building. In addition, results are also affected by the assumption in these calculations of an idealised, swirl-free flow at the exhaust outlet. Calculations applying VDI 3782 therefore lead to significantly higher values of ∆h than the calculations according to the livestock-farming standard VDI 3471. The results of the simulation calculations carried out here lie between

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Table 2: Flow velocity of exhaust air after discharge from diffuser outlet 2:

<table>
<thead>
<tr>
<th>Electrical voltage V</th>
<th>Average flow velocity without GVW (m/s)</th>
<th>Distance from diffuser [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>230</td>
<td>7.7</td>
<td>8.8</td>
</tr>
<tr>
<td>180</td>
<td>6.4</td>
<td>8.1</td>
</tr>
<tr>
<td>160</td>
<td>5.7</td>
<td>6.7</td>
</tr>
<tr>
<td>140</td>
<td>3.7</td>
<td>5.6</td>
</tr>
<tr>
<td>120</td>
<td>2.4</td>
<td>3.7</td>
</tr>
<tr>
<td>100</td>
<td>1.0</td>
<td>2.1</td>
</tr>
</tbody>
</table>

1) Mean of 3 measured values: centre of axis and ± 0.25 m radial distance; measured values are not quoted for the 80 V voltage setting as a maximum speed of just 0.2 m/s was measured directly at the diffuser outlet.

those of the aforementioned approximation formulas.

Simulation calculation with/without guide vane

Based on the results of the aforementioned flow velocity measurements, it can be seen that the axial component of the flow is significantly higher with the guide vane. This is a result of the reduced swirl in the flow when the guide vane is installed. As the formulas of the VDI standards do not take account of the obvious influence of swirl, plume rises were calculated using numeric flow simulation for different flow states (FAL Braunschweig).

In this simulation, a massless particle is released at the centre of the axis of the exhaust stack’s diffuser surface and a defined concentration of 20 ppm ammonia is released at the rim of the stack. The particle’s trajectory is used to determine the plume rise; the concentration distribution is used to elucidate the discharge behaviour.

The simulation calculation is based on the following starting parameters:

- Building height: 10 m;
- Flow rotation (swirl): 153 rpm (value from applicant) without guide vane and 0 rpm (determined) with guide vane;
- Pig fattening house with 875 places, 6 compartments and exhaust ventilation
- Building floor area: 34 x 26 m; roof slope: 14°, ridge height above floor: 6.4 m
- Stack outlet height: approx. 1.5 m above roof

Meteorological conditions during test

- Air temperature: 17 °C; air pressure: 986 hPa; cloudy
- Wind speed: 1.5 to 2 m/s
Figure 8: Representation of the simulated discharge behaviour via the dispersion of the ammonia plume with and without guide vane (GVW) for the tested exhaust stack system

**Explanations of diagram:**
- Ammonia concentration areas: blue = 0, green = 10 and red = 20 ppm;
- Ammonia concentration lines (c0 = 20 ppm) for 1/10 c0 and 1/100 c0: black lines;
- Path of massless particle: yellow line;
- Represented area: 50 x 50 m.
- Flow velocity at outlet: 8 m/s (with and without guide vane), corresponding to an operating voltage setting of 230 V; and
- Wind speed as a parabolic inflow at a height of 10 m: 0.3; 1.5 and 4.5 m/s.

The dispersion behaviour of the ammonia plume was mapped at the simulated inflow velocities to demonstrate the discharge behaviour (Figure 9). Table 3 summarises the results determined for plume rise. The plume always reaches greater heights with the guide vane installed. Within the range of these simulated low wind speeds (~4.5 m/s corresponds to < 3 Beaufort), the height differences reach values of approx. 2 to 4 m, which in turn corresponds to an increase of approx. 20 to 90%.

The speed range was extended to 10 m/s using the mathematical functions determined in the simulation, and the results are shown in Figure 10. Here, it can also be seen that the effect of the wind speed diminishes from approx. 3 m/s upwards. At a wind speed of 10 m/s, the plume rise still reaches approx. 5 m with the guide vane and 2.5 m without.

At reduced operating voltage, the level of the plume rise is lower for operation both with and without the guide vane. Accordingly, the differences between the two operating states also become smaller.

Figure 11 shows an example of the plume rises at different voltages determined using the approximation formula (FAL Braunschweig) derived from numerous simulation calculations; see Figure 2 and/or Table 1 for associated volume flow rates.

![Figure 9: Schematic diagram and calculation of plume rise according to VDI 3471/3472 “Emission control; livestock management; pigs/hens”](image)

![Figure 10: Plume rise up to an inflow velocity of 10 m/s – exhaust stack system at 230 V operating voltage and with 10 Pa resistance of the assumed ventilation system](image)

**Figure 9:**
Schematic diagram and calculation of plume rise according to VDI 3471/3472 “Emission control; livestock management; pigs/hens”

**Table 3:**
Plume rise

<table>
<thead>
<tr>
<th>Inflow velocity</th>
<th>Guide vane</th>
<th>Without</th>
<th>With</th>
<th>Height increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Absolute</td>
</tr>
<tr>
<td>0.3 m/s</td>
<td>24.9 m</td>
<td>29.3 m</td>
<td>4.4 m</td>
<td>18 %</td>
</tr>
<tr>
<td>1.5 m/s</td>
<td>11.5 m</td>
<td>13.3 m</td>
<td>1.8 m</td>
<td>16 %</td>
</tr>
<tr>
<td>4.5 m/s</td>
<td>3.7 m</td>
<td>6.8 m</td>
<td>3.1 m</td>
<td>86 %</td>
</tr>
</tbody>
</table>

\[ h = \text{effective source height} \]
\[ H = \text{height of exhaust outlet above ground} \]
\[ \Delta h = \text{plume rise} \]
\[ \Delta h = \frac{c}{u} \sqrt{V} \] (1) where \( V = \frac{w}{4} \pi \]
\[ \Delta h = \frac{c}{u} \sqrt{V} \] (2)

where:
- \( c \): factor for height layer
- \( V \): exhaust volume flow
- \( w \): speed at exhaust outlet
- \( d \): diameter of exhaust stack
- \( u \): inflow velocity (wind speed) at exhaust outlet

\[ h = \frac{c}{u} \sqrt{V} \]

\[ \Delta h = \frac{c}{u} \sqrt{V} \]
Explanations of diagram:

- is generally defined by the expression: $x = \frac{V_d}{u} \cdot d$

  with $d = 0.65 \text{ m}$ for the tested exhaust stack, this expression provides the x-axis label;

- See Figure 8 for symbol definitions

Figure 11:
Plume rises for selected operating voltages at two speeds in the low-wind range with guide vane installed in the exhaust stack system and a 10 Pa resistance of the assumed ventilation system.
Test

The Focus Test included analyses under laboratory conditions, a practical test and numeric flow simulation.

Based on the results presented here, the “Guide vane for agricultural applications” satisfies the requirements (assessment of ○ or better) with regard to the test criterion “Plume rise”, and the DLG-FokusTest test mark is awarded.

Other criteria were not tested.

Test execution

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