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# Improved energy efficiency in troughed belt conveyors: Selected factors and effects

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***Abstract*— Power consumption in belt conveyor systems can be reduced at the design phase which can result in an improved design from both economic and environmental points of view. This study investigates the effect of various design factors on the power demand of a long belt conveyor using general factorial experiment techniques. Power demand values for a 1 km long horizontal troughed conveyor were simulated using Sidewinder Conveyor Design according to the DIN/ ISO methodology, and further analysed using analysis of variance (ANOVA) techniques to test the effect of each factor on power consumption. The study shows that power consumption of belt conveyor systems is significantly affected by the operating belt speed, ambient temperature, idler roll material and diameter, in addition to the idler spacing along the belt. In contrast, trough angle and idler bearing type did not prove to have significant effect on power demand.**

***Index Terms*— belt conveyors, power consumption, idler, ANOVA, Sidewinder Conveyor Design.**

## I. INTRODUCTION

Belt conveyors are used to transmit bulk materials, usually from their production or collection areas, to processing or storage facilities. They are currently used in many fields, such as mining, ship loading, construction, manufacturing, food processing, agriculture and power generation. Due to latest developments in this field, length and width of belt conveyors can nowadays reach 48 km and 6.4 m, respectively [1], [2]. Fig. 1 shows the main components of a typical belt conveyor system.

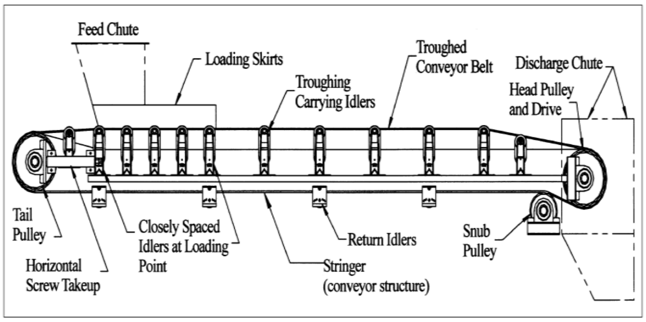

Fig. 1 – Main components of a belt conveyor system [1]

Belt and idlers are considered the main contributing components of resistance to belt conveyor system motion, where they are responsible for indentation rolling resistance, flexure resistance of the belt and bearing resistance of the idler. These may constitute together around 72% of the total motion resistance of a long-distance horizontal belt conveyor. In a1 km long horizontal belt conveyor, indentation rolling resistance typically consumes around 61%, idler roll rotating resistance consumes about 6%, whereas belt flexure resistance commonly consumes 5% of the belt system total motion resistance, as can be depicted from Fig. 2 [3, 4].

The reduction of the above mentioned resistance conceivably lowers energy consumption rates for belt conveyors, thus allowing the use of smaller conveyor components, such as drive stations, idlers, and supporting steel structure systems. This additionally saves raw material and energy consumed during processing of these components. Moreover, decreased power consumption rates imply reduced $CO_2$ emissions, and in turn lower environmental impact [4], [5].

This study investigates the effect of the main conveyor design parameters related to idlers, on power demand. It is desired to determine the significance of each parameter as well as the interaction between the individual parameters targeting a decrease in system power demand.

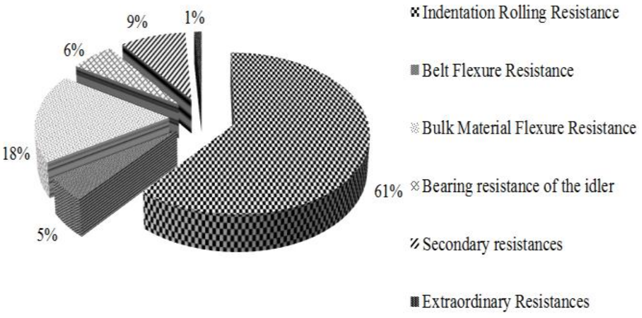

Fig. 2 – Distribution of motion resistances in a typical long horizontal conveyor [3], [4]

The most important design parameters for belt conveyor systems influencing power demand as discussed in literature can be summarized into the following:

- Idler roll material, which directly affects idler roll mass and in turn system power demand. The increase of rotating mass per unit length conceivably increases required driving force for a conveyor system [6], [7].
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Belt trough angle, affects the load distribution on the idler rolls, which has to be accounted for during idler design and selection as it affects power requirements for the system [8], [9].

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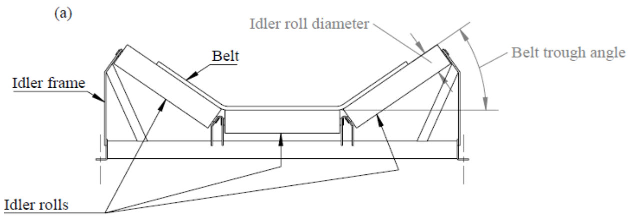

Fig. 3a – A typical carry idler at belt cross section.

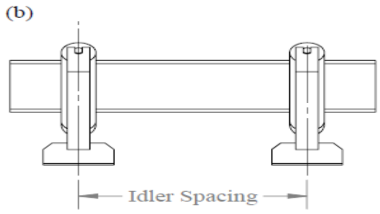

Fig. 3b – Typical arrangement of carry idlers in a typical belt conveyor system.

- Idler spacing, where literature reports that widely-spaced idlers increase belt sag which accordingly increases belt and material flexure resistances. Moreover, belt spacing affects the belt indentation rolling resistance, which is a result of the squeezing pressure exerted on the belt bottom cover when contacting the idler rolls. This hinders belt advance, and thus tends to increase power consumption. From another point of view, widely-spaced idler configurations are favored as they allow for better belt training and lower system initial cost [1], [8], [10], [11], [12].
- Idler roll diameter controls the indentation rolling resistance and belt flexure resistance. Using large rolls increases predicted bearing life (L10) and shell wear life [1], [6], [5], [13], [12].
- Idler roll bearing design influences the idler resistance to rotational movement, where deep groove ball bearings are expected to have less resistance to rotation compared to roller bearings [1], [7], [14].
- Belt speed increase requires higher driving power for belt conveyor systems. Additionally, belt speed also affects roller rotational speed, which in turn affects roll bearing life [7], [15].
- Ambient temperature significantly affects power requirements of belt conveyor systems, where operating systems at low temperatures consume higher energy [1], [5], [7], [16], [17].

## II. METHODS

### A. *Modelling and Simulation*

A simulation for the power demand was performed using Sidewinder software in compliance with DIN 22101 and ISO 5048 standards. The simulation model was developed by feeding the software with fixed system parameters, as given in Table I, which are drawn from a realistic case study and involving a number of assumptions, as will be elaborated at a later stage. The above mentioned design parameters under consideration are then entered in various levels/values as variable parameters (detailed in Table II) to simulate the power demand for the various conditions under investigation.

Table I Fixed parameters of the simulation model

| **Parameter** | **Value** |
|---|---|
| Conveyor center-to-center length/ profile | 1000 m/ horizontal |
| Belt width | 1829 mm (72 in.) |
| Capacity | 9075 t/h |
| Bulk material handled | Copper |
| Bulk material density | 1650 $kg/m^3$ |
| Belt weight per length | 60 kg/m |
| Idler roller axle diameter[a] | 50 mm |
| Inline carry idler rolls | 3 |
| Return idler rolls | 2 (trough angle 10°) |
| Idler installation and alignment | according to CEMA[b] 5th edition |
| Deep groove ball bearing | SKF 6310 |
| Roller bearing | SKF 21308E |

[a] Idler roll axle sizing is based on withstanding worst case loads safely.

[b] Conveyor Equipment Manufacturers Association

The simulation model was based on the following set of assumptions:

- For simplification, a concept applied by ZISCO [18] is adapted, assuming idler spacing for return idlers to be double the spacing used for carry idlers.
- Within the same simulation run, the same bearing type is used for both carry and return idlers (i.e. either deep groove ball bearings or roller bearings as per Table 1).
- The artificial friction coefficient ($f$) , a factor covering both idler rolling and belt advance resistance, is assumed to be 0.02, as a standard quality [6], [19], [20] in case of high temperature experiment values and 0.03 in case of low temperature runs as per ISO 5048.
- The idler roll shell thickness for steel rolls is set automatically by Sidewinder according to the South African National Standards (SANS 1313). For Aluminum rolls, a thickness multiplier factor of 1.5 is used to compute idler roll shell thickness compared to the values stipulated by SANS 1313, while for polyurethane rolls, a thickness multiplier factor of 3.5 is considered appropriate.
- Material spillage problems at belt speeds ranging between 0.5 and 3 m/s are neglected to focus on the effect of speed on power consumption.

Table II Variable parameters for the simulation

| **Factor** | **Description** | **Levels** |
|---|---|---|
| Factor A | Idler roll Material | Steel<br>Aluminum<br>Polyurethane |
| Factor B | Trough Angle | 35°<br>45° |
| Factor C | Idler spacing | 1 m<br>1.5 m<br>2 m |
| Factor D | Roll diameter | 152 mm (6 in.)<br>178 mm (7 in.) |
| Factor E | Bearing type | Deep Groove Ball Bearing |

| | | |
|---|---|---|
| | | Roller bearing |
| Factor F | Belt Speed | 0.5 m/s<br>3 m/s<br>6 m/s |
| Factor G | Ambient Temperature | -45 °C<br>20 °C |

### B. *Statistical Analysis*

Factorial experiment is a powerful methodology that is used to analyze data fed from experiments to investigate the effect of several factors and their interactions on a response variable. Generally, experiments are typically performed for all possible combinations of the factor levels under investigation, where significance of these factors is tested by comparing their F-values (Minimum Significant Ratio) to the corresponding F-statistic at the required confidence level [21], [22].

This case study was analyzed using the factorial experiment methodology, where the response variable is the power demand of the conveyor system, while the investigated factors and their values are as listed in Table II. A design of experiments tool was used to analyze the simulation results using general factorial experiment design in order to define the significance of each design parameter and the interaction effects of the combinations of each two parameters on the power demand. The analysis was performed using the classical sum of squares – Type II, where only the main effects and the two factor interactions were considered.

## III. RESULTS AND DISCUSSION

### A. *Effect of roll material*

Sidewinder results reveal the effect of roll material on the power demand of a belt conveyor system as shown in Fig. 3. It can be observed that least power demand was recorded when using aluminum as the roll material. In contrast, polyurethane rolls yield the highest power demand. At first sight, this result may not seem conceivable, based on the relatively low density of the polyurethane leading to the expectation of lower power consumption. However, to fulfill design requirements, it becomes necessary to increase roll shell thickness to allow polyurethane rolls to carry the applied loads. Thus the total roller mass in case of polyurethane becomes even greater than that in case of steel or aluminum. This explains the increased demand in power when running polyurethane rollers.

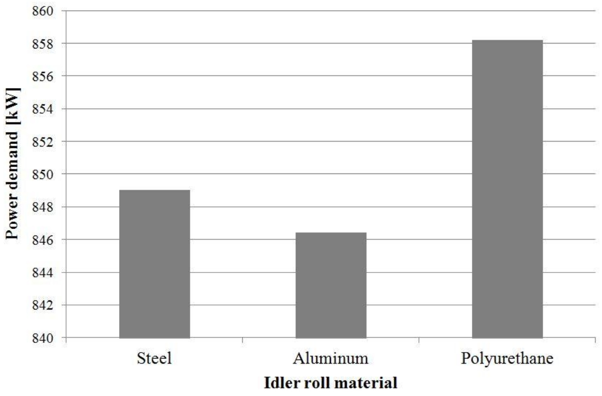

Fig. 3- One factor plot for roll material (Factor A)

The above results prove that proper selection of idler roll materials at the design stage can contribute to a reduction of required driving forces. Literature supports this idea, stating that appropriate roll material can help withstand applied static and dynamic loads, while minimizing the roll rotating mass [6], [7], [11]. Moreover, proper material reduces idler roller wear rates and impact resistance providing a prolonged service life.

### B. *Effect of idler spacing*

Literature 23 reports that, closely-spaced idler sets can have positive effects in reducing the loads exerted on each roll, in addition to decreasing belt sag. This in turn decreases belt and material flexure resistances and accordingly, material spillage chances can be minimized. However, locating idlers closely is observed to increase idler rotation resistance as a result for the accumulative seal drag and bearing rolling resistances, thus requiring higher power to drive the system [12], [16], [23], [24]. Simulation results confirm this latter finding and show that the use of widely spaced idlers proved to demand less power, as can be depicted in Fig. 5. However, it must be noted that the study investigated only three values for idler spacing, which do not cover a broader range to provide a general trend for the effect of idler spacing. In this respect, it is expected according to Wheeler [25] that there is a minimum motion resistance at idler spacing of around 2 meters. Narrower or wider spacing would again cause an increase in power consumption.

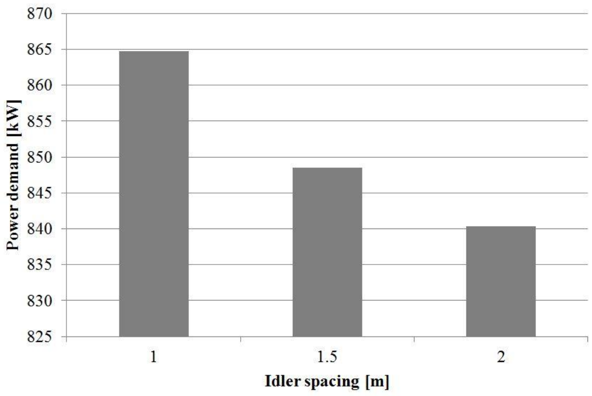

Fig. 4- One factor plot for idler spacing (Factor B)

Idler spacing has two contradicting effects on power demand. On the one hand, wide spacing increases belt sag, which results in increased bulk solid and belt flexure resistances, and thus calls for higher power demand. However, the wide-spaced idler arrangement, on the other hand, is witnessed to reduce power demand as it reduces the belt-idler shell contact zones, which results in a reduced indentation rolling resistance. Generally, using wide-spaced idlers provides a better economic solution as it requires less start-up and maintenance cost [1], [11], [12], [23].

### C. *Effect of idler roll size*

Fig. 5 presents the effect of idler roll size on the power demand of the belt conveyor system. As illustrated in the Fig., an increase in idler roll diameter requires greater power.

These results contradict with the concept presented in ISO 5048 and DIN 22101, where both assign a higher friction coefficient (*f*) for smaller idler rolls, to account for the higher power demand [6], [12], [16], [20].

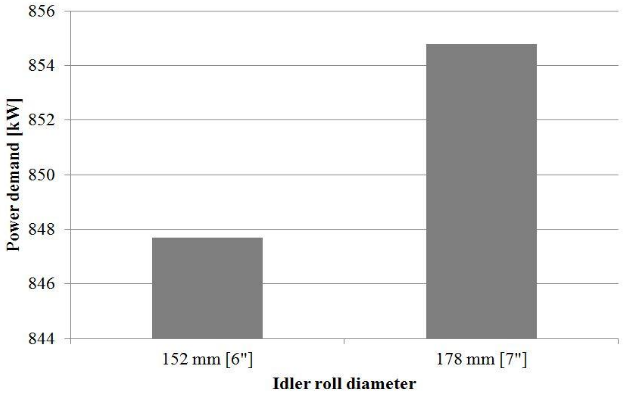

Fig. 5- One factor plot for idler roll size (Factor C)

Idler roll diameter is an influential design parameter which controls the idler roll/ belt contact area and accordingly determines idler indentation and rotation resistance. Therefore, many recent developments are carried out by belt manufacturers in order to produce belts with superior rolling resistance properties that would be able to significantly lower power demand of conveyor systems [26]. Novel technologies can result in reducing the DIN friction factor (*f*) to 0.0075 [17] thus achieving power saving starting from 10 to 60% [5, 13], [15], [27].

### D. *Effect of belt speed*

The effect of belt speed on the power demand is presented in Fig. 6. Simulated results show that belt speed has a great impact on power demand, where increasing belt speed calls for a higher power demand. This lies in agreement with ISO 5048 and DIN 22101, which assigns a higher friction coefficient (*f*) for belt speeds exceeding 5 m/s [6], [20].

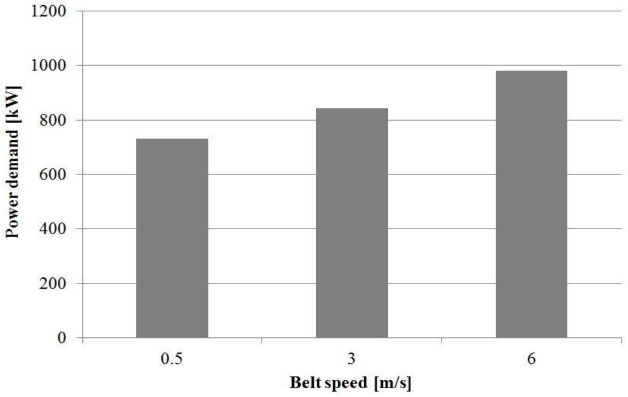

Fig. 6- One factor plot for idler spacing (Factor D)

It can be concluded from above results that low speed conveyors consume less energy, which makes it a challenge in case of engineering processes requiring high rates of material transportation. This problem however can be mitigated using increasing belt width.

### E. *Effect of ambient temperature*

Simulated results show that ambient temperature directly affects the power demand, as can be depicted from Fig. 7. A reduction in temperature from 20 to -45 °C increases the demand for power by 50%.

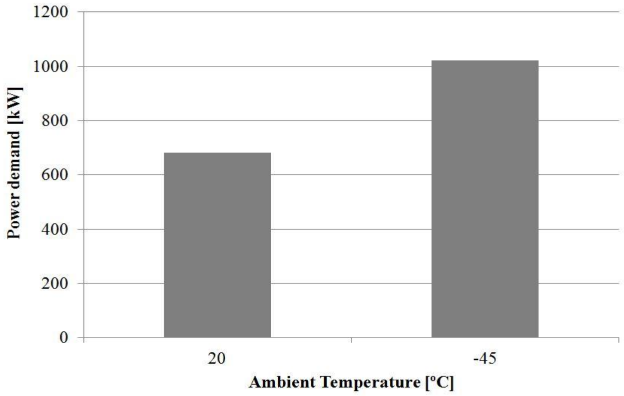

Fig. 7- One factor plot for ambient temperature (Factor E)

Again this lies in complete agreement with ISO 5048 and DIN 22101 principles, which assign a higher artificial friction coefficient (*f*) for ambient temperatures less than 20 °C [6], [20]. Ambient temperature is one of the challenging factors as it cannot be accurately foreseen in most cases [27].

### F. *Factor significance and interaction*

Analysis of the simulation results using general factorial designed experiment shows that the model is significant at a 95% confidence level, where the main significant factors are roll material, idler spacing, roll diameter, belt speed, and ambient temperature. The significant interaction factors are roll material-idler spacing interaction, roll material-roll diameter interaction, roll material-belt speed interaction, roll material-ambient temperature interaction, idler spacing-belt speed interaction, idler spacing-ambient temperature interaction, roll diameter-belt speed interaction, roll diameter- ambient temperature interaction and belt speed-ambient temperature interaction.

According to the computed F-value, the ambient temperature and the belt speed factors are the most influencing factors among the studied ones, where they formed almost 99% from the F-value shares for all the investigated factors, as shown in Fig. 8.

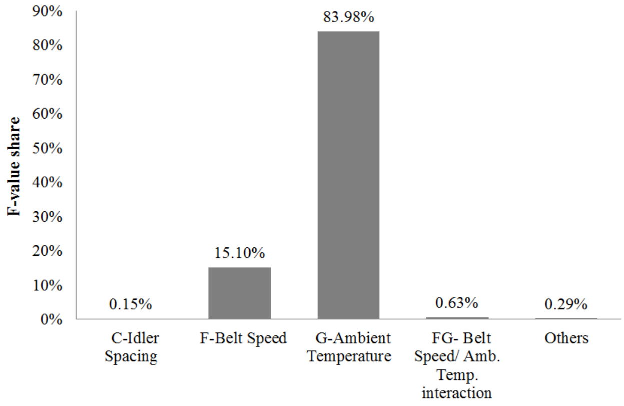

Fig. 8 – Analysis of Variance results - F values shares for the most significant model terms

Based on statistical analysis, roll material and idler spacing had a significant interaction influencing the power demand of the conveyor system. Least power demand, as can be observed from Fig. 9 can be achieved with aluminum rolls at large idler spacing. In contrast, maximum power demand can be inevitable when using polyurethane rolls at low idler spacing.

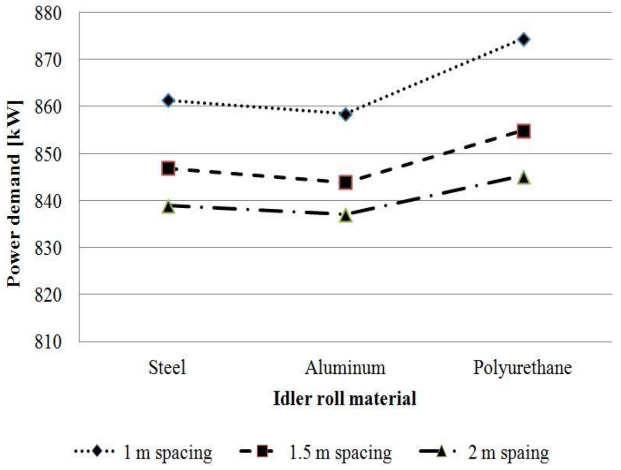

Fig. 9- Interaction plot for roll material and idler spacing (Factors A and C)

Roll material and belt speed were also found to significantly interact with each other, where it is noted that more interaction takes place at higher belt speeds. Minimum power demand, observed for aluminum rolls at low belt speeds, lies in contrast to the maximum values for polyurethane rolls at high belt speeds, as can be depicted in Fig. 10.

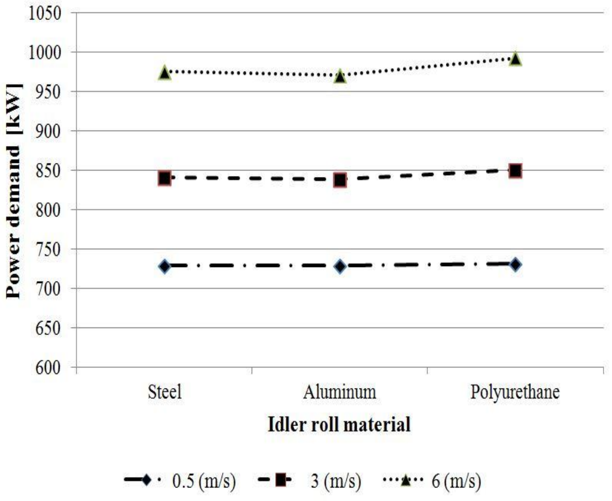

Fig. 10- Interaction plot for roll material and belt speed (Factors A and F)

Roll material (factor C) and belt speed (factor F) were also found to have a significant interaction effect. Whereas at low belt speeds, power demand is almost not affected by idler spacing, a moderate and high speed results in a reduced power demand with increasing idler spacing. In this respect, it could be observed, that increasing idler spacing from 1 to 2 meters can save about 4.5% energy at a belt speed of 6 m/s.

The least power demand was observed when using wide idler spacing at low belt speeds. In contrast an undesired high power demand results at the combination of narrow idler spacing and high belt speeds, as illustrated in Fig. 11.

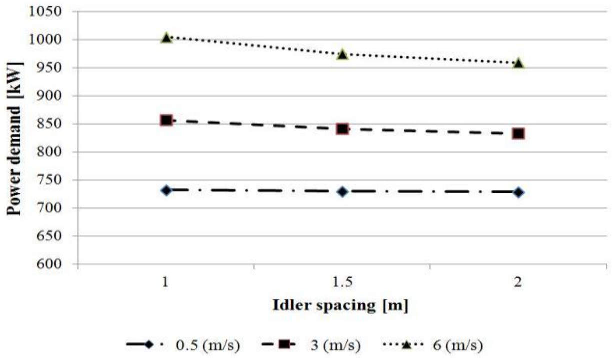

Fig. 11- Interaction plot for idler spacing and belt speed (factors C and F)

In addition to the idler spacing, the belt speed (factor F) was found to additionally interact with the roll diameter (factor D). Here, it was noted that the roll diameter has no considerable effect on power demand at low belt speeds, as can be depicted in Fig. 11. However, power demand increases with increasing roll diameter, which becomes more evident at medium and high belt speeds. At this level, the synergy effect of both factors seems to aggravate. Thus, it is to be noted, that a 152 mm idler roll would save about 1.3% of the required energy compared to a178 mm roll at the same belt speed of 6 m/s.

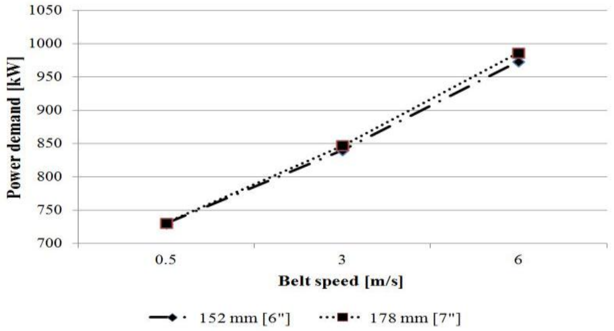

Fig. 12- Interaction plot for roll diameter and belt speed (Factors D and F) using average values for all design parameters

Idler spacing (factor C) and ambient temperature (factor G) were also found to have a considerable interaction effect, where systems operating at low ambient temperature consume additional driving power. The most power-saving solution for this case is using widely-spaced idlers at temperatures equal or higher than 20 °C.

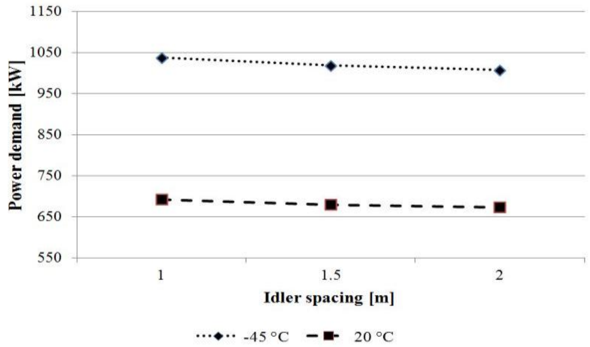

Fig. 13- Interaction plot for idler spacing and ambient

temperature (Factors C and G) using average values for all design parameters.

The interaction of idler roll diameter and ambient temperature can demonstrate that replacing 152 mm rollers with 178 mm ones at 20 °C do not result in a considerable change in power demand as shown in Fig. 14. In contrast, the same action results in a greater effect on power demand, where the optimum case in this situation is using small sized rollers at high temperatures.

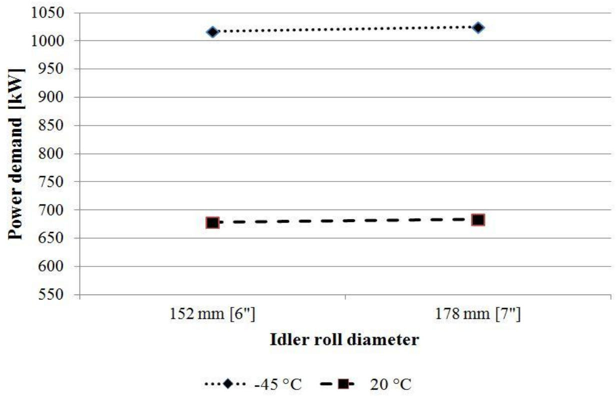

Fig. 14- Interaction plot for idler roll diameter and ambient temperature (Factors D and G) using average values for all design parameters

Simulated results show that there is an interaction between idler roll diameter and roll material, where the most appropriate solution to minimize power demand is using small aluminum rolls as shown in Fig. 15.

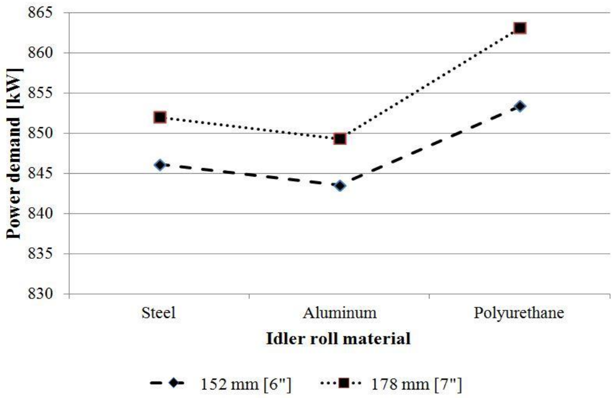

Fig. 15- Interaction plot for idler roll material and ambient temperature (Factors A and D) using average values for all design parameters

An appropriate combination of ambient temperature and belt speed has a considerable effect on power demand, where designing a slow conveyor at 20 °C may reduce the system power demand to half what is required on using a fast-driven conveyor at -45 °C as shown in Fig. 15.

## IV. CONCLUSION

Analyzing simulation results shows that roll material, idler spacing, idler diameter, ambient temperature and belt speed have a significant effect on the the total power demand of a belt conveyor system, while belt trough angle and idler roll bearing design do not significantly affect the power demand. ANOVA results reveal that the most significant factors among these are the ambient temperature, where it has the highest sum of squares value, followed by belt speed, ambient temperature/belt speed interaction, idler spacing, roll material, and finally roll diameter.

Simulation results show that an increase in power demand takes place on operating the system at one or more of the following operating conditions: low ambient temperature, high belt speed, using small idler spacing and using large-sized idler rolls. Moreover, the present study proves that proper selection of idler roll materials at the design stage can contribute to a reduction of required driving forces. Here, aluminum rolls were found to require less power demand compared to steel and polyurethane ones.
Power demand for the system ranges from 1242 kW to 583 kW. Selecting optimum operating conditions can save power up to 53.1% compared to the maximum power demand value.

## ACKNOWLEDGMENT

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