AN ANALYSIS OF A DETAILED ENGINEERING STUDY IN ACCORDANCE WITH IESO IAP REQUIREMENTS.

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ABSTRACT

An Independent Electricity System Operator Industrial Accelerator Program (IESO IAP) case study was completed for a mine in Ontario, Canada by SRK Consulting, Inc. The purpose of the study was to analyze the ventilation system to determine whether and which system improvements could reduce the overall electrical power demand of the mine. Financial incentives are offered by the IESO IAP grant program to help cover the capital costs of these improvements. This study included the completion of a full mine ventilation survey as well as measurement of a full suite of electrical parameters of the surface and underground ventilation fans. After these measurements, a base ventilation model was created and established as the system baseline. Changes to the ventilation system were modeled, and their effects on the power demand were projected. The results of the study showed that several improvements were possible which may significantly improve the efficiency of the ventilation system and reduce mine electricity demand.

KEYWORDS

IESO IAP, Electricity, Energy, Efficiency, Financial Incentive, System Improvements

INTRODUCTION

In 2017, a ventilation study was conducted in accordance with the Independent Electricity System Operator Industrial Accelerator Program (IESO IAP) at a mine in Ontario, Canada. The IESO IAP is designed to assist eligible transmission-connected Canadian companies operating in Ontario to fast track capital investment in major energy conservation projects. The program will provide financial incentives to encourage investment in innovative process changes and equipment retrofits to reduce electricity consumption on the provincial system and to help companies become more competitive by positively impacting their bottom line.

There are now four initiatives under the Industrial Accelerator Program:

1. Retrofit
2. Process & Systems, including Small Capital Projects
3. High Performance New Construction
4. Energy Managers – a new initiative under the Industrial Accelerator Program

Within the program, companies may propose energy saving changes to their current systems where applicable and appropriate. Companies may then be awarded funding to implement the proposed changes. The program allows partial financial compensation to implement certain energy saving changes that would otherwise not be considered due to high capital costs. For larger projects, such as underground mine ventilation systems, a detailed engineering study must be submitted. This study must detail each energy saving change or measure, its savings, and calculate the financial incentives using the IESO IAP Payment Structure. The payment structure for a project is an amount equal to the lowest of the following:

1. 70% of the Eligible Costs of the Project or,
2. The product of the estimated Annualized Electricity Savings:
   a. In the case of a Project that is not otherwise part of a Portfolio (a set of more than one project), multiplied by $230/MWh; or
   b. In the case of each Project within a Portfolio, multiplied by $320/MWh; and
3. The amount that would provide a Project Payback of one year for a Project.

(Independent Electricity System Operator, 2015)

For the purposes of this study only one project was considered (item 2b from above was not applicable).

The payment structure is designed to narrow the list of eligible cost saving measures that may be implemented for a given project. Measures with payback periods of less than one year are not eligible and projects without a payback are ineligible. Some measures, while they may provide savings, may cost very little to implement and therefore would not be eligible. Other projects may save a lot of energy but may cost too much to implement and therefore may not have a reasonable payback period. The purpose of this study was to analyze a mine ventilation system to determine power saving measures in which may save on power and award the mine with incentives to implement these changes. Calculations in this paper demonstrate the IESO IAP incentive calculation process and are not actual results from the case study which was completed for the mine in Ontario, Canada.

BASELINE METHODOLGY AND DATA COLLECTION

To begin the study, a baseline set of data needed to be established. This was accomplished by conducting a full ventilation survey of the mine along with a full suite of power metering measurements on the main fans. Airflow quantities were determined by performing full section vane anemometer traverses or centerline smoke tube measurements and multiplying by a measured cross-sectional area. Static pressure differentials across bulkheads, doors, and regulators were measured directly using a digital manometer connected to a length of tubing. The gauge-and-tube traverse method was used to measure the frictional (total) pressure drop along mine airways where the airflow quantity was substantial enough to render meaningful data. To assist in the quantification of natural ventilation energies and fan operating points, dry bulb temperature, relative humidity, and barometric pressure were measured at key locations throughout the mine. Measurements of fan pressures were obtained for the primary fans throughout the mine. Using this data, a base ventilation model was created based upon the assumption of compressible flow. Ventilation measurements correlated to base model results to within 10% error. Fan power measurements were also obtained to create a baseline for primary ventilation fans power usage at the mine. For most of the primary fans, measurements of amps, volts and power factor were measured directly with power metering equipment. Power measurements were completed by qualified mine personnel. Other primary fan power measurements were obtained by computer screenshots of fan controls.

ANALYSIS AND CALCULATIONS

After the baseline methodology was established, several measures were considered for optimization of the ventilation system to save on power demand. Measures considered included fan optimizations and ventilation infrastructure changes. Fan optimizations included:

- adding inlet cones only
- outlet evasés only
- adding both inlet and outlet evasés
- and installing variable frequency drives (VFD)

Since some fans did not have access doors installed in fan bulkheads, bulkhead deconstruction and reconstruction were required. For certain fans, improvements to the location of the fans were suggested which would require development of additional fan drifts.

These changes could increase the efficiency through the fans as losses through the fans themselves would be more adequately reduced or recovered. This would allow fans to be turned down using the VFDs and therefore save on power demands.

An example calculation of a fan needing an inlet cone and outlet evasé is provided in Table 1. It was estimated that a shock loss factor of 1.0 would be used to calculate shock resistance due to turbulence at the inlet of the fan without an inlet bell or cone. It was also estimated that a shock loss factor of 1.0 would be used to calculate shock resistance at the outlet of the fan without an evasé which equates to a direct loss of kinetic energy (McPherson, 2009). In total this sums to a total loss through the fan without an inlet cone or evasé to a shock loss factor of 2.0. By installing both an inlet cone and evasé it is estimated that these shock loss factors are reduced to 0.2. To convert these shock loss factors to pressure losses on the system the following Equation 1 was used.

$$\text{Pressure (Pa)} = \frac{Q^2 \rho X}{2A^2} \tag{1}$$

Where:

ρ = air density (kg/m^3)

X = Shock Loss Factor (dimensionless)

A = Cross sectional area of the fans (m^2)

Q = airflow quantity (m^3/s)

(McPherson, 2009)

Power cost savings were calculated for each fan measured and compared with the capital costs associated with fan parts, bulkhead construction and deconstruction, and drift development. From these cost calculations, incentives were calculated based on the IESO IAP criteria.

Table 2 provides capital costs for the previous power cost example and also includes estimated costs for construction and deconstruction of bulkheads. Associated incentive calculations for this example are illustrated in Table 3.

The example illustrated by the previous discussion and Tables 1-3 demonstrates how fan operating pressures are reduced by recovering losses through the fan. Increases in fan efficiency would result in the fans delivering higher airflow quantities for similar or lower fan total pressure; however, it was assumed that these fans would be decreased to their original operating airflows to save on power costs. For these improvements, the overall net effect on the rest of the ventilation system is zero since, fan improvements only affect the individual fan power costs and would not have interactive effects on the rest of the ventilation system. For the other ventilation infrastructure changes however, these interactive affects need to be considered and therefore infrastructure changes were also taken into account. These effects included:

- turning off one or more main fans
- installation of airlock doors
- sealing inactive levels
- adding additional parallel raises
- installing new primary ventilation raises
- observing the interactive effects of installing more than one of these new changes on the system.

To analyze these infrastructure changes, the base ventilation model was modified. For each measure, changes were added to the base ventilation model and the effects on the primary ventilation fans monitored. Changes in power demand for each fan in the model were monitored by changes in the air power from the base ventilation model. Air power is calculated based on the Equation 2.

$$\text{Air Power (kW)} = p \times Q \qquad (2)$$

Where:

p = Fan total pressure (kPa)

Q = Airflow Quantity (m^3/s)

(Hartman, 1997)

Fan operating points from modified ventilation models were adjusted to manufacturers' fan curves according to density and fan speed differences from fan manufacturers' curves. From the air power, motor powers were estimated by plotting adjusted main fan operating points on fan manufacturers' curves to estimate fan efficiency. By summing the total net power change from all the main fans underground, measures were able to be qualified as increasing or decreasing power demands from the base ventilation model.

Table 1. Calculation of system air power and fan air power

Assumptions	
Hours of operation per year	8,760
Power Cost per MWh (CAD)	$100.00
Currency	CAD
1. Calculate system air power and fan air power	
Total Airflow (m^3/s)	70.4
Delivered Total Pressure Measured (kPa)	0.334
Pressure Loss - no inlet cone or evasé (kPa)	0.628
Fan Pressure (kPa)	0.962
Measured Air Density (kg/m^3)	1.2
System Air Power (kW)	24
Fan Air Power (kW)	68
2. Calculate System inefficiencies and power costs	
Amperage	100
Voltage	600
Power Factor	0.85
Motor Power (kW)	88.2
System Efficiency	27%
Fan Efficiency	77%
Motor Power (MW)	0.0882
Total Power Consumption per year (MWh)	773
Annual Power Cost (CAD)	$77,300
Power wasted due to inefficiencies (MWh)	567
3. Calculate new system air power with inlet cone and outlet evasé	
Total Airflow (m^3/s) (Given in Step 1)	70.4
Fan Pressure (kPa) (Calculated in Step 1)	0.962
Pressure Loss -> Inlet cone + outlet evasé (kPa)	0.063
Delivered Total Pressure Measured (kPa)	0.899
Measured Air Density (kg/m^3) (Given in Step 1)	1.2
System Air Power (kW)	63
Fan Air Power (kW)	68
4. Calculate annual power savings using new reduced fan losses	
System Efficiency	72%
Fan Efficiency (Calculated in Step 2)	77%
Motor Power (MW) (Calculated in Step 2)	0.0882
Total Power Consumption per year (MWh) (Calculated in Step 2)	773
Annual Power Cost (CAD) (Calculated in Step 2)	$77,300
Power Saved (MWh)	349
Annual Power Savings (CAD)	**$34,900**

Table 2. Example capital costs.

Equipment Type		Cost (CAD)
Inlet Cone	$	3,000
Outlet Evasé	$	4,000
Deconstruct Bulkhead	$	3,000
Construct Bulkhead	$	50,000
Total:	**$**	**60,000**

Table 3. Example calculated measure incentives and project payback.

Annual Electricity Savings (MWh)	349
A) Project Incentive (Annual Electricity Savings x $230/MWh)	$80,200
B) Project Incentive (based on 70% of total eligible costs)	$42,000
C) Project Incentive (based on a minimum 1 year project payback)	$31,200
Project Incentive (minimum of A, B, and C)	$31,200
Project Incentive ($/MWh)	$89.44
Project Benefits ($/year) Electricity Savings	$34,900
Actual Eligible Costs	$60,000
Third Party Contributions	$0
Project Payback with incentive (years)	**1.00**

One of the raises in the mine was observed to have a high pressure drop during the ventilation survey. A measure was therefore considered to add a second parallel raise to decrease resistance. Adding a parallel raise would have the effect of decreasing the overall pressure losses and therefore decrease the required operating pressures on some of the main fans located near the raise. The result of this measure is that the capital costs of developing the raise greatly exceeded the operating cost savings associated with decreased fan operating points. This measure was not recommended based on IESO IAP requirements since it did not yield an eligible payback period.

A new primary ventilation raise spanning multiple levels was also considered to help ventilate future development. While this measure did result in power savings, capital costs were orders of magnitude higher than the operating cost savings and therefore was not recommended based on the IESO IAP criteria.

Other measures were included based on interactive effects of preventing unnecessary leakage and reducing fan operating settings. By analyzing the ventilation base model and measurements from the ventilation survey, it was estimated that as much as 30% of the air in the mine was being fed directly to exhaust from intake sources, instead of being usefully employed on development or production levels. Based on this information, a measure was suggested to increase volumetric efficiency in the mine, and decrease required operating points on the main fans. This measure included removing several ventilation fans, adjusting regulators, installing bulkheads to seal old inactive levels, adding airlock equipment doors to separate main intake and return raises, and installing single equipment doors to limit airflow to areas needing minimal access and ventilation.

For each infrastructure change, measures were analyzed for individual changes to the system. This, however was shown to marginally affect the overall ventilation system. For example, if only one inactive level off the main ramp was sealed, airflow would redistribute itself in the model around the bulkhead on other inactive levels, thereby nullifying the effects of the sealed level. To realize the power savings of these infrastructure changes, multiple changes needed to be considered at the same time. After adding infrastructure changes, the base model shows an increase in operating power. While sealing of ventilation levels prevents fresh air from being wasted on inactive levels and limited use areas of the mine, it also adds resistance to the ventilation system which increases power requirements on main fans. To combat these effects, main fans were turned down using each fan's VFD. Fans were adjusted such that airflows through the active areas of the mine were similar to flows that were measured on those levels during the ventilation survey. In this way, power costs were saved while still maintaining airflows to appropriate areas. This measure yielded significant project incentives and a reasonable projected payback period.

The last measure in the study included combining the results of some of the fan optimizations from the first measures as well as swapping smaller fan motors for several fans with oversized fan motors. In this way fan efficiencies would be optimized since the specified fans would be using less power. This measure yielded an acceptable payback period while also requiring the least amount of development costs and additional installations.

CONCLUSIONS AND DISCUSSION OF RESULTS

Results of the analysis demonstrated that most of the fan optimizations resulted in power saving improvements which resulted in qualifying incentives for those measures. These improvements included fans which needed any two or more of the following improvements: installing inlet cones, outlet evasés, deconstructing/reconstructing fan bulkheads, redeveloping fan chambers, and installing VFDs. One measure included only adding a single inlet cone. Because this improvement yielded a payback period of less than one year, incentives could not be awarded from this change. However, based on the short payback period, this improvement was still recommended.

During the study, a potential paradox between study objectives and mining objectives was discovered. As stated earlier, the purpose of the IESO IAP program is to incentivize energy saving projects that a company may undertake for the purposes of saving on the electrical demands of an eligible entity. It could be stated that the purpose of a mine, however, is to make money through mining of ore. These two purposes can be at odds with each other in certain circumstances. For instance, one potential measure that may exist is one in which a low efficiency fan without an evasé is replaced by a higher efficiency fan with an evasé. In order for this measure to save on electricity costs and therefore be an IESO IAP eligible improvement, the new fan system would be installed and turned down so that its operating point (pressure and airflow) matches that of the previous low efficiency fan. In this way, less electricity is being used to meet the same delivered operating point. This practice, however, may be contradictory to mine objectives. If this new fan is installed in an active area of the mine, management may elect to increase the airflow through this fan. This may allow the mine to boost production since more airflow may be available for more equipment than with the previous fan. This however may mean that the installation of the fan would not be eligible for incentives under the IESO IAP program, since the increased operating airflow may maintain or increase electricity demands at this location.

Most of the ventilation control changes (adding bulkheads, doors, raises) did not single-handedly yield power saving opportunities under the IESO IAP criteria. The ineligibility of certain improvements for the IESO IAP program may not disqualify an improvement from being a recommended option the mine may want to install. For instance, a measure such as adding an outlet evasé to a fan may be ineligible for incentives if the improvement has a payback period of less than a year. However, in practice adding evasés to fans is considered best ventilation practice and should be implemented regardless of whether it is an approved measure for the IESO IAP program. Another example of this may be the installation of a new ventilation shaft as previously described. For instance, a 7m diameter shaft that extends 300m from surface may be necessary for the purposes of mining a new ore zone. However, this installation would likely never have an eligible payback period since power cost savings would likely be orders of magnitude less than the capital costs associated with the installation of the relatively large shaft. Therefore, even if the IESO IAP program won't cover an improvement, this doesn't necessarily mean the improvement should not be completed.

Based on the study, mine improvements which may yield incentives under IESO IAP criteria seem to be limited to bulkhead installations, fan installations, regulators and door installations, and minor mining drift development modifications. Large multi-million-dollar capital projects such as the installation of a new raise primary shaft or primary ventilation drive may be too costly to be partially covered under IESO IAP incentives. Installation of raises and shafts were found to be too costly to yield a reasonable payback period per the incentive program.

In order for infrastructure changes to yield IESO IAP qualifying incentives, these improvements needed to be changed together and in tandem with other fan adjustments. This is because individual changes usually result in a slight redistribution of airflow without major energy savings benefits. It also requires that fans be turned down once changes are completed for the mine to receive financial incentives from the IAP program, which may be contrary to the mine requirements.

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