ENERGY AUDIT METHODOLOGY FOR BELT CONVEYORS

By

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SUMMARY

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The electricity cost is one of the largest components of operating costs on a belt conveyor system. This dissertation introduces a unique Conveyor Electricity Cost Efficiency Audit Methodology (CECEAM). In the CECEAM the conveyor system is evaluated from a high to detail level in order to identify opportunities to improve electricity costs. The CECEAM includes methodologies and tools developed to analyze not only the conveyor belt alone, but also the materials handling system as a whole.

The outline of the dissertation is structured as follows: Chapter 1 includes the background and problem identification by means of a literature study. The main objective, as well as specific objectives, is defined in this chapter. In chapter 2, the CECEAM is introduced and an overview of the total methodology is discussed. The data acquisition part of the CECEAM; documentation, personnel, walk, technical audit as well as the conveyor database is discussed in chapter 3. Chapter 4 concentrates on the Conveyor Energy Conversion Model (CECM) and the verification thereof. The Integrated Conveyor Energy Model (ICEM) methodology is introduced (in chapter 5) and the economic evaluation concepts and energy management basics needed in the CECEAM are covered. Chapter 6 covers a CECEAM case study where the practical application of the CECEAM is illustrated with ICEM simulations,

opportunity identification and recommendations. The conclusion and recommendations for further studies is proposed in chapter 7.

Keywords:

Conveyor Electricity Cost Efficiency Audit Methodology (CECEAM), Conveyor Energy Conversion Model (CECM), Integrated Conveyor Energy Model (ICEM), Demand Side Management (DSM), Measurement and Verification (M&V). Electricity Tariff, Conveyor Speed, Conveyor Belt Loading, Energy Management, Energy Audits, Economic Evaluation.

OPSOMMING

ENERGY AUDIT METHODOLOGY FOR BELT CONVEYORS

deur

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Elektrisiteitskoste is een van die grootste komponente van bedryfskoste in ‘n vervoerbandstelsel. Hierdie verhandeling stel ‘n unieke Vervoerband Elektrisiteitskoste Rendement Oudit Metodiek (VEKROM) bekend. In die VEKROM word die vervoerbandstelsel vanaf ‘n hoë vlak tot op ‘n detail vlak ge-evalueer om geleenthede te identifiseer om elektrisiteitskostes te verbeter. Die VEKROM sluit in metodieke en gereedskap wat ontwikkel is om nie net die vervoerband alleen te analiseer nie, maar ook die wyer material hanteringstelsel in geheel.

Die verhandeling is as volg uiteengesit: Hoofstuk sluit in die agtergrond en probleem identifikasie deur middel van ‘n literatuurstudie. Die hoofoogmerk asook spesifieke oogmerke word hier gedefinieer. In hoofstuk 2 word die VEKROM bekend gestel en ‘n oorsig word gegee oor die metodiek. Die inligtingsverkrygings gedeelte van die VEKROM wat bestaan uit die dokumentasie-, personeel-, loop- en tegniese oudit asook die vervoerband data basis word bespreek in hoofstuk 3. Hoofstuk 4 konsentreer op die Vervoerband Energie Omsettings Model (VEOM) en die verifiëring van dit. Die Geïntegreerde Vervoerband Energie Model (GVEM) word bekend gestel in hoofstuk 5 sowel as die ekonomiese evaluasie konsepte en basiese energie bestuur konsepte. Hoofstuk 6 hanteer ‘n gevalle studie waar die praktiese implikasie van die metodiek geïllustreer word met GVEM simulasies, geleentheids identifikasie en aanbevelings. Die opsomming en aanbevelings vir toekomstige navorsing word in hoofstuk 7 hanteer.

Sleutelwoorde:

Vervoerband Elektrisiteitskoste Rendement Oudit Metodiek (VEKROM), Vervoerband Energie Omsettings Model (VEOM), Geïntegreerde Vervoerband Energie Model (GVEM), Aanvraag Kant Bestuur (AKB), Meet en Verifieer (M&V). Elektrisiteits Tarief, Vervoerband Spoed, Vervoerband Belasting, Energie Bestuur, Energie Oudits, Ekonomiese Evaluasie.

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To my study leaders Dr. G.J. Delport and J.E. Calmeyer for encouragement and support

LIST OF ABBREVIATIONS

CECEA	Conveyor Electricity Cost Efficiency Audit
CECEAM	Conveyor Electricity Cost Efficiency Audit Methodology
CECM	Conveyor Energy Conversion Model
DC	Direct Current
DF	Diversity Factor
DOL	Direct On Line
DSM	Demand Side Management
EA	Energy Auditing
ECO	Energy Conservation Opportunity
EMO	Energy Management Opportunity
EMR	Energy Management Recommendation
ESCO	Energy Service Company
HVAC	Heating Ventilation and Air Conditioning
ICEM	Integrated Conveyor Energy Model
IRR	Internal Rate of Return
LF	Load Factor
MARR	Minimum Attractive Rate of Return
M&V	Measurement and Verification
MD	Maximum Demand
NPV	Net Present Value
PEA	Preliminary Energy Auditing
PF	Power Factor
PFC	Power Factor Correction
ROM	Run of Mine
SCADA	Supervisory Control And Data Acquisition
TA	Technical Energy Audits
TVM	Time Value of Money
VSD	Variable Speed Drive

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CHAPTER 1

PROBLEM IDENTIFICATION AND BACKGROUND

1.1 MOTIVATION FOR THE STUDY

Energy Management becomes an important aspect in industry today. From a holistic point of view, there is pressure from environmental affairs to reduce energy consumption in order to minimize carbon oxide emissions and the effect of global warming.

From an Industry specific perspective, there is pressure on companies to reduce operating expenditure and add more value to shareholders interest. Electricity cost as part of the operating expenditure can be reduced by effective energy management methodologies.

The focus on electricity cost savings on conveyor belts was in the past more on the energy reduction of mechanical components of the conveyor system. Work has been done on conveyor belts to improve efficiencies by controlling multiple drive units.

The need was identified to evaluate the electricity cost efficiency of a conveyor system by integrating all the factors that have an influence on the electricity costs of the conveyor system. This need is addressed in this dissertation by the development of a Conveyor Electricity Cost Efficiency Audit Methodology (CECEAM).

The literature study in the rest of Chapter 1 is an investigation of what has been done in the field previously and how it can contribute and how the existing methodologies can be extended upon to address the specific need.

1.2 CONTRIBUTIONS OF THE STUDY

The problem identified is that there is no methodology available to audit the electricity cost efficiency of a conveyor system; and to identify and quantify electricity cost savings. This dissertation includes a literature study to prove the above statement.

The main contribution is the development of a Conveyor Electricity Cost Efficient Audit Methodology (hereafter styled CECEAM).

Specific contributions that are made that supports the main contribution were the following:

1 Improvement of existing Conveyor Energy Conversion Models (styled CECM henceforth) to focus on electricity cost dependent aspects.

2 Development of an Integrated Conveyor Energy Model (referred to as ICEM hereafter) that integrates all influencing electricity cost factors.

3 Extension of existing per unit transfer energy measures to accommodate more relevant details.

4 Focus on the influence of belt loading on conveyor energy efficiency.

Two articles have been published out of this research:

a) D.J.L. Marx and J.E. Calmeyer: "An Integrated Conveyor Energy Model Methodology", Transactions of the South African Institute of electrical Engineers Vol. 95 pp. 256-264, 2004.

b) D.J.L. Marx and J.E. Calmeyer: "A Case Study of an Integrated Conveyor Belt Model for the Mining Industry", 2004 IEEE Africon Conference, Vol 2, pp 661-666, Sept ember 2004.

1.3 BACKGROUND

1.3.1 Introduction

Energy consumption plays an increasingly significant role in industry today. Industries are pressurized to improve their energy consumption trends from a financial and an environmental perspective.

The environmental impact [1] of carbon oxide emissions in the air due to power generation becomes a more and more critical measure. The responsibility of carbon oxide emission reduction is not only that of the electricity suppliers, but also of the end- users as well to utilize energy more effectively.

Energy consumption forms a significant part of operating expenditure in industry. Through the ongoing drive in industries to become more cost effective, the need exists to explore and investigate more opportunities to lower costs. Electricity is one of the components of operating costs that can be lowered by the effective management of the usage thereof.

Increasing electrical loads causes demands for new power stations, but by managing energy more effectively, the building of new power stations can be put on hold. For this reason electricity suppliers provide more opportunities for the larger end-users, like industries, by using specific tariff structures to manage energy more effectively. This leads to benefits for the supplier as well as for the end-user. The supplier benefits in lower peak demands, and the end-user in electricity cost savings. The benefits of effective energy management of electrical loads are increasingly explored and recognized throughout the industry.

Energy management initiatives, however, need to be identified and carefully verified before any capital is spent on the implementation of the initiatives. An energy audit is a tool to identify and quantify possible energy cost savings. During an energy audit process quite a large amount of data acquisition takes place. The data then needs to be compiled to be useful in any decision making process.

The Implementation of energy management initiatives is recently more strongly supported, however, a lack of understanding in this field throughout industry leaves the need to present initiatives identified to management in a more effective way. The modeling and simulation of a specific electrical load as part of an energy audit process is a method to identify, define and present opportunities for energy management in a more effective way.

Electrical load modeling is an energy management-planning tool. A model is normally developed for a specific load application and used to forecast several outputs with certain scenarios of inputs.

The focus of this work is on the development of an audit methodology for conveyor systems to identify and verify opportunities to implement energy management plans.

Conveyor belts are one of the major consumers of electricity in the materials handling facilities in industry. The energy consumption can be up to 40% of the operating cost [2] of a conveyor belt. The remaining 60% is due to operational costs and maintenance.

The majority of papers on energy savings on conveyor systems focus on improving the efficiency of the mechanical and electrical equipment deployed on the conveyor system that is used in order to save energy. Examples of this are improving idler [3] or drive [4] efficiencies.

Existing power consumption models are used to calculate the power consumption of the conveyor for design purposes [5] In this work the emphasis is on managing the energy consumption in accordance with the electricity tariff to minimize energy costs on a belt conveyor system rather than reducing the amount of energy consumption.

Measurement and Verification (M&V) methodologies developed in the past to prove energy savings of a controller on a belt conveyor [4] make use of a baseline technique where actual measurements are done to determine the power consumption as a function of the tonnage moved. No parameters of the conveyor belt are presented in the model. The model is only a tool to measure and verify what has already been done. In this dissertation a model is developed to determine the operational energy consumption baseline. This avoids time consuming measurements and baseline determination. When the baseline is used in conjunction with the relevant electricity tariff, it is a useful management tool to perform offline simulations to reduce the running costs in terms of energy savings.

Belt conveyors are materials handling equipment that is widely used in the industry today. In the mining and industry environment conveyor belts are used to move material from the mining or storage areas to the different plant areas, and from one process to the next. Conveyors are normally driven with electric motors. The motors that are usually used for this purpose are AC squirrel cage induction motors. The reason for this is that the motor's cost is relatively low. Other motors that are sometimes used, although not often, are the synchronous machines.

1.3.2 Conveyor belt overview

During conveyor design there is, as in any design, key design parameters. Some of these parameters have a great influence on the energy consumption of the conveyor.

In the first place, a conveyor is designed to move a certain amount of material at a certain rate over a specific distance. This can be horizontal displacement of material or it can be vertical. An example of this is an incline conveyor. The typical conveyor belt is illustrated in Figure 1.1 below.

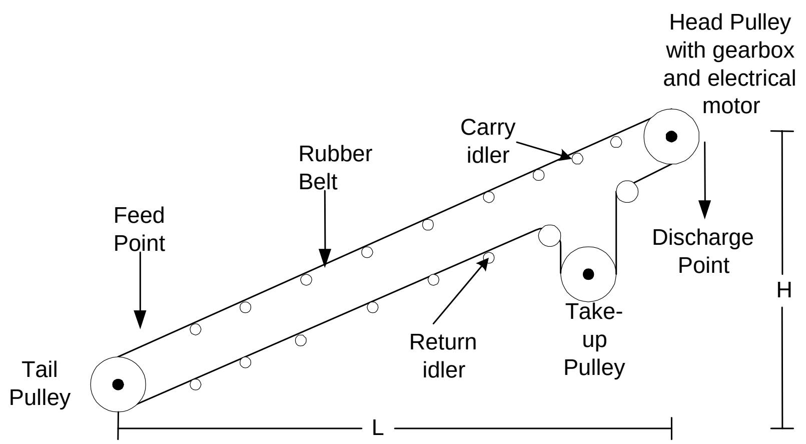


Figure 1.1 Typical Conveyor Belt

The conveyor belt system in total consists of the following components [5]:

a) Rubber belt.

b) Head pulley with gearbox and electrical motor.

c) Tail pulley.

d) Carry idlers.

e) Return idlers.

f) Take-up Pulley.

There is a tail pulley and a head pulley. The material to be conveyed is loaded onto the conveyor near the tail pulley and discharged again at the head pulley. In simple conveyor designs, the drive unit is normally situated at the head pulley. In more complex designs, the drive pulley is situated somewhere in the middle of the conveyor on the return side of the conveyor. A take up pulley gives the belt tension. This pulley is usually a distance away from the head pulley. The tensioning of a belt can vary from a fixed tension by using a mass over a pulley or a mechanical tensioner like a bolt and nut. Control systems with electric motors and hydraulic arms also exist that control the tension in the belt.

There are also carrying and return idlers. The idlers have cylindrical wheels under the conveyor belt that support the belt and in the case of the carrying idlers, the load. The return idlers generally support the return side of the conveyor belt, but there are cases where the return side is also used to carry material. This is sometimes used in the underground mining application where the Run of Mine (hereafter styled ROM) material is carried on the top and the waste material out of the plant is carried on the return side of the conveyor belt to do back filling. This reduces the energy consumption of the conveyor because the return side generates energy back to the system.

1.4 LITERATURE STUDY

In the literature study, relevant literature is investigated to form a background of what has been done in the specific field. The emphasis is on what is applicable and contributes to the solution of the problem of this specific research and why some of the work that has been done does not contribute. The literature study is divided into different areas. Each area concentrates on a specific part of the problem. The areas are as follows:

- Energy Audits.
- Energy Management of the Conveyor System.
- Method of Propulsion.
- Energy Losses in Conveyor Systems.
- Existing Conveyor Models.

1.4.1 Energy Audits

Energy audits are conducted to learn more about the way energy is consumed in a specific load or plant. During the energy audit data is collected, compiled, investigated and opportunities are communicated back to management.

In the paper of Spratt [6], he concentrates on preparing an energy audit. In the article he refers to six steps to be followed in preparing for an energy audit. These steps are discussed below:

1 Set Priorities

Look at the facilities and determine the priority of each facility. Determine where to focus first.

2 Look for Obvious Savings Opportunities

After looking at the consumption history, walk through each facility and look for obvious energy-savings candidates. While you may not be able to quantify energy-saving opportunities, you should be able to get a "gut feeling" of the potential return by conducting an energy audit.

3 Set Priorities and Policies

Don't forget the people aspect of the equation. Your organization will be more effective in its conservation efforts if it has officially endorsed and promoted its sustainable philosophy.

4 Investigate Funding Sources

Look into government programs offering assistance and money to help reduce energy consumption and greenhouse gases.

5 Decide on your Hurdle Rates

Energy consultants can do a better job for you if you can communicate your economic decision criteria. Decide on your maximum payback period or internal rate of return.

6 Get Baseline IAQ Measurements

It will be helpful knowing the level of your indoor air quality before looking at HVAC savings.

The article provides useful information that is applicable in general to energy audits. Points one to five can be used in the development of an audit methodology for conveyor systems, but point six is applicable to HVAC systems and will not contribute to this study.

In the paper of Capehart [7] the focus is on improving industrial energy audit analysis. According to the paper the frequent criticism of energy audits is that they overestimate the savings potential available to the customer. The paper addresses several problem areas, which can result in over-optimistic savings projections, and suggest ways to prevent mistakes.

Energy and demand balances are stressed as the initial step a careful analyst should take when starting to evaluate the usage of energy at a facility. These balances allow one to determine what the largest energy users are in a facility, to find out whether all energy uses have been identified, and to check savings calculations by determining whether more savings have been identified than are actually achievable.

Some analysts use the average cost of electricity to calculate energy savings. This can give a false picture of the actual savings and may result in overoptimistic savings predictions. This paper discusses how to calculate the correct values from the electricity bills, and when to use these values. Finally, the author discusses several common energy saving measures that are frequently recommended by energy auditors. Some of these may not actually save as much energy or demand as expected, except in limited circumstances. Others have good energy saving potential but must be implemented carefully to avoid increasing energy use rather than decreasing it.

In conclusion the author stresses the fact that energy auditing is not an exact science, but makes a number of opportunities available for improving the accuracy of the recommendations.

What is applicable in the article is that there is the general warning about the optimistic estimations of savings in an energy audit.

Capehart focuses on motors and Variable Speed Drive (referred to as VSD hereafter) applications to save energy, but there is no indication of the influence of VSD's on conveyor systems.

Although there is a lot to learn from the article more could have been said about how these problems in energy audits can be addressed. He refers to "rules of thumb" that will be implemented to give indications of what the possible savings from certain alterations are; however, no methodology is given that can be followed.

In another paper of Capehart [8] he concentrates on how to write user-friendly energy audit reports. He stresses that energy audits do not save money and energy for companies unless the recommendations are implemented. Audit reports should be designed to encourage implementation, but often they often impede it instead. In the paper, the author discusses his experience in writing industrial energy audit reports and suggests some ways to make the reports user-friendlier. The goal in writing an audit report should not be the report itself; but rather, it should be to achieve implementation of the report recommendations and thus achieve increased energy efficiency and energy cost savings for the customer.

The article focuses on the report writing part of an energy audit. This can be used in an audit methodology to structure the results in a report.

In the article the focus is on energy audit reports in general. No specific indication is given on how to report or represent a recommendation on a specific load, like a conveyor system. Nothing is mentioned about what specific information is essential to include in the report.

Spain [9] illustrated how an end-user group can be audited to find out what is needed in the facility to save energy cost. Questions included are:

a) How much energy of each type is being used over a period of time?

b) How much does the energy cost?

c) For what is the energy used?

d) What opportunities exist for reducing energy usage and / or cost?

Spain uses three levels of auditing namely:

a) Preliminary Energy Auditing (PEA)

b) Energy Auditing (EA)

c) Technical Energy Audits (TA)

The PEA audit is to obtain more information about the total operation of the organization or plant. This includes the basic walk through to see what types of energy are used and how they are used. The purpose of this walk through is to learn the layout of the plant to see how all the processes work.

What Spain did not mention is that during this phase you can look out for the largest end-users as well as for buffer capacities. The production line can also be followed to see exactly where processes occur along the line. Questionnaires can be sent out to the different sections to get information about plant layouts flow diagrams, single power line diagrams and so forth.

During the EA the flow of energy through the system is investigated in more detail. Load profiles are investigated to see what is the conservation of electrical energy is at certain points in the system. During this audit the unit cost of electricity per product measure is calculated.

When the TA is carried out the technical issues are covered like metering, data systems, SCADA (Supervisory Control and Data Acquisition), etc.

After the audits, all the ideas, data, suggestions and general information are combined to see where the problem areas are or where the optimum can be achieved with the smallest effort.

The energy audit steps in the article are relevant. The article did not give much detail regarding how the data can be used in an investigation to determine opportunities for energy cost savings. In a conveyor audit methodology more steps are needed to explore cost savings opportunities.

1.4.2 Measuring of Conveyor Power and Production

The correctness of energy, as well as production data, is essential in an energy study.

According to Daish et al [10], how and where measurements must be done is very important. In the article Daish refers to a "what to look for" approach when dealing with measurements. In this approach the correct measuring points need to be identified as well as the way measurements will take place.

The important and relevant part of the article is the measurement methodology to be followed. Measurements on conveyor systems are not addressed; therefore the work that has been done in this article needs to be extended in order to incorporate conveyor belts.

The basic principles of energy management are not discussed. The importance of the data is emphasized but the actual need for the data for energy management purposes is not discussed. Software considerations and tools are discussed.

Hager [6] touches on the concept of an energy norm for conveyor systems. The unit kilowatt-hour per ton kilometer [kWh/tkm] is used as a norm to describe the amount of energy that is used to convey the material. In this case the energy for a year is divided by the total production tonnage, times the distance it was conveyed. Although the paper describes that 40 % of the operating cost of the conveyors are brought about by the energy consumption, and mention is made of the ways to improve energy-savings by better physical design; nothing is said about energy management, for example how load scheduling can save money in the entire conveyor system. The need exists to investigate the influence of such scheduling on production, and in the end on electricity cost. In the article of Hager there are mechanical simulations to show the benefits of mechanical improvements on energy consumption. A simulation technique can be developed to simulate the effect of load management electricity cost.

Post implementation measurements of energy management initiatives done by an ESCO (Energy Service Company) are called M&V

(Measurement and Verification). In the review of Dalgleish the M&V of a motor sequencing controller on a conveyor belt is discussed. The focus is on measuring and verifying the predicted savings of the implementation of the controller. According to the article savings cannot be measured, only determined. In the M&V methodology a baseline is developed from actual data using regression analysis to express energy, maximum demand and reactive energy in terms of production.

The work referred to in the article is relevant after implementation verification. The methodology followed to establish a baseline is relevant and may be used in a conveyor audit program.

The focus of the M&V article is more on the savings of implemented energy management initiatives on a conveyor belt rather than on the detail of the measurement methodology itself.

1.4.3 Energy Management of the Total Conveyor System

Several methods have been documented where energy is generated using a conveyor system [11]. There are cases where the mining areas are on a hilltop and the ore is transported via conveyor belt to a plant lower down the hill. In this process the advantage of the potential energy difference is used to generate energy utilizing the conveyor system for the plant or part of the plant.

The focus in these articles is more on the technical detail of the generating process and not on the integration of the total energy management plan for the whole mine, i.e., part of the total cost. The conveyor system model can be used to develop an energy management plan for the mine. In such a case the conveyor is not seen as an end-user of electricity but more as a generator or a source of energy.

1.4.4 Method of Propulsion

Method of propulsion on conveyor belts is important in energy management in the sense that there is a relationship between the power consumption and the speed.

In the article of Dunn [12] “Why use electronic variable speed drives on conveyor applications” a comparison is made between earlier and recent methods of starting and stopping conveyors. The first method that was been employed in controlling the squirrel cage motor that is coupled directly to the head pulley via a suitable gearbox is the Direct On Line (henceforth referred to as DOL) method. During the start-up the breakaway torque of the motor is 2,3 times rated full load torque for smaller motors in the region of 74 kW and 1,1 times for motors in the region of 630 kW. The breakdown torque or pull out torque is the maximum torque a motor can develop at rated voltage. This parameter value is 2,5 times rated torque for small motors and 2,8 times for large 4 pole motors. Thus, during start-up the conveyor will experience a very high rate of change or jerk that can cause resonance on the conveyor. As the speed increases the developed torque increases until the pull out torque peak is reached, where after the developed motor torque decreases until the net acceleration torque is reduced to zero. The criteria for small values of jerk cannot be realized. Long acceleration times cannot be tolerated. Starting currents is seven times full load current during start-up and 3,5 times when breakaway torque speed is reached. This causes harmful temperature rise in the motor. Each motor is given a permitted starting time parameter; e.g. a 75 kW 4 pole motor is 18 seconds. The conveyor length for this type of starting is very short.

Reduced stator voltage starter of a squirrel cage motor is another method of starting. In this method star/delta, reactor or reactor resistor starting equipment can be used. Hence the starting- torque and current is reduced; e.g. a star/ delta is one third of DOL starting.

Slipring motor with rotor control equipment is a third method of starting that can be used to control the torque and starting current.

The fourth method of starting is mechanical soft starters or variable speed units situated between the motor and the gearbox.

The fifth method introduced is the electronic VSD that uses the vector control pulse wide modulation control philosophy or direct torque control philosophy. This method overcomes shortcomings of all the other types of starting equipment. In a down hill conveyor application the VSD is capable of breaking the load on a continuous basis. The VSD allows energy flow from the DC busbar back to the supply network, thus helping to reduce energy cost. With a VSD there are no limited starts per hour. A conveyor can be restarted while in motion without comprising the ideal conveyor starting requirements. The same is not valid for a fluid coupling application.

VSD's on conveyor belts reduce maintenance. Belts speeds can be varied to operate at a constant speed; hence reducing the up keep. Nothing is mentioned in the article about the effect of variable speed and constant loading on energy consumption.

Running costs of VSD's are noticeably lower than that of fluid couplings. VSD efficiencies are better than 98% and the power factor better than 0,93 throughout the speed range. Capital costs of VSD applications are lower than fluid coupling applications.

Harmonic currents is one disadvantage that is injected into the network by a VSD.

The article does a very in-depth discussion on the method of propulsion and starting of motors driving conveyors with the emphasis on a VSD driven conveyor. The applicable information in the article that is of the essence for this study is the energy-generating mode of the conveyor with the VSD, the variable speed - constant loading concept, as well as the power factor of the VSD. Great emphasis is placed on the advantages of a VSD method of propulsion in terms of control, maintenance, capital and operational expenditure; but the benefit of energy management opportunities and energy savings is not addressed.

Another article concentrating on different types of drives point out other aspects. [13] Larger belts require more power and this has brought the need for larger individual drives and for multiple drives such as four drive units of 1000 kW each on one belt. After the power on a conveyor belt is calculated, a decision can be taken whether the belt should be fitted with single or multiple drives. Comparison is made between DOL start motors and slipring motors. It is stated that slipring motors are more attractive in places where maximum demand plays a role in the electricity tariff. The losses in Slipring motors are 7 – 8% and that for DOL starters 10 – 12%. Although the author refers to savings that can be obtained on maximum demand by using the right drive, the actual impact of motor start – up on the maximum demand, integrated over a period of a half an hour, is not investigated to motivate the argument.

VSD's, according to the article, are more efficient than the usual fix speed drives. Half the power consumed by motors before the belt reaches its rated speed is converted into heat in the resistors or couplings. Applied to the operating period, these starting losses represent an equivalent power loss of between roughly 1 and 2% of the rated output of the motor. In this literature it is clear that work has been done in the past on the saving of energy by adapting the speed of the conveyor to the haulage rate. A model was developed where these savings are illustrated, but a case study has not been mentioned for this specific model. It would be of worthwhile to test the model's practicality and to comment on the outcome of the practical evaluation. It is shown in the model that a saving of up to 15% on the demand capacity is possible on horizontal conveyors and up to 5% on incline conveyors. This is feasible if the belt speed is reduced to 75% of the rated speed, meaning that the actual haulage is 75% of the rated haulage capacity. The reason for this is that in the case of an incline conveyor, the hoisting capacity may be roughly two-thirds of the demand capacity at the rated haulage capacity. The hoisting capacity is; however, independent of the belt speed and depends only on the haulage capacity, the height of the lift and the gravitational acceleration. The only potential savings here concerns the friction power and turning power. This is in contrast with the horizontal belt, where the entire demand capacity is made up of the friction power and the turning power. Potential savings of between 8 and 21% are possible.

This application is not tested on an incline conveyor for a typical mine application and not integrated in a whole energy management system for a conveyor belt and other surrounding activities. In other applications of VSD's savings of up to 25% were possible [14].

There is quite a lot of detail included in the article that can be useful in conveyor modeling. The method of propulsion is not included in a total energy audit methodology. The article focuses more on a stand-alone approach and does not integrate the savings into electricity tariffs to see what the effect is on different types of tariffs.

1.4.5 Losses in Conveyor Systems

Swinderman [15] paid some attention to the power consumption of belt cleaners, which is a power loss in the whole system. He developed a model to calculate the power consumed by a belt cleaner as well as the power consumed in external losses like frozen idlers and accumulation on return idlers. This expression of losses can be used to develop a model where the energy consumption, according to bad maintenance practice, can be addressed to form an integral part of a least cost energy plan for conveyor systems.

This information will be essential in an audit. The reason for the model in this case is to calculate the power to determine the size of the electric motor and not for the energy management purposes. It will be wise to change the model according to the need of energy management. For this reason, the time when the conveyor is running and how long the conveyor is running will form an integral part of the energy conversion model.

Losses are present in every power transfer element in the entire conveyor system. Different drives experience-varying efficiencies [13]. Today there are highly efficient motors available where efficiencies of up to 96% are available against the usual type of efficiency between 89 and 92%. Mechanical losses in the gearboxes and conveyor components contribute to a total loss of about 10%. The physical properties of the conveyor belt cover plates manufactured from rubber influence the level of conveying systems' energy consumption. Hager [16] also states that the dynamic modulus and the phase lag angle are rubber parameters whose size and temperature dependence can themselves be influenced by varying the compounding and processing parameters. In this specific literature, attention is focused on the physical design of the conveyor belt cover plates to reduce energy consumption. For the purpose of this dissertation a detailed study will not be made of the mechanical design, but will be taken from an energy management point of view and the interaction with other linked systems in the total process. The information acquired from the literature will be used to improve the system, if possible, in terms of mechanical design parameters.

1.4.6 Existing Models

There are different models available that calculate the required power of a conveyor system. The required power for a conveyor can be divided into three parts namely [5]:

a) Power to run the empty conveyor.

b) Power to move the load horizontally.

c) Power to move the load vertically.

Roberts [17], describe the procedure for optimum design of continuous conveyors for bulk material solids handling. The performance characteristics are seen as the throughput and power of the conveyor.

Several mines and industries use the existing Goodyear Conveyor Model [5]. The model includes the three parts mentioned above.

Some assumptions are made and compensation values incorporated in the Goodyear Conveyor Model. The total focus of the Goodyear Model is to get an idea of the size of drive in a certain conveyor configuration. The focus in this model is not on energy. There are no tariff inputs.

These models are used in a mechanical sense where the power is calculated to size the motor for the application. For the purpose of this study the way of energy consumption and, more importantly, the time – of-use are the key factors in the management of the energy of a specific conveyor. The influence of a variable load on the total energy cost and maximum demand cost is not incorporated in the existing models and this can be investigated with a higher-level model. Such a model can be expanded to one with the relevant inputs such as tariff structure, required production profile, system and process limitations, buffer systems, etc.

Dalgleish [4] developed a model for M&V purposes as mentioned in section **1.2.2**. Measured data is taken and a baseline is established through regression analysis. The savings of implemented energy management initiatives are determined against the baseline by measuring the data before and after implementation. Electricity tariffs are incorporated in the models to determine the savings.

The focus his work is not to do simulations in order to identify savings opportunities, but rather to evaluate initiatives already identified. No conveyor parameters are expressed and therefore no effect of these parameters, like speed of the conveyor, etc., can be simulated accordingly.

Delport [18] focuses a lot on models and energy conversion methodology in the mining environment. The model inputs and outputs out of an energy management perspective were investigated in detail with case studies. A lot of systems were addressed, but a typical conveyor system is not part of the scope of work. The methodology can be modified for a conveyor system.

1.5 CONCLUSION

From the existing work it can be seen that a lot of effort has been done on the mechanical side of the conveyor system to make it more energy efficient. Very little work has been done on the development of energy management and even less on energy cost planning on conveyor systems with the incorporation of tariffs.

The ideal methodology would be one that integrates the energy consumption of the belt conveyor system or systems with a model that has outputs proposed operating philosophies for different scenarios. The existing models, although accurate enough for the purposes they were developed, cannot fulfill the requirements for this study.

This leads to the following main objective and specific objectives of the study:

1.6 OBJECTIVES

1.6.1 Main Objective

Develop a total electricity cost efficiency audit methodology for conveyors, including the modeling, simulation and minimization of energy cost.

1.6.2 Specific Objectives

- Document the total energy auditing methodology and physical layout by using the following:
  a) Questionnaire.
  b) Walk audit.
  c) Measurement audit.
  d) How to compare and interpret results with benchmarking.
- Improve on existing models by:
  a) Incorporating the operating philosophy parameters.
  b) Linking production to energy.
  c) Link no-load to energy.
- Measure existing conveyor systems by addressing the following:
  a) Production.
  b) Construction.
  c) Energy consumption.
  d) To verify and evaluate models by simulating and comparison to measurements.
- Use models and conveyor information to simulate necessary production with minimum energy cost.
- Recommend a better maintenance plan, design and/ or operating method for a specific system.

CHAPTER 2

INTRODUCTION TO THE CONVEYOR ELECTRICITY COST EFFICIENCY AUDIT METHODOLOGY (CECEAM)

2.1 INTRODUCTION

The literature study in chapter 1 identified the need for the research to develop a CECEAM.

The electricity cost efficiency audit of the conveyor will give an indication of the scope of improvement in electricity costs that exists without production losses and within plant operating rules. Operating rules refer to rules like safety rules, management rules, design limitations, etc.

A CECEAM is a methodology to evaluate the electricity cost efficiency of a conveyor system in steps to identify opportunities and recommend the implementation of initiatives.

In the CECEAM data is captured and compiled in order to get a better understanding of the way energy is consumed in the conveyor system. Modeling and simulation tools are then used to analyze the data and identify possible savings opportunities.

In the CECEAM the most relevant question is: 'What is the per unit electricity cost to transfer material through a conveyor belt system?' The focus of the CECEAM is on the electricity cost efficiency of the system and does not concentrate on the detail of mechanical efficiencies, although obvious opportunities in this regard may be pointed out in the first phase of the process.

From an energy management perspective the emphasis of the CECEAM is on how much is paid for the energy used and what parameters in the system can be managed in order to lower the electricity cost. The cost per unit transferred is of more importance in the CECEAM than the amount of energy consumed per unit transferred.

2.2 CECEAM OVERVIEW

When a CECEAM needs to be followed on any conveyor system there some initial work needs to be done.

2.2.1 Preliminary Audit

The question may arise whether an audit is needed on a specific conveyor application. This question may be answered by doing a preliminary audit to see what possible scope there is for projects. Typical questions that could be relevant in such an audit are the following:

1) What is the electricity tariff applicable?
2) Does the conveyor run empty at certain times?
3) Is the material load constant on the conveyor?
4) In what time of the day is the conveyor operational?
5) Is the conveyor over-designed for the application?

Out of the preliminary audit a feasibility check could be done to see whether it is viable to conduct a further audit that not only concentrates on the lowering of energy consumption, but also on improving electricity cost efficiency.

2.2.2 Planning

The planning of the audit needs to be done thoroughly. It is important to draw up a schedule to indicate specific tasks to be executed which ensures that all aspects of the audit are covered. The objectives for the specific audit must be stipulated to communicate on a kick-off meeting.

2.2.3 Communication and feedback

A kick-off meeting with all the people involved in the audit is important so that everybody in the plant knows that an audit will take place and that they need to submit information on request. In the meeting everybody could introduce him or herself and brief everybody on their specific responsibilities. Contact personnel could be identified from where information can be obtained. The objectives for the audit need to be communicated clearly. Minutes of the specific meeting should be distributed afterwards with all the relevant information, responsibilities, contact numbers, etc. Follow-up meetings are preferable to track progress and to set up a formal forum to discuss any problems that may arise during the audit.

2.2.4 Financial Considerations

During initial consultation it is important to establish acceptable return on investment or simple payback, subject systems, and other criteria necessary for the energy audit.

2.2.5 Data Acquisition

The first phase of the CECEAM is the data acquisition phase of the methodology. In this phase the data acquisition takes place in the form of three steps: the walk audit, document audit, personnel audit as well as the technical audit. The data received during the data acquisition phase must be captured in a database. This section will be covered in detail in chapter 3.

2.2.6 Conveyor Energy Conversion Model (CECM)

When enough data is available the next phase, the CECM, of the CECEAM can kick off. The CECM is a model that takes the physical parameters of the conveyor as inputs and delivers the energy consumption as an output. The CECM is established with the data received during the data acquisition phase. During this phase the CECM is verified by testing certain operating points against measured values. The verification process is necessary to make sure that the model is reliable to use in the simulation process. All the mathematical calculations of the CECM are discussed in detail in chapter 4.

2.2.7 Integrated Conveyor Energy Model (ICEM)

The ICEM [19] is the next step after the CECM has been verified. The ICEM methodology takes into account all the other parameters that could have an influence on conveyor electricity costs. In the methodology certain outputs or requirements are defined. The inputs to the model, upon which the outputs are dependent, are then identified. The ICEM can then be used for simulations where potential projects can be identified. When the potential projects are identified, a feasibility study needs to be conducted on each project to prioritize the projects. The feasibility study entitles a total financial analysis of the system in determining whether the identified projects are feasible or not and what can be done to make it feasible if the first attempt failed.

2.2.8 Final audit report

When the total CECEA has been completed, the results need to be communicated back to all the relevant people in the organization. The report should "talk" to the specific audience for which it is meant and the detail must be limited to the essentials. The next section in this chapter will focus on the audit report, because this is an important part of the CECEAM

2.3 AUDIT REPORT

A user-friendly audit report as described by Capehart [8] is necessary for the success of the CECEAM. The audit report methodology for the CECEAM is based on the article of Capehart [8] , with the focus on conveyor systems.

2.3.1 Key Points for Successfully Writing a Audit Report

Key points for successfully writing a user-friendly audit report are summarized below:

- ***Know Your Audience.***

It is important to bear in mind who your audience is when you write anything and focus your report writing on that audience. When writing an industrial audit report, your readers can range from the company president to the head of maintenance. If recommendations affect a number of groups in the company, each group leader may be given a copy of the report. Thus, you may have persons of varying backgrounds and degrees of education all looking at the report. Not all of them will necessarily have a technical background. The primary decision maker may not be an engineer; the person who implements the recommendations may not have a degree.

To deal with this problem the report can be divided in three basic sections:

1) An executive summary that briefly describes recommend actions and tabulates results such as the energy and money savings and the simple payback times.
2) A brief description of a recommended energy management program.

3) Detailed technical section. This section includes the ICEM calculations and simulations that support the recommend actions and any specific information relating to implementation.

- ***Use Simple, Direct Writing Style.***

The writing of the audit report must be in a clear, understandable language. The reader may not have a technical background. Even a person who does have a technical background will not be offended if the report is easy to read and understand.

Technical jargon that the reader may not understand must be avoided, as well as acronyms such as ECO (Energy Conservation Opportunity), EMO (Energy Management Opportunity) or EMR (Energy Management Recommendation) without explaining them.

- ***Present Information Visually.***

Often the concepts to be conveyed in an audit report are not easy to explain in a limited number of words, therefore drawings can be used to show what is meant.

Energy utility data can be showed visually with graphs with the annual energy and demand usage by month. These graphs give a picture of use patterns. Any discrepancies in use show up clearly.

- ***Make Calculation and Simulation Sections Helpful.***

The ICEM methodology and calculations used to develop specific energy management opportunity recommendations are potentially useful in an audit report. By including the methodology and calculations the technical personnel are given the ability to check the accuracy of the assumptions and the work. However, not every reader wants to wade through pages describing the methodology and showing the calculations. This information can therefore be a technical appendix to the audit report. Since this section is clearly labeled as the technical appendix, other readers are aware of the purpose of this section.

- ***Use Commonly Understood Units.***

It is important to use units that will be understood. Kilowatt-hours for electricity are better units because most energy bills use these units.

- ***Make Recommendations Clear.***

It should not be assumed that the readers will understand the recommendation even if it is not explicitly stated. Although the implied recommendation may often be clear, the better practice is to clearly state the recommendation so that the reader knows exactly what to do.

- ***Explain Assumptions.***

Failure to explain the assumptions underlying the calculations can cause problems. For example, when operating hours are used in a calculation, it must be showed where the numbers come from, like the facility operates from 7:30 am to 8:00 pm, five days a week, 51 weeks per year. Therefore, we will use 3188 hours in the calculations.

When the basic assumptions and calculations have been shown, the reader can make adjustments if those facts change. In the example above, if the facility decides to operate 24 hours per day, the reader will know where and how to make changes in operating hours because we have clearly labeled that calculation.

It is useful to make a list of standard assumptions and calculations so that explanations for each of our recommendations do not have to be repeated. Some of the standard assumptions/calculations included in the list are operating hours, average cost of electricity, demand rate, peak standard and off-peak cost of electricity, etc.

- ***Be Accurate and Consistent.***

The integrity of a report is grounded in its accuracy. This does not just mean correctness of calculations. Clearly, inaccurate calculations will destroy a report's credibility. Other problems can also undermine the value of your report.

It is important to be consistent throughout the report. The use of the same terminology and values ensures that the reader is not confused.

Proof-reading of the report will minimize typographical and spelling errors that may devalue an otherwise good product.

2.3.2 Report sections

Executive Summary

The audit report should start with an executive summary that basically lists the recommended energy conservation measures and shows the implementation cost and money savings amount. This section is intended for the readers who only want to see the bottom line. Although the executive summary can be as simple as a short table, some brief text is useful to explain the recommendations as well as other special information needed to implement the recommendations.

Conveyor Energy Management Plan

Following the executive summary, information can be provided to the decision makers on how to set up an energy management program in their facility and how the conveyor energy management plans fits into it.

Energy Action Plan for the conveyor system.

In this subsection, the steps that a company should consider in order to start implementing the conveyor improvement recommendations are described.

Energy Financing Options.

Information could be included about methods to finance the recommendations.

Maintenance Recommendations.

Although it is not always possible to make formal maintenance recommendations, because the savings are not often easy to quantify, it is useful to include energy savings maintenance suggestions or to provide checklists.

Technical Section

This is the part of the report that contains the specific information about the facility and the audit recommendations. The technical part can be divided into two parts. Firstly the ICEM method, where simulations and assumptions are described and secondly a detailed description of the recommendations in detail including the calculations and methodology.

Standard Calculations and Assumptions

This section was briefly described above when the importance of explaining assumptions was discussed. Here the reader is provided with the basis for understanding many of our calculations and assumptions.

Standard values calculated in this section include operating hours, average cost of electricity, tariff information, etc.

The baseline assumptions and methodology are described in this section.

Audit Recommendations

This section contains a discussion of each of the energy management opportunities that have been determined to be cost-effective. Each Energy Management Recommendation (or EMR) that was capsulated in the executive summary is described in depth here.

Each EMR can start with a table that summarizes the energy, demand and cost savings, implementation cost and simple payback period. Then follows a short narrative section that provides some brief background information about the recommended measures and explains how it should be implemented at the facility.

The final section of each EMR is the calculation section. Here we explain the methodology that was used to arrive at the savings estimates. The ICEM, with the assumptions can be provided in software form. If the reader needs to change assumptions, they can. If some of the data used is incorrect, it can be replaced with the correct data and recalculated.

Appendix

An appendix could be used for lengthy data tables and ICEM simulation data. A lot of detail sources of information for the ICEM can be included in the appendix.

2.4 CONCLUSION

The overview of the CECEAM was given in this chapter with the main focus on the audit report. It is important that the information and recommendations developed in the CECEAM is communicated in a structured way by means of an audit report. The following chapter will concentrate on the data acquisition in the CECEAM.

CHAPTER 3

DATA ACQUISITION

3.1 INTRODUCTION

The first step in the CECEAM is to do the data acquisition. The data is needed to learn how the system works and how all the parts are related to each other. The data required for the next phases of the CECEAM is collected through the different data acquisition processes.

3.2 TYPICAL DATA REQUIREMENTS

When the data acquisition process kicks off and a team meeting is held, it is very important to have guidelines of where data can be acquired. Table 3.1 is a guideline of how the data needed can be obtained.

No	Data	Data Application	Acquisition method	Source
1	System Layout	ICEM	Document Audit	Layout Drawing
2	Storage Capacities	ICEM	Document Audit	Design Drawings
3	Start-up Sequence	ICEM	Document Audit	Control Philosophy Document
4	Operating Hours	ICEM	Document Audit	Operating Philosophy
			Personnel Audit	Production Foreman
5	Shifts	ICEM	Document Audit	Shift Reports
			Personnel Audit	Production Foreman
6	Applicable Tariff	ICEM	Document Audit	Electricity Account

No	Data	Data Application	Acquisition method	Source
7	Production requirements: tones per hour, tones per annum	CECM ICEM	Document Audit	Production Reports, Production Target Documents
9	Management Requirements	ICEM	Document Audit	Health and Safety Documents
			Personnel Audit	Management
10	Maintenance philosophy	ICEM	Document Audit	Maintenance Philosophy Document
			Personnel Audit	Maintenance team
12	Process Flow	ICEM	Document Audit	Process Flow Diagram
			Personnel Audit	Production Foreman
13	Measuring Data	CECEM, ICEM	Technical Audit	Electronic Files, Meters
14	Transfer Rates.	CECEM, ICEM	Technical Audit	Electronic Files on Control System

No	Data	Data Application	Acquisition method	Source
			Technical Audit	Measurements
15	Conveyor Parameters	CECEM	Document Audit	"As Built" Drawings
			Technical Audit	Measurements
16	Power Factor	CECEM Verification	Technical Audit	Measurements
17	Drive Unit Efficiencies	ICEM CECEM Verification	Technical Audit	Measurements
			Walk Audit	Nameplate Information
18	Electrical Measuring Points	CECEM Verification	Document Audit	Electrical Drawings.
19	General Orientation	Over-all	Walk Audit	Conveyor System

Table 3.1 CECEAM Data Source Guideline

3.3 DATA ACQUISITION PROCESS

The data acquisition process is illustrated in the following diagram.

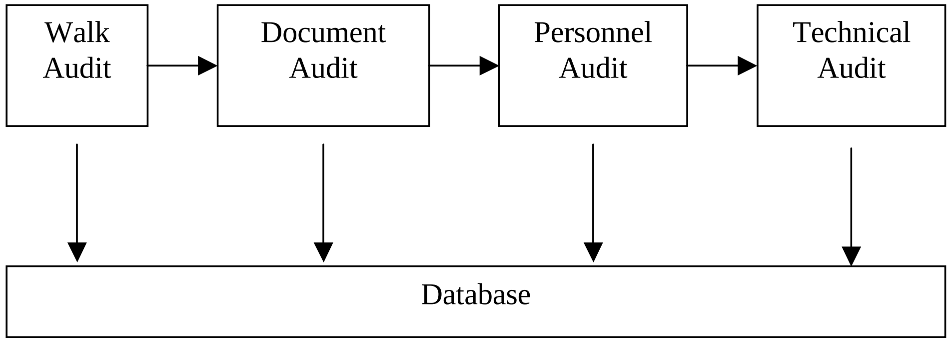


Figure 3.1 The Data Acquisition Process

The process starts with a walk audit followed by a documentation audit where after a personnel and technical audit follow. In the data acquisition process all the data collected must be stored or filled in a database. The best way to keep everything together is in electronic format. This information can then be issued as backup information to the final audit report as discussed in chapter 2.

The rest of this chapter will cover the detail of every part of the data acquisition process.

3.4 WALK AUDIT

3.4.1 Preparation and Planning

The walk audit needs to be planned to get the most out of it. A program or plant route to be followed is helpful to focus on the areas that are of the essence. Useful items to have with you during the audit are a notebook, camera (if allowed), cloth to clean nameplates, voice recorders etc. In some operations approval is needed beforehand in order to take a camera into a plant. This needs to be arranged.

3.4.2 Plant Overview

The walk audit is necessary to get an overview of the plant and realize how the different parts fit into the whole system. It is important to form a picture of how material flows through the plant and how energy is consumed in the different phases.

3.4.3 Important Data Identification

All relevant ideas and important information need to be put in writing for future reference.

During the walk audit a list can be made of all the obvious potential improvements and system inefficiencies. This can be done based on previous experience as well as visual insight. The information obtained during this phase can be used as a foundation for a in depth study.

Although a personnel audit will follow it is necessary to ask enough questions as the tour conducted through the plant.

3.5 DOCUMENT AUDIT

During the document audit a reasonable amount of data can be obtained for the CECEAM. The objective of the data acquisition process must not be overlooked and that is to create a model of the system and the nature of operation.

Too much information can distract the focus of the process and needs to be managed. Information regarding the conveyor system under investigation will be in different formats and forms. It is necessary to change some of this information to fit the purpose of the evaluation. A well managed filing system or database has to be developed in order to track the information of the system. Applicable references have to be allocated to the different documentation received, as well as a description of where it will be applicable in the next steps of the audit.

Information received needs to be re-evaluated several times and filtered for the essential stay of further stages of the audit process.

3.5.1 Drawings

Drawings are very useful in the CECEAM. It is important to use ‘as built drawings’ rather than ‘design drawings’, because there are in most cases, changes after the design and the drawings are then issued as ‘as built drawings’ after the installation is completed. The drawings that are usually available are:

Layout Drawings.

Layout drawings give an indication of how the site is laid out and how the equipment is related to each other.

Mechanical Installation Drawings.

These drawings are useful to obtain the parameters and sizes of the equipment under investigation, for example storage facility sizes.

Electrical Drawings.

Electrical drawings provide data regarding the electrical system that feeds the specific application. An electrical single line diagram is a high level presentation of the electrical network and can be drawn down to the low voltage level. Useful information like voltage levels, power factor correction installations, etc., can be obtained from a single line diagram.

Other electrical drawings, like motor control center drawings, give an indication of the motor sizes of the equipment as well as the type of starters like DOL or VSD that is used for the specific application.

Pipe and Instrumentation Drawings.

Measuring equipment is normally indicated on a pipe and instrument drawing. Relevant equipment for the CECEAM that is indicated on these types of drawings are conveyor belt speed monitors and belt scales.

Process Flow Diagram Drawings.

A process flow diagram shows the path of material flow through a plant. In a materials handling facility the diagram shows on what equipment, i.e. a conveyor belt, material is transferred from one point to another.

The process flow diagram will be valuable to see where the equipment fits into the production chain. It is important in any energy management approach to know what happens before the load or end-user, and what happens just after it.

3.5.2 Control Philosophy Document

The control philosophy document describes the philosophy of how the plant is controlled. In this document important inter-equipment relationships are identified. Operating parameters and conditions are specified in the control philosophy. This information is useful to obtain knowledge about the system regarding boundaries of operations and system limitations. Start-up sequences and start-up times can also be found in the document. The effect of any changes to the control philosophy of the plant can be investigated by studying the document.

3.5.3 Operating Philosophy Document

The operating philosophy can be a written document that describes the production process and how activities are executed. This document is generally used as a training document as well for the new personnel. The process flow description and method of operation can be found in such a document. The operating hours and shifts are indicated in the document as well. It may be found that the control and the operating philosophies are combined in one document.

3.5.4 Health and Safety Documents

These documents are vital to take note of where changes to the existing operations are investigated. The health and safety of the people operating the equipment in a plant is crucial and needs to be taken into account in the audit process. Legal requirements are important to take into account when considering any changes in operations like operating hours, etc.

3.5.5 Training Manuals

A training manual, if available, is normally a very good reference in the process of learning how the plant works and how it is operated. The equipment that is used in the plant is described as well. Although these documents will not reveal all the detailed information needed, it is a good overview of what the function of the different pieces of equipment is.

3.5.6 Electricity Accounts

The electricity accounts can be divided into internal accounts, if an individual internal measuring and billing system is applicable, and external accounts.

The internal accounts normally give an indication of the energy consumption of the different sections, as well as the tariff structure on which every section is billed. An important electricity consumption indicator, the per unit electricity cost for production, can be obtained from these accounts.

The external accounts are from the main supplier and give the detail of the total electricity costs.

In order to start and follow a certain energy consumption pattern it is useful to look at the electricity accounts of the past year. This will be necessary in developing a base case model of the specific equipment piece. It is important to have a global view of the operation under investigation.

To make sure that the focus and energy is concentrated in the right, direction and in the right places to reach the applicable objectives, it is vital to know what has happened in the past and to have a history around electricity consumption.

The applicable tariff will be indicated on the account as well.

3.5.7 Electricity Contracts

In some industries specific electricity contracts are negotiated with the electricity supplier. These contracts contain important information about the way the industry is charged for electricity.

3.5.8 Energy Policy

An energy policy is one of the most important documents in the CECEAM. The energy policy will give guidelines regarding the way energy is managed in the specific plant or industry.

3.5.9 Production Reports

This information will be related to the specific production profiles for the operation. This varies according to demand or according to maintenance programs. The production costs are normally a function of the production rate. One of the main objectives of least cost energy plans for any system is to lower electricity costs without influencing production throughput. In certain instances it may happen that the electricity cost may become such a contributing production cost factor that production will be influenced at certain times.

The data in the production reports can be fitted to the energy consumption patterns to find a more accurate relationship between production or material transfer and energy consumption behavior.

3.5.10 Maintenance Philosophy Documentation

Maintenance definitely plays a role in the way energy is consumed in any operation. Not only the time of large maintenance shutdowns can have an influence but also the frequency and the quality of the maintenance. Every plant or piece of equipment can be compared with a motorcar. In cases where the motorcar is not serviced regularly the fuel (energy) consumption increases. Where modular maintenance is applicable and different equipment pieces are serviced on different days, it is important to know where the specific piece of equipment under investigation fits into the maintenance plan.

3.5.11 System Parameters: Capacity, Physical Location and Lay-out, Incline/Decline

Certain system parameters can be obtained in the documentation audit through design and 'as built drawings'. The specific location and orientation of the equipment can be acquired. The design capacities are important if the efficiency of the system is investigated.

3.5.12 Process Flow Diagram

These diagrams will give an indication of the flow of material through the system.

3.5.13 Electrical Distribution Diagram with Electricity Measuring Points

In order to manage electricity effectively it is important to measure effectively. The distribution diagram of electricity can be useful to form an idea of the different load centers and how changes to the system will affect the distribution network.

3.5.14 Tariff Document

This document can be attained from the electricity supplier. In the document the specific tariff data is available that is needed in the audit process.

3.6 PERSONNEL AUDIT

Valuable data can be obtained by issuing a questionnaire to different sections that is familiar with the same equipment piece under investigation. The starting point of the whole process will be to inform management before the whole process starts in order to get their buy in on the process and to give them an understanding of the advantages of energy audit and management processes. The applicable sections that need to be targeted in this exercise are the maintenance, mining, production, management and services teams.

The questionnaire must have a specific date of completion to fit in the program of the overall audit program. It is very important to make the personnel an essential part of the total process from the beginning of the audit process in order to conclude the process as accurately as possible. Regular feedback meetings are essential throughout the whole process. The feedback just needs to inform the applicable people of the essential without too much detail. More detail can be made available as needed.

The whole process needs to be iterative and information needs to be filtered in order to achieve the best results as inputs for the model.

3.6.1 Management

Management needs to be informed about the audit that will be conducted on the plant. It is important to point out exactly what is going to be done and what information is needed. They can then identify the right people to contact or the right sources for obtaining the information needed in the audit.

3.6.2 Energy Manager

Where an energy manager is appointed, useful information can be obtained from him. The energy manager can form a key member of the team if a team is formed to execute the audit.

The data obtained from the energy manager is the energy policy, the energy strategy that is followed throughout the company, as well as work that has been done in the past on the specific equipment. Any other energy audits already conducted can be obtained from him.

3.6.3 Production Personnel

From discussions with the production personnel a picture can be formed of how the process works, as well as what the key drivers for the successful operation of the process are.

The production schedules, standing times, etc., can arise from the discussions.

Essential rules, production targets, future plans, etc., can be obtained from these people.

3.6.4 Maintenance Personnel

Maintenance personnel know the equipment and are probably aware of equipment inefficiencies. The maintenance strategy, planned maintenance periods, major shutdowns etc can be acquire from the maintenance personnel.

The electrical and instrumentation maintenance personnel can help with the information like the measuring points, motor control center locations, voltage levels, level of automation etc. They will have some of the equipment as well do the measurements, if there is no online equipment installed.

The mechanical maintenance personnel will have information on the conveyor mechanical part. Detailed information of the conveyor parameters is obtainable from them as well.

3.6.5 Project Manager

Any upcoming projects that may have an impact on the audit and simulation outcome need to be incorporated in the ICEM.

3.7 TECHNICAL AUDIT

The part of the audit that goes hand in hand with the walk audit is the technical audit. Areas identified in the walk audit will be focused on in the technical audit in order to form a deeper understanding of the specific area.

A typical example for such an item can be the following: During the documentation phase of the audit, a request for information can be issued on load profiles and measuring points on the applicable conveyor system. In return the request load profiles are received, but not the measuring points. During the walk audit the audit will be structured in such a way that the measuring points will be one of the areas to be examined. When the measuring points are identified during the walk audit, it will be added to the list of points for deeper investigation during the technical audit. In the technical audit the detail will be investigated to confirm that the load profiles received match the applicable measuring points.

During the technical audit the data received in the previous audits are confirmed by measurements. It may happen that some of the data received previously in the audit may seem to be suspicious. Special attention will then be paid during the technical audit to clear it out and confirm it.

During the model development it can be discovered that more information is needed. The phases of the audit process will be repeated until the model has been developed. The technical phase of the audit may be repeated without the other phases when the point is reach where the model verification takes place. Deviations on the model outputs may be due to desired limits, and the specific parameter deviation needs to be discovered.

A deeper understanding of the specific items listed in the first phases of the audit may be needed, like the applicable tariff or the control philosophy of the plant and specific equipment.

Other areas that will be investigated in the technical audit are discussed in the following paragraphs:

3.7.1 Control System and Type of System Data Available.

A lot of information may already be available in the control system. Typical SCADA systems store the data from the measured data for trending, fault finding, etc. Depending on the level of automation of the specific plant, data regarding transfer rates, bin level data, energy consumption, etc., will be available.

The distribution network SCADA system or measuring system, if available, will contain load profile data of the main feeders of the plant.

It may be possible to obtain data of larger conveyor systems feeding from medium voltage supplies like 3300 volt or 11 000 volt on the same system.

The process SCADA system will contain data of all the process equipment.

3.7.2 Measurements

Transfer Rates

The detail of the measurements is explained in the verification of the CECM in chapter 4.

Conveyor Belt Parameters

Measurements of conveyor parameter are required for the CECM. The data obtained in the form of drawings or data sheets need to be verified to make sure that the data used in the model is correct.

Electrical System Parameters and Variables

In order to verify the CECM, measurements of the electrical energy consumption is necessary. The electrical power measurements necessitate taking aspects like the power factor into account.

3.7.3 Drive Efficiencies

It is important to identify drive efficiencies. The power that is measured at the terminals of the electrical motor is not always the power that is consumed by the conveyor. The efficiency of the electrical motor, as well as that of the gearbox, must be taken into account in order to determine what the conveyor power consumption is.

3.8 CONVEYOR DATABASE

All information received or generated in connection with the audit process will be stored in a database. This consists of a hardcopy format as well as an electronic format. In the database all the information is categorized in the specific areas to simplify retrieval. The information received will be listed, numbered and filed in a specific document control system.

The list of the information received will have the following details in it:

a) Date received.

b) From who received?

c) Type of documentation.

d) Hard copy or electronic format.

e) Number allocated.

f) Application of data in the audit process.

The database will help the auditor to focus on the right information.

A checklist of the basic information needed through the audit process will be part of the database, and the drive and basis of information gathering.

3.9 CONCLUSION

The first step in the CECEAM is the data acquisition process. The typical data requirements necessary to evaluate the system cost effectiveness are identified during this phase. The data acquisition process consists of the walk, document, personnel and technical audit. All the data acquired during these audits is captured in a conveyor database. The next phase of the CECEAM is to use the data in models to simulate the plant.

CHAPTER 4

CONVEYOR ENERGY CONVERSION MODEL METHODOLOGY

4.1 INTRODUCTION

In the previous chapters up to now the focus has been on the study of the process flow and the different interactions between the different loads. In this chapter the next step of the energy audit process will be handled.

In order to manage the use of energy it is necessary to evaluate some different options of how the energy is used. In practice it is not always possible to test different scenarios with electrically power driven equipment. The reason for that is the high utilization of the equipment. Most of the time the equipment is in use except during maintenance shutdowns when maintenance is done on the equipment.

The need for a tool to evaluate the impact of certain changes in operation is the drive to develop a model of the system in practice. The model, as a tool, needs to behave in the same manner as the one in practice.

The information regarding the specific load under investigation is gathered in the previous phases of the audit process and kept in a central database. This information is the building blocks of the model. The more accurate the information, the more accurate the model presentation of the piece of equipment. As mentioned earlier, the function of a model is to use it as a tool to evaluate, test or simulate different scenarios. In the case of an energy model (the purpose of this study) the output of the model must represent the cost of the energy to produce or convey a product unit, generally in tons.

4.2 ENERGY CONVERSION MODEL METHODOLOGY FOR A CONVEYOR BELT

A conveyor belt is used to transfer material. In the process of material being transferred with a conveyor belt, electrical energy is converted into potential energy, movement energy, noise energy, heat energy, etc. An energy conversion model gives the relationship between energy and the conveyor parameters. The energy, in terms of the conveyor parameters, is the power integrated over a certain period of time.

The energy consumption in the typical belt conveyor system [5], as shown Figure 4.1 can be divided into three parts:

a) The energy needed to run the empty conveyor

b) The energy needed to move the material horizontally over a certain distance.

c) The energy needed to lift the material a certain height.

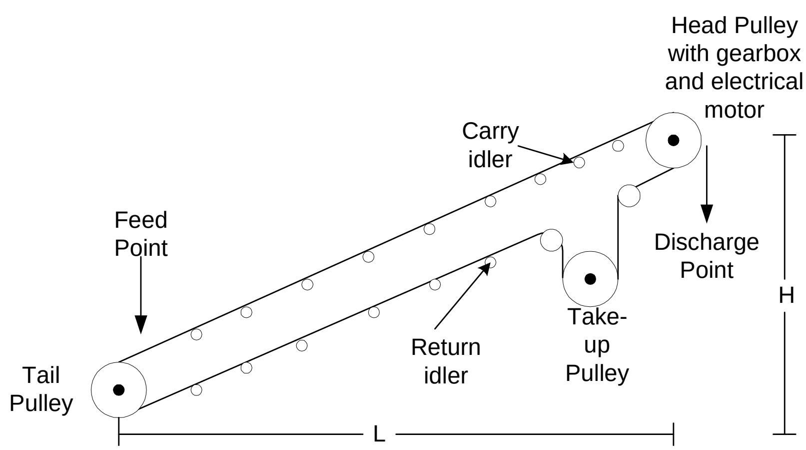


Figure 4.1 Conveyor Components

4.2.1 Energy to Run the Empty Conveyor

In order to run the empty conveyor (no load condition), energy is needed to move the different parts of the conveyor and to overcome friction in the conveyor system.

The empty conveyor friction force can be calculated as follows:

$$F_1 = gCQ(L + Lo) \qquad \textbf{4.1}$$

Where:

F_1 = empty conveyor friction force (N)

g = gravitational acceleration = 9.8 m/s^2

C = friction factor

Q = factor that represents the mass of the moving parts of the conveyor for center-to-center distance. (kg/m)

L = the centre-to-centre distance or the horizontal projection of this distance for incline or decline belts. (m)

Lo = compensation length constant or terminal friction independent of conveyor length (m)

The power to overcome this friction force is:

$$\begin{aligned} P_{ec} &= F_1 \times \frac{S}{1000} \\ &= \frac{gCQ(L+Lo)S}{1000} \end{aligned} \quad \textbf{4.2}$$

The units can be verified by:

$$\begin{aligned} &= \left[\frac{m}{s^2}\right] \times \left[\frac{kg}{m}\right] \times [m] \times \left[\frac{m}{s}\right] \\ &= \left[\frac{kgm^2}{s^3}\right] \\ &= \left[\frac{J}{s}\right] \end{aligned}$$

Where:

P_{ec} = power to run the empty conveyor. (kW)

S = belt speed. (m/s)

The energy consumption to run the empty conveyor is then the integral of the power over the period of time:

$$\begin{aligned} E_{ec} &= \int_0^t P_{ec}\,dt \\ &= \int_0^t \frac{gCQ(L+Lo)S}{1000}dt \\ &= \frac{gCQ(L+Lo)St}{1000} \end{aligned} \qquad \textbf{4.3}$$

Where:

E_{ec} = power to run the empty conveyor. (kW)

t = time period where in the belt operated. (h)

(Care should be taken in cases where the energy is measured in half hour periods, because the unit of *t* is in hours)

4.2.2 Energy to Move Material Horizontally

A loaded conveyor belt experiences an additional friction force due to the load on the belt. This friction force can be calculated as follows:

$$F_2 = gC(L+Lo)\left(\frac{T}{3.6S}\right) \qquad \textbf{4.4}$$

Where:

F_2 = load friction force (N)

T = transfer rate in tons per hour (t/h)

The power to transfer material horizontally can be obtained by the following;

$$\begin{aligned} P_h &= F_2 \times \frac{S}{1000} \\ &= gC(L+Lo)\left(\frac{T}{3.6S}\right) \times \frac{S}{1000} \\ &= \frac{gC(L+Lo)T}{3600} \end{aligned} \qquad \textbf{4.5}$$

The units can be verified by:

$$= \left[\frac{m}{s^2}\right] \times [m] \times \left[\frac{kg}{s}\right]$$
$$= \left[\frac{kgm^2}{s^3}\right]$$
$$= \left[\frac{J}{s}\right]$$

Where:

P_h = power for conveying material horizontally (kW)

The energy is then again the result of the integral of the power and results in the following:

$$E_h = \frac{gC(L + Lo)T}{3600} t \qquad \textbf{4.6}$$

Where:

E_h = energy to transfer material on the horizontally (kW)

In cases where the conveyor is skirted and the load is conveyed between skirt boards, the friction force is the following:

$$F_S = 0.2 g d^2 L M \qquad \textbf{4.7}$$

Where:

F_S = skirt friction force (N)

d = load depth (m)

M = material density (kg/m^3)

0.2 = constant make up of average material repose angle and coefficient of friction.

The power needed to overcome this skirt friction is then the following:

$$\begin{aligned} P_S &= F_S \times \frac{S}{1000} \\ &= \frac{0.2gd^2LMS}{1000} \end{aligned} \qquad \textbf{4.8}$$

Where:

P_S = Power to overcome skirt friction (kW)

The energy consumption due to these friction forces for transferring material horizontally can be obtained by multiplying the time period in which the conveyor operates.

4.2.3 Energy to Elevate or Lower Material

The vertical component of force along the incline to lift or lower the load can be calculated as follows:

$$F_3 = \frac{gTH}{3.6S} \qquad \textbf{4.9}$$

Where:

F_S = component of force along the incline (N)

H = the net change in elevation (m)

The power can be calculated as:

$$P_l = \frac{gTH}{3600} \qquad \textbf{4.10}$$

Where:

P_l = power to lift load or power generated in lowering the load (kW)

The energy applicable can be obtained by:

$$E_l = \frac{gTH}{3600}t \tag{4.11}$$

Where:

E_l = Energy to raise load or energy generated in lowering the load (kWh)

The influence of power to lift the material is illustrated in Figure 4.2. It can be seen that when Pl is zero, Pt is still positive because of the Pec and the Ph components. When the H is negative, it means a decline conveyor. As the value of H increases negatively, the value of Pl increases in a generating mode.

A point is reached where Pl equals Ph + Pec and results in Pt being zero. With H more negative, more left on the curve, the point is reached where the total conveyor is in a generating mode. In such cases the conveyor belt can be used to generate power and it can help to lower maximum demand, if managed effectively.

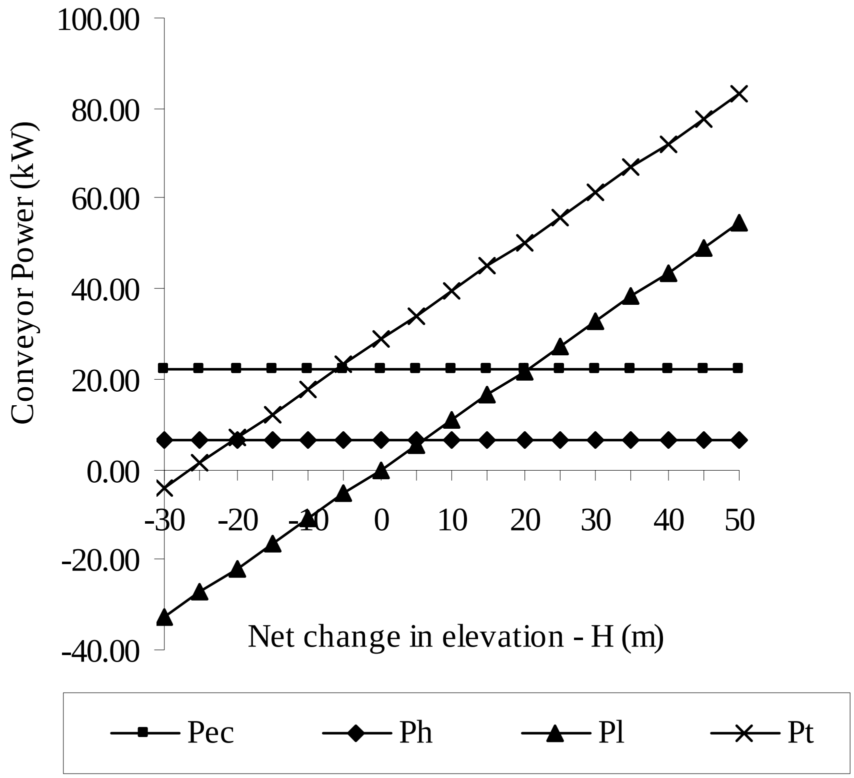


Figure 4.2 Influence of conveyor elevation on power

4.2.4 Total Energy For the Belt Conveyor System

Out of the previous discussions the total energy conversion model can be defined as the basic building block in the total energy model.

The total energy consumption in a conveyor system is the sum of the components of energy consumptions and can be represented as follows:

$$E_t \quad = E_{ec} + E_h + E_l \qquad \textbf{4.12}$$

Where:

E_t = total energy consumption (kWh)

4.3 THE INFLUENCE OF CONVEYOR SPEED ON THE CONVEYOR ENERGY CONSUMPTION.

In order to add value to the existing conveyor power models it is necessary to consider the effects of the conveyor speed in more detail. The conveying rate of a conveyor can be determined from the following parameters:

- The loading of the belt (kg/m)
- The speed of the belt (m/s)

The relationship between the transfer rate in tons per hour, the loading on the belt and the speed of the belt is the following:

$$T = 3.6MS \quad \textbf{4.13}$$

Where:

T = transfer rate of the conveyor (t/h)

M = mass of the material on one meter conveyor (kg)

S = conveyor speed (m/s)

If all parameters are kept constant the energy conversion model shows that only the energy consumption (Equation 4.13) of the empty conveyor system is affected.

From the above it can be seen that the energy to move the material horizontally, as well as to elevate the material (Eh and El), is independent of the speed. However, one of the parameters, the conveying rate (T), will change if the material is fed through a normal chute or static gate, this is due to the resultant change of speed. This concept should be considered in the conveyor energy study.

When the material is fed onto the belt through a chute or static gate, the material forms a constant profile. If the speed of the conveyor belt is increased, the profile on the belt stays more or less the same, but the rate in which the material is fed onto the belt increases. When the cross sectional load area is taken at any given speed it will be the same. The area is a function of the belt design, for example, for a 300mm belt with

20 degree rolls, the area for slumping material is 0.003 m2 and for 30 degree rolls it is 0.004 m2.

Figure 4.3 shows the trough angle of a conveyor system that can typically be 20° or 30°. When one-meter length of material on the belt is taken, the mass can be calculated as:

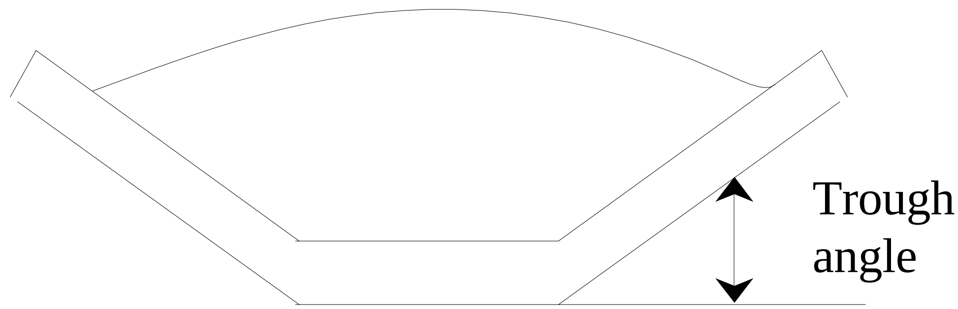


Figure 4.3 Typical Load Cross Section of Belt Conveyor

$$M\big|_{1m} = A \times \gamma \qquad \textbf{4.14}$$

Where:

M = mass of the material on one meter conveyor (kg)

A = cross sectional area of material on conveyor (m^2)

γ = density of the material (kg/m^3)

The conveying rate can then be determined by:

$$\begin{aligned} T &= 3.6MS \\ &= 3.6A\gamma S \end{aligned} \qquad \textbf{4.15}$$

Where:

T = transfer rate (t/h)

S = conveyor speed (m/s)

The relationship between material mass per meter, the speed of the conveyor and the transfer rate can be obtained from the following equation:

$$T = \frac{1000}{60} \times M \times S \qquad \textbf{4.16}$$

The equation can be derived from the units as follows:

$$\begin{aligned}
&\left[\frac{kg}{m}\right] \times \left[\frac{m}{s}\right] = \left[\frac{kg}{s}\right] \\
&\left[\frac{kg}{s}\right] \times 1000 = \left[\frac{t}{s}\right] \\
&\left[\frac{t}{s}\right] \times \frac{1}{60} = \left[\frac{t}{h}\right] \\
&\left[\frac{t}{h}\right] = \frac{1000}{60} \times \left[\frac{kg}{m}\right] \times \left[\frac{m}{s}\right]
\end{aligned} \qquad \textbf{4.17}$$

From the above discussion it is possible to change the energy conversion model of the conveyor in order to reflect the influence of the speed of the conveyor on the conveyor power. Figure 4.4 shows the influence of belt speed on the different power components if the transfer rate (tons per hour) is kept constant.

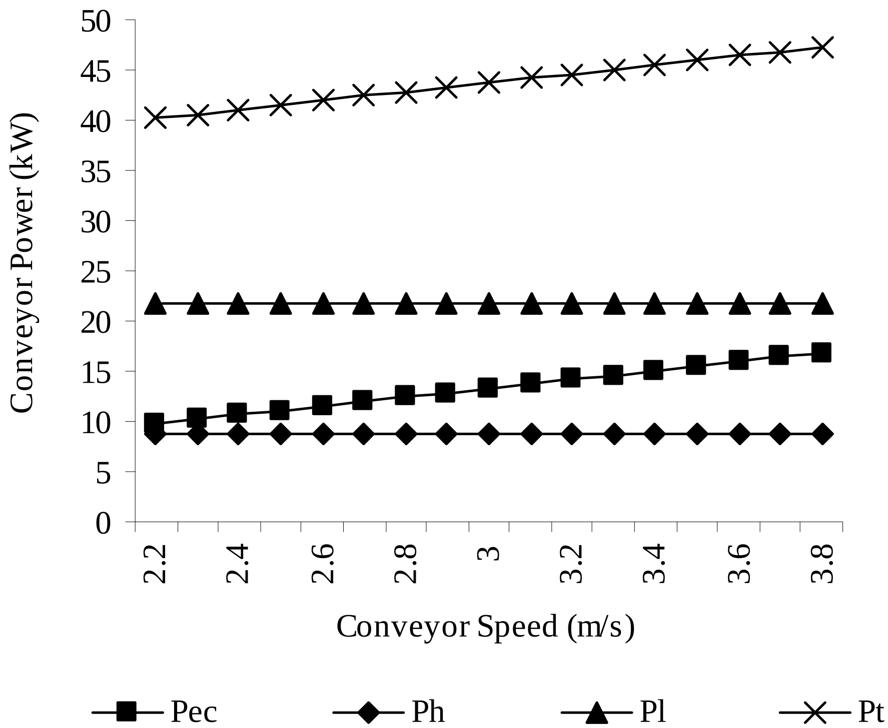


Figure 4.4 Influence of Conveyor Speed on Power with Constant Transfer Rate

The influence of the variation in speed can be recognized in the component Pec which represents the power required to run the empty conveyor, and which is proportional to the speed of the conveyor. The other components Ph and Pl (power required to move load horizontally and vertically) have no influence on the conveyor speed. This observation essentially illustrates that the conveyor belt is more energy efficient when it is running under full load conditions. It is important to take this into consideration when the electricity cost efficiency of operation of a belt conveyor is investigated.

In Figure 4.5 the concept is illustrated by the power consumption graphs of the same conveyor running at constant speed for the one scenario and at adapted speed to match the conveyor material load in the other scenario. The closer the conveyor running to full load condition, the smaller is the difference between the constant speed scenario and the adapted speed scenario. In practice the speed of the conveyor will have a bottom limit due to conveyor operation characteristics. The speed will thus be adapted only to these values in cases of very low flow rate.

In many applications, conveyor belts are running empty for long periods of time. By using this model the energy losses can be calculated and quantified. In cases where the conveyor belt is over-designed, the same principle is valid. The power to run the empty conveyor makes provision for a larger load than is needed in the application and therefore the material transfer via the conveyor is not as efficient as it could be.

This problem can be overcome by implementation of methods to ensure that the belt is equally loaded, in other words, to ensure that the kilogram per meter on the belt is constant.

This can be done by either implementing speed control on the conveyor belt or by installing a buffer in front of the conveyor to take up all the fluctuations of the feed and discharge at a constant loading on the conveyor. The conveyor belt can even be stopped and started when the bin reaches a specific level in order to run the conveyor fully loaded.

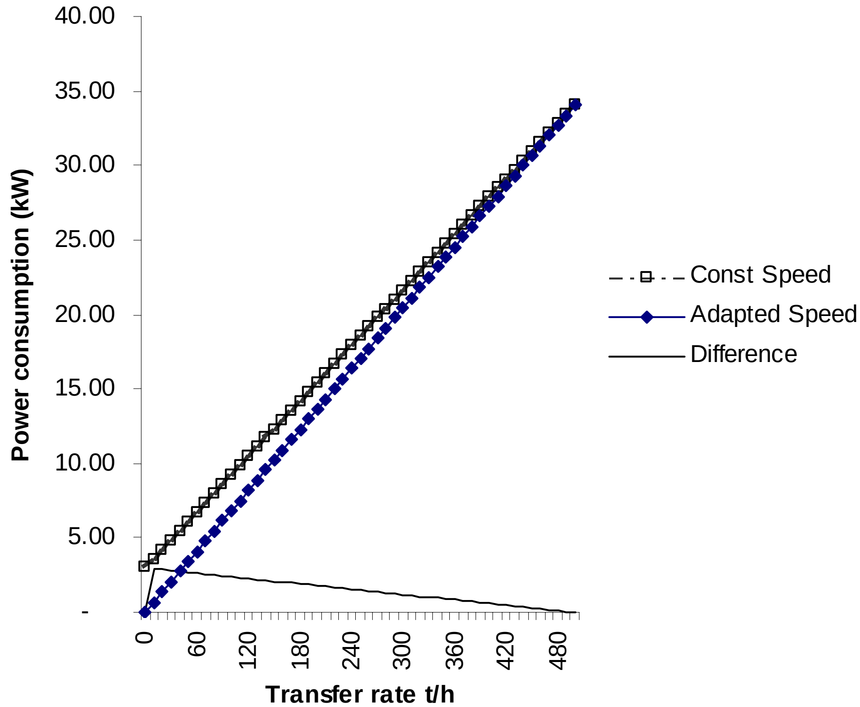


Figure 4.5 Influence of Transfer rate Adapted Speed on Conveyor Power

4.4 ENERGY CONSUMPTION LINKED TO TRANSFER OF MATERIAL

The per unit energy consumption for a conveyor belt is a benchmark measure that can be used to evaluate the conveyor energy efficiency.

Energy consumption for transportation of material is measured in kilowatt-hour per ton kilometer. In such a per unit value, only a distance is incorporated on the horizontal plane and no indication is visible regarding the vertical plane. For example, an incline conveyor moves material along the horizontal plane as well as along the vertical plane. A kilowatt-hour per ton kilometer will not give a benchmark regarding the components of the conveyor energy.

In order to develop a better method of expressing the per unit energy consumption the focus will be to separate the energy that is dependant on the horizontal distance from the energy dependant on the vertical distance for lifting the material. In the energy conversion model, the energy to lift the material is not dependant on the internal parameters of the conveyor but only on the capacity to be lifted as well as the distance to be lifted in the vertical plane.

From the energy conversion model the energy to lift the material can be divided by the tons T as well as the vertical distance H in kilometers to get the kilowatt-hours per kilometer. The expression for the per unit value is then as follows:

$$kWh/tkm = \frac{g}{3.6} = 2.725 \quad \textbf{4.18}$$

It can be seen that the per unit value to lift the material is constant and not conveyor parameter dependent, therefore this value will be the same for any conveyor.

The rest of the per unit energy is consumed in the horizontal distance dependent energy components.

The conveyor parameters do have an influence on the power dependant on the horizontal distance, the energy to move the material horizontally and the energy to move the empty conveyor.

In Figure 4.6 the differences in per unit conveyor energy consumption for the vertical and horizontal dependent components are illustrated. For the specific scenario it can be seen that the per unit power for the lightly loaded conveyor is very high compared to the fully loaded conveyor.

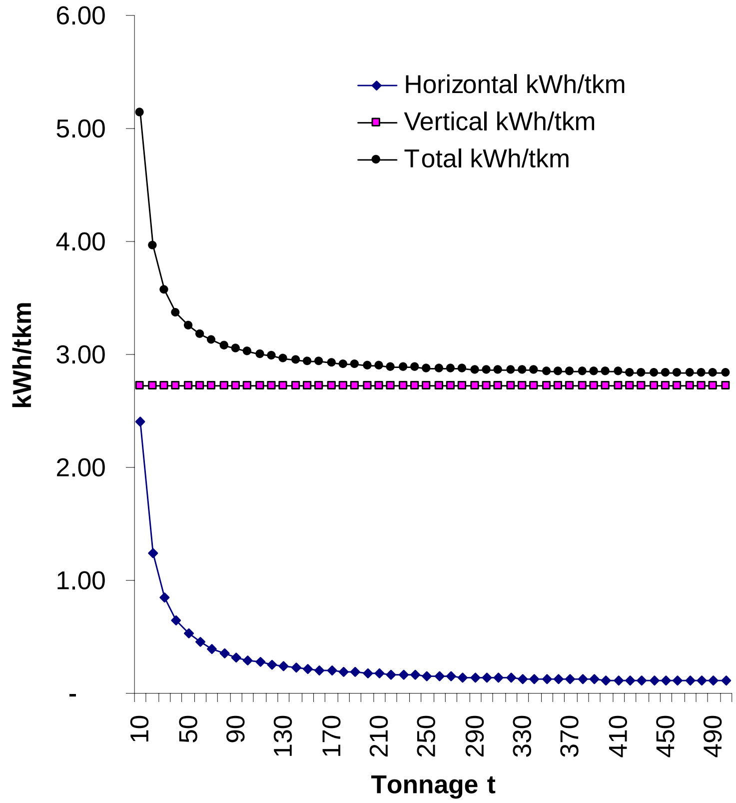


Figure 4.6 kWh/tkm for a Conveyor

4.5 CONVEYOR ENERGY MODEL VERIFICATION

The energy model verification process is necessary to prove the conveyor energy conversion model as a valid method to determine the conveyor energy consumption.

The verification process can be divided into the following steps:

a) Parameters to measure.

b) Measuring methodology.

c) Measurement data compiling.

d) Conveyor energy conversion model.

e) Result comparison.

f) Deviations Investigation.

g) Conveyor energy conversion model adjustments.

4.5.1 Parameters to Measure.

Some of the conveyor parameters are fixed and some of the parameters are variable. The fixed parameters are the parameters that are unique to the conveyor that can only be changed by changing the conveyor design.

Fixed conveyor parameters are:

g = gravitational acceleration = 9.8 m/s2

C = friction factor

Q = factor that represents the mass of the moving parts of the conveyor for center-to-center distance. (kg/m)

L = the centre-to-centre distance or the horizontal projection of this distance for incline or decline belts. (m)

Lo = compensation length constant or terminal friction independent of conveyor length (m)

H = the net change in elevation (m)

S = belt speed (m/s)

The belt speed depends on the application. For a variable speed application this parameter is not a fixed parameter.

The variable parameters are the parameters that can change during operation of the conveyor belt.

Variable conveyor parameters are:

T = transfer rate in tons per hour (t/h)

S = belt speed. (m/s)

As mentioned earlier, the belt speed can be fixed or it can be a variable.

Verification operating point:

In the verification process of the conveyor belt, an operating point is chosen with a specific set of variable conveyor parameters. The variable conveyor parameters, namely the transfer rate and the conveyor speed, are kept constant for the verification.

4.5.2 Measuring Methodology

Operating point measurements:

The parameters measured at the operating point can be done as follows:

Conveyor Speed:

Method 1:

In cases where the specific conveyor system has speed monitors installed, the speed can be obtained from these monitors that are usually displayed on a typical SCADA.

Method 2:

For installations where there are no speed monitors installed, the speed can be obtained by using a hand-held speed monitor.

Method 3:

When no other instruments are available the speed can be obtained by positioning a marker on a belt and measuring the time it takes to move a certain distance. A quick calculation can then be done to obtain the speed.

Method 3 is not so accurate, because there is a risk that human mistakes may occur. It is a very helpful method to quickly determine the belt speed without the necessary equipment available. Method 1 or 2 is more preferable for model verification measurements. Another aspect to consider is to ensuring that the instruments calibration is still valid.

Material transfer rate:

Method 1:

In cases where the specific conveyor system has a belt scale installed, the material transfer rate can be obtained from the belt scale display or from the data that is usually displayed on a typical SCADA system.

Method 2:

For installations where there are no belt scales installed the material transfer rate can be obtained by the following method:

1) Measure the belt speed with one of the methods discussed previously.
2) Stop the belt with the material on it.
3) Select a "belt cut" as part of the material on the belt, for example 10 cm of the belt.
4) Do a "belt cut" across the belt by carefully remove the material from the belt and putting it in a container.
5) Determine the mass of the material in kilogram.
6) Convert the mass to kilogram per meter.

Power measurements:

Method 1:

In cases where the specific conveyor system has power or energy meters installed, the power measurements can be obtained from these meters, which are displayed on the meter itself or on a typical SCADA system. Sometimes only the motor current is displayed. More measurements is then still needed, like voltage and power factors.

Method 2:

For installations where there are no power or energy meters installed the power measurements can be obtained by using a voltage and current recorder or a multimeter that can measure the voltage and current. The power factor plays a large roll in the verification process and needs to be determined in some way.

It should be noted that all measurements should be done under the same conditions. The loading on the belt must stay the same at times when the power measurements are done.

4.5.3 Measurement Data Compiling

When all the data has been collected from the measurements, the data needs to be compiled in order to use it in the conveyor energy conversion model verification process.

Transfer rate:

The transfer rate in tons per hour can then be obtained. The relationship between belt speed, per unit belt mass and the transfer rate in tons per hour can be obtained by converting the belt speed and per unit belt mass into the transfer rate.

From the following equation the transfer rate can then be expressed as the following:

$$T = \left(\frac{1000}{60}\right) \times P.U_{BeltMass} \times S \quad \textbf{4.19}$$

Where:

T	=	transfer rate of the material [t/h]
$P.U._{Belt\ Mass}$	=	per unit belt mass [kg/m]
S	=	Conveyor speed [m/s]

Power:

The power flow to the motor can be determined from [20]

$$P = \sqrt{3} VICOS\theta \quad \textbf{4.20}$$

Where:

P	=	power [kW]
V	=	voltage [V]
I	=	current [A]
COSθ	=	power factor

The motor power can then be obtained by measuring the motor voltage and current as well as the power factor.

This value does not take the motor and mechanical drive unit efficiencies into account. In order to determine the power absorbed by the conveyor these efficiencies are taken into account and the following equation can be used:

$$P_c = \eta_m \eta_d P_m \qquad \textbf{4.21}$$

Where:

P_c	=	*conveyor power (kW)*
P_m	=	*motor power (kW)*
η_m	=	*motor efficiency*
η_d	=	*mechanical drive unit efficiency*

The conveyor power is compared to the conveyor energy conversion model for verification purposes.

4.5.4 Conveyor Energy Conversion Model

The conveyor energy conversion model can be populated with the fixed conveyor parameters, as well as the variable parameters like the speed and the transfer rate at the specific verification operating point. Care should be taken that the correct units for the specific parameters are used.

4.5.5 Result Comparison

At this stage of the verification process the results of the model can be compared with the measured values. During the comparison any deviations can be identified where the model results does not meet the measured values.

Deviation in power is defined as:

$$\%\Delta P = \frac{P_{measured} - P_{cm}}{P_{measured}} \times 100 \qquad \textbf{4.22}$$

Where:

$\%\Delta P$	=	Percentage power deviation between the model power and measured power
$P_{measured}$	=	measured power (kW)
P_{cm}	=	model power (kW)

Assumptions can then be made about the deviations, the model adjusted accordingly and verified again.

4.5.6 Deviations Investigation

It may be necessary to investigate the whole installation again to seek answers why the deviations exist. The friction in the conveyor system may be higher due to poor maintenance that may influence the power consumption. More energy may be needed because of waste build up.

4.5.7 Conveyor Energy Conversion Model Adjustments.

When the reason for deviation is determined the model can be adjusted with the valid assumptions.

CHAPTER 5

INTEGRATED CONVEYOR ENERGY MODEL (ICEM) METHODOLOGY

5.1 INTRODUCTION

The basic principles of the energy conversion model were discussed in the previous chapter. In order to use this model for energy management purposes it is necessary to extend it to an ICEM that integrates the rest of the system and all factors that may have an influence on the electricity cost of the operation. As part of the CECEAM, such a model can then be used to identify electricity cost efficiency opportunities and improvements in the conveyor system. It can also be used for planning and evaluation purposes in the conveyor energy management environment.

5.2 ENERGY COST BASELINE

An energy cost baseline can be established for a conveyor or conveyor system with an ICEM. An energy cost baseline of a system is the energy cost of the system before any energy management initiatives are applied. By using the ICEM it is not necessary to do a lot of time-consuming measurements to determine the baseline. It is not always possible in a tight scheduled production environment to do a lot of measurements on a system.

5.3 THE ICEM METHODOLOGY DESCRIPTION

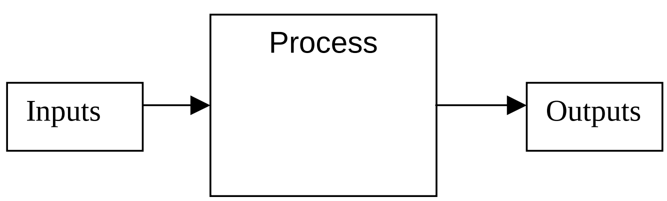


Figure 5.1 ICEM Methodology

The ICEM methodology [19] is a process followed to evaluate a conveyor system with the objective of improving the electricity cost efficiency of the system. The simulation results of the ICEM can then be used to do the least energy cost planning for a conveyor system. The principle of the ICEM is based on the principle inputs that are evaluated in a model or process where certain outputs are generated.

5.4 BASIC TERMS

When the electricity cost of a conveyor belt or any other load is considered, it is essential that certain basic energy management terms are understood in order to identify and address electricity cost savings opportunities.

The electricity cost applicable to a specific load depends on several characteristics of the load as well as the electricity tariff applicable.

5.4.1 Load Profile

The load profile of a load is the graph of the energy consumption of the load over a certain period of time. Information obtained from a load profile is items like the maximum demand of the load and the time when the maximum demand occurs. By investigating load profiles the nature of the operations can be explored. In such an investigation it is possible to identify possible load shifting opportunities to lower costs in cases where the tariff makes provision for such benefits.

5.4.2 Maximum Demand (MD)

The maximum demand is the highest demand calculated over an integration period of normally half an hour. In a two-part tariff where maximum demand is applicable there is a maximum demand charge that is relevant in specific time periods [21].

5.4.3 Load Characteristics

Load characteristics include all the aspects that are unique to the specific load. These aspects are the load factor, utilization factor, power factor, operating times, size of the load, etc. The load characteristics play a significant role in the total evaluation process.

5.4.4 Load Factor (LF)

The load factor is the ratio of the actual energy consumption in a period of time to a load that runs continuously at maximum demand over the same period of time. The equation to calculate the load factor is as follows [21]:

$$LF = \frac{kWh}{MD \times hours} \quad \textbf{5.1}$$

LF = Load Factor

MD = Maximum Demand

5.4.5 Diversity Factor (DF)

Diversity factor of a number of loads from a single point of supply is the ratio of their separate maximum demands to their combined maximum demand. The diversity factor is always greater than one. The reason why it is greater that one is because all the maximum demands will not happen at exactly the same time. It is an indication of the real maximum demand on a system to their combined maximum demand [21].

Equation 5.2 gives the diversity factor

$$DF = \frac{\sum_{i=1}^{n} MD}{MDtotal} \quad \textbf{5.2}$$

DF = diversity factor

MD = maximum demand

MDtotal = total maximum demand

For example, we might have a conveyor system that is running together with a couple of other loads in a plant for which the MD is measured and billed. The DF will then be the sum of all the MD's of the different loads divided by the MD of the supply point to all the loads.

5.4.6 Power Factor (PF)

The power factor is the ratio of active power to apparent power. The electrical distribution system needs to make provision for the apparent power although only the active power part is of significance in power transfer. A good power factor is in the region of 0.9 to 1.0 and a weak power factor is below 0.8. The power factor is lagging for a load of a more inductive nature and leading for a load of more capacitive nature.

5.4.7 Two-part Tariff

A two-part tariff is a tariff that includes an energy cost component (c/kWh) as well as a maximum demand component (R/kW or R/kVA).

5.4.8 Time of Use Tariff

In such a tariff the cost for the electricity differs for different hours through the week [21].

5.5 FOCUS AREAS IN THE ICEM METHODOLOGY:

In the ICEM methodology there is some focus areas that form part of the process to identify possible methods to make the system more electricity cost effective.

This data needed for these areas will be inputs to the model as described in the following section.

5.5.1 Load Shifting

In cases where a two-part tariff is applicable, it is viable to investigate the specific option. The load shifting is dependant on the operations. In cases where there is enough buffer capacities and it is not necessary to operate the conveyor belt in the peak periods, possible savings can be initiated. The ICEM can then be used to evaluate the impact of such load shifting initiatives through simulation. In a materials handling environment where operations are isolated with stockpiles or storage bins, the possibility becomes more attractive to do load shifting.

5.5.2 Conveyor Loading

As discussed in Chapter 4, the conveyor becomes more efficient when transfer capacity is closer to the designed parameters. There might be scope for improvement on total conveyor efficiency in cases where conveyors are running empty or only lightly loaded compared to design values, The possible solution would be the installation of a variable speed drive, a buffer to regulate the feed onto the belt, or a controller to control the operations and stop the belt if it is unnecessary to have it running. In cases where there is a huge difference in conveyor loading and designed values it might be beneficial to replace the conveyor, depending on the financial evaluation of such a project.

5.5.3 Power Factor

Power factor correction may have an impact on the reactive energy cost and or the maximum demand cost. There will be a reactive energy cost benefit to do power factor correction when the power factor is lower than the allowed value. For instances, where the maximum demand is charged in kVA it will be beneficial to do power factor correction in order to limit the apparent power.

5.6 ICEM INPUTS AND OUTPUTS

The answers we need from the model can be defined as the outputs of the model, and the information needed in the model to generate the answers defined as the inputs of the model.

The outputs of an ICEM are:

1) The energy cost profiles for the scenario.
2) Load profiles for the scenario.
3) Buffer levels for the scenario.
4) Maximum demand contribution.

The inputs for the ICEM are:

1) Electricity tariff.
2) Buffer capacities.
3) System configuration, like a material flow diagram.
4) Overall load profile.
5) CECM parameters.
6) Material demand and transfer requirements.
7) Operating time periods for all the conveyors.
8) System limitations.
9) Simulation cycle.

The following paragraphs will expound on the ICEM outputs and inputs.

5.6.1 ICEM Outputs:

1) *The energy cost profiles for the scenario*

The purpose of the ICEM is to do the least cost electricity planning for conveyor systems. With the energy cost profiles of the system as output of the ICEM, it is easy to identify areas where improvement of energy cost is possible.

2) *Load profiles for the scenario*

The load profile will give an indication of what the load looks like at a certain time of operation. This can be compared with the load profile of the total system in order to determine the contribution of the specific conveyor system to the total load profile.

3) *Buffer level profiles for the scenario*

Buffer level profiles of the conveyor system is necessary to make sure that buffer capacities are not over-loaded or under-utilized in a specific scenario. The balance of material flowing into the buffer, as well as material flowing out of the buffer, determines buffer levels. It is important that the buffer levels are the same after a production cycle as they were before the production cycle to ensure that there are no accumulating values that will cause the buffer to overflow over a certain period or run out of material.

4) *Maximum demand contribution*

In two part electricity tariff structures, where the electricity costs consist of maximum demand costs, as well as energy costs; it is important to take the contribution of the specific load to maximum demand costs into account when evaluating the conveyor system electricity costs. The maximum demand of the total system may not be the same as the maximum demand of the specific conveyor system, therefore the maximum demand cost applicable to the conveyor system is not necessarily influenced by the conveyor system maximum demand, but rather by the demand of the conveyor at the time when the total system maximum demand occurs.

5.6.2 ICEM Inputs:

1) *Electricity tariff*

One of the items needed to determine the energy cost for a conveyor is the electricity tariff. The electricity tariff normally depends on the application. In most cases there is specific load criteria for the specific electricity tariff structures.

2) *Buffer capacities*

The buffer capacities before and after a conveyor system in a material transfer line are important. Buffers can be stockpiles, silos or bins. The sizes of the buffer capacities must be considered when scheduling conveyor systems to reduce electricity costs.

3) *System configuration like a material flow diagram*

In order to form an ICEM it is easier to first draw up a layout of the system that shows the total system configuration. This will include the conveyors, buffers, transfer points, etc. In such a layout the flow of material can be seen through all the systems.

4) *Overall electrical load profile*

As already discussed in the outputs of the model, the overall load profile is necessary to determine the contribution of the specific system to the maximum demand cost.

5) *Conveyor energy conversion model parameters*

The physical parameters of the conveyor needed in the conveyor energy conversion model must be determined from datasheets and drawings or from physical measurements. These parameters are needed to determine the energy consumption of the conveyor at a specific time.

6) *Material demand and transfer requirements*

Materials handling equipment like conveyor systems are usually designed to supply a certain material demand. The demand can vary from time to time. It is important from an energy management point of view to know what the specific requirement for the system is at a specific time. A material load profile will give an indication of the material transfer requirements. The material load can be matched to the electrical load to estimate the kWh per ton transferred.

7) *Operating time periods for all the conveyors*

In order to do a load profile it is necessary to incorporate the operating times of the conveyor system into the model.

8) *System limitations*

There may be system limitations like conveyor speed limits, operating times, safety levels on storage areas, etc. These limitations must be incorporated into the model to make sure that there is a workable solution for each scenario in the system.

9) *Simulation cycle*

A simulation cycle will typically be a week or a month. The model outputs are given for the specific cycle.

5.7 ICEM ENERGY COST CALCULATIONS

The electricity cost contribution of a specific conveyor system is discussed in this section.

5.7.1 Total Electricity Cost

The cost of electricity for a specific load can be expressed as follows:

$$Cost_{Electricity} = Cost_{Energy} + Cost_{MaximumDemand} \qquad \textbf{5.3}$$

Where:

$Cost_{Electricity}$ = the total cost of the electricity for the specific load

$Cost_{Energy}$ = the cost of the energy for the specific load

$Cost_{MaximumDemand}$ = the contribution of the specific load to the maximum demand cost

In cases where there is no two part tariff applicable the maximum demand component is not included.

5.7.2 Energy Cost for a Typical Time-of-Use Tariff

In a typical TOU (Time of use) tariff structure the energy price per kilowatt-hour is different for certain periods through the day. Equation 5.4 takes this into account.

$$\begin{aligned} Cost_{Energy} &= C_o\int_{t_1}^{t_2} Pdt + C_s\int_{t_2}^{t_3} Pdt + C_p\int_{t_3}^{t_4} Pdt + C_s\int_{t_4}^{t_5} Pdt + C_p\int_{t_5}^{t_6} Pdt + C_s\int_{t_6}^{t_7} Pdt + C_o\int_{t_7}^{t_8} Pdt \\ &= C_o\left(\int_{t_1}^{t_2} Pdt + \int_{t_7}^{t_8} Pdt\right) + C_s\left(\int_{t_2}^{t_3} Pdt + \int_{t_4}^{t_5} Pdt + \int_{t_6}^{t_7} Pdt\right) + C_p\left(\int_{t_3}^{t_4} Pdt + \int_{t_5}^{t_6} Pdt\right) \end{aligned}$$

5.4

Where:

$Cost_{Energy}$ = the total cost of the energy for the specific load

C_o = price of energy in the off-peak period (R)

C_s = price of energy in the standard period (R)

C_p = price of energy in the peak period (R)

P = Power (kW)

5.7.3 System Maximum Demand

The system maximum demand is payable for each kW or kVA of the maximum chargeable demand supplied during the month measured over the integrating periods, payable in the applicable periods on specified days of the week.

The maximum demand is the sum of all the loads feeding from a specific billing point at a specific time when the maximum demand occurs. The maximum demand is expressed in

$$P_{MD} = \sum_{x=1}^{x=i} P_x \qquad for \qquad t_1 \le t \le t_6 \tag{5.5}$$

Where:

P_{MD} = system maximum demand

P_x = the load power of one of the loads contributing to the maximum demand (kW)

t_1 = the time of day when the applicable maximum demand period starts

t_6 = the time of day when the applicable maximum demand period stops

5.7.4 Specific Load Maximum Demand Contribution

The contribution of a specific load or conveyor system to the maximum demand can be determined by dividing the load by the total maximum demand. This will be at the time when the maximum demand for the total load occurs.

$$MD_x = \left(\frac{P_x}{P_{MD}}\right)\Bigg|_{t=t_{MD}} \tag{5.6}$$

Where:

MD_x = the contribution of the specific load to the maximum demand cost

P_x = the specific load that contribute to the maximum demand cost

P_{MD} = the maximum demand

t_{MD} = The specific time of maximum demand

5.7.5 Specific Load Contribution to Maximum Demand Costs

The contribution of a specific load to the maximum demand cost of a specific electricity billing point can be expressed as:

$$Cost_{MaximumDemand} = C_{MD}\left(\frac{P_x}{P_{MD}}\right)\Bigg|_{t=t_{MD}} \qquad 5.7$$

Where:

$Cost_{MaximumDemand}$ = the contribution of the specific load to the maximum demand cost

C_{MD} = maximum demand cost per unit

P_x = the specific load that contribute to the maximum demand cost

P_{MD} = system maximum demand

t_{MD} = the specific time of maximum demand

5.8 ICEM LOAD PROFILES

The load profiles for a conveyor system can be obtained from the conveyor energy conversion model. The model can be used over a time period of time to indicate the load value at a specific point.

5.9 ICEM BUFFER LEVELS

ICEM buffer levels are determined by calculating the difference between the inflow of material and the outflow of material.

$$B_L = B_{L_0} + T_{in} - T_{out} \qquad 5.8$$

B_L = the buffer level

B_{L0} = the buffer level at the beginning of the simulation

T_{in} = the flow of material into the buffer

T_{out} = the flow of material out of the buffer

5.10 FEASIBILITY STUDY

The feasibility study is an in depth study of the project identified to determine if the project is economically viable to implement. The feasibility is discussed under the following:

5.10.1 The Time Value of Money

Money value is related to time. The time value of money involves shifting monetary payments to future or present equivalents. Certain symbols are used in the basic time value calculations, as listed below [21]:

P present value

F future value

A uniform series payments

n number of compounding periods

i effective interest rate

5.10.2 Net Present Value (NPV)

The NPV analysis is a method of measuring costs and savings that will occur at different times on a consistent and equitable basis for decision-making. Differences between present values for project revenues and costs are determents in this method and this is called the net present value. A NPV of zero implies that the project will recover all the investments as well as interest rates. A NPV higher than zero shows that the project is worthy of further consideration and negative values show that a project will not recover its investment.

The NPV is expressed in the following equation [21]:

$$NPV = \sum_{t=0}^{n} \frac{Ft}{(1+i)^t} \qquad \textbf{5.9}$$

Ft = net cash flow during period (i.e. receipts minus disbursements)

5.10.3 Internal Rate of Return (IRR)

The IRR is the interest rate in the NPV equation that results in a zero NPV. This means that the project expenses equal the project revenues[21].

5.10.4 Payback Period

Payback period is the period of time that it takes from the initial investment made until the benefits have exceeded the initial investment. Projects with shorter payback periods are more attractive [21]. This is one criterion that can be used in the selection of projects.

5.10.5 Minimum Attractive Rate of Return (MARR)

The MARR is the percentage cut-off rate representing a yield on investments that is considered minimally acceptable. The value of the MARR is usually a management decision determined from the cost of the capital within the organization and the desired percentage return on investment. If the NPV is calculated using the MARR and the result is greater than zero, it indicates that the project is viable. It follows too that if the IRR is greater than the MARR, the project will be acceptable to management [21].

5.11 AN ICEM EXAMPLE

A Typical simulation scenario for a conveyor application can be seen in Figure 3[19].

Material is transferred from stockpile A with the conveyor belt to stockpile B. The conveyor runs continuously for 24 hours a day. Maintenance is done on the conveyor system once a month. The maintenance hours are a limiting factor to production. Management prefers that maintenance be done more often to improve on their preventative maintenance strategy.

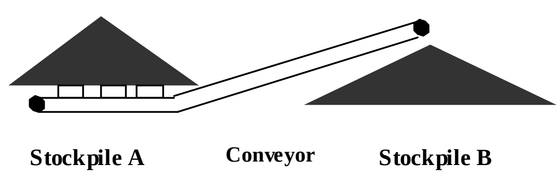


Figure 5.2 Typical Conveyor Application

The largest requirement is that a specific amount of material is transfered between stockpile A and stockpile B within a specific period of time.

The purpose of the ICEM, in this instance, is to simulate different "What if?" scenarios in order to find the operating philosophy with the minimum possible electricity cost possible without sacrificing operational requirements.

Outputs required from the ICEM for this example is the following:

1. *Proposed operating philosophy.*

   What operating philosophy for the conveyor to transfer material between stockpile A and B will result in the lowest possible cost for electricity per ton conveyed within certain requirements like production, maintenance, safety, management rules, etc?

2. *Electricity cost for the proposed operating philosophy.*

   What is the electricity cost for a week's operation of the conveyor belt?

3. *Difference between existing operating philosophy and the proposed operating philosophy.*

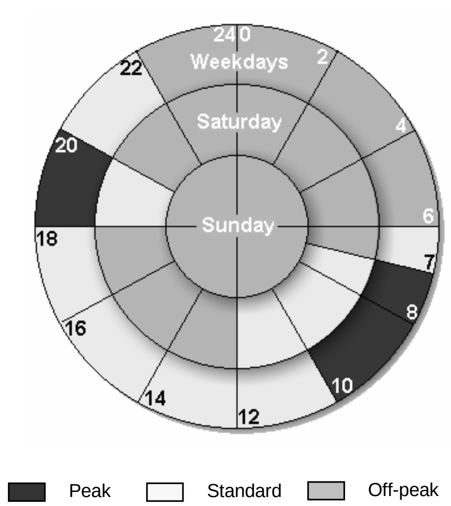
   What are the main changes to be incorporated in the existing operating philosophy of the conveyor belt to meet the new operating philosophy requirements? How can it be implemented? Are there any changes to be made to the existing installation in order to accommodate the new operating philosophy and what will the financial implications be?

4. *Influences on operations in the production line before and after the conveyor belt.*

   What is the influence of any changes on stockpile A and B?

The inputs to the model are the following, as indicated in Table 5.1:

1.	**ELECTRICITY TARIFF**		
1.1	Tariff type:	Time differentiated	
1.2	Specific Tariff:	Eskom Megaflex 2003	
1.3	Tariff Detail:		
1.3.1	Demand Charge:	R10,13/kW + VAT	
1.3.2	Active Energy charge:		
		High-demand season (June –August) (c/kWh).	Low demand season (Sept – May) (c/kWh).
	Peak	49,43	15,14
	Standard	14,26	10,02
	Off-Peak	8,46	7.56
1.3.3	Reactive energy charge:	3.09c/kvarh	
1.3.4	System power factor:	0.9	
1.3.5	Eskom's defined time periods:		



1.3.6	Month (s) applicable in simulation:	June.
2.	**TRANSFER REQUIREMENTS**	
	Weekly requirement:	70 000 ton/week.
3.	**SYSTEM CONFIGURATION**	
3.1	Pre-system:	Stockpile A: Capacity 75 000 ton.
3.2	Post-system:	Stockpile B: Capacity 75 000 ton.
4.	**SYSTEM LIMITATIONS AND CONSTRAINTS**	
4.1	Safety rules:	The conveyor will be stopped when any life is endangered.
4.2	Maintenance Shutdowns:	Six hours per week. Inspections once a day for half an hour.
4.3	Design limitations:	Max speed 3 m/s (Example for specific design).
4.4	Capacity limitations:	650 ton/hour.
4.5	Management rules:	None.
4.6	Operating rules:	Stockpile B may not run empty or exceed maximum capacity.
		Stockpile A may not exceed maximum capacity.
		Prevention of material degradation (breakdown of material at transfer points) by not exceeding a speed of 3.5 m/s.
5.	**CECM SYSTEM PARAMETERS**	
5.1	Mass/meter:	56 kg/m.
5.2	Friction Factor (C):	0.02.
5.3	Mass of Moving Parts (Q):	57kg/m.
5.4	Conveyor Length (L):	300 m.
5.5	Compensation length	60 m.

	(Lo):	
5.6	Conveyor elevation lift (H):	20 m.
5.7	Speed (S):	Variable.

Table 5.1 Typical Inputs to the ICEM

One of the best results of modeling different “What if” scenarios of operating philosophies is to do speed control on the conveyor belt in order to manage the energy consumption in certain time slots.

In practice, VSD’s are often installed on conveyor systems in order to “soft start” the conveyor system. This philosophy has the advantage of improving the mechanical component lifetime due to less stress. For this example, it is assumed that the conveyor has a VSD installed and no additional capital needs to be invested.

The scenarios will be discussed in terms of the baseline scenario or “as is” scenario and scenario 1 where energy management is implemented. The typical output results for the ICEM simulations are illustrated in **Table 5.2** and in **Figure 5.3** to **Figure 5.7**.

The comparison between the energy cost for the baseline scenario and that for scenario 1 where the speed is controlled, is shown in **Figure 5.3**. In the baseline scenario, the energy cost is high during the standard time and very high in the peak hours. This is managed in scenario 1 by stopping the conveyor during peak hours and lowering the speed during standard hours.

The reason the energy cost is higher in the off peak time for the scenario 1 is that the speed is higher and more material is transferred. Although energy costs are higher for this period, the energy cost per ton is much lower and no demand charge is applicable during this period.

No	Output Description	Output in Baseline Scenario	Output in Scenario 1
1	Control Philosophy:	Conveyor runs continuously at a constant speed.	Conveyor speed during the day: *Peak time*:

			0m/s . *Std. time*: 2m/s. *Off- peak time*: 3m/s.
2	Weekly electricity cost:	R 1321.88	R 783.43
3	Tonnage transferred:	74 289	74 088
4	Stockpile levels at the end of the week (tons) Stockpile A: Stockpile B:	710 74289	912 74088

Table 5.2 Typical Outputs of the ICEM

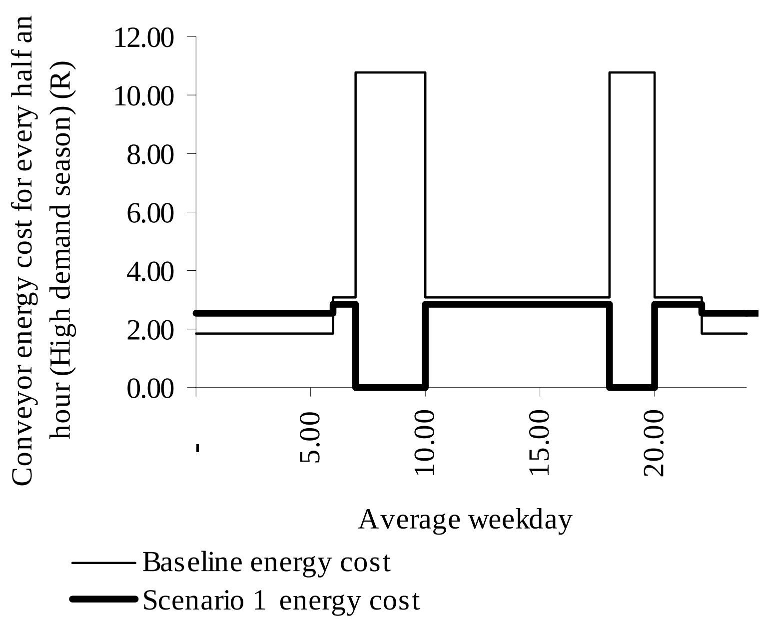


Figure 5.3 Energy Cost Comparison for Different Operating Philosophies

Figure 5.4 shows the accumulating energy cost for one week for the two scenarios. The significant saving in electricity cost of scenario 1 can be observed in the graph. As indicated in Table 1 this simulation is done for a week in the high demand season. The cost saving will be lower for the low demand season. Scenario 1 results a saving of 40% in the high demand season. The calculated saving per annum is R20 000. The assumption was that there is a VSD installed. In a case where a VSD should be installed at a price of say R60 000, the payback period would be 3 years.

The question arises as to whether the overall requirement is met in terms of transfer of material. **Figure 5.5** shows that the same weekly level of stockpile A is achieved despite differing transfer rates.

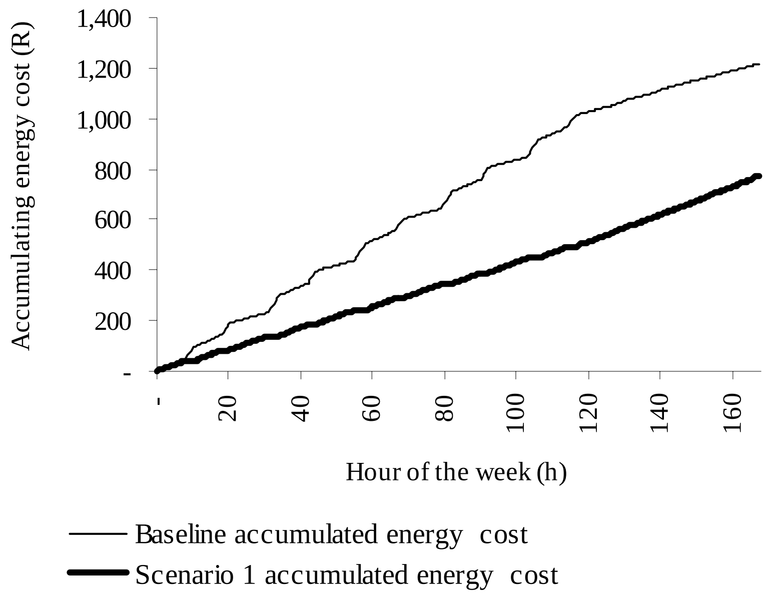


Figure 5.4 Accumulating Energy Cost for One Week in the High Demand Season

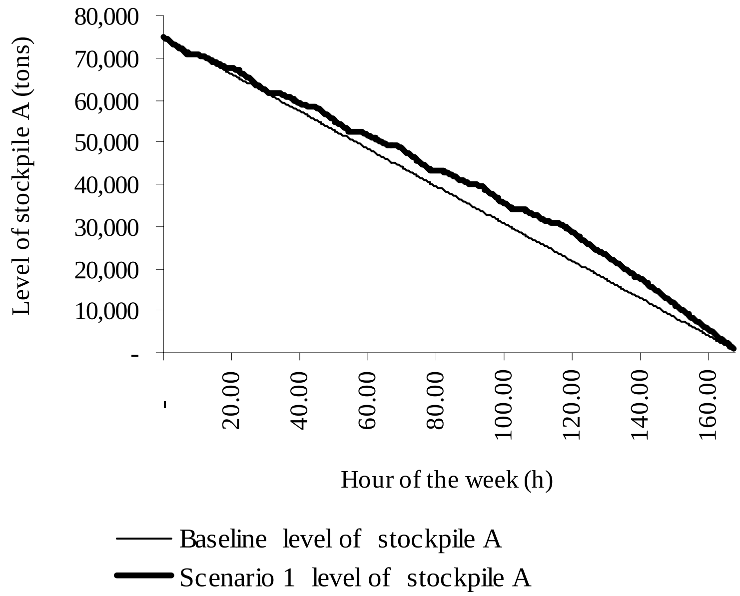


Figure 5.5 Level of Stockpile A

In **Figure 5.6** the level of stockpile B is shown for one weekday. It can be seen that in the case of scenario 1, because of speed control, during the off-peak hours (see tariff in Table 1), from midnight till 6:00, the incline of the graph is steeper than the baseline scenario. The speed of the conveyor is increased for this period of time. From 6:00 till 7:00 the rate of transfer decreases in the standard hours. During the time of the day when energy cost is the highest, during peak hours (see tariff in Table 1), the conveyor is stopped and that is why the level stays the same.

This shows the important role that the variable per unit cost plays in realizing energy savings under different control philosophies.

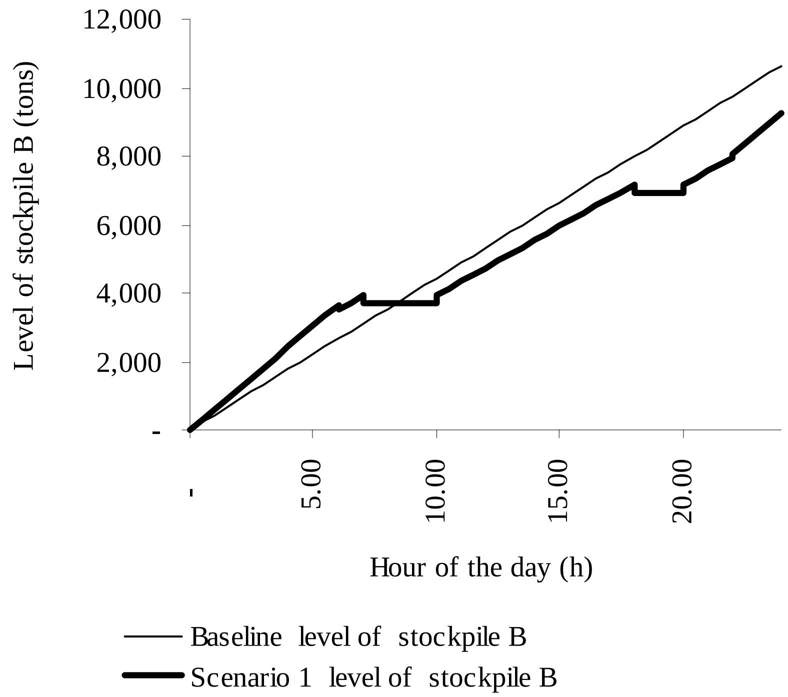


Figure 5.6 Level of Stockpile B for One Day

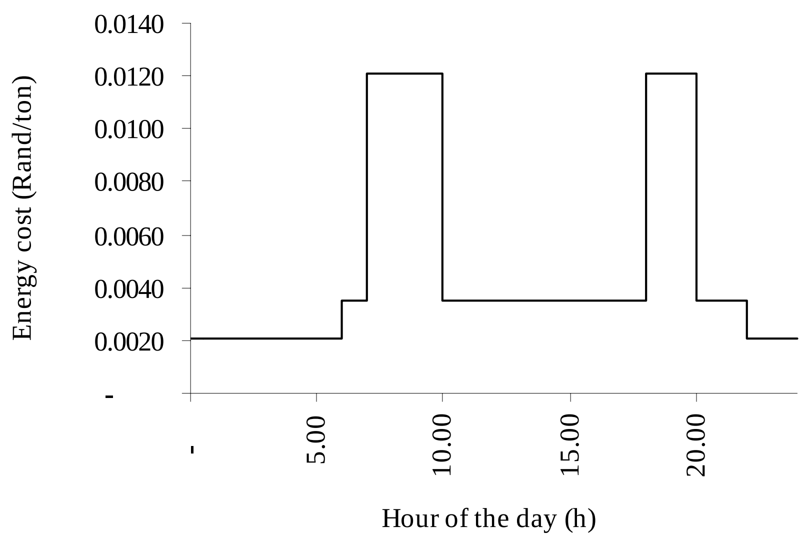


Figure 5.7: Difference in Energy Cost per Ton During a Weekday.

In Figure 8 the cost per ton product transferred in a weekday is shown. Although the Eskom Megaflex tariff was used in this example, the ICEM can be adjusted to accommodate any tariff structure into the simulation.

The benefits and flexibility for maintenance purposes in scenario 1 is tremendous as peak hours can be used to do maintenance on the conveyor belt.

Over and above the advantages of speed control on conveyors shown in this study, there are other advantages such as better torque control, reduced maintenance and belt wear.

This example shows the effectiveness of the ICEM. Large cost savings and mutually beneficial practices like energy management and maintenance can be demonstrated in such a simulation exercise with an ICEM.

5.12 THE ICEM AS PART OF THE ELECTRICITY COST EFFICIENCY AUDIT PROCESS FOR CONVEYOR SYSTEMS

Out of the previous discussions it can be seen that the ICEM forms an integral part of the total process. The previous phases gather all the information needed to build the model. In practice, the model process can start as soon as information is available. There will be a continuous loop process where the previous phases of the audit process will be repeated every time information is needed to improve the model.

When the phase of verification of the model is reached in the audit process, more information may be needed to solve deviations. This will lead to taking a step back into the audit process and rectifying these deviations by updating information in the ICEM.

5.13 CONCLUSION

The ICEM is a tool developed and used for scenario evaluation in the CECEAM. The acquired data in the previous phases of the audit process forms the inputs for the CECM and ICEM.

The ICEM can be used to establish an energy cost baseline for a specific conveyor belt. The methodology followed to built an ICEM for a specific application is define the outputs in terms of what is the required from the ICEM. The inputs to the ICEM are defined in order to match the outputs. Basic energy management terms that is relevant in the ICEM process is load profiles, MD, load characteristics, LF, DF, Power Factor, two part tariff and time-off-use tariff. In the simulation process of the ICEM the focus is on load shifting, conveyor loading as well as power factor. Electricity costs are calculated in the ICEM as well as load profiles and buffer levels. The financial evaluation or feasibility study is done in conjunction with the simulations to find the minimum electricity cost solution. A case study done to illustrate the ICEM simulations is handled in the following chapter, chapter 6.

CHAPTER 6

ICEM CASE STUDY - ZINC CONCENTRATE MATERIALS HANDLING

6.1 INTRODUCTION

The case study involves a zinc materials handling facility [22]. The materials handling facility consists of conveyors and storage buffers. In the case study a baseline is established with the ICEM in order to simulate baseline scenarios. The ICEM is then used to simulate certain operating philosophy scenarios.

6.2 DETAIL OF SYSTEM

Zinc concentrate is transported from the mines via rail to the zinc plant. At the zinc plant the concentrate is off-loaded in two storage areas with capacities 10 000 and 12 000 tons respectively. From the storage areas, the material goes through 3 stages till it reaches the roasters. See **Figure 6.1**.

The stages are the following:

6.2.1 Stage 1

The concentrate is transferred from either one of the storage or buffer areas to a 5000-ton intermediate buffer area.

6.2.2 Stage 2

The concentrate is screened and transferred from the 5000 ton intermediate buffer area to four buffer storage bins. Two bins can take 300 tons each and the other two 200 and 250 ton.

6.2.3 Stage 3

From the storage bins material is conveyed on demand to smaller surge bins just before the material goes into the roasters.

The following layout represents the total zinc concentrate materials handling facility:

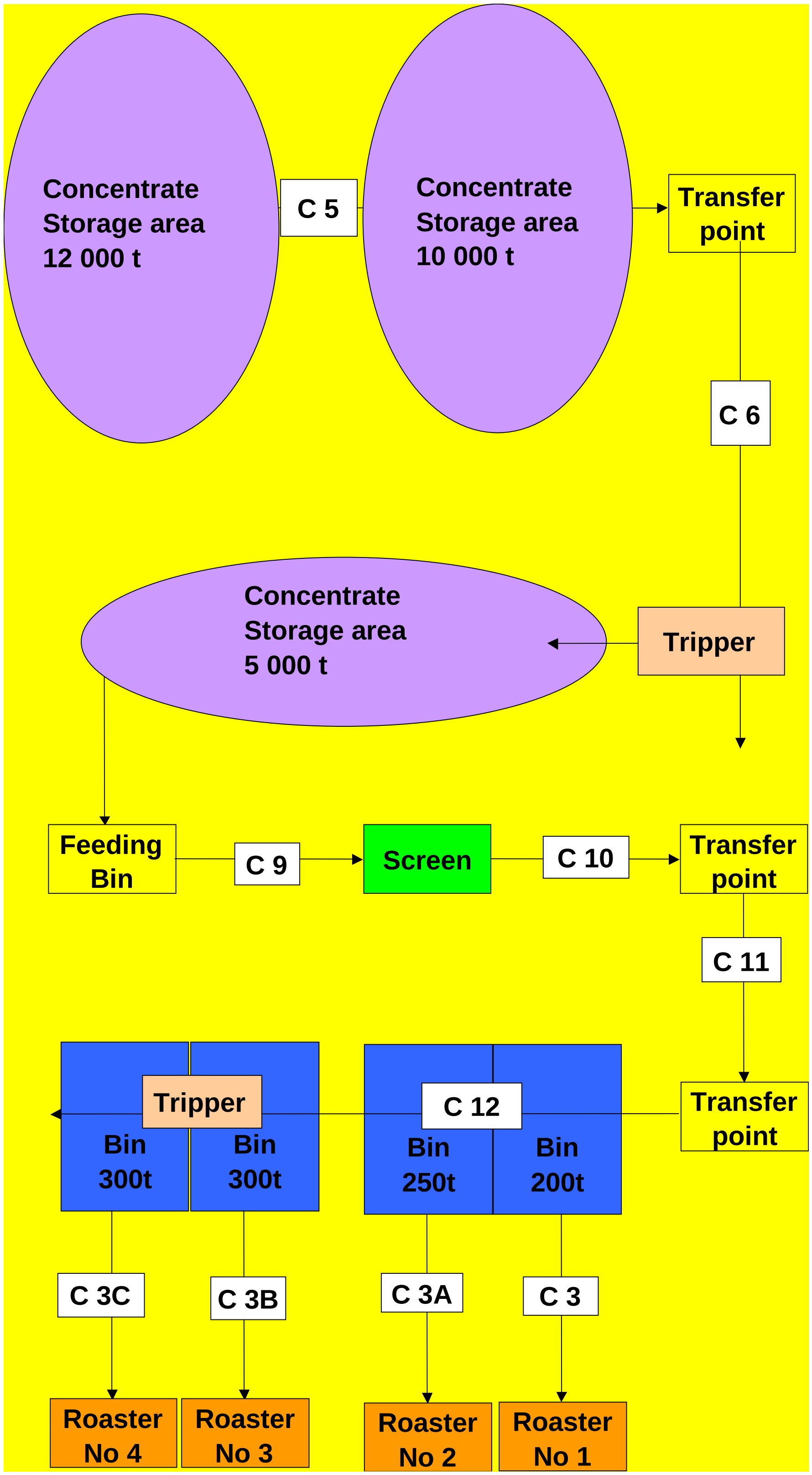


Figure 6.1 Zinc Materials Handling Layout

6.3 BASELINE

The baseline represents the situation as it is without any energy cost reduction initiatives. The inputs for the ICEM are according to the assumptions.

6.3.1 Baseline Scenario Detail – Stage 1

In the baseline scenario, material that is transferred in stage 1 takes place in a morning shift between 6:00 and 14:00. During this stage material is transferred every seven days of the week.

6.3.2 Baseline Scenario Detail – Stage 2

During this stage, material is transferred in the same shift, between 6:00 and 14:00, but the material is only transferred during weekdays from Monday to Friday and not over the week ends.

6.3.3 Baseline Scenario Detail – Stage 3

Material transfer in, stage 3 takes place on a continuous basis. In this stage the surge bin level, in front of the roasters, controls the conveyors running periods.

With this information as basis an ICEM is developed for the specific materials handling facility and the current situation simulated.

6.3.4 Baseline ICEM Verifications

The purpose of the baseline ICEM is to reflect the real world as true as possible. In order to fit the theory with the practical application certain measurements and verifications are necessary. As part of the ICEM methodology that followed, deviations were identified, investigated and corrected. Some of the deviations experienced in this case study were:

1. Some of the conveyors were equipped with tripper cars and the original energy conversion methodology did not allow for this.
2. When the conveyor motor current is measured and converted back to power at a measured voltage, the power factor can play

a significant role and can influence the verification of the energy conversion methodology to a great extent.

3. The transfer rate was not always constant on all the conveyor belts. It would be ideal to measure the transfer rate and energy consumption simultaneously to find the relationship and compare them with the model. Adjustments were needed in the model to reflect the average transfer rate for a specific period of time.

4. Operational factors like the exact time and durations of stoppages for tea breaks when operations are stopped need adjustments.

6.3.5 Assumptions and Conditions for the ICEM Simulation. The Simulation Period is a Week.

In order to do the simulations with the ICEM certain assumptions are made as basis for the simulation:

1. System conditions are monitored in 5 minute intervals.
2. The simulation cycle starts at the end of a shift when the bins are 100% filled.
3. The surge bins before the roasters are controlled to a minimum level of 5 tons.
4. No storage facility may run empty.
5. The roasters may under no circumstances be without feeding material.

6.3.6 Baseline Simulation Results

The simulation results for the baseline can be seen in Figure 6.2 to Figure 6.5. In Figure 6.2 the load of the operations in the morning shifts can be seen as well as the random load for the roaster feed. It is important to take note out of Figure 6.3 and Figure 6.4 that the levels of the bins are the same at the beginning and at the end of the weekly cycle. These levels should be the same when any scenario is tested in order to prove that the system reaches the same state at the end of a cycle. In Figure 6.4 the increase of material in the 5000 ton area through the week can be seen. This is due to the standing time over weekends of this part of the operations. The standing time over weekends is visible in the load profile in Figure 6.2 as well.

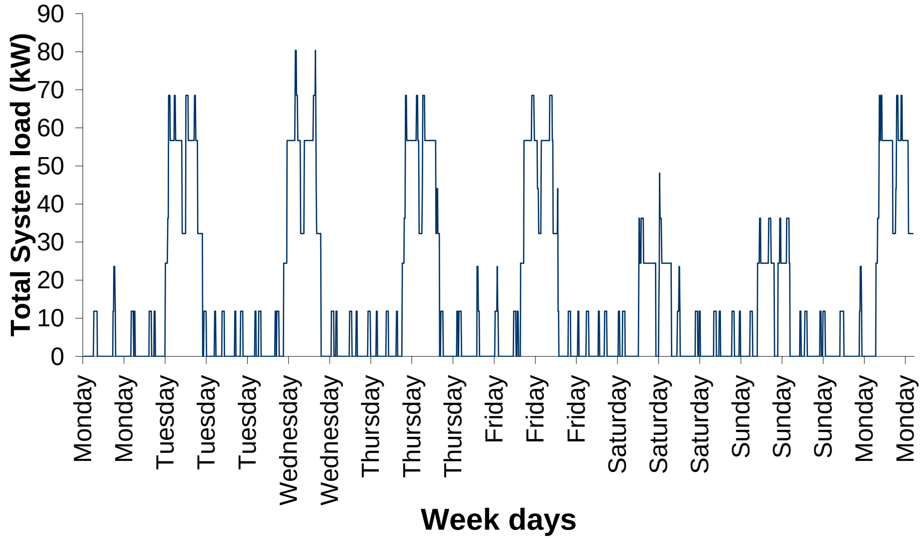


Figure 6.2 Load Profile of the Total Conveying System.

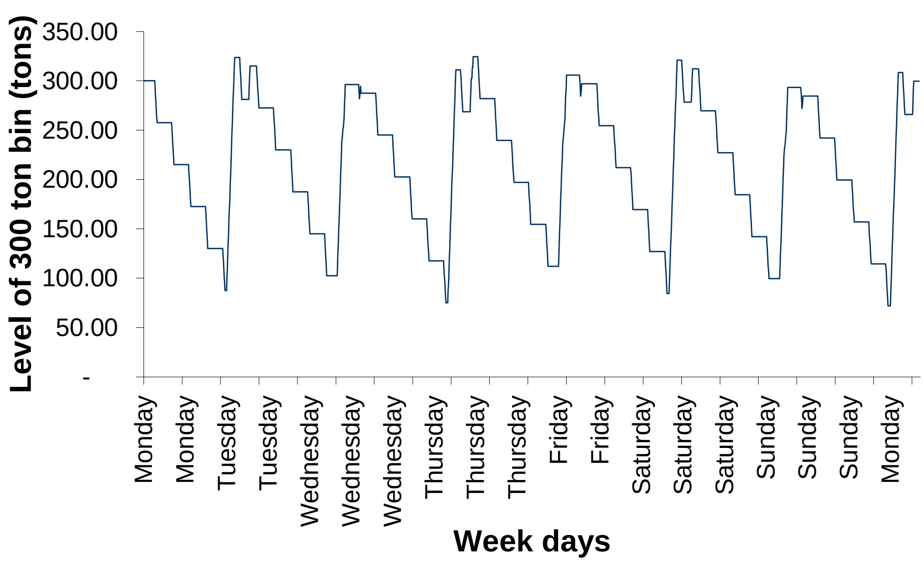


Figure 6.3 Level of the 300 ton Bin over a Period of a Week.

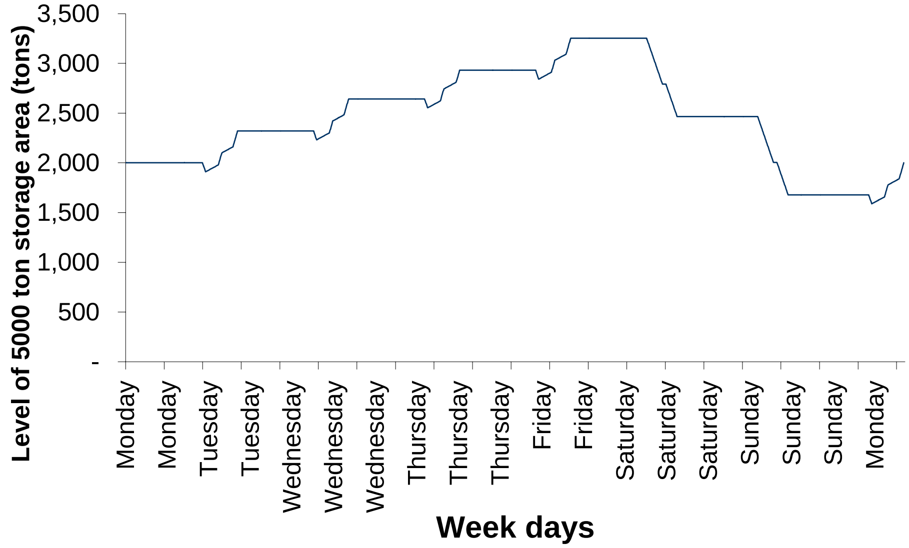


Figure 6.4 Level of the 5000 ton Storage Area over a Period of a Week.

The applicable tariff is the Eskom Mega Flex tariff. According to this tariff, energy is most expensive during peak and standard hours. Peak hours are between 7:00 and 10:00 in the morning and 18:00 and 20:00 in the evening. Standard hours are from 6:00 to 7:00, from 10:00 to 18:00 and from 20:00 to 22:00.

From the weekday load profile in Figure 6.5 it can be seen that the load is at its highest in the time when energy is the most expensive. This figure illustrates the value of the ICEM where potential savings can be identified. The solution for the problem may look simple - just run the system when electricity is less expensive. This is not so easy because of all factors that have an influence on the system like bin- and storage area levels, management rules, etc. The reason for the development of an ICEM is to take all these factors into account.

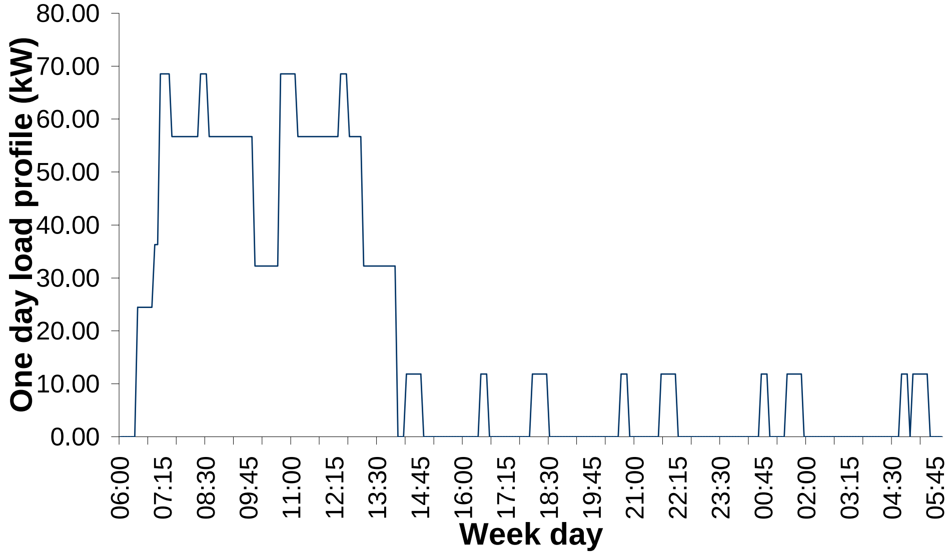


Figure 6.5 Load Profile of a Typical Weekday.

A scenario will now be discussed where the conveyor systems are re-scheduled with the same assumptions for the system.

6.3.7 Re-Scheduled Scenario

During the ICEM simulation of the current situation three important aspects arose:

1. The total conveying system can be divided into 3 sub systems or stages that can function separately.
2. The conveying capacities of the first two systems are much higher than the third system. This gives the flexibility that the first two parts can run for shorter time periods.
3. There are storage capacities available between the systems and it can run independently.

These aspects give flexibility and are the main drive for re-scheduling simulation of the conveyor system.

In the re-scheduling scenario the conveyors were scheduled to run during night shift. One of the largest challenges of using the ICEM to simulate the different conveyor schedules is to ensure that all the bins are at 100% level at the end of the shift. This is determined by the tripper car position schedule over the storage bins. In other words to determine when to convey material to which bin and for how long, because there is a random extraction of material from the bins to the roaster surge bins.

6.3.8 Re-scheduled Scenario Simulation Results

The final simulation results can be seen in Figure 6.6 to Figure 6.8:

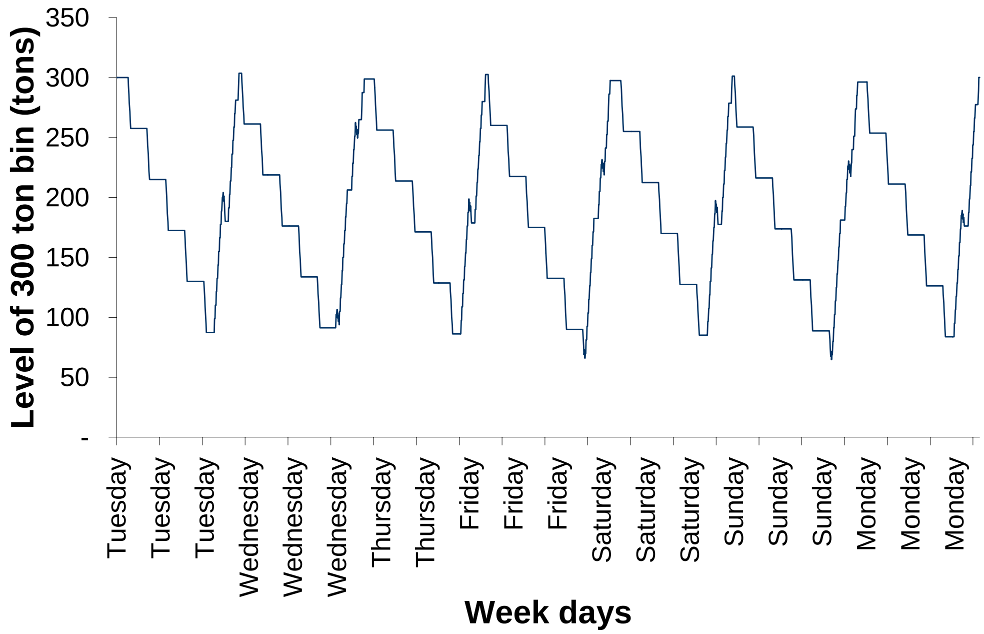


Figure 6.6 Level of the 300 ton bin over a period of a week.

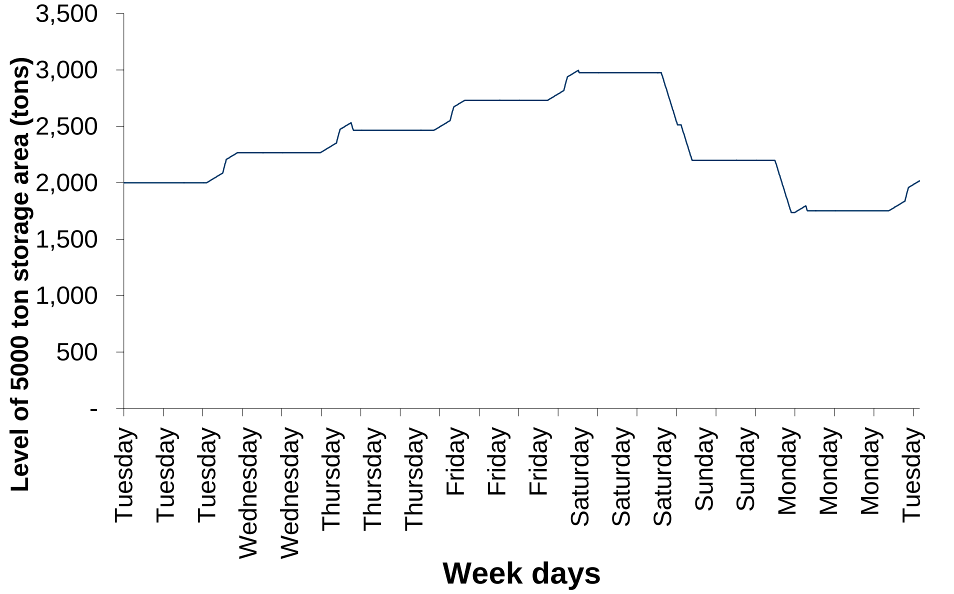


Figure 6.7 Level of the 5000 ton storage area over a period of a week.

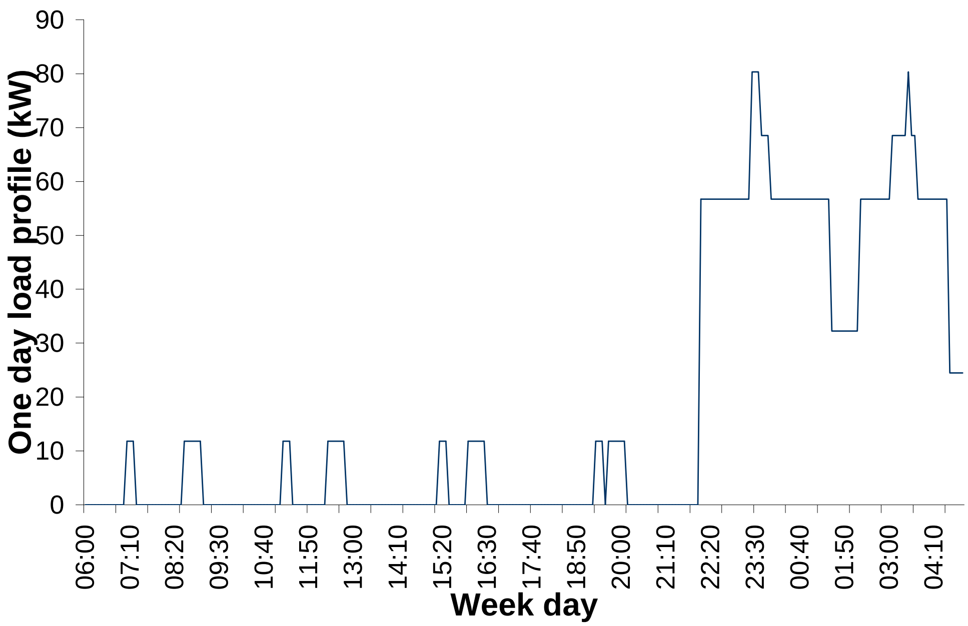


Figure 6.8 Weekday load profile.

The bin levels are at 100% at the start and end of cycle. The system requirements are fulfilled.

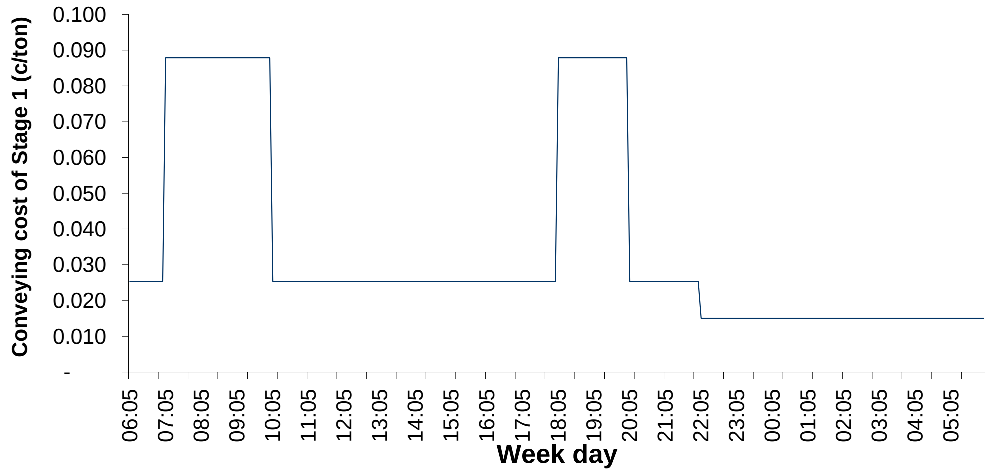


Figure 6.9 Conveying Electricity Cost per Ton - Stage 1.

The re-scheduling of the conveyor system results in an electricity cost of 4c/ton conveyed where the current operation electricity cost is 12c/ton. This indicates a saving of 66%. The operating times must change to off-peak periods and that mean that the workers need to work at night. In the case where there are 5 workers with an average salary of R3 000 per month, their salary could be increased by 5% to compensate for the change in working times and still have a saving of 36%. The other option is to install a control system to control the materials handling facility automatically. This will result in a saving of labour and electricity cost.

Figure 6.9 shows how the electricity cost per ton to convey material varies through a typical weekday for the specific tariff.

The ICEM can be used for different tariff structures and is not only applicable for the specific tariff in this case study.

6.4 CONCLUSION

The energy costs in a conveyor system are one of the largest components of the operating costs and can be lowered using modeling techniques. A basic energy conversion methodology forms the basis of the ICEM. The ICEM takes all factors into account that have an influence on the outcome of any simulation scenario. With an ICEM simulation of the current situation, potential energy management strategies can be identified in order to save on electricity costs. The ICEM must be verified before it is used as a model in the simulation process.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 GENERAL CONCLUSION

Industries and mining strive to manage operating expenditure down. Energy cost is part of the operating expenditure of most of the industries. In conveyor belts electricity cost is a large component of the operating expenditure. Methods to decrease these costs will therefore be of great value for the industry. Before such methods can be defined it is necessary to know the factors that have an influence on the electricity cost to transfer material with a conveyor belt. The influence of these factors needs to be identified and investigated in order to make certain recommendations regarding any improvements.

Objectives for the study were defined in the beginning of the study to address this need. The main objective was addressed by the development of the CECEAM where modeling, simulation and minimization of energy cost were included. The data acquisition process through questionnaires, walk audits, measurement audits, was used to reach the first specific objective. The rest of the specific objectives were addressed as follows: Existing models were improved to incorporate operating philosophy parameters like operating times, etc. In this improvement of the models the production and no load conditions was linked to energy. Special attention was paid to the influence of speed in the process of improving existing models. As part of a case study, existing conveyors were measured in terms of production, construction and energy consumption in order to verify models. The ICEM developed were used to simulate necessary production or transfer and minimize energy cost. Out of this better recommendations regarding maintenance, design and operating methods can be suggested as discussed in the case study.

7.1.1 CECEAM

To fulfill this need the CECEAM was developed in as a tool to investigate the electricity cost efficiency of the total conveyor system. The audit process includes a data acquisition phase where data is acquired for evaluation purposes. The data received can then be populated into the CECM. The model is then verified to ensure that the followings steps of the CECEAM are based on a reliable CECM. The ICEM is an extension of the CECM and are then used to establish a baseline for electricity cost. Simulations of "what if" scenarios can then be executed with the ICEM to identify possible savings and to define the scope of work necessary to implement any projects to realize the savings. Any improvements in the system can be compared against the baseline to quantify its impact. A financial evaluation process follows there after to evaluate every identified project within the investment criteria of the specific company. The last step in the CECEAM is a report with all the relevant information and recommendations to the owner of the equipment.

7.1.2 CECM

An important phase of the CECEAM is the CECM and the ICEM. In the literature available on conveyor models and electricity cost savings, there are mathematical models that can be used to determine the power consumption of a conveyor. These models are used to determine the motor size of the conveyor. The models are the basis of the CECM.

The CECM provides the relationship between the energy consumption and the conveyor parameters. Distinction is made between three activities that use energy in the process of material transfer. These activities are: the energy to run the empty conveyor, the energy to transfer material horizontally and the energy to lift the material a certain height. The conveyor is usually designed for a specific capacity. In cases where the conveyor runs below designed transfer capacity, the empty conveyor power component stays the same and therefore implies that the conveyor is less energy efficient. The solution to the inefficiency problem is to ensure that the conveyor belt is fully loaded to designed value where possible. This problem can be addressed by either implementing a buffer facility in front of the conveyor and constantly feed the conveyor or by controlling the speed of the conveyor to obtain a fully loaded conveyor.

7.1.3 ICEM uniqueness

The aim of some electricity pricing methodologies, implemented by suppliers of electricity, is to send out price signals to the larger end-user market by means of a specific designed tariff. This is done to achieve DSM (Demand Side Management) of the peak loads. The end-user can benefit from this opportunity if the load is managed accordingly. In order to identify, quantify and implement changes on the existing operating philosophies, such changes need to be tested forehand. The way to do it is to built a model of the load and test or simulate “what if “ scenarios.

Some conveyor models in literature that is built to determine electricity cost takes electricity tariffs into account and are based on physical measurements of the conveyor power consumption against transfer rate. Such models are unique to the specific application and can’t be used to simulate the influence of the change in conveyor parameters on the electricity cost. These models are used for M&V purposes and not to simulate certain scenarios. The ICEM developed and described in this dissertation integrates the electricity tariff and operating philosophies into one model to simulate certain scenarios that can deliver potential savings.

7.1.4 ICEM applications

The ICEM can be very useful as part of a DSM project evaluation process. The effect of load management and conveyor efficiency improvements can be tested and verified by using the ICEM. The implementation of scheduled maintenance programs in high electricity cost time slots to reduce load can be simulated and evaluated with the ICEM for maintenance recommendations. One of the benefits of using the ICEM in the CECEAM is that all the factors that plays a role on the electricity cost for instance the operating philosophy, etc. is taken into account in the “what if” scenario simulations. Management rules, legal requirements, safety aspect, etc. are built into the ICEM to represent the boundaries of the real world situation. In general, the implementation of energy management initiatives like load shifting of any load is a well-known concept. The integration of all electricity cost efficiency factors of a unique load, in this case a conveyor belt, is not common knowledge, hence it is addressed in this dissertation.

7.2 RECOMMENDATIONS FOR FUTURE RESEARCH

7.2.1 Optimization

The ICEM developed to do simulations and improve electricity cost efficiency do not make use of any optimization algorithms to optimize the process. It is therefore recommended that such algorithms be developed in future to improve on the total CECEAM.

7.2.2 Financial Evaluation

More work can be done to improve on the financial evaluation process of possible projects. The ranking of projects according to financial parameters can be extended upon. The role of electricity improvement projects in the larger financial picture of a specific company can be addressed. The decision making methodologies followed in the different companies can be investigated to find out when is a project feasible and when not.

7.2.3 Speed Control on Conveyors

In this study the advantages of speed control on conveyor belts is investigated. The implementation of speed control on conveyor belts to match the load on the conveyor can be investigated in more detail. The practical implications that the speed control can have on the rest of the systems need more attention.

7.2.4 Materials Transport in Mining

For future studies the ICEM can be extended to compare the electricity and operating cost of a conveyor belts application in the mining environment with the cost of haulage truck operating costs.

7.2.5 Maintenance

More focus can be on the maintenance of the conveyor system. The introduction of maintenance periods in peak times can be investigated in more detail and suggestions can be made.

7.2.6 M&V Applications

This work focuses on the establishment of a baseline. The M&V process to be followed for such conveyor electricity cost savings initiatives can be developed in detail.

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