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# Determination of actual characteristic curve of main ventilation fan at Quang Ninh underground coal mines using field measurement method

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ABSTRACT

Determining a proper operation mode of the main ventilation fan at an underground coal mine primarily uses the theoretical characteristic curves of the fan's manufacturer. Because these curves are developed in laboratory-standard conditions, the characteristic curves under different conditions in practice significantly change, seriously impacting the ventilation efficiency and environmental safety of mine. This paper presents a determination of the main fan's actual characteristic curve using a field measurement method. The method involves the (i) simultaneous measurement of airflow and air pressure at designated locations in fan drift and ventilation crosscut and (ii) statistical analysis and interpolation of the measured data. The results show that the fan actual pressure curve is permanently displaced to the left and steeper than the corresponding theoretical pressure curve in an on-site operating mode. The finding points out that on-site fans operate in overload mode that can quickly damage their mechanical components. This method provides mining engineers with an easy-to-apply tool for proper adjustment of the operation mode. This improves ventilation efficiency, increases environmental safety, and reduces the underground coal mine operational costs.

*Keywords:* Underground mine ventilation, main fan, characteristic curve, field measurement method.

## 1. Introduction

Ventilation for underground coal mines is critical in ensuring safety and working environment for miners and maintaining the production as scheduled the main ventilation supply a necessary and sufficient fresh air volume for workers obeying technical regulations, to dilute toxic and explosive gas concentrations down to safe limits, dilute the concentration of mining-induced dust down to the allowed limit, remove it away from mine, and improve microclimate conditions at the working area (Tran et al., 2012). Mining ventilation dramatically contributes to preventing the explosion of methane gas, coal dust, and sulfur ore dust. The ventilation for the underground coal mine is mainly implemented by using the main fan installed at the fan station and an auxiliary fan in the roadway.

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In different underground coal mining industries, characteristic curves of the main ventilation fan (e.g., static pressure curve, efficiency curve, and power curve) usually are inspected according to more or less similar standards before the fan is installed at the site. For instance, standards for inspection of the main fan in China, Japan, Russia, and Vietnam (China University of Mining and Technology, 1995; Zhang, 1999; Vietnam Ministry of Science and Technology, 2013a, 2013b; Pham and Hoang, 2017) were established based on the standard ANSI/AMCA 210-99//ANSI/ASHRAE 51-1999 of USA (American National Standards Institute, 1999). During the practical operation at the field, the characteristic fan curves change because the on-site conditions such as temperature, air pressure, air density, and mine resistance are significantly different from those in laboratory-standard states. At the same time, the laboratory standards are no longer applicable for the inspection. The determination of actual characteristic curves is therefore of great importance for proper operation of the main fan and efficient ventilation of mine accordingly.

Many investigations have been implemented to improve ventilation efficiency at an underground coal mine in the literature. At the local scale, various techniques such as numerical modeling (Mishra et al., 2016; Xia et al., 2017), physical modeling (Aitao and Kai, 2018), and field experiment (Sun et al., 2017) were applied to understand gas drainage problem and improve its control. At the mine scale, several studies focused on selecting appropriate fans, which can be based on fan-manufactured characteristic curves or multi-criterion and multi-objective decision-making processes (Kursunoglu and Onder, 2015). Some other studies developed cost-effective ventilation systems using mathematical and computational modeling, as reviewed in Sasmito et al. (2013). The ventilation network can also be traditionally optimized through analytical studies (Li et al., 2018; Bascompta et al., 2018) or field measurement (Li and Wang, 2009). To the best of the authors' knowledge, although all the above studies improved the mine ventilation efficiency, no research successfully investigated the actual fan performance during progressive coal mining one critical controlling factor of overall mine ventilation. A likely explanation for this is the significant cost and time required for periodically monitoring fan performance under different stages of mining. For a comprehensive review of mine ventilation practice, readers can find it in Wallace et al. (2015).

This paper presents a determination of the actual characteristic curve of the main ventilation fan at an underground coal mine using a field measurement method. The actual characteristic curve, mainly referred to as the static pressure curve in this study, was determined by simultaneous airflow and air pressure at designated locations in fan drift and ventilation crosscut and statistical analysis and interpolation of the measured data. The method was used at five main fan stations at Quang Ninh coalfield, Vietnam. The paper's findings are beneficial to mining engineers in the proper operation of the main fan corresponding to progressive extraction, which improves ventilation efficiency, increases environmental safety levels, and reduces operational costs in the underground coal mine.

## 2. Description of field measurement method

### *2.1. Study site*

Quang Ninh coalfield holds the largest anthracite coal reserves in Vietnam, with more than 20 underground coal mines in operation. Each mine employs two to six main fans (Pham and Hoang, 2017; Tran, 2013; Green Science Development Joint Stock Company, 2016a, b; Green Science Development Joint Stock Company, 2017a, 2017b; Mong Duong Coal Company, 2017; Green Science Development Joint Stock Company, 2018). The central fans are mainly axial and installed in two typical station designs. In Design I, the station is built for long-life operation in where the fan is installed in a solid building with a large and high air-outlet tower. This station design is created for the installation of fan series 2K56, 2K58 made in China (Shen Yang Fan Manufacturer, 2012a; b) and fanned VOKD-2.4 made in the former Soviet Union, as seen at Mong Duong, Khe Cham, Nam Mau, and Duong Huy coal mines (Fig. 1). In Design II, the station is constructed in which the fan is installed outdoors, and the motor is placed inside the fan while the electrical cabinet is placed in a simple house. This station design is applicable for fans BD-II and FBDCZ (Qin Feng Fan Manufacturer, 2012a, b), as seen at Mong Duong, Hong Thai, and Ha Lam coal mines (Fig. 2). It is noted that in each fan station, there are always one working fan and one backup fan whose structure and capacity are identical. The measurements were performed at Mong Duong and Ha Lam coal mines in Quang Ninh coalfield (see Section 3).


*Figure 1*. Main fan station - Design I: (a) 2K56-No.24 at East Wing and (b) 2K56-No.24 at Vu Mon, Mong Duong coal mine


*Figure 2*. Main fan station - Design II: (a) FBDCZ-II-No.18 at North Mong Duong, Mong Duong coal mine; (b) FBDCZ-No.20 at Hong Thai coal mine; (c-d) FBDCZ-8-No.24/2×280 at Ha Lam coal mine

### *2.2. Static pressure curve and measurement technique*

Characteristic curves of the main fan include pressure curve, power curve, and efficiency curve. These curves represent the relationships between fan static pressure (h), fan power (N), fan efficiency (ŋ), and fan airflow (Q) at a fixed rotation fan speed for a total resistance of mine workings. The characteristic curves vary under different angles of the fan blade. This paper focuses only on the actual static pressure curve. This characteristic is affected by the real mine's resistance, while the power and efficiency curves, which are the inherent fan characteristics, are not studied.

To determine the fan's actual pressure curve, the air pressure and airflow created by the fan at an angle of the blade are simultaneously measured. The pressure is measured via a U-shaped manometer and Pitot tube. The airflow is determined by multiplying the averaged air velocity in fan drift/ventilation crosscut by cross-sectional area. The averaged air velocity is calculated from five positions at fan drift/ventilation crosscut (Eq. 1 and Fig. 3) while the cross-sectional area is adjusted. Due to the large quantity of airflow, an electronic rather than mechanical anemometer is used for velocity measurement. Also, the measure cannot be implemented during working days as it complies with mine safety regulation. It is only applicable on, for example, weekends.

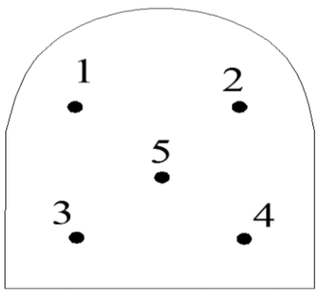


*Figure 3*. Points measuring air velocity in fan drift/ventilation crosscut

$$V_a = \frac{\sum_1^5 V_i}{5} \qquad \text{(Eq. 1)}$$

where $V_a$ is the averaged air velocity; $V_i$ is the air velocity at point $i$.

### *2.3. Layout of measurement*

There are two layouts for measuring air velocity and air pressure, corresponding to the use of inclined shaft or vertical shaft, as shown in Figs. 4-5. The ventilation method in the layouts is suction due to the high methane gas emission from Quang Ninh coal seams. For the inclined shaft (Layout I in Fig. 4), iron bars are installed inside the fan drift where total return air can be measured. The points for measuring air velocity are set some meters ahead of the bars. The Pitot tube is placed near air velocity measuring points. The manometer is put on the surface near the shaft collar and is connected to the Pitot tube through a rubber pipe. For the vertical shaft (Layout II in Fig. 5), iron bars are installed inside the two sides of the crosscut rather than fan drift. The points for measuring air velocity are also set near iron bars. The Pitot tube, similar to that in Layout I, is placed inside the fan drift. The manometer is connected to the Pitot tube through a rubber pipe and an inspection door. The manometer here is put on the surface near the inspection door rather than the shaft collar.

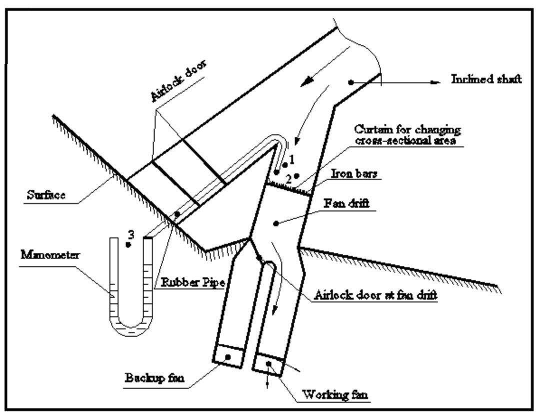


*Figure 4*. Monitoring Layout I - fan drift connected to inclined shaft: 1- point measuring air velocity; 2- point setting Pitot tube; 3- U-shaped manometer

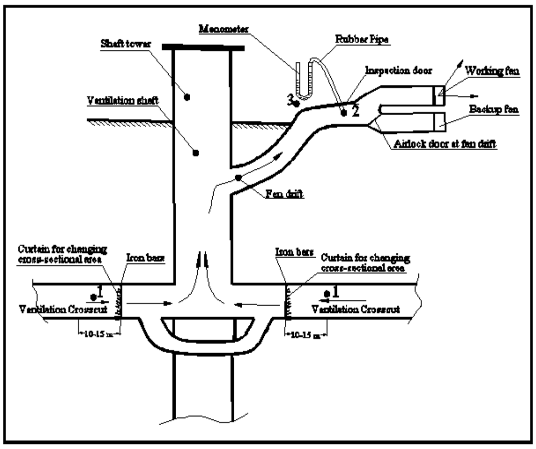


*Figure 5*. Monitoring Layout II - fan drift connected to vertical shaft: 1- point measuring air velocity; 2- point setting Pitot tube; 3- U-shaped manometer

### *2.4. Adjustment of cross-sectional area*

The cross-sectional area for airflow in fan drift/ventilation crosscut can be adjusted using a canvas curtain or wooden plank. For example, when using a canvas curtain, the curtain is set at the position where iron bars have been installed (Fig. 6). In Fig. 6(a), the curtain is rolled up in its highest place, whereas in Figs. 6(b-h), the curtain is unrolled in an interval of 20-30 cm down to the fan drift/ventilation crosscut's floor. Similarly, when using a wooden plank, the plank is piled up in a vertical or horizontal direction for the adjustment. For each time of area adjustment, five pairs of airflow and air pressure values are measured, as described in Section 2.2.

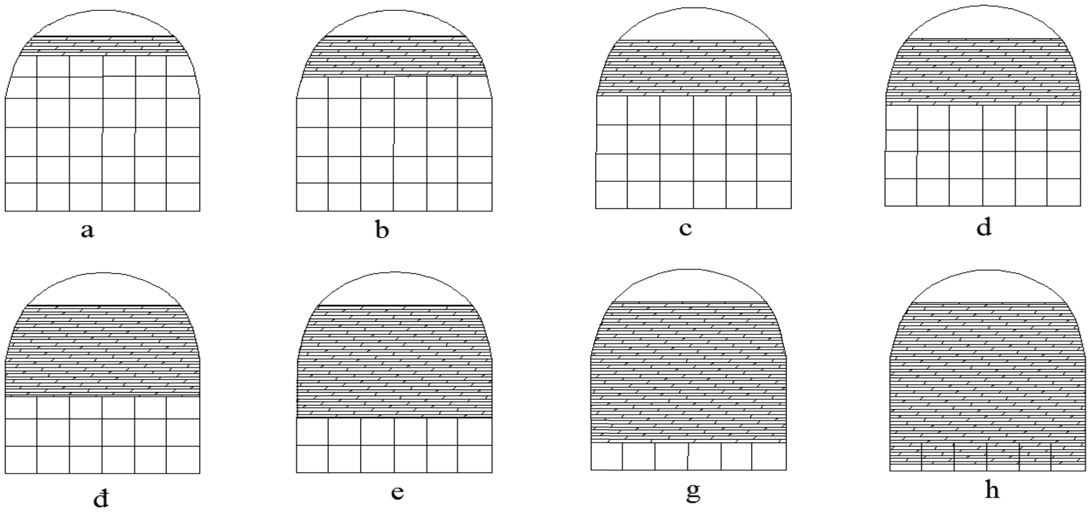


*Figure 6*. Adjustment of cross-sectional area for ventilation by using canvas curtain

### *2.5. Change of blade angle and timing*

For traditional axial fans such as BOK, BOKД of the former Soviet Union and 2K56, 2K58 of China, it is easy to manually change blade angle as the angle positions are explicitly marked on the wheel (i.e., 20, 25, 30, 35, 40, 45 and 50 degrees). Since the fan blade has to be stationary when changing the angle, the working and backup fans at one station need to be shifted in operation. For example, if the first fan operates under an angle of 20 degrees, the second fan should use at 25 degrees in its shift. The first and second fans in the next round will operate in 30 and 35 degrees, respectively. Pairs of air pressure and air flow are measured at every blade angle from 20 to 50 degrees. For fans BD-II and FBDCZ, the angles of -5, -2.5, 0, 2.5, and 5 degrees are not explicitly marked on the wheel. The angle change here is accordingly inaccurate and difficult to maintain dynamic fan balance. For these two fans, the measurement is therefore only performed on a current blade angle. The actual pressure curves of the fans at other angles are interpolated (see Section 4).

Since the locations for measuring fan pressure and air velocity underground are typically far away from each other and cannot be communicated via phone due to safety and noise, it is necessary to set a time frame for simultaneous measurement. As a rule of thumb, every 10 minutes, five pairs of pressure and velocity values are measured. The averaged value of the five pairs is recorded as one measurement. The total sizes range from 15 to 20, corresponding to 15-20 times changing the cross-sectional area of fan drift/ventilation crosscut.

## 3. Results and discussions

The field measurement method has been implemented for three main fan stations at Mong Duong coal mine and two main fan stations at Ha Lam coal mine, representing the two typical fan stations at Quang Ninh coalfield. Because the fan theoretical pressure curve (developed in the laboratory) is typically parabolic, the actual pressure curve is assumed in a similar form, as expressed in Eq. 2. The non-linear regression method is used for developing the actual curve.

$$H_f = a + b.Q_f + c.Q_f^2 \qquad \text{(Eq. 2)}$$

where $H_f$ is fan static pressure; $Q_f$ is fan airflow; and *a*, *b* and *c* are constant.

### *3.1. Actual characteristic of main fans at Mong Duong coal mine*

Mong Duong coal mine extracts underground from -100 to +250 m compared to sea level with an annual production of approximately 1.5 million tonnes (Mong Duong Coal Company, 2017). There are three districts at the mine, namely Vu Mon, East Wing, and North Mong Duong. They are ventilated using Fan 2K56-No.24 at a motor speed of 1000 rpm, 2K56-No.24 at 750 rpm, and FBDCZ-II-No.18 at a motor speed of 740 rpm, respectively. At all stations, the fan drift is connected to the inclined shaft in Layout I (Fig. 4), and the cross-sectional area is adjusted using a canvas curtain (Fig. 7).

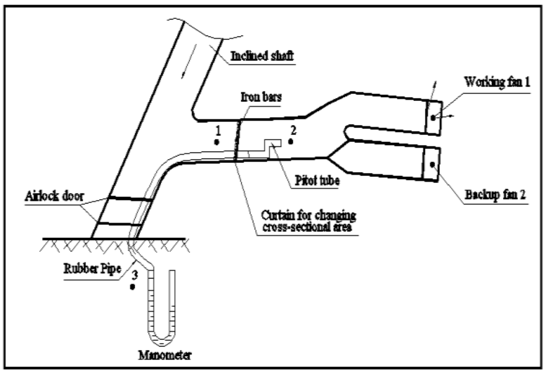


*Figure 7*. Layout for measurement at Mong Duong coal mine: 1- point measuring air velocity; 2- point setting Pitot tube; 3- point setting U-shaped manometer

#### *3.1.1. Actual pressure curve of Fan 2K56-No.24, 1000 rpm at Vu Mon*

The measurement results of airflow and air pressure of the main fan at Vu Mon corresponding to fan blade angles of 25, 30, 35, and 40 degrees are shown in Table 1. The actual pressure curves are developed using non-linear regression analysis from the results, as displayed in red color in Fig. 8. This figure also shows the theoretical pressure curves of the fan in black color.

It is seen from Fig. 8 that when working at blade angles from 25 to 40 degrees, the fan should theoretically create airflow from 44 to 166 $m^3/s$ and air pressure from 800 to 6100 Pa. In real operation, it, however, creates a lesser quantity of airflow, which is in the range of 32-136 $m^3/s$. At the same time, the fan produces an air pressure in the range of 2800-6800 Pa, which is partly beyond its theoretical reasonable use field. The difference is because the actual mine resistance from all workings is greater than that designed in laboratory-standard condition. Also, the actual pressure curves are steeper than the theoretical curves. This confirms that the fan is operating under a greater magnitude of resistance. The fan correspondingly works in overload mode that can quickly damage its mechanical components. Note that the blue dash curve sections in Fig. 8 illustrate the interpolated data obtained from the method described in Section 3.1.3.

*Table 1*. Measurement results of Fan 2K56-No.24, 1000 rpm, Vu Mon

| Blade angle, Degree | Time | Fan pressure, Pa | Fan airflow, $m^3/s$ | Blade angle, Degree | Time | Fan pressure, Pa | Fan airflow, $m^3/s$ |
|---|---|---|---|---|---|---|---|
| 25 | | | | 35 | | | |
| | Time 1 | 2800 | 76.2 | | Time 1 | 3120 | 114 |
| | Time 2 | 3320 | 67.8 | | Time 2 | 3840 | 108.2 |
| | Time 3 | 4200 | 58 | | Time 3 | 4450 | 96 |
| | Time 4 | 5210 | 50 | | Time 4 | 5020 | 87.6 |
| | Time 5 | 6040 | 40 | | Time 5 | 6110 | 73.8 |
| | Time 6 | 6450 | 34 | | Time 6 | 6200 | 71.5 |
| | Time 7 | 6800 | 30 | | Time 7 | 6720 | 66.4 |
| 30 | | | | 40 | | | |
| | Time 1 | 3010 | 96.2 | | Time 1 | 3240 | 136.6 |
| | Time 2 | 3960 | 87.0 | | Time 2 | 4040 | 129 |
| | Time 3 | 4250 | 80 | | Time 3 | 4400 | 126.4 |
| | Time 4 | 5000 | 65 | | Time 4 | 4810 | 116.6 |
| | Time 5 | 5810 | 60 | | Time 5 | 5800 | 110 |
| | Time 6 | 6450 | 48 | | Time 6 | 6180 | 96 |
| | Time 7 | 6630 | 46 | | Time 7 | 6780 | 93.2 |

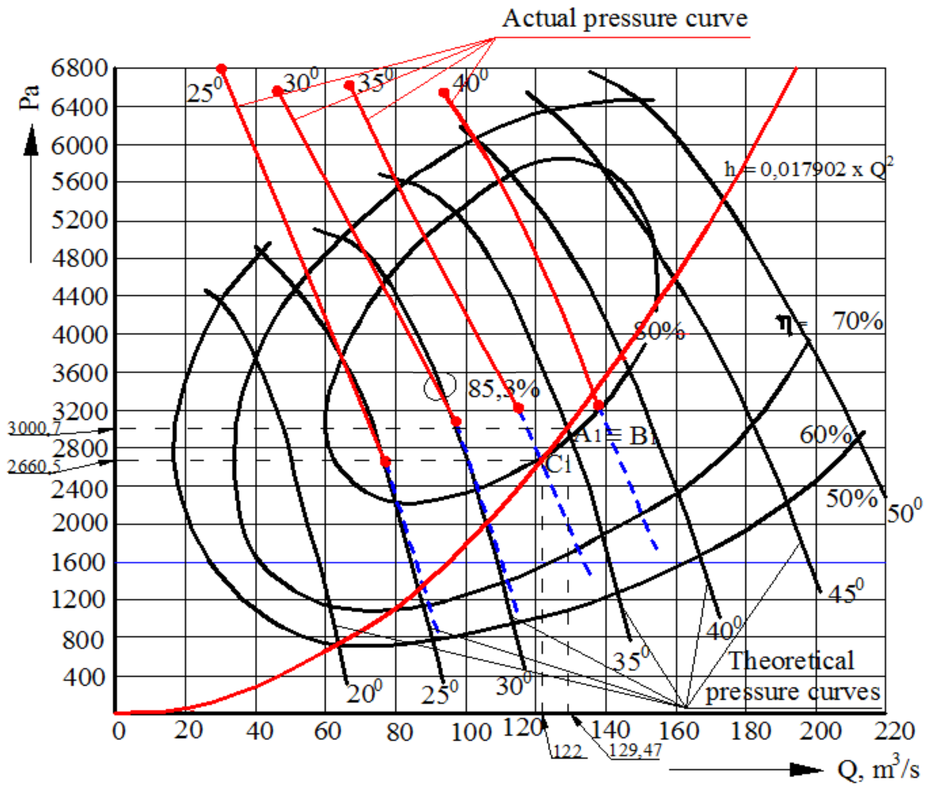


*Figure 8*. Theoretical and actual pressure curves of Fan 2K56-No.24, 1000 rpm, Vu Mon

### *3.1.2. Actual pressure curve of Fan 2K56-No.24, 750 rpm at East Wing*

The measurement results of airflow and air pressure created by the main fan at East Wing corresponding to fan angles from 25 to 40 degrees are listed in Table 2. The theoretical and actual pressure curves of the fan are displayed in black and red colors in Fig. 9, respectively.

*Table 2.* Measurement results of Fan 2K56-No.24, 750 rpm, East Wing

| Blade angle, Degree | Time | Fan pressure, Pa | Fan airflow, $m^3/s$ | Blade angle, Degree | Time | Fan pressure, Pa | Fan airflow, $m^3/s$ |
|---|---|---|---|---|---|---|---|
| 25 | | | | 35 | | | |
| | Time 1 | 1400 | 60.4 | | Time 1 | 2050 | 84.1 |
| | Time 2 | 1500 | 59.1 | | Time 2 | 2350 | 81 |
| | Time 3 | 1680 | 56.05 | | Time 3 | 2600 | 75 |
| | Time 4 | 2000 | 50.4 | | Time 4 | 3130 | 68 |
| | Time 5 | 2410 | 43.6 | | Time 5 | 3400 | 62.7 |
| | Time 6 | 3100 | 40 | | Time 6 | 3700 | 60.05 |
| | Time 7 | 3340 | 32 | | Time 7 | 3900 | 58 |
| 30 | | | | 40 | | | |
| | Time 1 | 2020 | 68 | | Time 1 | 2350 | 98 |
| | Time 2 | 2260 | 66.5 | | Time 2 | 2690 | 95 |
| | Time 3 | 2720 | 62 | | Time 3 | 2910 | 90.2 |
| | Time 4 | 2910 | 59 | | Time 4 | 3250 | 85.6 |
| | Time 5 | 3160 | 56.9 | | Time 5 | 3730 | 74 |
| | Time 6 | 3500 | 54 | | Time 6 | 3950 | 71.2 |
| | Time 7 | 3930 | 47.97 | | Time 7 | 4160 | 68 |

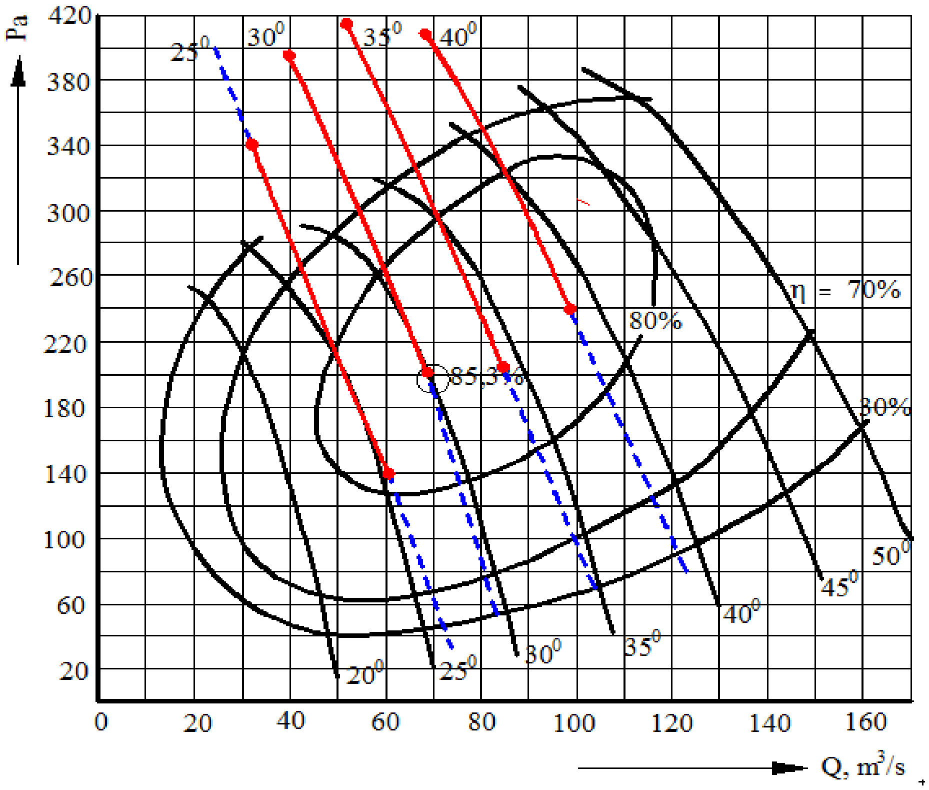


*Figure 9.* Theoretical and actual pressure curves of Fan 2K56-No.24, 750 rpm, East Wing

Figure 9 shows that when working at blade angles from 25 to 40 degrees, the fan should theoretically create an airflow range of 20–127 $m^3/s$ and an air pressure range of 400–3400 Pa. In practice, the fan creates an airflow range of 32–98 $m^3/s$ and an air pressure range of 1400–4160 Pa. In this case, although the fan provides sufficient airflow into the mine, it produces a greater pressure range than its theoretical capacity at a working angle. The actual pressure curves are also in second-order nonlinear but steeper than the theoretical curves. A significant portion of the actual curves is outside the theoretical reasonable use field of the fan. This is consistent with the fan operating under a greater mine resistance than that designed in laboratory-standard condition.

### *3.1.3. Actual pressure curve of Fan FBDCZ-II-No.18, 740 rpm at North Mong Duong*

The measurement results of the main fan at North Mong Duong at a blade angle of 0 degrees are reported in Table 3. The actual pressure curve at this angle is developed in Fig. 10. As aforementioned, it is difficult to change the Fan FBDCZ's angle accurately. Thus, the measurement is only performed at 0 degrees which are being used at the site. To develop the actual reasonable use field of the fan, the other actual pressure curves at -5.0, -2.5, +2.5, and +5.0 degrees are interpolated from the actual curve at 0 degrees (original actual curve) theoretical curves. The logic is observed from the field measurements at Vu Mon and East Wing districts. According to which at the exact value of pressure (same ordinate), the difference in airflow between two adjacent theoretical curves is similar to that between two adjacent actual curves. An actual curve at a blade angle, for example, +2.5 degrees, is developed in Fig. 11. First, at a pressure value (e.g., 900 Pa), the difference in airflow between two theoretical curves at 0 and 2.5 degrees (X1) is measured. Then, at the same ordinate (900 Pa), a new point is horizontally set X1 distance unit away from the original curve. Other new points are similarly set at different pressures (ordinates). The actual curve at +2.5 degrees is finally formed by fitting the new points into a curve by non-linear regression. The actual curve at a blade angle of -2.5 degrees is interpolated in the same way (Fig. 11).

*Table 3.* Measurement results of Fan FBDCZ-II-No.18, 740 rpm, blade angle of $0^0$, North Mong Duong

| Fan airflow, $m^3/s$ | 24.94 | 23.1 | 22.8 | 21.6 | 20.8 | 19.4 | 18.8 | 17.06 |
|---|---|---|---|---|---|---|---|---|
| Fan pressure, Pa | 1350 | 1560 | 1750 | 2070 | 2300 | 2510 | 2690 | 2900 |

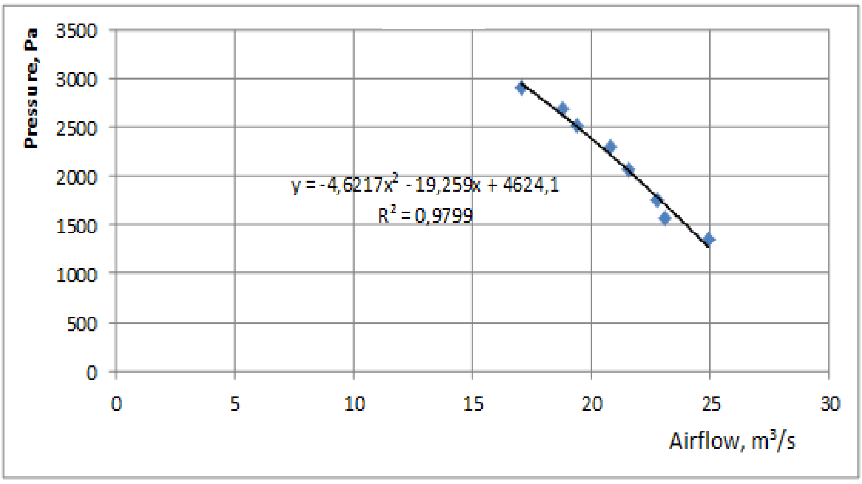


*Figure 10.* Actual pressure curve of Fan FBDCZ-II-No.18, 740 rpm, blade angle of 0°, North Mong Duong

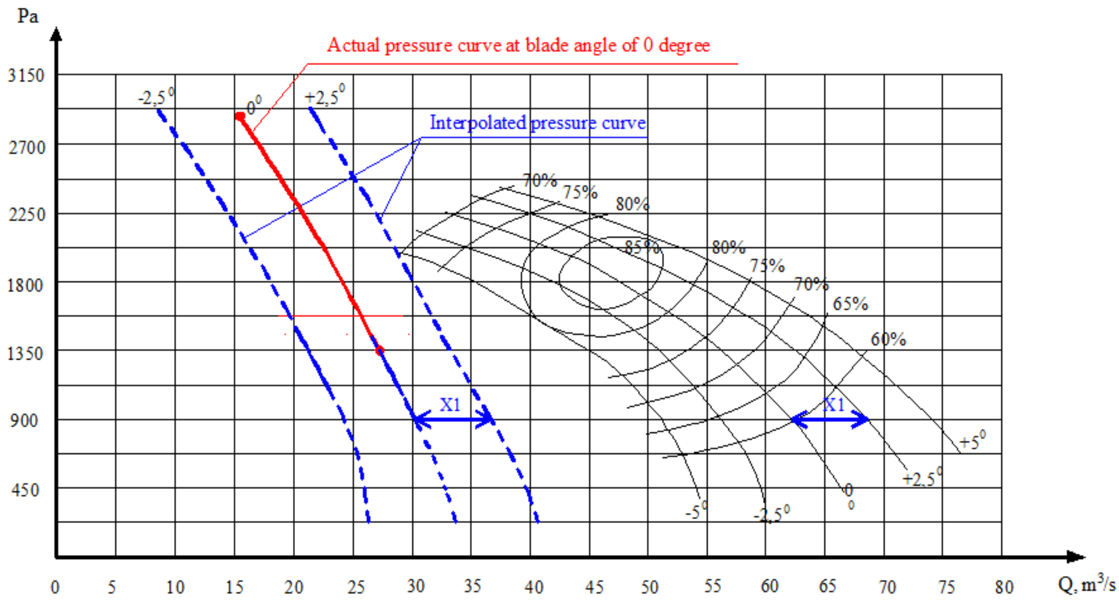


*Figure 11*. Theoretical and actual pressure curves of fan FBDCZ-II-No.18, North Mong Duong

### *3.2. Actual characteristic of main fans at Ha Lam coal mine*

Ha Lam coal mine produces 2.0 million tonnes of coal annually from five longwall faces and dozens of roadway face installed in two districts (Ha Lam Coal Company, 2018; Ha Lam Coal Company, 2019). In the first district, which is located from surface to level -150 m, the deposit was opened using two inclined shafts starting at level +28 m. This district is ventilated using a fan station built at level +90 m with two fans FBDCZ-8-No.24C/2x280. In the second district, located from level -50 to -300 m, two vertical shafts starting at level +75 m and one ventilation shaft starting at level +29 m were built. The fan station at level +29 m contains two fans FBDCZ-8-No.30A/2x500. All the fans use the suction ventilation method.

#### *3.2.1. Actual pressure curve of Fan FBDCZ-8-No.24C/2 x280*

The fan drift of Fan FBDCZ-8-No.24C/2x280 is connected to the inclined shaft in Layout I. At present, the fan is working at the blade angle of 460/380. Measurement results of airflow and air pressure are presented in Table 4. The fan actual pressure curve is developed in Fig. 12. Using the interpolation technique and regression analysis described above, this fan's actual reasonable use field is created from the theoretical reasonable use field and actual pressure curve at 460/380, as shown in Fig. 13.

*Table 4*. Measurement results of Fan FBDCZ-8-No.24C/2x280, blade angle of 46°/38°, Ha Lam

| Order | Time | Fan airflow, $m^3/s$ | Fan pressure, Pa |
|---|---|---|---|
| 1 | 9.20AM | 70.80 | 2600 |
| 2 | 9.30AM | 68.50 | 2730 |
| 3 | 9.40AM | 67.70 | 2830 |
| 4 | 9.50AM | 67,90 | 2900 |
| 5 | 10.00AM | 64.50 | 3080 |
| 6 | 10.10AM | 63.20 | 3100 |
| 7 | 10.20AM | 62.10 | 3200 |
| 8 | 10.30AM | 60.50 | 3200 |
| 9 | 10.40AM | 61.80 | 3360 |
| 10 | 10.50AM | 59.70 | 3600 |
| 11 | 11.00AM | 57.50 | 3610 |
| 12 | 11.10AM | 56.10 | 3630 |
| 13 | 11.20AM | 54.00 | 3640 |
| 14 | 11.30AM | 50.80 | 3680 |

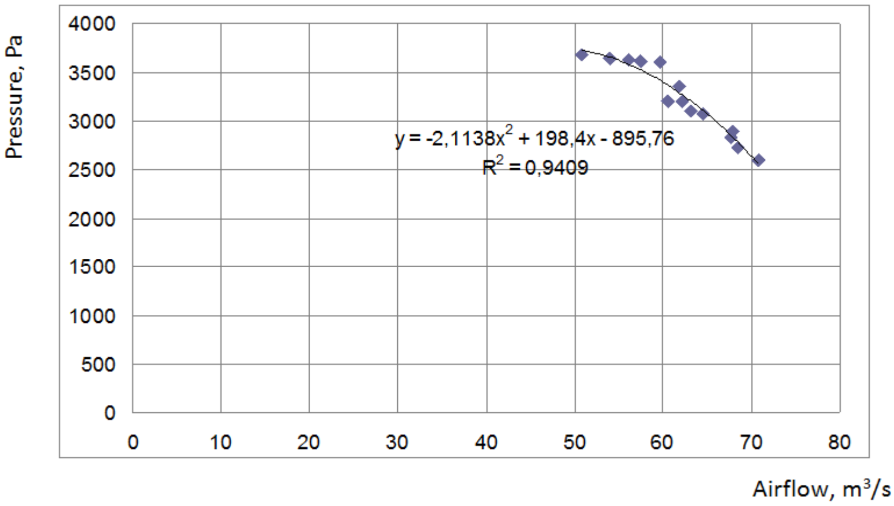


*Figure 12*. Actual pressure curve of Fan FBDCZ-8-No.24C/2x280, blade angle of 46$^0$/38$^0$, Ha Lam

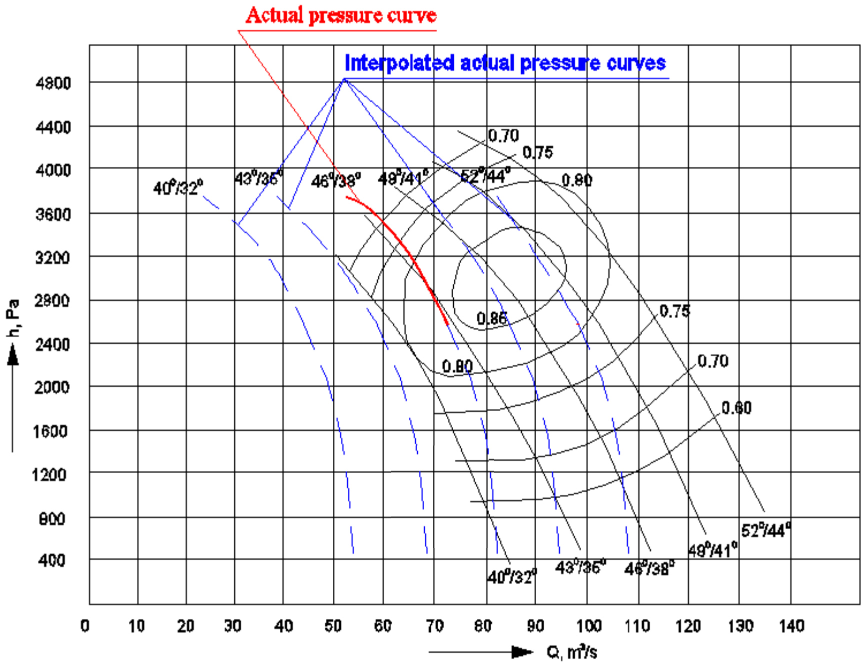


*Figure 13*. Actual reasonable use field of Fan FBDCZ-8-No.24C/2x280, Ha Lam

It should be noted that in Table 4, the records of air pressure (at surface) and air velocity (in the underground) were implemented at the same time every 10 minutes. For a more accurate timing of the measurements, a better communication method between surface and underground such as local safety landline telephone is suggested for future studies.

### *3.2.2. Actual pressure curve of Fan FBDCZ-8-No.30A/2x500*

Fan FBDCZ-8-No.30A/2x500 is working at level +29 m and connected with the vertical shaft through fan drift in Layout II. Monitoring points for air pressure and airflow are designed as in Fig. 14. The measurement results when the fan works at a blade angle of

460/380 are shown in Table 5. The fan actual pressure curve at this angle is developed in Fig. 15. Using the interpolation technique and regression analysis, this fan's actual reasonable use field is obtained in Fig. 16. These figures confirm that the actual pressure curves are significantly displaced to the left of the theoretical curves. This is because the actual mine resistance is much greater than the resistance from the laboratory-standard condition, as explained in the previous subsection.

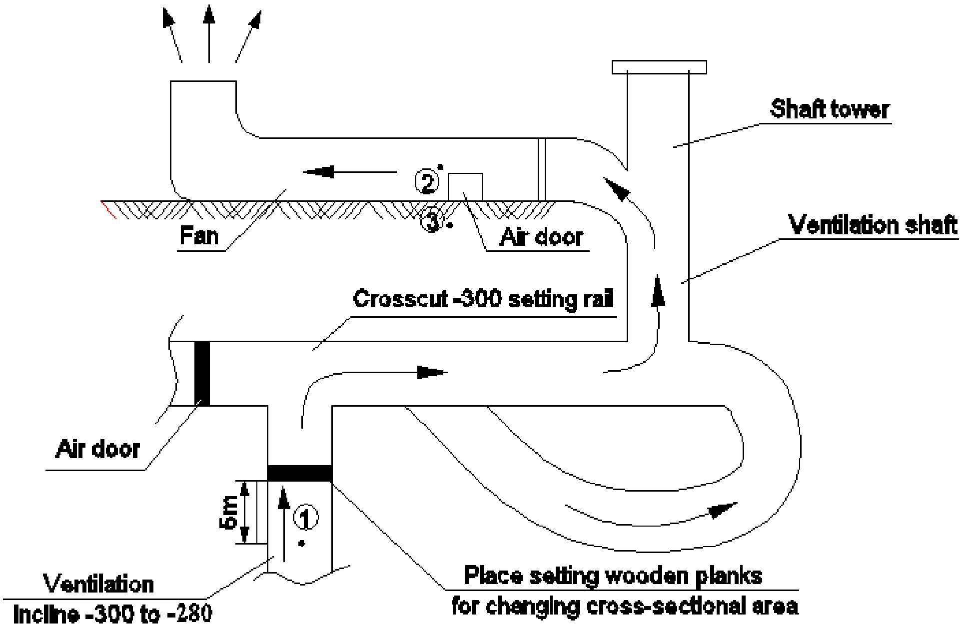


*Figure 14.* Layout for measurement at Ha Lam coal mine: 1- point measuring air velocity; 2- point setting Pitot tube; 3- point setting U-shaped manometer

*Table 5.* Measurement results of Fan FBDCZ-8-No.30A/2x500, blade angle of 46°/38°, Ha Lam

| Order | Time | Fan airflow, $m^3/s$ | Fan pressure, Pa |
|---|---|---|---|
| 1 | 9.10AM | 170 | 1400 |
| 2 | 9.15AM | 165 | 1510 |
| 3 | 9.20AM | 160 | 1600 |
| 4 | 9.25AM | 154 | 1740 |
| 5 | 9.30AM | 150 | 1940 |
| 6 | 9.35AM | 148 | 2000 |
| 7 | 9.40AM | 136 | 2040 |
| 8 | 9.45AM | 136 | 2060 |
| 9 | 9.50AM | 130 | 2090 |
| 10 | 9.55AM | 125 | 2180 |
| 11 | 10.00AM | 123 | 2200 |
| 12 | 10.05AM | 121 | 2210 |
| 13 | 10.10AM | 118 | 2270 |
| 14 | 10.15AM | 110 | 2390 |
| 15 | 10.20AM | 100 | 2650 |
| 16 | 10.30AM | 88 | 2700 |
| 17 | 10.35AM | 86 | 2770 |
| 18 | 10.40AM | 75 | 2840 |

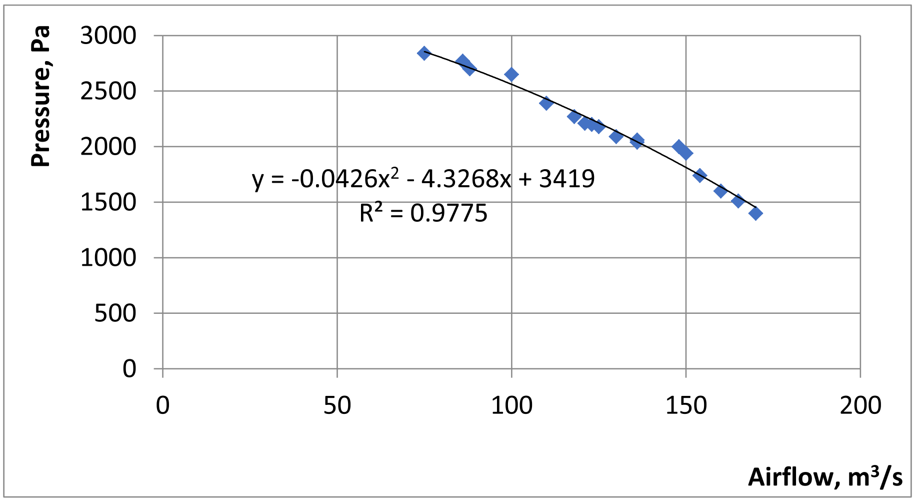


*Figure 15*. Actual pressure curve of Fan FBDCZ-8-No.30A/2x500, blade angle of 46°/38°, Ha Lam

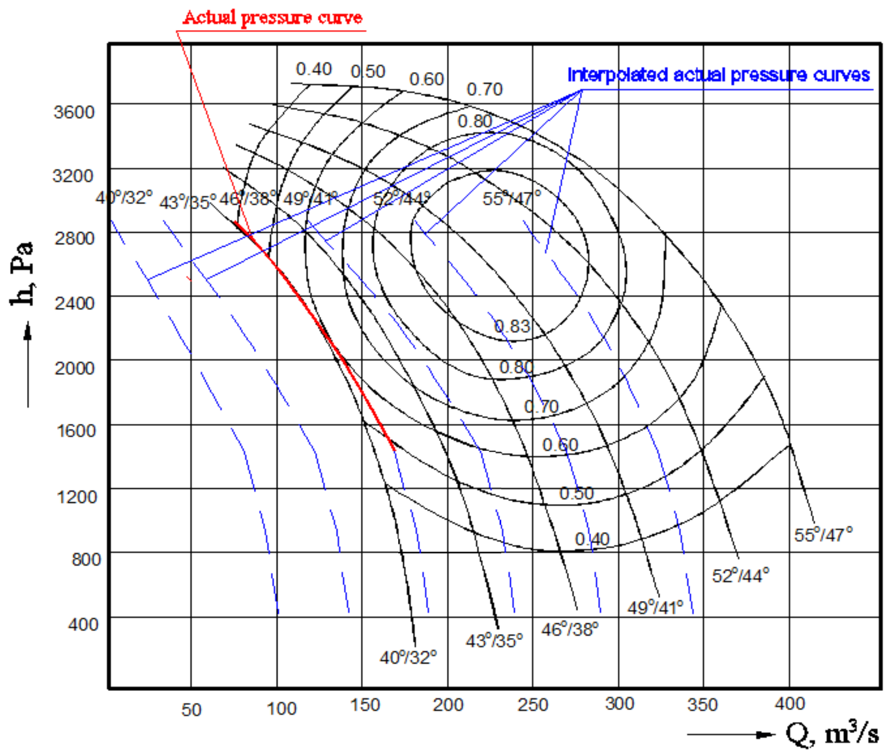


*Figure 16*. Actual reasonable use field of Fan FBDCZ-8-No.30A/2x500, Ha Lam

### *3.3. Time period for re-determination of fan actual pressure curve*

According to a recent study regarding the actual characteristic curve of the main underground fan (Center for mining science, 2021), the measurement and assessment of the main fan at Quang Hanh coal mine in 2016 showed that the actual pressure curve (for example, at blade angle of -5 degrees) displaced to the left of the corresponding theoretical curve. This reduced the airflow into mine by approximately 4%. After three years, the results measured by the same authors in 2019 showed that the actual pressure curve of the fan displaced further to the left of the theoretical curve, reducing the airflow into mine by 7.5–8%. As a result, in this study, the authors propose 2–3 years for re-determination of the fan actual pressure curve for Mong Duong and Ha Lam coal mines. The period may vary depending on the existing mine production, mining scope, and depth. Figure 17 illustrates the actual and theoretical pressure curves of Fan FBCDZ-No.22 placed at Portal +30 of Quang Hanh coal mine in 2016 and 2019.

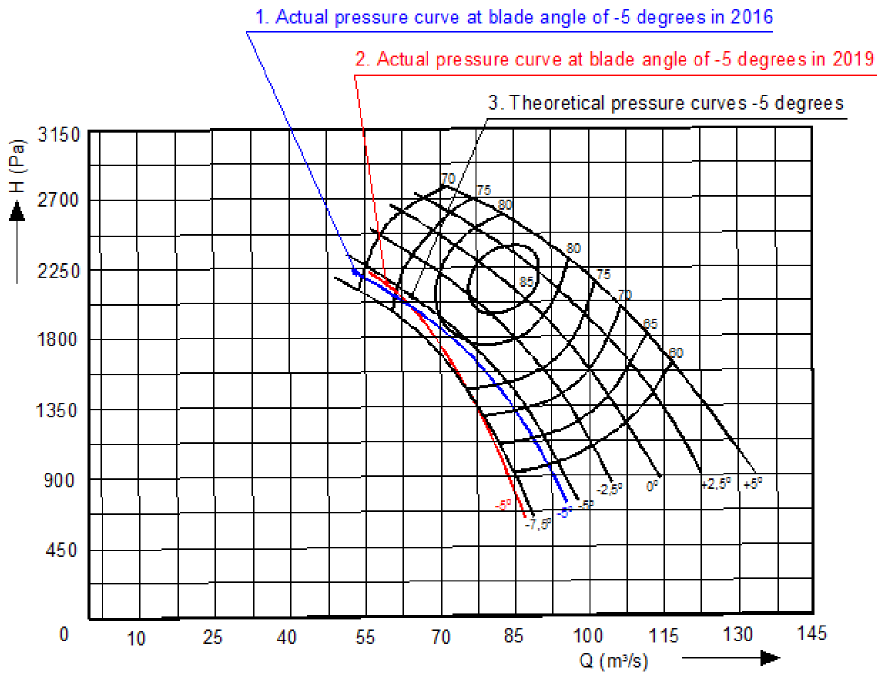


*Figure 17.* Actual and theoretical pressure curves of Fan FBDCZ-No.22, Quang Hanh

## 4. Conclusions

This paper presents the determination of the actual static pressure curve of the main ventilation fan for an underground coal mine using a field measurement method. The method first proposes two layouts for field measurement in where the fan drift is connected to the vertical shaft or inclined shaft. In both designs and at a working angle of the fan blade, the fan-created air pressure and airflow are simultaneously measured by using simple equipment (i.e., U-shaped manometer, Pitot tube, electronic anemometer, and canvas curtain/wooden plank) at designated locations in fan drift and ventilation crosscut whose cross-sectional area is varied. An actual pressure curve is accordingly developed through non-linear regression analysis of measurement results. For any angle at which the measurement cannot be accurately performed, the actual pressure curve is interpolated from the basic and corresponding theoretical curves at that angle. The actual reasonable use field of the fan is developed accordingly.

The proposed field measurement method was used at five main fan stations in two underground coal mines at Quang Ninh coalfield, Vietnam. The results show that in an on-site operation mode of the main ventilation fan, the actual pressure curve is permanently displaced to the left and steeper than the corresponding theoretical pressure curve. This is because natural mine resistance is significantly greater than the resistance designed in laboratory-standard conditions. The finding points out that on-site fans operate in overload mode that can quickly damage their mechanical components. Although the method is only applicable on non-working days, it provides mining engineers with an easy-to-apply tool for proper adjustment of the operation mode of the main fan corresponding to progressive extraction. This improves ventilation efficiency, increases environmental safety levels, and reduces operational costs in underground coal mines.

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