Evaluating Shaft Guide System and Hoisting Operation Through Ventilation and Motion Studies

Quan Situ (Ph.D., P.Eng)
Thomas Li (P.Eng)
Julius Butty (P.Eng)

G. L. Tiley & Associates Ltd.
46 Dundas Street East, Flamborough, Ontario L9H 7K6, Canada
Tel: 1-905-689-7275
Fax: 1-905-689-5361
Web: http://www.tiley.on.ca
email: qsitu@tiley.on.ca

ABSTRACT

In evaluating the influence of increased mine ventilation utilizing the vertical production shaft as intake or exhaust, various factors, such as conveyance motion and especially the shaft guide system, have been studied.

Case studies of two typical conveyance guide systems, namely rope guide (in a potash mine) and fixed guide (in a hard rock mine) are presented. Field measurement was carried out to record the conveyance motion and major ventilation parameters, such as air velocity, various pressures and temperature, during the vertical travel of the conveyance in typical operation. The field test data was correlated to the computational fluid dynamics (CFD) models created from specific shaft parameters to perform the studies. Once the calibrated CFD model reproduced the results in good agreement, the CFD model was considered as “correlated” and could be employed to extrapolate parameters to the proposed new flow volumes. The air pressure profile from the CFD model was exported and superimposed to the conveyance motion model. With various other factors, such as rope tension and Coriolis effect, the conveyance motion, or conveyance displacement, under increased flow volume, could be predicted. As long as the minimum desirable clearance of the conveyance in the shaft can be maintained while passing mid shaft, the increased flow velocity would be considered an acceptable velocity. Other parameters would provide reference for the consideration of power consumption on the ventilation system during hoisting operation.

Successful predictions have been validated in field after guide changes were made. Also, guidelines have been obtained to determine the shaft layout of the rub rope arrangement.

KEYWORDS

Mine ventilation, conveyance motion, shaft guide system, hoisting, CFD

BACKGROUND

Increasing ventilation on the mine shaft often comes to an issue whether the “limit air velocity” has been reached, especially for a mine utilizing the vertical shaft as intake or exhaust. Design guidelines, such as the McPherson’s maximum relative velocity have been suggested (McPherson, 1988). Some survey data of fill coefficient and maximum relative velocity have been provided and generally utilized to evaluate the frictional resistance of the shaft to flow. One recent work employing the computational fluid dynamic (CFD) technique was carried out to investigate the various factors that influence the shaft pressure loss, such as the influence of conveyance travel in the shaft, pipe and bunton influence, etc (Kempson, 2012). The Tiley authors’ work was to establish a methodology to evaluate the ventilation influence on the hoisting operation, specifically the horizontal movement of the rope guide system and additional drag force from the fixed guide system. Although obtaining the pressure drop in the shaft is also related to the determination of the motor / fan capacity and the power consumption, it will not be discussed in this work.

Investigations of two typical guide systems in vertical shaft arrangements, namely rope guide system and fixed guide system are presented in this work (Figure 1). Similar methodologies were implemented in the studies. The current operating conditions, such as the mine shaft ventilation and the conveyance motion, were measured from...
field tests and utilized to correlate the models sufficiently to represent the current conditions. Extrapolations would then be carried out with the proposed conditions, such as increased flow volume or conveyance velocity, etc. Determining the possibility of increasing the flow to certain volume was to examine if the minimum clearances between the conveyances or shaft wall can be maintained under such a flow velocity. The air flow studies were carried out with software of SolidWorks CosmosFlow, whereas the conveyance motion studies were carried out with ANSYS WorkBench.

Horizontal motion of the conveyance in a rope guide system may reduce the spacing between the conveyances or shaft wall. The main factors that influence the conveyance horizontal motion are mainly the Coriolis effect, air pressure, stiffness of rope guide, rope vibration, etc. In considering the hoisting operation under increased ventilation volume, the spacing between the conveyances and the shaft wall would be critical and should be studied employing some guidelines to avoid collision either between conveyances or shaft wall. This ventilation study of the shaft employing computational fluid dynamics (CFD) would not only provide the features of the airflow or barriers of the ventilation network, but also the influence on the conveyance displacement, incorporating a motion study from an finite element analysis (FEA). The ventilation limit could then be determined for the conveyances running at higher air flow and/or hoisting speed.

For a fixed guide system, the factors influencing the ventilation in the shaft include shaft geometry (shape and wall roughness), steelwork (bunton and guide), conveyance velocity and geometry (shape, quantity, position). The increased flow volume on the hoisting operation will cause noise, vibration of ropes and pressure loss over the conveyance, which will increase both the vertical force and horizontal force to the fixed guide that further produces additional frictional force vertically, especially when the contact is improper. Among these factors, the consideration of noise is not in the scope. The rope vibration may be considered only in the modal analysis and rope resonance. To predict the rope excitation due to the air turbulence is not practical. Since the horizontal motion of conveyance is restrained, hence increasing air flow will only affect the power consumption of the ventilation and the hoisting power. There will likely be higher impact on the fixed guides.

**MOTION PREDICTION AND VERIFICATION OF A ROPE GUIDE CONVEYANCE**

The investigation of the rope guide system of a potash mine shaft included calibration...
with initial field measurement, model simulation and field verification.

Initial field measurements were carried out in August 2010 to obtain the conveyance motion, especially the clearances between the east and west skips, and also the pressure with the travels of the skips in the shaft. The motion sensors provided the displacement of the east skip and the ventilation test unit provided the pressure over the conveyance. With regard to the east skip motion, loaded and moved upward, there was about 3.3” displacement westward in the mid-shaft, whereas the emptied east skip moving downward was about 2.4” eastward. For the scenario of east skip moving upward, the Coriolis effect tends to reduce the clearance in between the two skips, whereas in the other scenario of east skip moving downward, the Coriolis effect pushes the two skips away. The ventilation test provided the two skips away. The ventilation test provided the readings of pressure at the various locations of the shaft, and also the pressure at the skip-skip interface and the skip-wall interface. The recordings of conveyance motion and pressure along travels did not exhibit oscillating data due to the rope vibration. No noticeable jump in the reading was captured along the travel especially at the mid-shaft. This seemed to indicate that although the measured displacements were combined influences of air flow, Coriolis effect and guide rope vibration, the rope vibration appeared to be minor, whereas the main factors influencing the skip clearance seemed to be air pressure and Coriolis effect.

In the air flow study, the geometric features of the shaft along all the airway were modelled. The conveyances, such as the cage in the service shaft and the skips in the production shaft were modelled as walls in motion. The guide ropes and headropes were not incorporated in the flow study. The process when the two skips approach, meet and pass each other at the mid-shaft, was especially studied (Figure 2). At time of study the operation velocity of the conveyance of the potash mine was 3300 fpm. The proposed velocity for investigation was 4000 fpm. Also, it was required to determine a suitable flow volume for this velocity. Per the rule of thumb, such as McPherson’s maximum relative velocity, a limit velocity for the air flow may occur at the flow volume of 515 k·cfm. Various flow volumes of 500, 550 and 600 k·cfm, were considered for evaluation. Typical simulation results showed that the main barrier of the air flow was due to the construction and equipment layout, such as the air flow entry and exit to the shaft. Shaft wall roughness exerted minor influence in the flow. The pressures over the conveyance surfaces at each step were obtained for further motion studies.

FIGURE 2. Pressure result of shaft ventilation under various flow volumes.
Motion studies were first carried out on calibrating the existing conveyance (48 ft length and 3300 fpm velocity) with field test data and then extrapolating to the proposed condition (65 ft length, 4000 fpm velocity). Guide ropes and headropes were modelled in the motion simulations. Various factors, such as Coriolis effect, vibration of guide rope with cheese weight, and air pressure, were considered, to match the displacements from field tests. Among the factors, the modal analysis for the guide rope vibration was carried out separately. The amplitude of guide rope vibration was about 0.05 in, indicating the contribution of the guide rope vibration to the conveyance horizontal motion was minor compared to the Coriolis effect and air pressure. The main influence to the skip horizontal motion was from the Coriolis effect and air flow. The corresponding minimum clearances between the skips under various flow volumes were obtained (Figure 3). For the test conditions, no collision was predicted to occur. As per prediction, for the flow volume higher than 500 k·cfm, the east skip would already be in contact with the rub ropes, whereas the west skip would still be clear of the rub ropes. Even under 600 k·cfm flow volume, there would be still minimum 15.6” clearance in-between the two skips as per prediction, which indicated that the skips may travel under the guideline limit velocity without a collision. It should be noted that the rub rope in the east-west direction should be moved at least 1” minimum per the motion simulation.

Further extrapolation employing the correlated model was carried out for the prediction of the hoisting operation with only three guide ropes on one conveyance. To prevent a contact between the conveyance and the rub rope, the maximum velocity was determined at nearly 70% of the full production speed, higher than the mine empirical of 50% of production speed, which significantly reduced the production loss during main tenance.

![Clearances between skips under various airflow volumes (east up and west down).](image)

The prediction on asymmetric guide rope configuration was verified with the field measurements carried out in November 2011. As three guide ropes were employed in the hoisting operation, both planar and rotational motions were captured. Coriolis...
The Coriolis effect tended to produce westward planar displacement on the east skip when it was loaded and moved up. As the north-west corner was free of restraint due to the rope replacement, the skip tended to rotate counter-clockwise. The clearance between the two skips reduced. In the travel of east skip moving down, the skip tended to have planar displacement westward due to the Coriolis effect. Clockwise rotation would occur for the asymmetric restraints of the guide ropes, which would increase the clearance between the two skips. At 70% of the production speed, the clearance between the two skips were still higher than the centre line distance of the rub ropes at rest, indicating no contact between the skip and rub ropes. Higher than 77% of the production speed, the clearance significantly dropped to lower than the rub rope centre line distance, indicating a contact between the skip and rub rope. To prevent a risky motion, the velocity at 70% of the full production speed was recommended as the limit operation speed for the three guide rope configuration. This approach was successfully implemented during the rope change.

VENTILATION FIELD TEST AND MODELLING OF A FIXED GUIDE CONVEYANCE

A fixed guide system is employed in the hard rock mine of study. The ventilation system uses the production shaft to introduce the air into the mine using fans underground and exhausts the circulated air up the ventilation shaft. Measurements were taken in the shafts only; no measurements were taken underground. Field measurements provided air pressure, velocity and temperature during conveyance travels. The flow modelling provided results of air flow pattern, velocity, pressure drop and temperature in the airways. Although the motion of the conveyance was not a concern due to the fixed guide configuration, the modelling work would provide guideline for further investigation, as rattling motion of the conveyance at certain airways would likely occur.

Among the factors that influence the conveyance motion, the pressure variation around the conveyance is the main contributor, or the dynamic pressure due to the flow. Compared to the length of the shaft, the potential energy of air due to the conveyance length of about 32 ft was negligible. Only the kinetic energy of the air flow was considered for the pressure loss, which would be influenced directly by the velocities. For the other factors, the cross section of the conveyance was rectangular, perpendicular to the flow direction. The fill ratio of the largest conveyance was about 25%, lower than the empirical recommendation of 30%. Also, the measurement of the pressure loss over the conveyance would be sensitive to the location of sensor. As per the results from the field tests, the variation of the pressure loss between the top and the bottom of the conveyance from the shaft bottom to the surface was negligible. Or, the travels of the conveyance in the shaft did not necessarily introduce significant change of pressure loss in the studied case. The recordings from the transducers also provided the differential pressure between the shaft surface and the shaft bottom. The test data shows the major influence of air flow on the conveyance, include the velocity change and pressure drops at various locations around the conveyance, and the pressure change along the shaft as well. The models for the flow study were correlated to match the results of field test and extrapolated to new flow volumes.

Ventilation studies with various flow volumes were carried out. Flow pattern in the shafts, pressure at various locations (pressure drop over the conveyance, and also in shafts) and velocities at various locations of the network were obtained. An increased flow velocity would mainly influence the pressure loss over the conveyance surfaces, or an increased load for hoisting, and would affect the energy required for the operation. Therefore, the major concern of this study was the ventilation capacity and the economic limit of power consumption. The pressure over conveyance surfaces could be obtained and superimposed onto the conveyance bodies for motion analysis, if necessary.

The CFD models incorporated the major geometric features of underground network,
station, total length of shaft, entry / exit. Conveyances were modelled as walls in motion at various velocities. Various flow volumes, environmental pressures and temperatures were applied to the surface and underground. Steelwork in shaft was modelled as wall. Ropes were not modelled in the CFD simulations. Major features of the current shaft ventilation have been captured in the simulations, such as significant turbulences in the shaft entry/exit, and around the conveyances. Even though there are steelworks inside the two shafts, they do not necessarily produce severe turbulences. Also, velocities under various flow volumes along the airways were obtained. The data was in close agreement with the test values. The key conclusions of these observations could be summarized that the steelwork and wall roughness in the shaft have limited influence in the flow, whereas the construction, such as the entry/exit to the shafts, fan room passage, has greater influence on the flow. The results were mainly evaluated for the pressure and the velocity. The pressure results were utilized to obtain the pressure drop in the shafts. The velocity was employed to investigate the flow in the airway. The dynamic pressure was post processed to show the pressure loss over the conveyances (Figure 4). The modelling of the current ventilation system produced results in reasonable agreement with the tests and was extrapolated to the proposed conditions, in order to examine the increased pressure losses over the various locations of the shafts and around conveyances.

A. Under existing flow volume. B. Under proposed flow volume.

FIGURE 4. Pressure result of shaft ventilation under various flow volumes.

The influence of conveyance position over the flow in the shaft was also investigated by studying the interrupted motion at given positions, such as at the station near underground, at mid-shaft and close to collar. In each group of comparison, the variation of conveyance position does not exhibit noticeable change, although the flow may locally change. The flow patterns showed relatively little sensitivity to the
change in conveyance position under various flow volumes. The dynamic pressure over the surfaces of the conveyance was exported to evaluate the possible influence on the conveyance motion (Figure 5), although a motion study was not necessary as it is running on fixed guides. Only the conveyance at an underground station in the production shaft is presented, as it could be a major concern when the conveyance is parked at the airway. The dynamic pressure over all the surfaces of the conveyance obtained from the modelling was post-processed to show the influence on the conveyance. It should be noted that pressure loss due to dynamic pressure (or velocity influence) could only be measured at one spot. However, the simulation produced the scenarios not captured in the field tests. Test data obtained pressure loss between top and bottom surfaces of conveyance on one edge, whereas the modelling provided pressure losses over all surfaces. The predicted pressure loss over the conveyance at the station shows that the turbulence at this location might have already caused unbalanced surface loading over the conveyance body. These observations show that the conveyance itself does not introduce severe turbulence, but the geometry of the construction in shaft entry/exit causes strong air turbulence. When the flow was extrapolated to the proposed higher flow volume, the influence of the velocity pressure would subject the conveyance to more turbulence and more unbalanced loading.

**FIGURE 5.** Pressure losses over the conveyance at an underground station under existing flow volume.

Based on the relative velocities of various conveyances under the current and proposed flow volumes, the drag forces could be estimated. The increased vertical load on the conveyances should be within the hoisting capacity. Structural details would be necessary for evaluating the influence of the side pushing force on the conveyance. The influence of dynamic pressure over the conveyance body was only regarded as a guideline. It provides a reference for a more dimensional motion study. Further, under the proposed higher flow velocity in the shaft, the generally
referenced limit velocity of 6000 \text{fpm} 
(relative velocity) per McPherson’s “rule of 
thumb”, will be reached, especially when 
the two skips pass each other. Even though 
the conveyances could run under the 
unstable condition of the flow, since the 
conveyances are running on fixed guide, 
there will be no horizontal collision in the 
motion. Therefore, the air velocity should 
not be the limitation in the motion or 
operation of the conveyance.

In summarizing the investigation of the 
ventilation system, including the field test 
and the modelling work on the shafts and 
the underground network, the results of flow 
pattern, pressure drop and air velocity over 
the construction (between surface and 
bottom of shafts) and around the 
conveyances have been obtained. The 
simulations of the current flow volume 
closely reflect the current operation 
conditions. The test values have been 
correlated in the modelling and reproduced 
with reasonable agreement with the test 
data. Therefore, the extrapolations to the 
proposed flow volumes were sufficient to 
predict the possible influence of the higher 
flow in the ventilation network and on the 
conveyances without choking the system. 
The increased flow volumes would then be 
achievable.

**SUMMARY**

The motion study of conveyances 
employing rope guide system of a potash 
mine shaft was investigated for the 
influences of guide rope, air pressure and 
Coriolis effect, incorporating experimental 
data from the current hosting operation and 
extrapolating to the proposed conditions. 
The correlated model has been utilized to 
determine the maximum operation velocity 
with 3 guide ropes only during the rope 
change period and was validated with field 
tests, which increase the empirical value 
from 50% to 70% of the full production 
velocity. The conveyance motion under 
various flow volumes should be examined 
during mine upgrades to validate the 
methodology to be applicable for prediction 
beyond the guideline limit.

Characteristics of ventilation in a hard rock 
mine shaft, such as air flow velocity, and 
pressure loss over conveyances and shaft, 
have been investigated in the field test, and 
utilized to validate the modelling. Although 
there would be less concern of horizontal 
motion of the conveyance running beyond 
empirical velocity limit, the additional force 
for operation due to an increased flow 
should be considered.

**ACKNOWLEDGEMENT**

The authors would like to thank Tim Mierau 
and Bradley Voss for their cooperation to 
complete these studies. The authors would 
heartily thank Greg Stevens and Erick Gow 
in building the test system and the field 
measurement.

**REFERENCES**

Kempson, W.J., *Optimizing Shaft Pressure 
Losses Through Computational Fluid 
Dynamic Modelling*, Ph.D. Thesis, 

McPherson, M.J., *An analysis of The 
Resistance and Airflow Characteristics of 
Mine Shafts*, Fourth Internaional Mine 
Ventilation Congress, Brisbane, 