Designing energy-efficient mineshaft systems

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The mining industry in South Africa faces many challenges, primarily in the area of electrical energy consumption. In 2007, South Africans faced increasingly stringent load shedding of the electricity supply. In January 2008, Eskom took the unprecedented step of informing its key industrial consumers (KICs), including mines, that it could no longer guarantee its electricity supply to them. This announcement resulted in the temporary closure of all deep-level mines associated with large mining houses, such as Anglo American and Gold Fields, because of safety concerns in the event of power failures.

As the mining industry is one of the mainstays of the South African economy, it was decided to evaluate the design of mineshafts to determine whether their total energy consumption could be reduced. The Department of Mining Engineering at the University of Pretoria was approached to discuss potential opportunities for the reduction of energy requirements in mines, thus emphasising the impact of future mine design.

Prof Ronny Webber-Youngman, Head of the Department of Mining Engineering, and William Kempson, a postgraduate student, concluded that there was potential for optimising the design of vertical shafts, specifically with regard to reducing the pressure losses that occur in deep-level vertical shafts. The initial calculations showed that more than 50% of the pressure generated by a mineshaft's main ventilation fans is dissipated as the ventilation air is forced through these shafts. The contribution of Prof Josua Meyer, Head of the Department of Mechanical and Aeronautical Engineering, is acknowledged in this research.

Impala Platinum was approached to conduct the necessary research, and a few mineshafts were tested to obtain the data needed to verify the assumption. The actual pressure losses on the Impala 14 Shaft were measured. These measurements for the main downcast shaft were obtained by installing a pitot tube manometer 15 m above the main cage, stopping at various points in the vertical shaft to take pressure, temperature and velocity measurements.

The results were compared to calculations that were made by using the current theory. They showed good agreement. This confirmed that the vertical shafts consume a significant amount of energy to allow the ventilation air to move through them. The complication of the shaft conveyances that provide additional obstructions past which the ventilation air would have to move was also a cause of concern. A method needed to be found to include these variables while the shaft evaluations were being conducted.

It became clear that results acquired from this study would be thorough and directly applicable to industry. Consequently, the researchers set about the work in the following four phases:

- **Phase 1:** A detailed evaluation of the current body of knowledge associated with the design of shaft systems and the flow of ventilation air through them.
- **Phase 2:** A detailed testing of actual shafts to understand the flow of ventilation air through them. This would need to include the movement of the conveyances to measure the pressure differences against time in conjunction with the movement of the shaft conveyances. These measurements were then compared to the current theory.
- **Phase 3:** A computational fluid dynamic (CFD) model would be completed for each of the measured shafts to allow for the calibration of these models against the measured data.
- **Phase 4:** Once a CFD model had been calibrated and proved, the researchers would be able to make a careful modification to this model to try and reduce the shaft system's energy consumption.

Building and calibrating the CFD model

As the CFD model was being built (using Star CCM+), various versions of the same model were run, The current theory does not provide sufficient accuracy to design new shafts, as it does not account for the effect that the shaft equipment has on the ventilation flow.

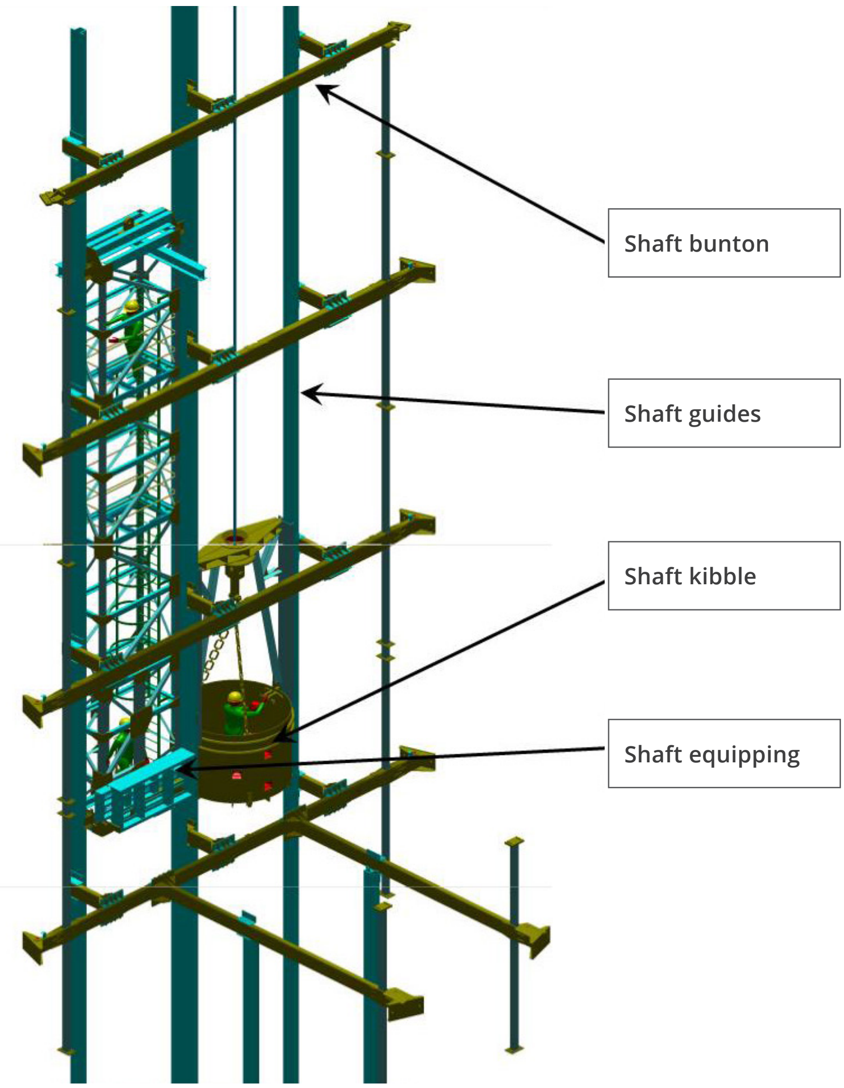


Figure 1: The various components of a mineshaft.

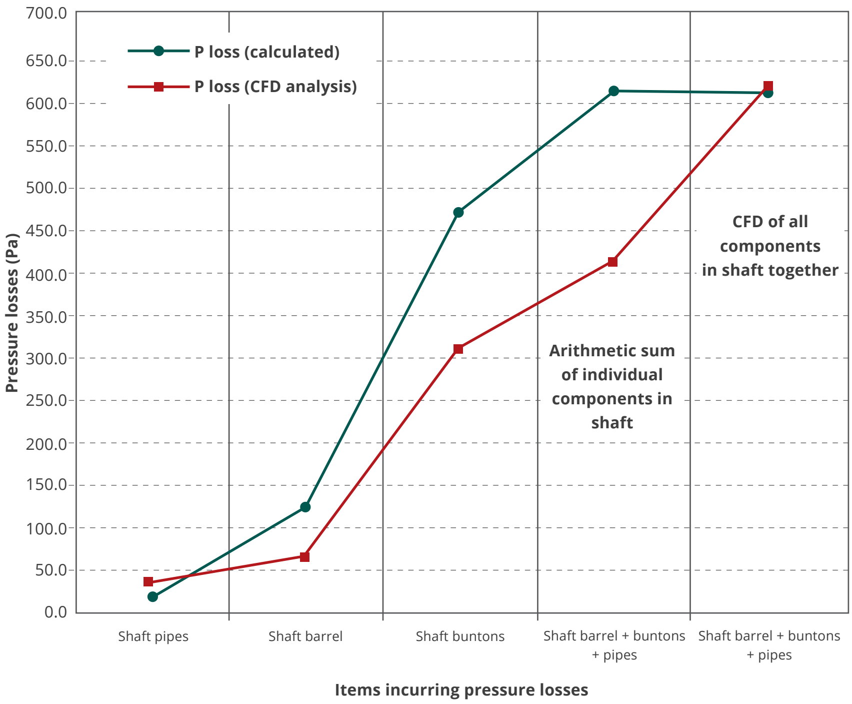


Figure 2: Calculated and CFD-analysed pressure loss in a shaft.

while pieces of shaft equipment (for example, shaft buntons and shaft guides) were added. This approach allowed the researchers to understand the contribution of each individual obstruction to the overall shaft pressure loss. The current theory also allowed the evaluation of these individual obstructions, and was used for comparison as the models were constructed. The current theory already proved accurate according to the physical shaft measurements obtained in Phase 2.

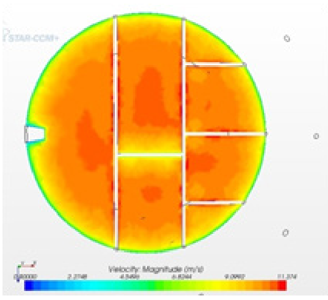
At first, there was very little agreement between the CFD model results and the values calculated from the current theory. The differences in the pressure losses between these two calculations exceeded 30%. However, as the researchers continued to build the model and the complexity of the model increased, so did the agreement between the measured data and the CFD data. When the entire shaft was modelled, there was almost complete agreement between the two models.

Figure 2 illustrates the differences between the various obstructions in the shaft and the shaft pressure loss calculations. When the items in the shaft are considered in the CFD model, the individual and cumulative pressure losses of the items in the CFD analysis are not equal to the calculated data. However, when the shaft equipment is considered as a whole and the model is run, there is close agreement between the results.

This means that the current theory does not provide sufficient accuracy to design new shafts, as it does not account for the effect that the shaft equipment has on the ventilation flow. Furthermore, the assumption made for the pressure losses associated with the pipes and the shaft conveyance was calculated incorrectly.

The illustrations in Figure 3 show the pressure losses and velocity distribution over the shaft at various cross-sections. This shows that the separate items have markedly different velocity profiles when compared to the profile of the equipment as a whole.

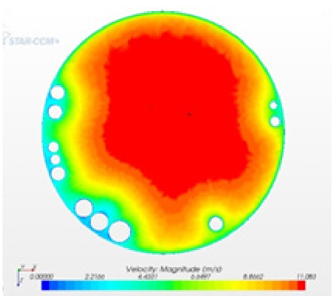
This particular result demonstrates the dangers of measuring systems and then adjusting the known theory to fit the results. While this allows some prediction of pressure losses in similar systems, significant errors can be made when different systems are evaluated using the same theory.



Calculated pressure loss (Pa/m) – 0.65

CFD-derived pressure loss (Pa/m) = 0.44

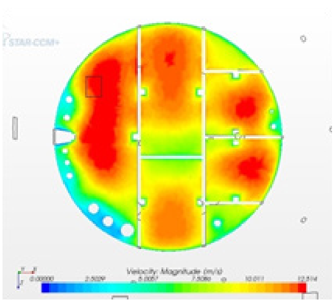
Red: 11.3 m/s
Blue: 0.0 m/s



Calculated pressure loss (Pa/m) – 0.15

CFD-derived pressure loss (Pa/m) = 0.11

Red: 11.1 m/s
Blue: 0.0 m/s



Calculated pressure loss (Pa/m) – 0.71

CFD-derived pressure loss (Pa/m) = 0.71

Red: 12.5 m/s
Blue: 0.0 m/s

Figure 3: Pressure losses and velocity distribution over the shaft at various cross-sections.

With this new knowledge, a typical shaft system was modelled. In an effort to reduce the pressure loss over the shaft length, changes were made to the shaft buntons and the placement of pipes around the shaft. Table 1 and Table 2 demonstrate that significant savings can be accrued if this technique is used to analyse shaft systems.

This research demonstrates that the use of modern analysis techniques, together with good engineering, can yield results that are beneficial in situations where researchers think they already understand the theory. This has resulted in an analysis technique that will help with the design of future mines and has the potential of saving significant sums of money at no additional capital costs.

Table 1: Difference associated with bunton shapes

Item	Description	Shaft P_{Loss} (Pa)	Ratio differences	Life of mine (20 years) (potential savings)
1.01	Airflow buntons	822	1.00 (baseline)	–
1.02	Streamlined buntons	774	0.94	-R5 738 460
1.03	Square buntons	1 608	1.95	R94 046 991
1.04	I-beam buntons	1 324	1.61	R60 413 237

Table 2: Difference associated with piping placements

Item	Description	Shaft P_{Loss} (Pa)	Ratio differences	Life of mine (20 years) (potential savings)
2.01	Piping along shaft edge (no flanges)	857	1.13	R12 114 528
2.02	Piping away from shaft edge (no flanges)	819	1.08	R7 651 281
2.03	Piping distributed around shaft (no flanges)	755	1.00 (baseline)	R -
2.04	Distributed piping with flange	867	1.14	R13 310 040

__William Kempson__ is a senior engineering manager with more than 15 years' experience in the design, engineering, construction and operation of mines and their associated plants and infrastructure. He obtained his undergraduate degree, as well as his master's degree in Engineering from the University of the Witwatersrand, and his PhD in Mining Engineering from the University of Pretoria in 2012.