THE ENERGY SAVING MEASURES IN CONVEYOR DESIGN

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1. INTRODUCTION

The influence of conveyor parameters on the energy consumption should be systematically determined and analysed. Taking into account an increase in rates and distances at which materials are conveyed it becomes, not to mention some of the ecological pressures, almost an imperative to minimise conveyor inherent resistance to achieve increased efficiency of operation reflected by decreased energy requirements, reduced capital expenditure and lower operating costs. Current state of our knowledge and available tools make such a task significantly easier.

The main aim of the paper is to indicate ways and means of achieving a more efficient conveyor design. A number of conveyor designed in the past have been selected for the purpose of comparison. They vary in length, capacity, belt width and belt velocity.

2. CONVEYOR RESISTANCE TO MOVEMENT

For a horizontal conveyor in a steady state operation conveyor energy demand is determined by its frictional resistance to movement. Components of conveyor frictional resistance are:

- idler rotation (dependent on: bearing and seal design, quality and quantity of grease, idler rpm, load, ambient temperature, etc.) ;
- deformation of belt bottom cover when moving over an idler (dependent on: viscoelastic properties of belt cover, belt structure, load, idler diameter, etc.);
- belt flexing (dependent on: belt properties, belt tension and idler spacing, load, belt velocity, trough shape, etc.);
- material flexing/ deformation when moving between idler sets (dependent on: material properties, belt tension and idler spacing, load, etc.).

Indentation resistance (bottom belt cover deformation) in some instances may constitute up to 60% of the total frictional resistance. It is, however, important to note that two components, namely belt and material flexing resistance increase their respective contribution to the total when operating at relatively low belt tensions ranging between 2% to 5% of the ultimate belt strength [1],[2],[3]. Figure 1 presents stated interdependence.

Figure 2 illustrates contribution of each of the described components to the total frictional resistance of a long horizontal conveyor. [4]

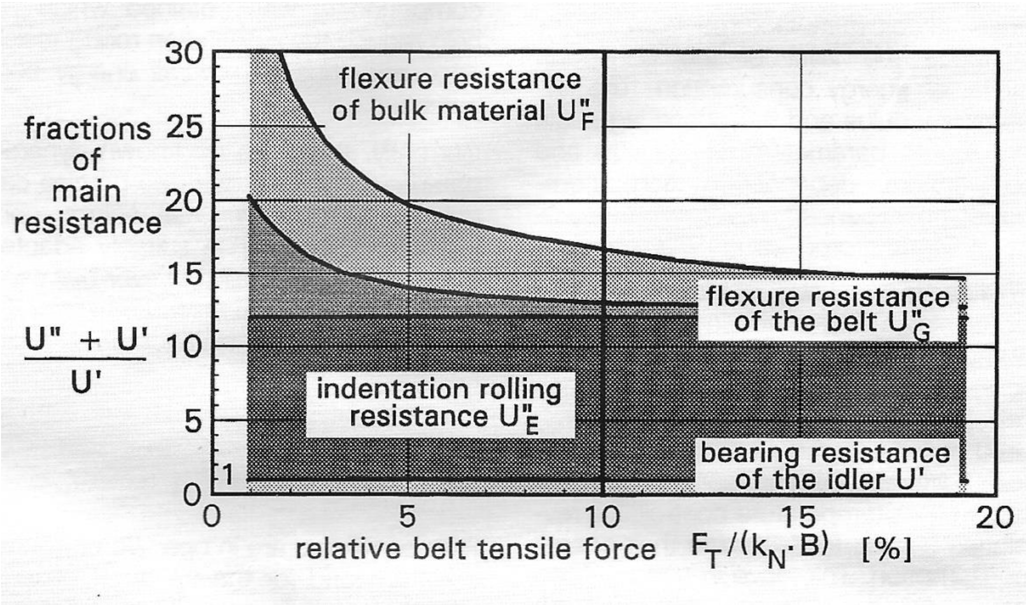

Figure 1. Influence of belt tension on the individual main resistances with respect to the bearing resistance of the idlers. F_T – belt tension [kN]; k_N- ultimate belt tension [kN/m]; B – belt width [m]

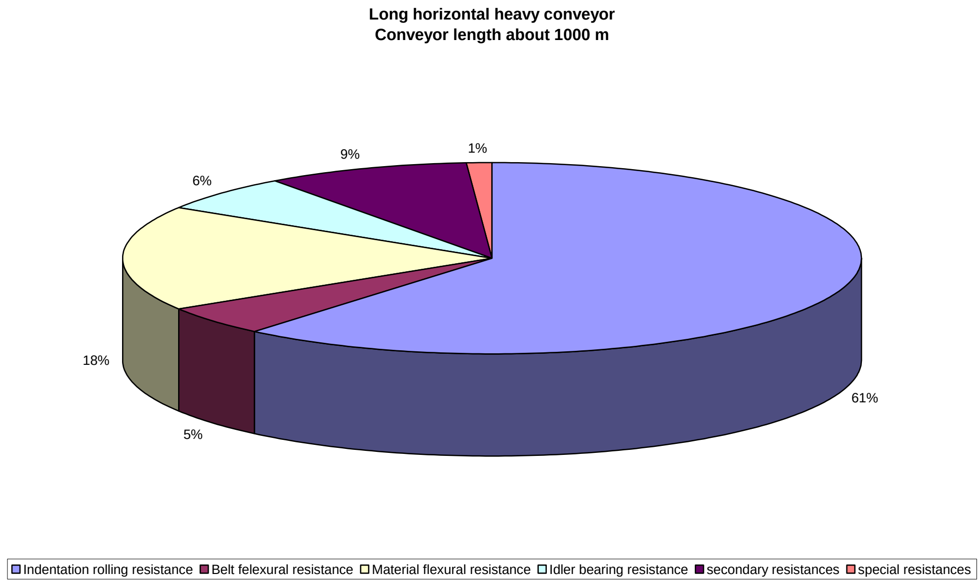

Figure 2. Percentage distribution of the individual motion resistances of a horizontal conveyor [4].

Above summary gives an indication of which specific parameters should be subject to design "manipulation" with the aim of minimising conveyor frictional resistance and consequently energy/power requirements.

3. WORK PERFORMED

Several conveyors were selected for the purpose of the work. An attempt was made to have variation in length, capacity, belt speed and belt volumetric utilisation. Summary of main technical parameters of the conveyors is presented in Table 1.

Conveyor	Length	Capacity	Material	Belt Width	Belt Speed	Trough Angle	Volumetric Utilisation	Top Idler Spacing	Top Idler Diameter	Drive Location	Take Up Type	Comments
	[m]	[t/h]		[mm]	[m/s]	[deg]	[%]	[m]	[mm]			
A	2160	1500	Copper ore	1200	1,9	35	71,0	1,2	152	Head end	h..gravity	
B	2400	10000	Iron ore	1650	4,3	45	85,0	1,0	178	Head and tail ends	h. .gravity	
C	3450	2000	Coal	1050	5,5	45	87,0	3,0	152	Head end	h. .gravity	
D	3450	2000	Coal	900	7,5	45	89,6	3,0	178	Head end	h. gravity	
E	4000	900	Bauxite	1200	2,3	45	79,0	1,2	127	Head end	h. gravity	
F	6900	2400	Coal	1050	5,7	45	98,3	2,2	152	Head and tail ends	h. gravity	
G	7200	2700	Coal	1500	6,6	45	50,0	4,0	219	Head end	h. gravity	
H	8500	2000	Coal	1200	4,0	35	99,0	2,0	152	Head and tail ends	Electric winch	
I	11500	1600	Coal	1200	4,5	45	69,0	4,0	152	Head and tail ends	h. gravity	
J	12300	2000	Coal	1200	4,0	35	99,0	2,0	152	Head and tail ends	Electric winch	
K	21000	2000	Iron ore	900	4,5	35	65,0	4,0	152	Head and tail ends	h. gravity	
L	24600	1950	Coal	1050	7,5	35	73,0	4,0	178	Head and tail ends	h. gravity	

Table 1. Conveyor technical details

Analysis were done changing specific design/equipment parameters presented in Table 2.

Case	Description	Comments
1	Base Case. Conveyor as designed	Commercial grade M of tested parameters
2	Commercially available LRR belt bottom cover	Commercial LRR (Low Rolling Resistance) grade of tested parameters
3	Specially developed LRR belt bottom cover	Non commercial Special LRR grade of tested parameters.
4	Increased diameter of the trough central roll	Roll diameter increased by one size
5	Increased diameter of the top rolls	Roll diameter increased by one size
6	Unequal length trough rolls	Central roll equivalent to a belt one size narrower, wing rolls – one size wider
7	Increased /decreased trough idler spacing	Conveyors A,B,F,H, and J spacing increased to 2 x nominal spacing Conveyors C,D,G,I,K and L spacing decreased to 0,5 x nominal spacing
8	Low resistance trough idlers	Rolls of very low rotating resistance as obtained from tests – single supplier
9	Combined commercial LRR cover, low resistance idlers and increased trough idler diameter	Cases 2, 5 and 8 combined

Table 2. Technical options

It is important to note that when changing between various cover grades one common grade M, LRR (Low Rolling Resistance) and Special LRR covers were used of identical tested properties which had not been the case when the conveyors were originally designed. For the purpose of simplicity all results were converted to a product of C and f factors as used by DIN and/or ISO standards.

The work was performed using in-house designed and developed simulation software commissioned in 1990/91. While originally designed as purely dynamic simulation program it has been continuously developed, refined and expanded to allow a wider range of applications.

4. EVALUATION OF RESULTS

The following diagrams give some insight into practical measures which may be applied in the pursuit of increased energy efficiency when designing a conveyor.

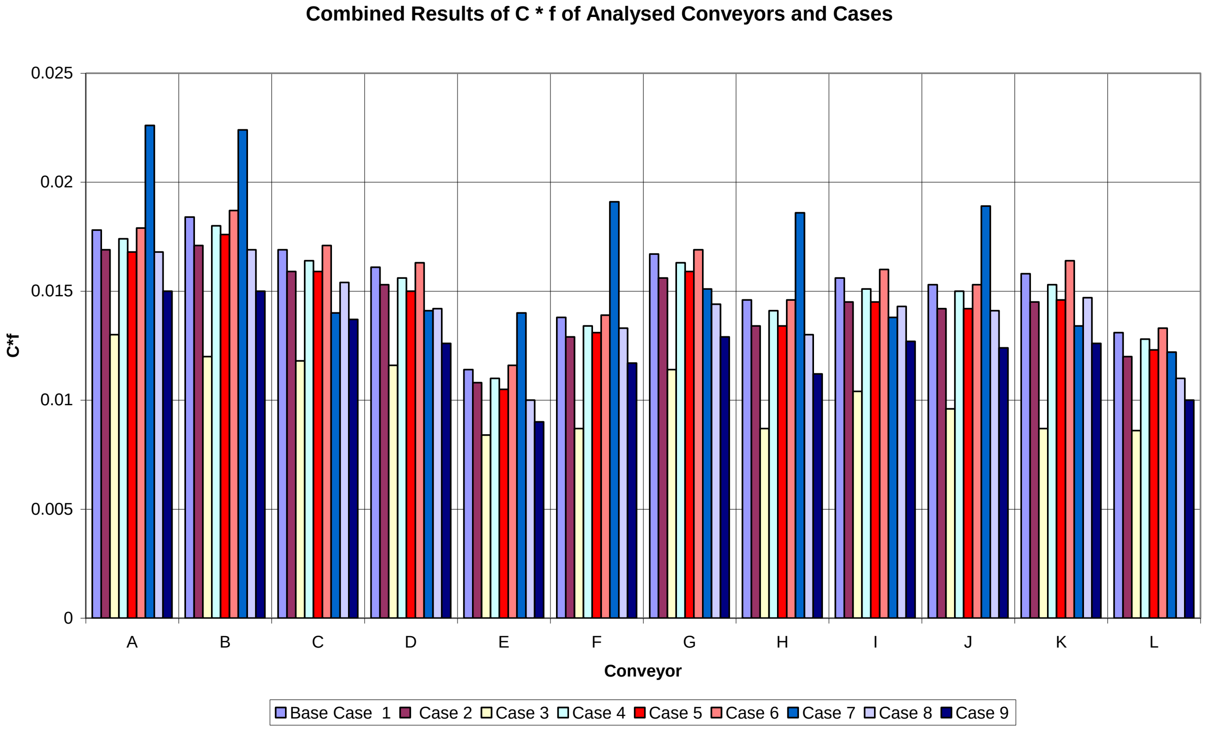

Figure 3. Combined results of the analysed conveyors and cases.

A number of distinct features can be noted namely:

- A significant reduction of the C*f value when the Special LRR rubber compound is utilised (case 3) .
- A distinct increase of the C*f value when the top idler spacing is increased by a factor of two (Case 7, conveyors C, D, G, I, K and L).
- The LRR compound (Case 2) used in the evaluation does reduce frictional resistance of a conveyor but the savings achieved are not as significant as expected and in some instances similar reduction can be obtained by other means such as increased idler roll diameter or the use of idlers with very low resistance to rotation.
- Combination of several measures may produce more than satisfactory result as indicated by Case 9 where LRR compound was used together with idlers of increased diameter and low resistance to rotation. In fact this combination produced the second best results of the evaluation.

4.1 Effect of Belt Cover Grades

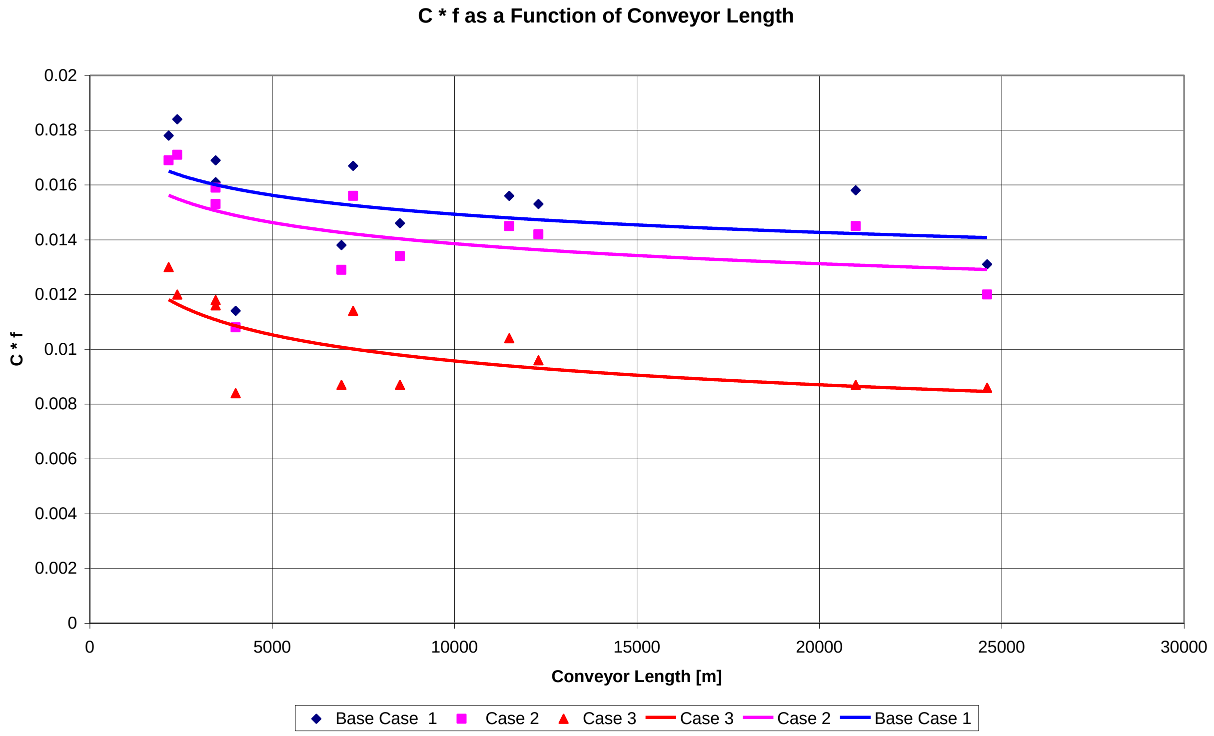

Figure 4. Values of C*f as a function of conveyor length. Grade M cover (Base Case 1), LRR cover (Case 2) and Special LRR cover (Case 3)

Figure 4 allows a more in detail look at the performance of conveyors when three different grades of cover are used. All three graphs underline a distinct benefit of the use of long conveyor flights vs. short ones. This does not mean that medium length conveyors cannot be energy efficient as indicated by a very low value of C*f =0,0114 of conveyor E – in fact the lowest value of all standard designs evaluated. Reasons for a decreased frictional resistance of long conveyors can be indirectly explained by Figure 1 where the increased belt tension results in diminishing levels of both belt and material flexural resistance.

While LRR grade cover does reduce frictional resistance to a noticeable degree, performance of the Special LRR grade cover is more than impressive. The results clearly indicate that investment in development, testing and application of such cover will be more than compensated for by the reduction in capital and operational expenditure. As an indication LRR and Special LRR grade covers may reduce overall frictional resistance by approx. 6% and 30% for the shorter conveyors and by approx. 9% and 40% respectively for the very long ones.

4.2 Effect of Idler Parameters and Configuration

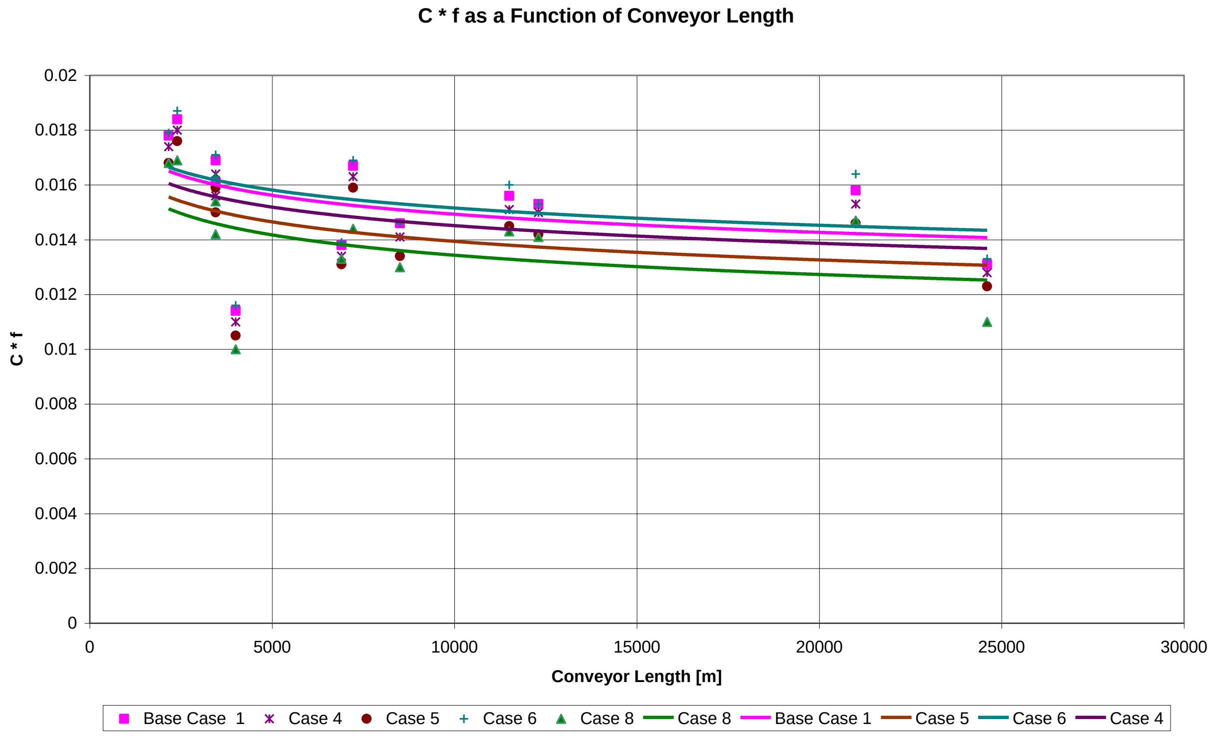

Figure 5. Values of C*f as a function of conveyor length. Grade M cover (Base Case 1), increased central trough roll diameter (Case 4), increased trough rolls diameter (Case 5), unequal trough rolls length (Case 6), low resistant idlers (Case 8).

The relationship between C*f and other cases i.e. increased diameter of the middle troughing roll (Case 4), increased diameter of troughing rolls (Case 5), unequal length troughing rolls (Case 6), low resistance idlers (Case 8) is represented by Figure 5. It may be noted that application of the unequal length troughing rolls slightly increases overall frictional resistance of a conveyor partly as a result of increased indentation resistance (see Figure 6). Increased diameter of just the middle troughing roll provides a slight improvement in the values of C*f over a full spectrum of conveyor length. More significant benefits are obtained when all three troughing rolls are of bigger diameter while further improvement is achieved when the idlers are of low resistance type. In fact, in this investigation the latter solution provides results similar to the application of the LRR grade bottom cover.

4.3 Effect of Combined LRR Cover, Increased Idler Diameter and Low Resistance Idlers

As stated earlier Case 9 combined three of the possible solutions i.e. LRR grade belt cover, increased trough idler diameter and low resistance idlers. Resulting C*f values for this solution have been compared with those of Grade M, LRR and Special LRR grade belt covers as presented by Figure 7. Common application of three different measures has produced the second best reduction of C*f after Special LRR grade cover. Caution should be expressed here as the results apply to specific products. However, these results suggest a specific avenue to achieve improved energy efficiency in a conveyor design.

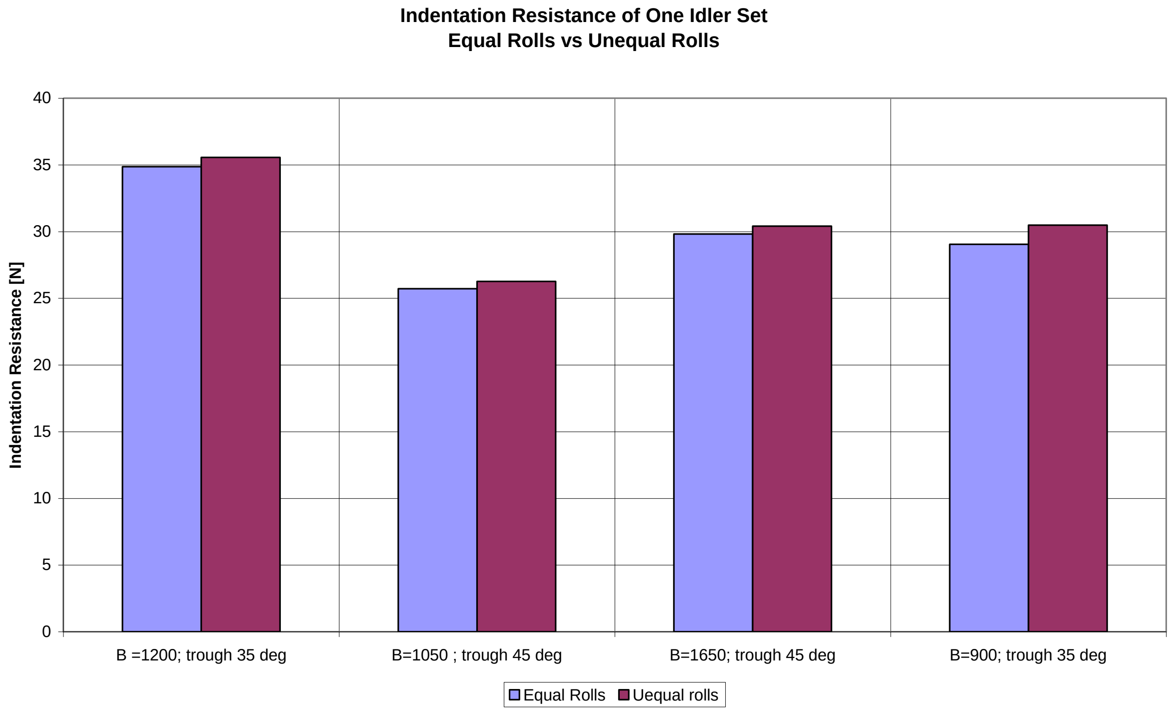

Figure 6 Comparison of indentation resistance of equal and unequal roll length idler sets.

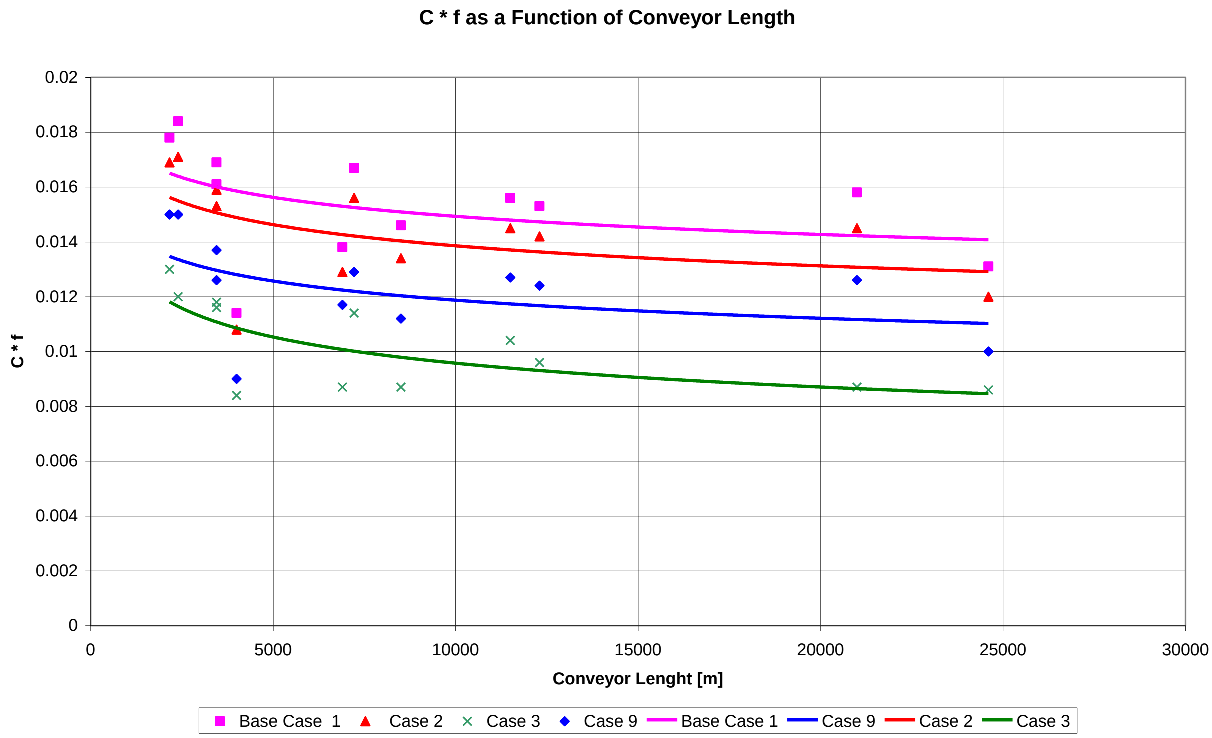

Figure 7. Values of C*f as a function of conveyor length. Grade M cover (Base Case 1), LRR cover (Case 2), Special LRR cover (Case 3), combined LRR cover, increased trough roll diameter, low resistance idlers (Case 8)

4.4 Effect of Increased/Decreased Idler Spacing

For the purpose of this investigation the influence of reduced/increased idler spacing is presented by Figure 8 as a relation between C*f and average load acting on an idler set. As already indicated by Figure 3 increased idler spacing and/or load significantly increases value of C*f - reduced spacing and/or load leads to a lower value of C*f. With the spacing increased or decreased by a factor of 2 the highest increase of the C*f value was 38% and the highest decrease 17 %. The two highest C*f values (0,0226 and 0,0224) are of conveyors A and B when their design idler spacing was increased from the original 1,2 and 1,0 meters to 2,4 and 2,0 meters respectively. As originally designed conveyor B has the highest load per idler of all of the investigated conveyors (initial C*f =0,0184) while idler load of conveyor A (original C*f =0,0178) represents an average value for the group of the conveyors analysed but less than the loads of some of the longer conveyors with extended idler spacing of 3,0 or 4,0 meters. However, once the idler spacing is increased idler load becomes the second highest of the group. In an effort to minimise adverse effects of the increased loads one would have to apply some of measures depicted by Figures 3,4 and 5.

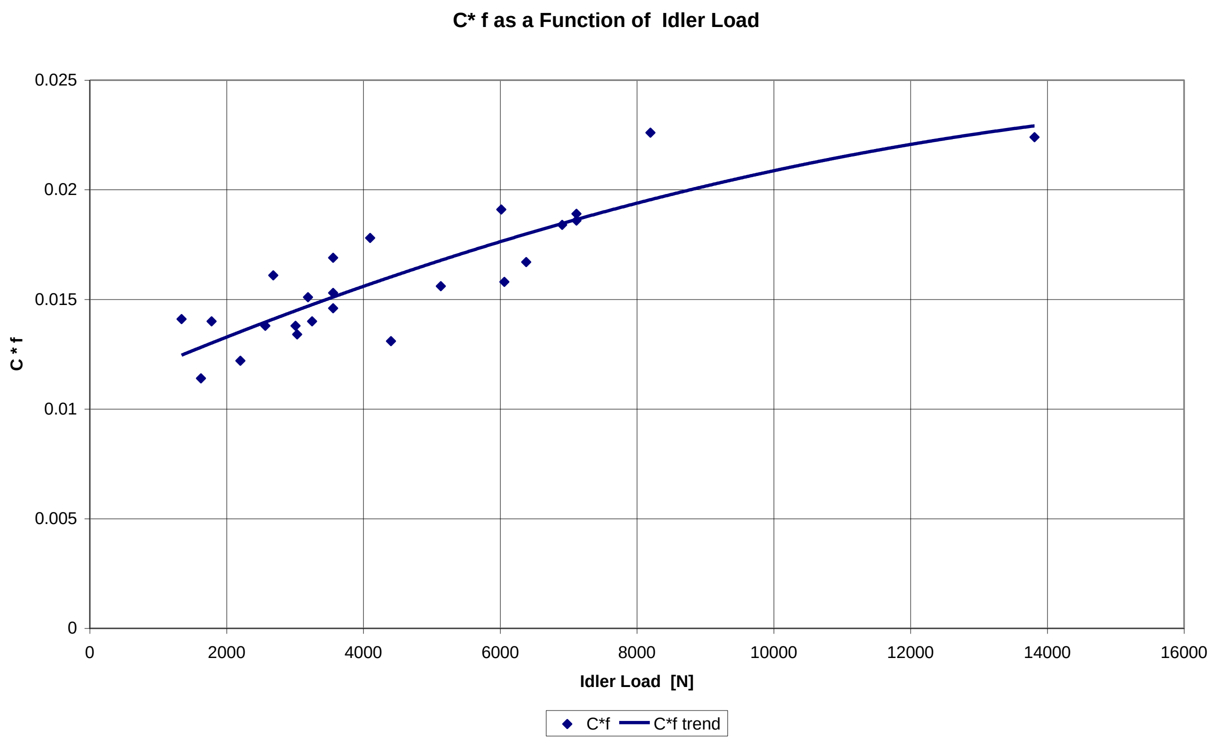

Figure 8. Values of C*f as a function of idler load Grade M cover (Base Case 1)

4.5 Influence of Belt Velocity, Belt Volumetric Utilisation and Belt Width

Figures 9, 10 and 11 look at the influence of three other factors, namely belt velocity, belt volumetric utilisation (maximum cross sectional area of material as per ISO 5048 represents 100% volumetric utilisation of the belt) and belt width.

Based on the obtained results it appears that belt velocity has a minor influence on the level of frictional resistance and conveyor energy requirements. At least within the limits of this investigation this could be supported by the design results of conveyors C and D - two design options of the same unit. Original C*f of conveyors C and D is 0,0169 and 0,0161 respectively while power demand to overcome frictional resistance is 0,134 kW/m and 0,136 kW/m. Looking at the full range of the results, power demand of conveyor C ranged between 0,134 kW/m to 0,094 kW/m and of conveyor D between 0,136 kW/m to 0,098 kW/m.

The influence of belt volumetric utilisation as depicted by Figure 10 should be treated with caution. The trend favouring higher volumetric utilisation might be influenced by the fact that three of the conveyors (F, H and J) with very low value of C*f are characterised by the highest volumetric utilisation (98% to 99%) and below average load per idler. This further may be influenced by their length between 6,9 km to 12,3 km. It is important to note that the lowest values of C*f (0,0114 and 0,0131) were achieved by conveyors with volumetric utilisation of 79 % and 73% (conveyors E and L).

Due to a limited spread of belt sizes the results presented by Figure 11 should also be treated as indicative only. Non – linear character of the relationship will have to be confirmed by a bigger sample. The point of minimum C*f value positioned at around width of 1,2 m may be influenced by a predominance of this specific size in the sample analysed.

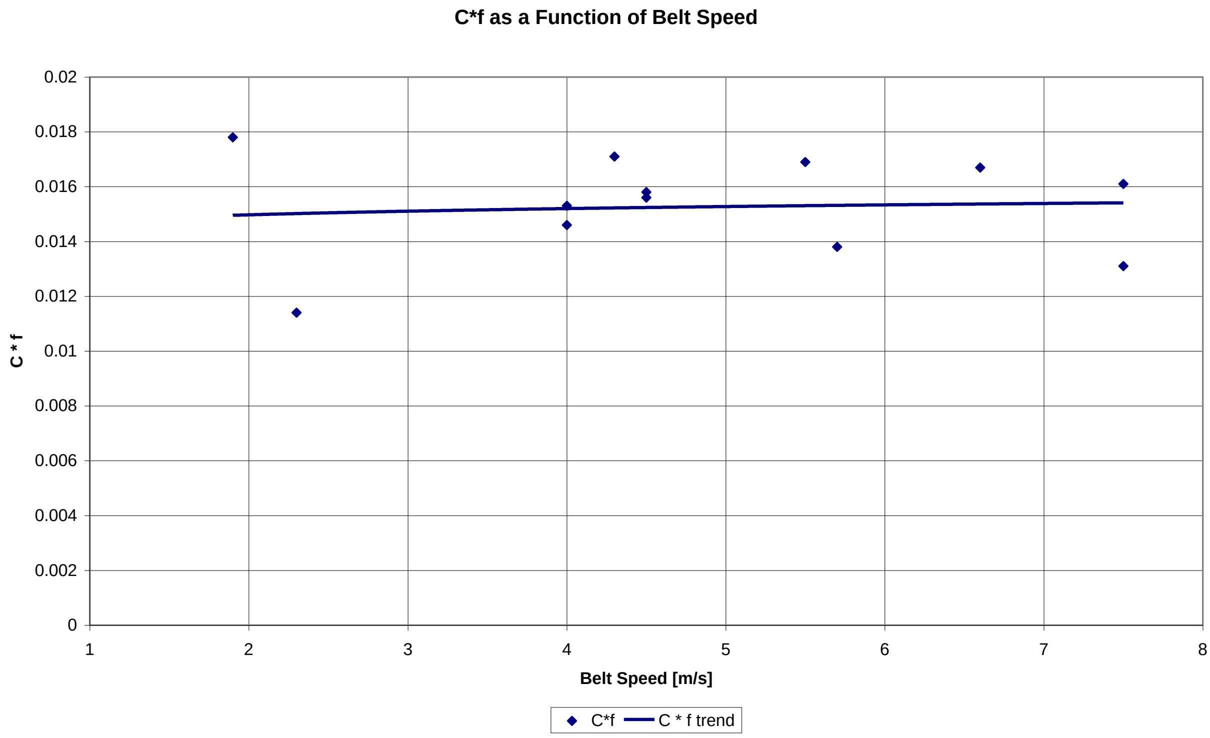

Figure 9. Value of C*f as a function of belt speed. Grade M cover (Base Case 1)

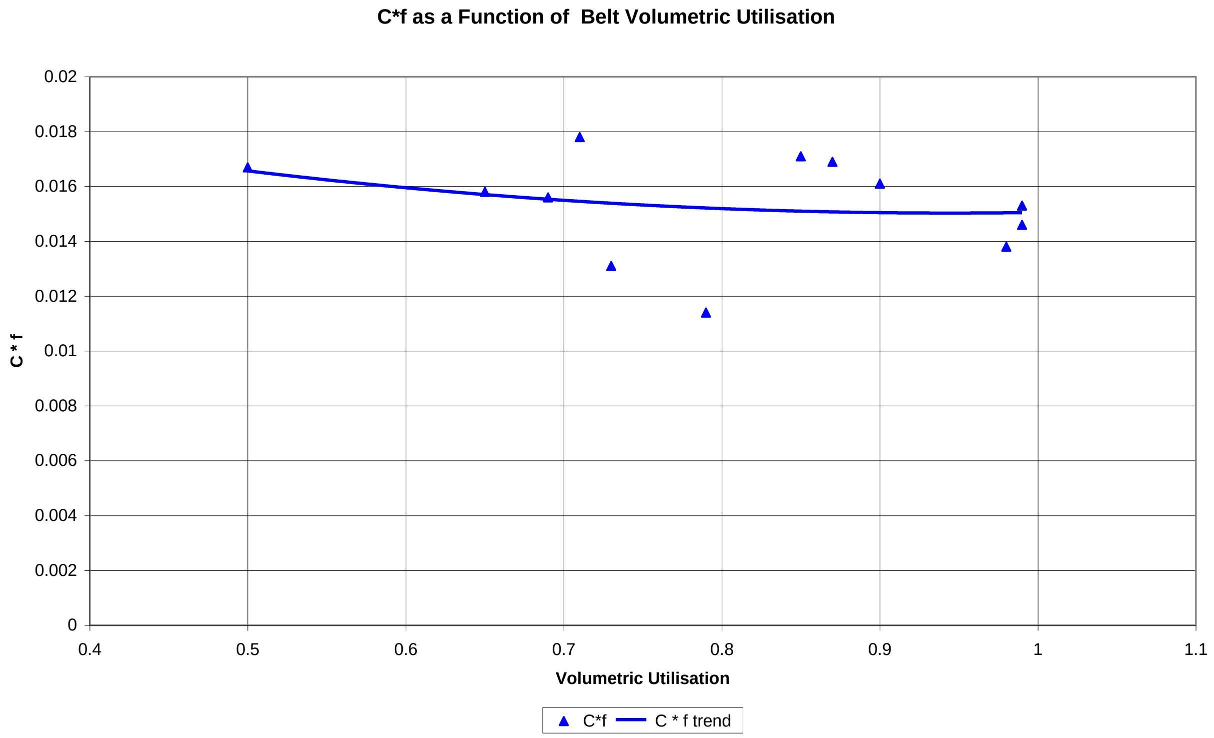

Figure 10. Value of C*f as a function of belt volumetric utilisation. Grade M cover (Base Case 1)

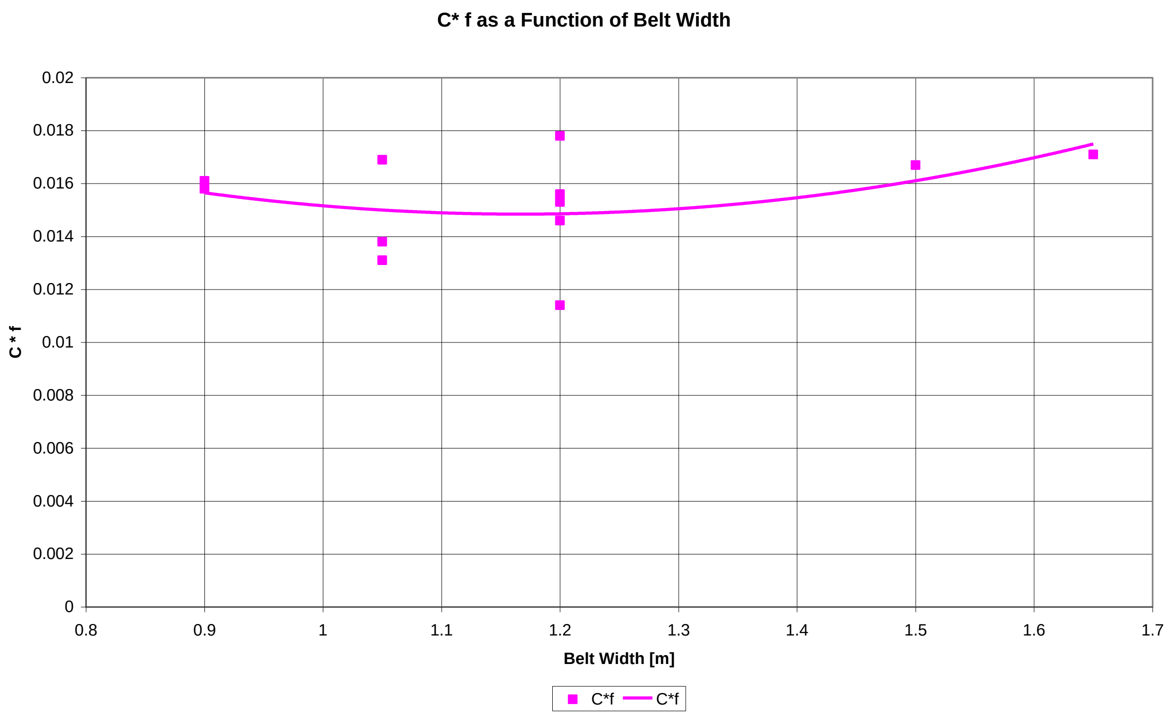

Figure 11. Value of C*f as a function of belt width. Grade M cover (Base Case 1)

4.6 Correlation of Power Demand and Frictional Resistance

Figure 12 attempts to show a relationship between conveyor power demand and conveyor frictional resistance represented by the product C*f. Due to a range of conveyor length, capacities, belt velocity of the analysed conveyors power demand is represented by unit of power [W] per unit of conveyor length [m], conveyor capacity [t/h] and conveyor belt velocity [m/s].

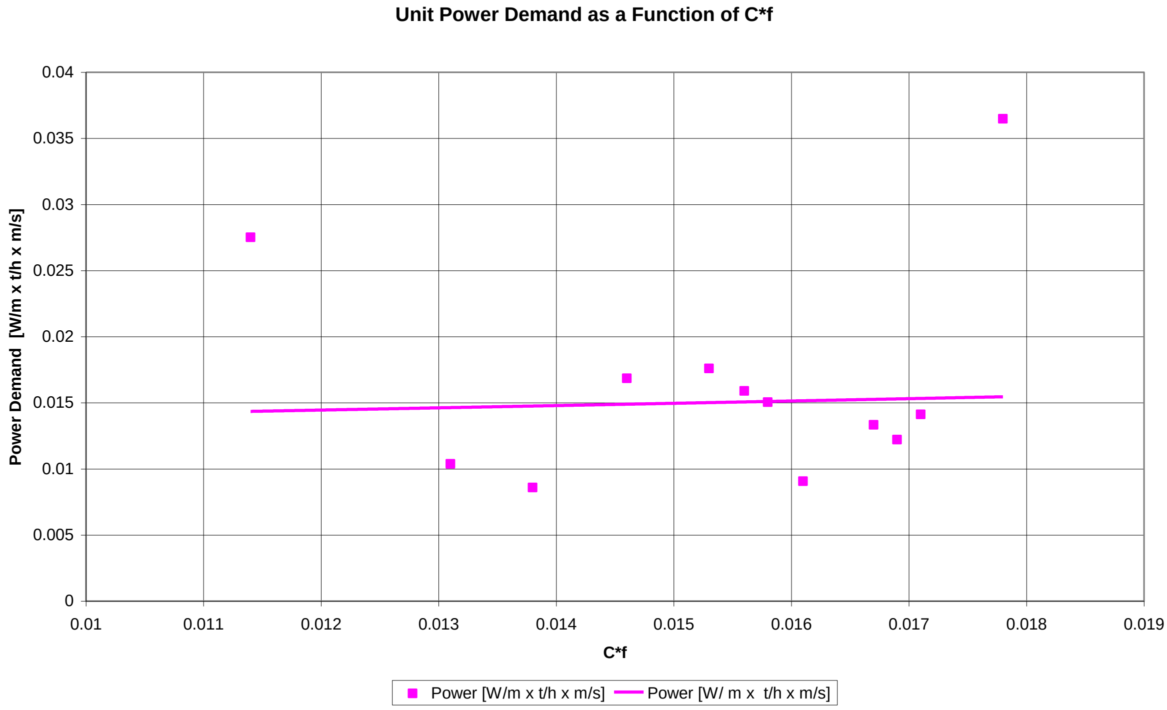

Figure 12. Conveyor unit power demand as a function of C*f (Base Case 1).

For most of the analysed conveyors unit power – C*f results are concentrated within a fairly narrow band. Two of the conveyors (A and E) show distinctly higher values of the unit power demand. It is interesting to note that the conveyor E is characterised by the lowest f value of C*f = 0,114 while the conveyor A has the second highest C*f= 0,178. Both, however, are the slowest moving at v= 1,9 m/s (conveyor A) and v=2,3 m/s (conveyor E).

To evaluate influence of belt velocity on the results unit power demand was modified to a unit of power [W] per unit of conveyor length [m] and conveyor capacity [t/h]. The results are represented by Figure 13. In addition a separate relationship between belt velocity and unit power demand is presented by Figure 14.

As a result of the revision, unit power demand of the slowest conveyors has been brought more in line with the overall trend. However, there are three conveyors which are now distinctly outside of the main body of the results. These are conveyors F, G and L. Value of C*f of conveyor L is the second lowest (C*f=0,131) of all conveyors analysed but in this case returns second highest value of the unit power demand. The highest value is returned by conveyor G. Both of them belong to the group of three conveyors with a very high belt velocity i.e. v= 7,5 m/s (conveyor L) and v=6,6 m/s (conveyor G). At the same time relatively high velocity conveyor F (v=5,7 m/s) returns the lowest value of the unit power demand.

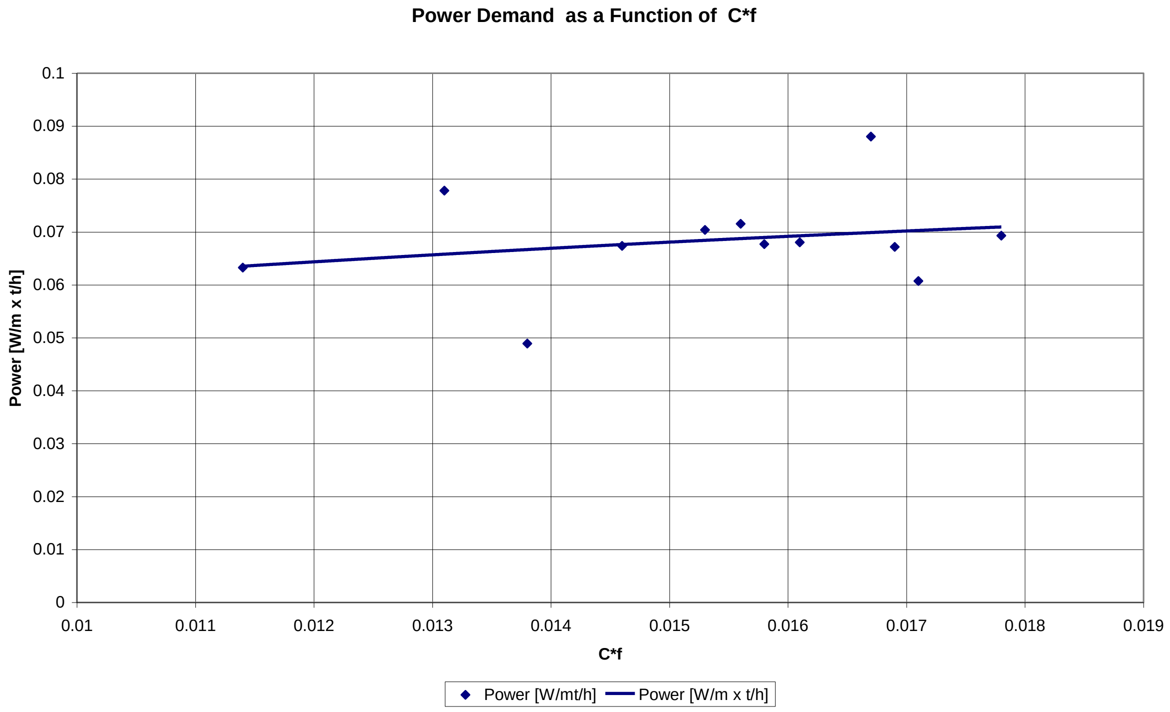

Figure 13. Conveyor unit power demand as a function of C*f (Base Case 1).

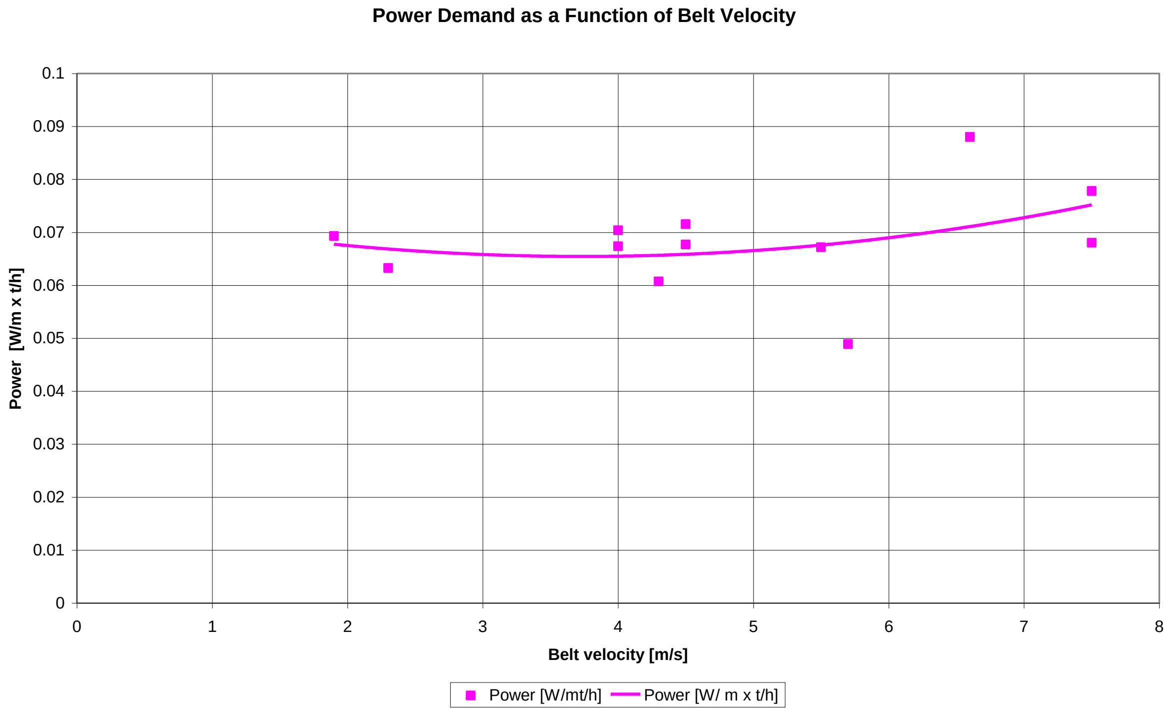

Figure 14. Conveyor unit power demand as a function of belt velocity (Base Case 1).

5. Additional Comments

Due to the nature of this investigation all of the selected conveyors are characterised by a low average gradient (below 1%) and very specific distribution of frictional resistance forces. Together with the increasing gradient contribution of material lift resistance increases to become, at some stage a dominant source of conveyor power demand. Consequently, as shown by Figure 15, influence of the material lift resistance can no longer be ignored. At 5% gradient the material lift resistance constitutes 66% of the total conveyor resistance while the indentation rolling resistance second largest at only 22% and as a result practically limiting available means of increasing conveyor energy efficiency to just one or two most effective like Special LRR or LRR belt covers. Even then the end result may not justify the costs incurred.

At this stage the work has not dealt with at least two parameters which most likely will have influence on conveyor frictional resistance and by implication on power demand.

Firstly, in view of Figure 1, one will have to look at the correlation between overall belt tension level and the above parameters. This in turn may lead to questions of drive positioning and type of tensioning device to be used.

Secondly, in view of some of the results, more work is needed to assess how idler geometry affects frictional resistance of a conveyor.

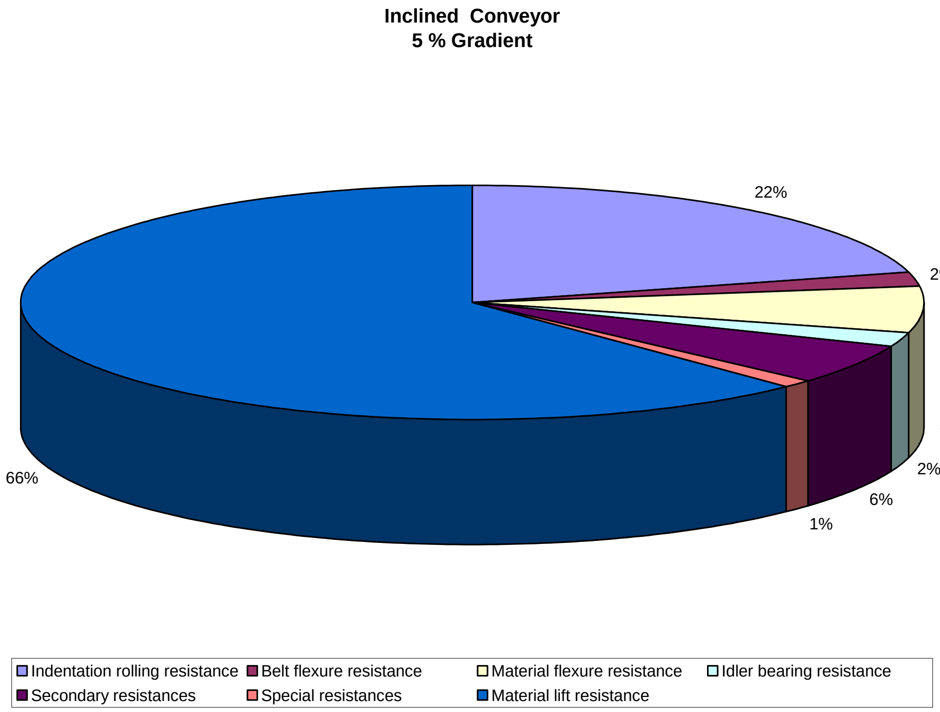

Figure 15 Percentage distribution of the individual motion resistances of an inclined conveyor [4].

5. CONCLUSIONS

By carefully selecting conveyor components and attending in detail to their application a significant reduction of conveyor frictional resistance and consequently energy requirement can be achieved.

The best results have been achieved by application of highly efficient belt bottom cover (Special LRR grade) which produced up to 40% frictional resistance reduction. Specific commercially available LRR grade cover produced reduction of up to 9%. Application of bigger diameter idlers produced much more limited effects.

Idlers with unequal roll length tended to increase frictional resistance of conveyors. However, additional work is required to evaluate in more detail the influence of idler geometry on conveyor frictional resistance.

Load acting on an idler significantly affects frictional resistance of a conveyor. By careful selection of idler spacing one may improve a design from the point of view of resistance levels and energy requirements.

Good results obtained by the use of low resistance idlers points to the value of equipment testing and selection based on the test results.

It is possible to achieve a significant reduction in friction levels by combining several methods which on its own do not seem to offer a lot. This was shown by Case 8 where LRR grade cover was used together with increased roll diameter and low resistance idlers. This combination achieved second best results after Special LRR grade cover.

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Mr. M.Otrebski graduated in 1976 from The Wroclaw University of Technology with a masters degree in mechanical engineering - design and application of bulk materials handling systems and equipment. Since then Mr. Otrebski has worked in the open cast mining environment, has been involved in a detail design of major bulk materials handling machines and conveyors, development of bulk materials systems including export and import terminals as well as turn key project execution.

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