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Evaluating the impact of auxiliary fan practices on localised subsurface ventilation

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A B S T R A C T

Mines are continually expanding in size and depth, leading to an increased reliance on localised subsurface ventilation systems. The use of underground auxiliary fans is a favoured method to increase and control airflow in working areas. However, the effectiveness of auxiliary fans in this regard is not clear. This paper evaluated the performance of these underground fan systems in four different South African deep-level gold mines. A total auxiliary fan system efficiency of 5% was found across six systems, with the average fan efficiency of 33 fans at 38%. The results showed that these fans deviate significantly from their design operating points. Therefore, there are significant shortcomings in current underground fan practices. Our detailed investigations led to the conclusion that the assemblage of underground auxiliary fan systems results in significant energy inefficiencies. Therefore, maintaining good underground fan practice such as optimal fan selection, ducting design and maintenance is crucial for the efficacy of a mine ventilation network.

1. Introduction

The extraction of mineral resources has become increasingly more complex as easy to reach reserves are being depleted [1]. This has resulted in mines continually expanding in size and depth in order to reach new production zones [1]. To ensure a safe and productive mining environment, underground ventilation systems are used to provide adequate fresh air to parts of a mine where mine personnel and equipment travel and work [2]. However, due to the increasing expansion of mine networks there is a subsequent increase in ventilation network size and complexity, making fresh air distribution and management of the ventilation network challenging and energy intensive [3].

With increasing mine depth there is a subsequent increase in the airflow demand and system pressure [4]. These pressure demands become a concern when surface extraction fans can no longer supply the required suction pressure which ultimately restrains mine expansion [4]. Therefore, the use of smaller underground auxiliary fans is commonplace in deep-level mine ventilation systems in order to overcome these restrictions [3–6].

Various types of fans exist in deep-level mines as illustrated by the basic schematic of a mine ventilation network given in Fig. 1. Fig. 1 also illustrates the typical location and types of mine ventilation fans [6]:

(1) Primary fans are large fans that have a significant impact on the total mine airflow such as surface extraction fans.
(2) Booster fans are smaller fans that are in series with one or more primary fans. These fans are installed to assist the primary fans in overcoming mine airflow resistances.
(3) Development end fans are auxiliary fans used to ventilate a workplace with no air flowing through it.
(4) District or circuit fans are auxiliary fan assemblages that are used to direct air into a specific district or area. Typical districts can be one or more mining areas, underground bulk air coolers, raise boreholes, return airways, and up and downcast shafts.

Research on primary ventilation fans has shown that fan assemblages can have a major impact on the total performance of a fan installation [7]. De Souza found that up to 40–80% of the energy consumed by primary ventilation fans, is used to overcome the resistances of fan assemblages components [7]. However, with proper engineering design and installation, these systems could operate at efficiencies above 80% resulting in an improvement of between 20% and 65% [7]. This leads us to the question of whether similar problems exist in other ventilation components such as underground auxiliary and district fan assemblages.

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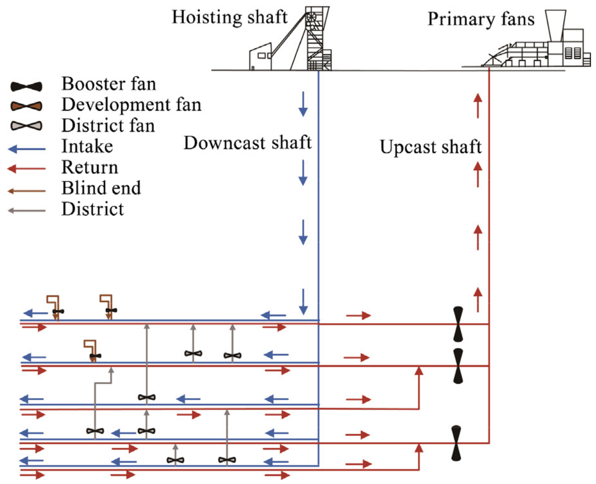

Fig. 1. Basic schematic of a typical underground ventilation network.

Literature describes various energy inefficiencies present in mine auxiliary fan assemblages such as ducting leakages, fan inefficiencies, door leaks, ducting pressure losses due to friction factors, poor fan performance and poor fan installations [7–11]. Levesque also highlighted the need for testing to determine leakage values that can be used for design purposes as well as assessment of the quality of fan assemblage installations [10]. It is thus evident that there exists a need to evaluate and understand the impact that underground auxiliary fan systems have on subsurface ventilation.

Underground district fan assemblages typically consist of axial fans, corrugated spiral-ducting, and airlocks (walls, seals or doors) [12,13]. This paper investigates the effective interaction between the components of district fan assemblages and the actual performance of these systems. Throughout this study, auxiliary fans will be considered as the fan only while district fans will be considered as the localised fan system which will include the fan and fan assemblage consisting of ducting and airlocks.

The novelty of this study is that it focuses on the efficiency of underground auxiliary fan assemblages. No literature is available that explicitly evaluates underground fan assemblage practices and how efficient the conversion of electrical energy to ventilation energy is. It is therefore of utmost importance for the mining industry and related mechanical engineering fields to understand the status of underground district fan assemblages and the implications of poor engineering practices.

1.1. The practice of underground district fan assemblages

District and auxiliary fans do not have a significant influence on the total airflow rate and ventilation pressure of a mine [12]. Total airflow is a function of the suction pressure created by the main ventilation fans while district and auxiliary fans distribute this airflow to the correct areas [6]. However, the efficacy of airflow distribution in any underground fan system is highly dependent on the quality of district and auxiliary fan installation, fan selection and assemblages maintenance [13]. Their performance plays a vital role in the safety of mine workers and subsequently production [14]. The design, planning, and monitoring of underground fans are therefore of utmost importance for an underground ventilation network to function. Diligent steps for underground ventilation controls' design, management, and monitoring are available in literature [15]. However, the efficacy of the design, management, and monitoring of ventilation controls is highly dependent on how well industry is adhering to available guidelines and practices.

Knowing the resistance of the underground districts and the fan assemblages is crucial when designing or selecting underground fans. The criteria for underground fan selections are listed in literature [16–18]. However, the characteristics of the districts can change dynamically as the mine expands [18,19]. In addition, the pressure effects of nearby underground fans and natural ventilation pressure can influence the operating point of a fan significantly [5]. Further, energy lost due to inefficiency are directly induced into the air stream as thermal energy [20]. Ideally, a ventilation simulation model could thus assist personnel with the underground fan selection procedure [21].

Diligent steps are in place for the design and installation of surface extraction fans and their assemblages in the mining industry. However, there are fewer efforts on the design and installation of underground district fans [9]. Thus, underground district fans may have operational and financial implications when not correctly managed [9]. The thermal comfort and safety of mine personnel are also highly dependent on the effective airflow distribution of these fan systems [22]. Due to the impact on safety, there should be no compromise with the control and management of these underground mine ventilation fans.

A previous case study by Krog demonstrates the energy implications due to shock losses when underground fans are installed without any silencer [9]. Krog found that energy cost savings of up to 60% can be achieved when discharge cones for fan outlets are used rather than fans delivering airflow directly to the air stream. This is due to the reduction of shock losses, which are often neglected when underground fans are installed [9].

The measured operating points of underground fans often lie well off the manufacturer's curve due to various reasons [8]. The reasons why these underground fans are operating off their manufacturer's curves are however absent in literature. In deep-level mines, there is a significant number of district and auxiliary fans which absorb a large amount of electrical power [6]. The impact underground fan assemblages have on an underground ventilation network is therefore a topic worth investigating. Furthermore, various inefficiencies are present in underground fan assemblages, which can have a significant compounding effect on the overall fan system performance [5,7–9,20]. Thus, we investigate the impact of fan practices on underground district fan systems' performances and how well the electrical energy is converted to ventilation energy.

2. Method and materials

This study investigated the impact district fan assemblages have on an underground ventilation network. Ventilation data

Table 1
Airflow and fan assemblage measurements and equations.

	Parameters	Measuring instrumentation or calculation
1	Static pressure $\triangle P$ (kPa)	Delta Ohm HD2134P.2-manometer
2	Velocity V (m/s)	Tenmar 404-vane anemometer
3	Area A (m^2)	Bosch GLM 20 distance meter
4	Volumetric flow rate Q (m^3/s)	$Q = VA$
5	Barometric pressure BP (kPa)	Tenmar 404-barometer
6	Air wet-bulb temperature T_{wb} (°C)	Basic whirling hygrometer
7	Air dry-bulb temperature T_{db} (°C)	Basic whirling hygrometer
8	Density ρ (kg/m^3)	$\rho = f(T_{wb}, T_{db}, BP)$ [23]
9	Fan total pressure $\triangle P_T$ (kPa)	$\Delta P_T = \Delta P + \Delta\rho V^2/2$
10	Electrical power consumption P_{fan} (kW)	UNI-T UT204A clamp-multimeter
11	Airflow resistance R	$R = \Delta P/\rho Q^2$
12	Airpower P_{air} (kW)	$P_{air} = Q \times \Delta P_T$
13	Mass flow rate m (kg/s)	$\dot{m} = Q \times \rho$
14	Total efficiency η_{total}	$\eta_{total} = (P_{air}/P_{fan})$

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