Conveyor Models as Quantitative Platforms for Belt Conveyor Energy Options

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Abstract

Many papers over the years have explored the effect of a wide range of belt conveyor design parameters and components. While taking the tangent of the slope versus effective frictions in the range of 0.020 explains the overwhelming effect of slope on energy and capital costs, the relative importance of these reported developments on flat conveyors and on power consumption is less obvious. Generalizations on the importance of any one source of energy loss, including belt cover indentation, can be shown not to be as universally true so that the value of higher priced equipment and appropriate design attention are confusing decisions unless clear and consistent baselines are available.

The framework and elements of the 'Main Resistance' loss categories used in the 6th edition of Belt Conveyors for Bulk Materials, published by the North American trade group, Conveyor Equipment Manufacturers Association (CEMA), will be discussed for its ability to provide this baseline in combination with commercial conveyor design software. Specific inputs to the commonly accepted loss categories are identified paralleling the range of friction coefficients 'f' recommended in DIN 22101. The intent is to recommend a basis of evaluating improvements in conveyor designs and technology, including refinements to the loss category equations themselves.

1 INTRODUCTION

The purpose of this paper is to describe the prediction of conveyor power, tension, and component specification for various applications and design details for use as a benchmark of design improvement. The author brings a perspective from participating in the development of the power prediction chapter of the 6th edition of Belt Conveyors for Bulk Materials [4] by North America's Conveyors Equipment Manufacturers Association (CEMA) and its use in Overland Conveyor Company's Belt Analyst[TM] software.

Conveyor functional design takes inputs of path, loading and operating temperature with material properties and uses numerous calculations of various interacting elements to quantify the requirements of the various components and controls. Using the language of tension, the net result is increasing force in the belt required for movement due to the combination of various energy consumption sources around the belt line. This tension distribution for various operating conditions and the required capacity of the load support idlers define the requirements for reliable operation. Component and operating costs can then be assessed and various scenarios compared for design optimization. The energy costs are often predicted or compared in terms of net friction for the conveyor system. The basic definition of this net friction is the tension change along the conveyance path divided by the load supported. This calculation can be done for individual locations along the conveyor but is usually a summation along the full conveyor path. DIN 22101 [5] defines the load as the sum of the bulk material, the belt weight and the rotating idler weight while CEMA [4] neglects the rotating weight from this steady state operating parameter. The former definition is more common and will be used herewith. An understanding of the tension

change or energy loss due to the range of energy loss mechanisms also aids in design optimization as it points at design options with high potential for improved performance and cost. This process is of primary interest in this paper.

Conveyor design technology has evolved over the past century from empirical and often proprietary estimates of the accumulated effect of the loss sources. In the 1960's one of these methods was published by CEMA in their first Belt Conveyors for Bulk Materials [2] design guide. This calculation used the results of a set of tests, primarily of woven fabric belts [1], to quantify the internal belt and material losses including the effect of belt tension called Ky summed with the rolling resistance of the idlers, Kx, and the various individual contributions of other components. It became a common design method in North America over the next 40 years. In that time many countries developed their own standards, many of which were patterned after DIN 22101[5] which uses a friction factor assessed from the various characteristics of the design being considered.

In addition, researchers continued their pursuit of understanding the energy loss and power requirements due to various components and the system operating conditions, especially that of belt tension. The works of Behrens [2] and Spaans [9] stand out for the latter. These are briefly discussed here because, with misalignment losses, they offset the paradigm of the dominant role of viscoelastic indentation in heavy duty conveyor friction.

Behrens' tests using a loaded stationary conveyor and a moving set of idlers showed quantitatively the effect of the operating tension on the energy loss. He correlated reduced loss to decreasing belt sag between idlers due to increasing tension as well as idler spacing. Hager and Hintz [6] referenced these results in a compilation of seven loss sources including the almost obvious and often dominant role of conveyor inclination. For the flat case, their pie chart showing 61% of the loss due to idler roll indentation into the belt can be seen frequently in conveyor literature to demonstrate the reason for the respective author's interest in indentation. As discussed herein, this result was the combined effect of many other design details, including those affecting material trampling or loss due to internal movement of the bulk material, a complex and often underappreciated contribution to conveyor energy requirements. Replicating Figure 1 is part of the scope of this paper.
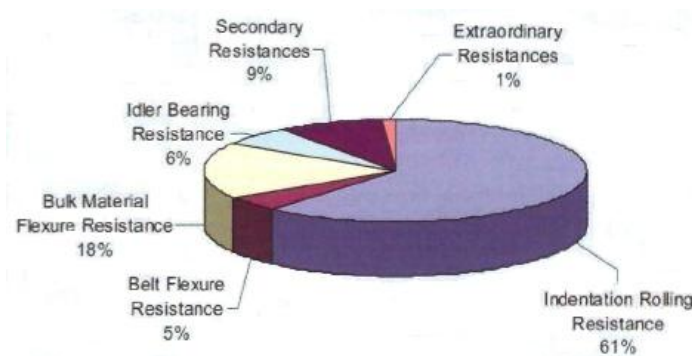

Fig. 1: **Energy loss distribution for a long flat conveyor per Hager and Hintz [xxxxx]   Ref paper by Wheeler [xxxxx]**

Spaans [9] provided a basis for the theoretical prediction of the bulk materials resistance to deformation and energy recovery during motion imposed by sag. This was used in the development for the effect of sag on energy consuption in the 2005 6th edition of CEMA's Belt Conveyors for Bulk Materials [4] and referred to by Wheeler [10]. The updated CEMA method [4] is used in this paper to explore the range of loss distributions for long belt conveyors handling bulk materials operating at steady state.

2   EXPLORING BELT CONVEYOR ENERGY LOSS SOURCES

While long conveyors are frequently have low net lift or decline, the dominant effect of gravity on belt operating tension and motor requirements should be acknowledged.   When long inclined or declined sections are on the belt path, optimization is primarily found on the basis of operating energy since major capital investments are dictated by the tension to resist gravity which does not vary with the system design.

Likewise, decisions relating to resistance due to point sources of resistance such as cleaners, pulleys and loading points have minor effect with long conveyors and made on the basis of their effect on life and maintenance.

With increasing length, the contributions due to distributed friction or main resistances become dominant. These are seen as forces on the idler but result from internal movements. Analysis of a proposed long flat conveyor design results in an overall friction that represents the total loss for that combination of component and system inputs. The analysis method can be accomplished by assigning the overall friction from a qualitative assessment as done per DIN 22101 or by calculating each loss as shown in Fig 1 and summing them as described in CEMA's <u>Belt Conveyors for Bulk Materials</u> [4]. In both cases, the range of possible contributions from various component design and manufacture must be acknowledged and incorporated into the analysis for acceptable accuracy. In the method offered by CEMA, worst case expected performance characteristics are provided for ranges of product specifications. This assures reliable operation in most cases. In the others, such as declined conveyors when low friction might require regenerative control, a range multiplying factor 'R_x' is provided.

In CEMA's method, the conveyor is divided into a set of 'flights' with individual lengths and lifts. The tension exiting one is the tension entering the next, including the return side while pulleys remove, add or set tensions ('takeups') around the belt loop. The loss due to gravity, tension independent losses and tension dependent sources are calculated at the first flight and used for the next flights calculations and son on all around the loop.   Tension independent losses are seen as idler reactions and are due to 1) rolling resistance, 2) sliding resistance to lateral belt forces and 3) belt cover indentation. Tension dependent loss is due primarily due to 4) bulk material motion as the belt sags. In addition, a calculation to limit the possibility of material liftoff or launching at the idler is also provided. Belt viscoelastic loss due to bending is neglected as minor compared to the deeper bed of bulk material. It should be acknowledged that this contradicts Behrens' [2] findings.

The current CEMA loss calculations [4] were derived from a combination of theory, test and numerical analysis. The indentation methods have been published [7], [8] but the effect of sag has not. Spaans' [9] problem of predicting the real belt sag deformation different from the simplified catenary or pretensioned beam solutions, was solved with a large set of FEA models of laterally loaded, pretensioned, trough shaped membranes, similar to those described by Wheeler [10], [11]. These first order results were fit to the classic solution of a pretensioned beam across the belt, which were integrated for the material volume between a pair of idlers per Spaans [9] and normalized to the catenary case of sag loss.   The results for belts with woven fabric carcass were found to match the results of the earlier K_y CEMA methodology [3]. Of significant importance, belts with stiffer steel cable tension members were found to sag much less than belts with woven fabric and therefore have correspondingly less trampling loss.

The sum of individual losses was found to parallel the overall performance for a wide range of conveyor designs, especially when the often neglected but easily measured effect of idler roll alignment (see 2 above) is included. The end result is a set of loss equations and component characteristics whose importance and varies with the application but can be assessed consistently.   Accuracy comes from breaking them down into subcomponents and incorporation of a wide range of

potentially important details. Utility comes from predefined values being available though they can be overridden, without losing the contribution of the other details, when better information is available to the designer or if a single loss category is found to dominate as in the case suggested by Hager and Hintz [xxxxx]. Importantly this approach allows analysis to be automated which makes it practical for comparison or optimization and for evaluating operating conditions such as with varying loading and temperature.

The software package Belt Analyst[TM] by Overland Conveyor Company was used for the results that follow. It uses the formulae discussed above from CEMA's 6th edition of <u>Belt Conveyors for Bulk Materials</u> [4]. The CEMA calculation's quantitative consistency and completeness is particularly useful compared to individual loss theory or test for this purpose. The net friction approach of DIN 22101 does not provide the loss distribution information of interest. The Belt Analyst[TM] software allows a wide variety of flexible control to easily evaluate case studies, just as it does for a wide variety of conveyor layouts and operating conditions in real conveyor design, though most of these features were not used in this study.

3 REPLICATING HISTORICAL RESULTS

In the following, the loss distribution from Hager and Hintz [6] as shown in Fig 1 is analyzed for its implications to the inputs necessary for recreating it. The length of 1 km and slope of 0 degrees with the reference to Behrens' [2] results and, by implication, his test conditions provides a starting point. Fig 2 compares Hager and Hintz [6] with a Belt Analyst[TM] result for a flat, 1 km long, conveyor handling 16,000 mtph of gravel with a 2.2 m wide, 45 degree troughed, 8mm covered ST 2000 belt at 5 m/s and an assumed laboratory temperature of 20 C.
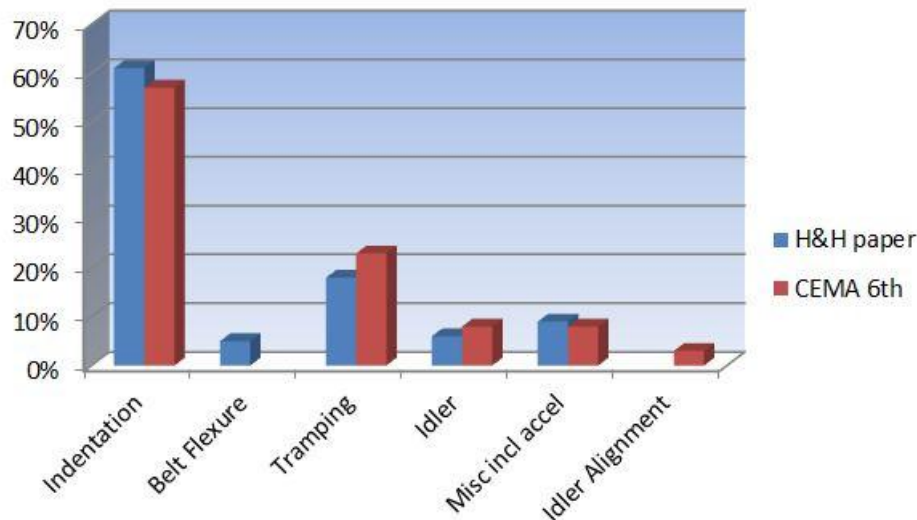

Fig. 2: Correlation of Loss Distribution per Hager and Hintz [6]   and CEMA Belt Conveyors for Bulk Materials 6th Edition [4]

The following adjustments were made in order to obtain this degree of correlation

- The takeup tension was set to 135 kN so that the tension at 500 m along the conveyor would be 300 kN at paralleling Behrens [2].
- CEMA 6th's [4] indentation prediction was used.
- An 'R' range value of 0.6 was applied to the worst case published rolling resistance of a CEMA E idler.   This compares to a recommended 'R' multiplier range of 0.2 to 1.0.
- A efficient loading spoon was assumed to load the material (effectively at 4 m/s)
- Low levels of misalignment of .08 degrees expected for a laboratory setting and similarly for accessories were used.

Fig 2 shows that the CEMA methods can correlate with empirically generated results but demonstrates the need for a wider range of specific inputs for a clear definition of the operating case. In addition, the defined loss cases do not correlate perfectly (refer to the belt bending and misalignment categories) and identify the need for continuing the work of quantifying possible loss sources and continuing to evolve our models in an development environment open to possible loss contributors. It should also be noted that the overall ratio of tension required to the material and belt load, f_{eff}, for the portion defined by Behrens [2] is .035 versus .026 for the attempted reproduction shedding significant doubt on the accuracy of the assumptions made for the components and operating conditions. This case is still interesting from the perspective of a heavily loaded application.

The above model was modified to evaluate the effect of several operating conditions. These include the independent effects of 2 and 3 meter idler spacing, loading with a lighter material, a 50% higher takeup tension and a higher speed as shown in the figures 3 and 4.
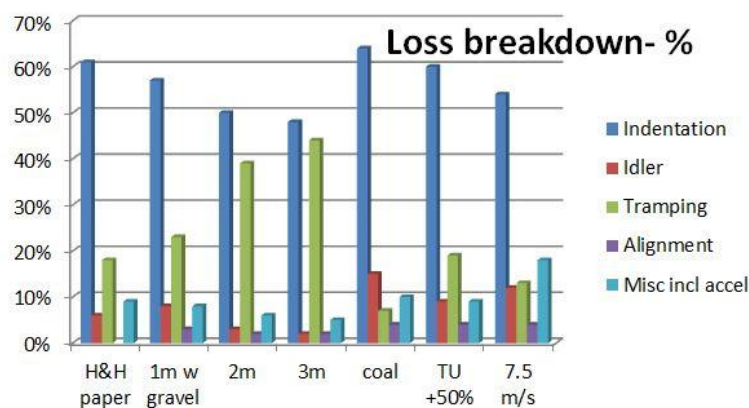

Fig. 3: Effect of a range of operating conditions on loss distribution

Figure 3 shows that cover indentation loss is a relatively consistent contributor to the overall power consumption for this range of conveyor configurations while trampling loss, changed significantly due to changing sag. Fig 4 shows the same results in terms of actual power. A much wider variation in indentation loss can be seen paralleling the total power required for the conveyor.
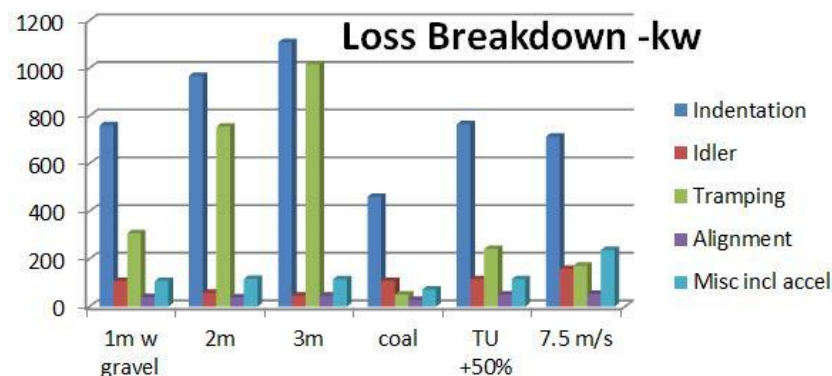

Fig. 4: Effect of a range of operating conditions on power consumption of various loss sources

4 PARAMETRIC STUDY FOR A RANGE OF LONG CONVEYORS

A set of long conveyor configurations with common but more moderate design specifications was considered for their variation in loss source distribution. In comparison to the above exercise, these used narrower belts and allowed for belt strength and takeup tension was adjusted by the Belt Analyst™ software as needed per common sag and slip control criteria.

The details including the idler rotating weight used in calculating f^{DIN} are listed in the Appendix. In brief, the odd 'Ex' number references are 1 m wide belts while the even 'Ex' number references are 1.8 m wide. For reference, Fig 5 shows the friction for the base case of the inputs used in this example or aflat, 1 km long, using steel cable belts on rigid idler in comparison to the higher resistance default (R=1) case. It can be seen that these are relatively well performing conveyors.
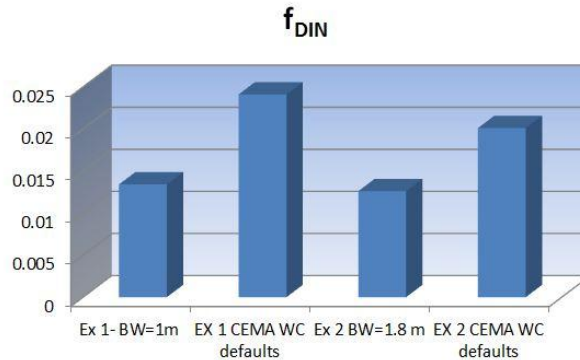

Fig. 5: Effect of a range of operating conditions

With this perspective, the basic configurations were modified for several special cases. These are summarized in Table 1.

Conveyor applications

		Belt Width	Length	Incline	Material	Belt	Temperature
1	Mine Conveyor	1m	1 km	0	Overburden	Steel Carcass	20 C
2	Mine Conveyor	1.8 m	1 km	0	Overburden	Steel Carcass	20 C
3	Underground	1m	1 km	0	Coal	Fabric Carcass	20 C
4	Underground	1.8m	1 km	0	Coal	Fabric Carcass	20 C
5	Low Temperature	1m	1 km	0	Overburden	Steel Carcass	-20 C
6	Low Temperature	1.8m	1 km	0	Overburden	Steel Carcass	-20 C
7	Overland Conveyor	1m	5 km	0	Overburden	Steel Carcass	20 C
8	Overland Conveyor	1.8m	5 km	0	Overburden	Steel Carcass	20 C
9	Special Case	1m	1	-1 deg	Overburden	Steel Carcass	20 C
10	Special Case	1.8m	1.8	-1 deg	Overburden	Steel Carcass	20 C

Table 1: Ex cases compared in the following graphs

Figure 6 provides an overview for the range of power required by each of the loss sources discussed previously.
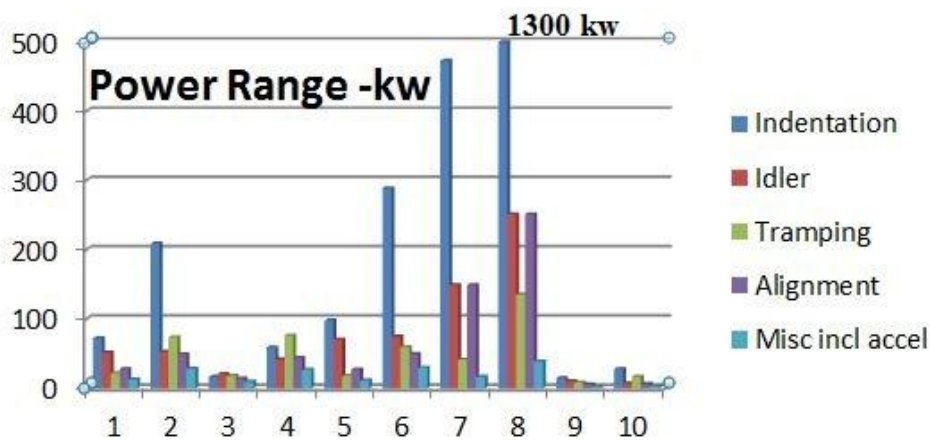

Fig. 6: Effect of the Table 1 range of operating configurations on conveyor power

Again, the loss distribution shown in Figure 7 is more consistent than the actual power per Fig 6 but wider variations in indentation as well as with trampling loss can be seen than in the case discussed in section 3. The latter is shown with more detail in Figure 8.
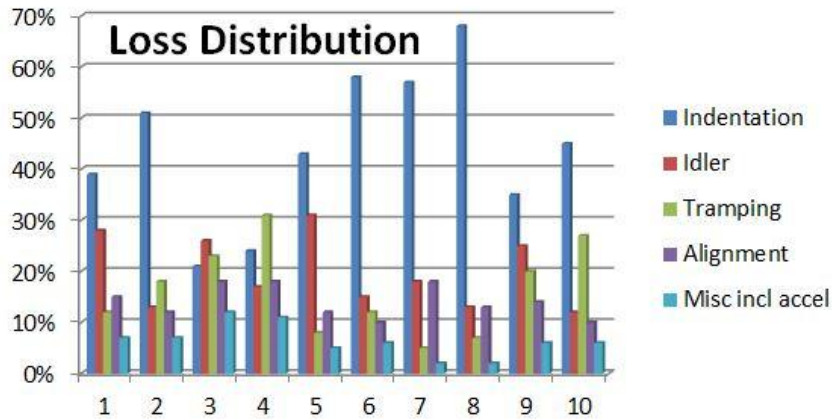

Fig. 7: Effect of the Table 1 range of operating configurations on loss source distribution
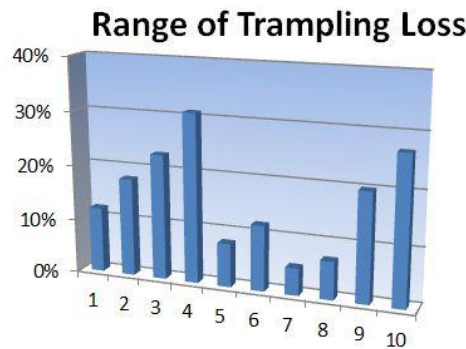

Fig. 8: Range of trampling loss contributions for Table 1's range of operating configurations

Something of the opposite of the distribution in Figure 1 is shown in Figure 9 with indentation loss only comprising 24% of the loss. This is due to the higher sag of fabric belt, a poor loading chute, and worse idler alignment, all more common in underground applications.
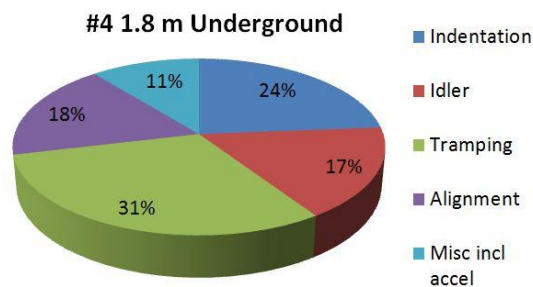

Fig. 9: Distribution of loss contributions for a representative 1.8 m underground coal conveyor

Another example of the role of trampling loss related to sag and idler spacing is provided in Figures 10 and 11.
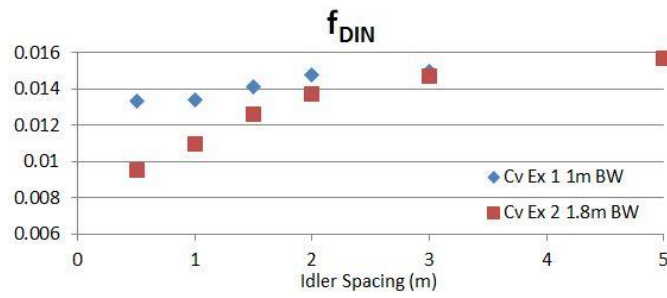
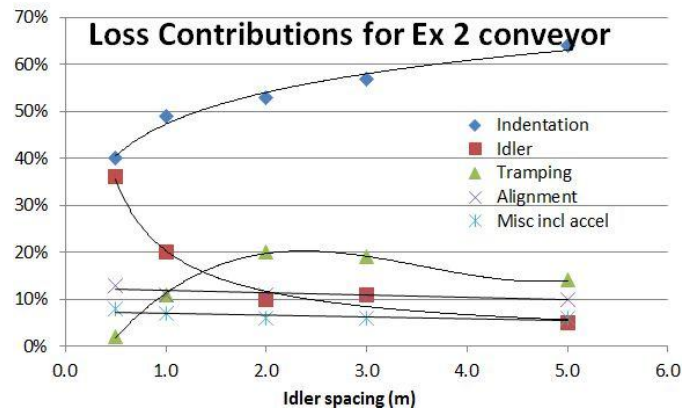**Fig. 10: Overall loss due to idler spacing for Table 1 Cases 1 and 2**

Fig. 11: Loss source distribution due to idler spacing for Table 1 Case 2

These results demonstrate the importance of detail on conclusions regarding energy loss contributions.

5 CONCLUSIONS

The results for a range of specific conveyor configurations demonstrate the utility of fully quantified design methods such as that provided in CEMA's 6th edition of <u>Belt Conveyors for Bulk Materials</u> [4] when used in belt conveyor design software. Developments in conveyor power prediction and specific components or operating criteria are expected to continue and statements of their relevance and importance are useful to establish a context for application by practicing engineers. This paper attempts to demonstrate the importance of defining the overall operating conditions when doing so and providing several options for future reference. In particular, we can make the following observations;

- Importance of energy loss categories varies with application

- Behrens' results with a 2.2m heavily loaded steel cable belt operating at high belt tension on short idler spacing is not representative of many common conveyors

- High indentation loss is common for heavily loaded steel cable belted conveyors

- Optimization requires acknowledging a wide range of possible influences

- Conveyor CAD software with CEMA's quantitative breakdown provides a method of optimization

- Several benchmarks are provided but rely on a specific range of inputs for relevant comparisons. These are documented in the paper.

6 REFERENCES

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7 APPENDIX

Reference Number	1	2	3	4	5	6	7	8	9	10
Conveyor Name	Ex 1	Ex 2	Ex 1 F	Ex 2 F	Ex 1 LT	Ex 2 LT	Ex 1 OL	Ex 2 OL	Ex 1 -1	Ex 2 -1
Conveyor length -km	1	1	1	1	1	1	5	5	1	1
Slope- deg	0	0	0	0	0	0	0	0	-1	-1
Matl	overburde	overburde	coal	coal	overburde	overburde	overburde	overburde	overburde	overburden
Density kg/m^3	1600	1600	880	880	1600	1600	1600	1600	1600	1600
Angle of repose	32	32	29	29	32	32	32	32	32	32
Belt Construction	ST	ST	Woven Fabr	Woven Fabr	ST	ST	ST	ST	ST	ST
BW- m	1	1.8	1	1.8	1	1.8	1	1.8	1	1.8
Loading- mtph	3200	8000	1200	4000	3200	8000	3200	8000	3200	8000
Velocity m/s	5	5	4	4	5	5	5	5	5	5
Temperature C	20	20	20	20	-20	-20	20	20	20	20
Loading speed m/s	1.7	1.7	0.0	0.0	1.7	1.7	1.7	1.7	1.7	1.7
Idler- CEMA Class; with drag x .4	D	E	C	C	D	E	E	E	E	E
Idler spacing m	1	1.5	1.5	2	1	1.5	2	2.5	1	1.5
Idler roll alignment	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Idler frame misalignment mm	4	5	10	10	4	5	4	6	4	6
Idler alignment deg	0.46	0.56	0.90	0.89	0.46	0.56	0.46	0.64	0.46	0.64
Idler diameter	150	178	150	150	150	178	150	178	150	178
Trough angle	35	35	35	35	35	35	35	35	35	35
Catenary sag limit	1%	1%	3%	3%	1%	1%	2%	2%	2%	2%
Belt cover thickness mm	6	8	8	8	6	8	6	8	6	8
Motors	1	1	3	3	1	1	1	1	1	1
Idler rotating mass for use in fDIN kg	22.3	70.1	22.3	54.2	22.3	70.1	22.3	70.1	22.3	70.1