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Optimization of Belt Conveyor System by Increasing Its Energy Efficiency

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***Abstract*- Material handling systems is one of the current interests in both public and private sectors whether the material to be handled is people, mail, solid waste, in-process goods, finished goods, etc. In current age, the energy models of the belt conveyor system when operate away from the design conditions there is a lot more difference in energy calculation. The purpose of this research is to create a optimized energy model of belt conveyor system which will show the results based on the field experiments instead of the design parameters. Finally we get a successful optimal belt conveyor system.**

Index Terms- Design Conditions, Design Parameters, Energy Calculation.

1. INTRODUCTION

Material Handling [MH] involves short distance travel of goods within a building like warehouse or between a building and a transportation agency. It can be used to create time and place utility between the stages of handling, storage and control of material. The material handling systems include conveyors, cranes, industrial trucks, etc. Among this Conveyors are widely used in power generation, mining and process industries. In an operational sense, the conveyor is an element of larger system, including loading and unloading system ,material supply and demand, operating disciplines and human compounds as well.

The goal of this paper is to direct us towards the conveyor theory, its types of classifications, its overview literature, the areas of further study. In this research work, belt conveyers are optimized by giving a design data for more efficient conveyor which is also non-dangerous for the workers operating it, making financial and environmental sense by increasing its operational efficiency through optimization.

2. CONVEYOR CLASSIFICATION

According to different models in market – a] Belt conveyor b] Chain conveyor c] Roller conveyor d] Gravity conveyor e] Screw conveyor f] dust proof conveyor g] Overland Conveyor h] Wire mesh conveyor i] Pneumatic conveyor

The choice of selecting however depends on the volume to be transported, speed of transportation, size and weight of materials to be transported, height or distance over which the material to be transported, nature of material, the process of production employed etc.

A belt conveyor system is an conveyor with endless belt supported by two pulleys that are driver and driven at two fixed positions supported by rollers. Pulleys are used for providing the drive to the belt through a drive unit gear box powered by an electric motor. It also helps in maintaining the proper tension to the belt. A belt conveyor is a typical energy conversion system from electrical energy to mechanical energy. Its energy efficiency can generally be improved at four levels: performance, operation, equipment, and technology.

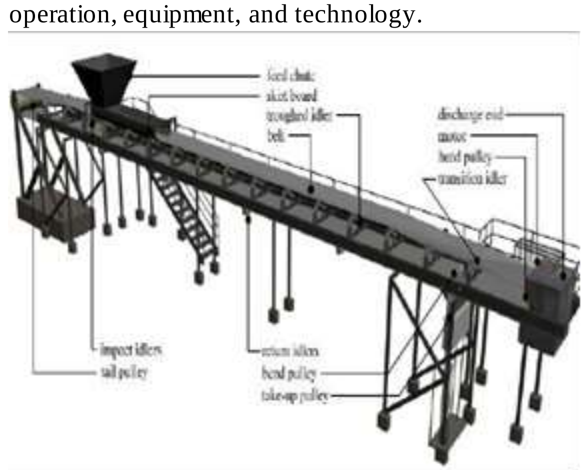


Fig 1.1 Belt Conveyor

Belt conveyors are being employed to form the most important parts of material handling systems because of their high efficiency of transportation. It is significant to reduce the energy consumption or energy cost of material handling sector. We intend to use the methodology of optimization to improve the operation efficiency of belt conveyors. Our approach will be based on an energy model of belt conveyors. There exist several energy calculation models for the drive system design of belt conveyors. These models originate from well-known standards or specifications, such as ISO 5048, DIN 22101, and Conveyor Equipment Manufacturers Association (CEMA). This task accordingly depends on the improvement of the energy efficiency of belt conveyors, for they are the main energy consuming components of material handling systems. They employ either complicated equations or inaccurate constants for the calculation of the energy consumption of belt conveyors. These models are suitable for the design purpose and can hardly be used for optimization calculation. Existing energy models are mostly built under the design conditions. When a belt conveyor operates away from its design condition, Surely, these models will result in large differences of energy calculation. In practice, most belt conveyors are not working under the design conditions and some of them are working far away from their design conditions, for instance, some belt conveyors even operate with empty belts. These dynamic models don't focus on energy optimization.

On the other hand, an energy model suitable for optimization purpose will require that it is possible to estimate its characteristics through field experiments rather than just the design parameters only. So, first of all we will begin with the analysis of existing working models. After it we will propose an analytical working model which will aggregate the parameters in four different coefficients by the the method of parameter identification or with the help of design parameters. Least square and recursive least square are the two different techniques used for parameter estimate. Simultaneously we will use least square and recursive least square method for online and offline estimation of four coefficients of new energy model. After getting the energy model, we introduce optimization to belt conveyors for optimal energy efficiency. Precisely, the optimization will be done at the operational level with two performance indicators, energy cost and energy consumption, employed as the objectives of optimization. In addition, the time-of-use, the feed rate constraint, will be taken into account as well. These problems will be solved with the help of some optimization problems.

Fig 1.2 Inclined Belt Conveyor

Next initiative that can be taken for increasing optimal operational efficiency is by properly designing the design parameters of a belt conveyor system like roller diameter, belt dimension, capacity and speed, belt width, toughing angle, belt power, tensions another important factor in determining the efficient belt capacity is surcharge angle. Steeper the conveyor is kept more is the carrying capacity and lesser the surcharge angle.

The final improvisation that can be made for saving the energy and power consumption is proper choosing of the conveyor system for the required job among from the single drive, single tandem drive and multi-drive conveyor system

3. LITERATURE REVIEW

Shirong Zhang, Xiaohua Xia [1] – Currently the belt conveyors field results are different from design calculations. This research paper tries to reach the optimal energy efficiency by adjusting various parameters such as reduced feed rate, energy consumption, feed rates and working time, energy cost, ramp rate of belt speed, unit mass limit. These innovations are divided in different optimization problems with certain assumptions solved by matlab simulation. In each problems certain parameters as mentioned above are varied to get the most efficient energy consumption or energy cost for same working time [TOU tariff- Time Of Use tariff duties] Aniket Jagtap, Shubham Vaidya, Akash Samrutkar, Rahul G Kamadi and Nikhil Bhende [2] – The method used in this research has the same aim of getting the optimal energy efficiency of conveyor by another method of changing the certain dimensions of the conveyor components like conveyor belt, motor, pulley and idlers, rollers, pneumatic cylinder, etc. The changes in the parameters which needs to be done are mentioned by calculating them with formulas.

Mukalu Sandro Masaki, Lijun Zhang, Xiaohua Xia [3] – There are different types of belt conveyor systems like single drive belt conveyor, single-tandem belt conveyor and the multi-drive conveyor belt drive are compared in terms of the EAC [Equivalent Annual Cost] savings of energy consumed in working. By using the matlab simulation process the graph explains precisely how the multi-drive

$$F_{bA} = \frac{TV}{3.6},$$
$$F_f = \frac{T^2}{6.48\rho b_1^2},$$

conveyor belt system consisting of two motors, two gear boxes ,two drive pulleys and N number of drive units approaches the least equivalent cost. Also if the EAC and water consumption is compared in the multi-drive systems the optimized model MD-3 indicating no of drive units is the most efficient model in both the cases

4. METHODOLOGY

4.1 Energy efficiency optimization

Remarks on existing conveyor models The normal models almost consider all the issues contributing to energy consumption, thus they are believed to be more accurate but leads to complicated equations. On the other hand, the energy conversion based models simplify the calculation because these models one or few constants to compensate all the cases, with a cost of compromised accuracy. Further these models use design parameters to calculate power of belt conveyor. When these are applied to practical condition, large difference of energy calculation will be generated because the practical operation condition deviates from design one.

Model calculations [Analytical]

Force analysis of a belt conveyor is proposed here to meet the requirement of energy optimization

$$F_N = F_{bA} + F_f + F_w + F_t.$$

Ft and Fw are relatively small hence omitted. Fw is treated as Cft constant. If initial speed of conveyor is taken 0 and the frictional factor between the material and the belt is taken as the same the frictional factor between the material and the skirt board then Fba and Ff equations are as followed.

Further putting the following values in the above equation Fn can be rewritten

$$F_N = \frac{TV}{3.6} + \frac{T^2}{6.48\rho b_1^2} + C_{Ft}.$$

The specific resistances Fs of an existing conveyor model is given by

$$F_S = k_1\frac{T^2}{V^2} + k_2\frac{T}{V} + k_3,$$

Where k1, k2, k3 are constants coefficients which relate to the structural parameters of belt conveyor.

Combining the above equations we get the mechanical power of belt conveyer system

$$P_T = \frac{V^2T}{3.6} + \frac{VT^2}{6.48\rho b_1^2} + \left\{gfQ\left[L\cos\delta + L(1-\cos\delta)\left(1-\frac{2Q_B}{Q}\right)\right] + k_3 + C_{Ft}\right\}V + k_1\frac{T^2}{V} + \left(\frac{gL\sin\delta + gfL\cos\delta}{3.6} + k_2\right)T.$$

Further, let

$$\theta_1 = \frac{1}{6.48b_1^2\rho},$$
$$\theta_2 = gfQ\left[L\cos\delta + L(1-\cos\delta)\left(1-\frac{2Q_B}{Q}\right)\right] + k_3 + C_{Ft},$$
$$\theta_3 = k_1,$$
$$\theta_4 = \frac{gL\sin\delta + gfL\cos\delta}{3.6} + k_2,$$

We get the analytical energy model of belt conveyor as follows

$$P_T - \frac{V^2T}{3.6} = \theta_1T^2V + \theta_2V + \theta_3\frac{T^2}{V} + \theta_4T.$$

Where the theta's are considered the four coefficients from the structural parameters i.e design parameters rather than the practical field experiments hence for the experimental results the optimization conditions are applied to the energy model and the last equation is improvised.

4.2 Design Considerations

According to the design of an effective and efficient material handling system which will increase productivity and minimize cost, the guidelines normally followed are:

1. Designing the system for continuous flow of material
2. Going in for standard equipment which ensures low investment and flexibility
3. Incorporating gravity flow in material flow System
4. Ensuring that the ratio of the dead weight to the payload of material handling equipment is minimum

The transportation route affects the overall cost of material handling. An efficient material handling equipment will reduce cost per volume of material transported and ensure that materials are delivered to the production line safely The design of belt conveyor system involves determination of the correct dimension of the belt conveyor components and other critical parameter values so as to ensure optimum efficiency during loading and unloading conditions. Some of the components are: Conveyor belt, motor, pulley and idlers, rollers, pneumatic cylinder, etc.

4.3 Types of Drive Technology

In this technique the cost-effective bulk transport of multi-drive conveyor is which is composed of three intermediate drive units on the carry side and a fourth drive unit on the return side is compared over the single drive unit and single-tandem drive belt conveyor [in this typical layout of single tandem drive belt pulley, two drives are mounted in tandem each driven by a single motor-gearbox assembly.] Ilustrative diagrams of above conveyors are given to understand.

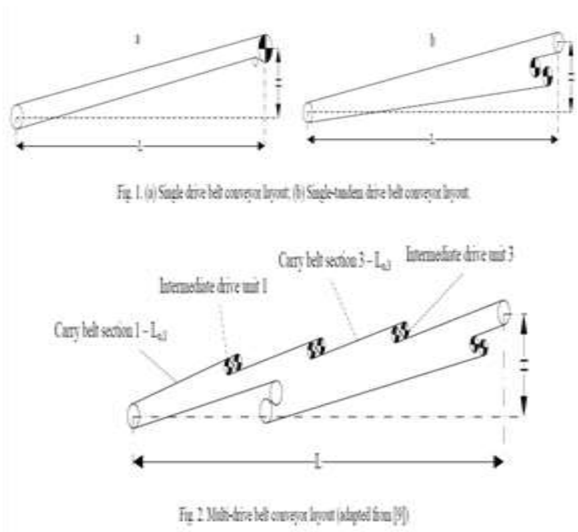


Fig 4.1 Belt Conveyor Technologies

In this we identify the conveyor system for which the lowest operating cost will be ensured over its life span when used. Considering a specific type of belt conveyor, the design with the minimum cost among all three will be chosen.

The equivalent annual cost of belt conveyor is adopted as a common performance indicator because of the popularity of this parameter in assessment of engineering projects. The total cost is classified in two categories operating cost and capital cost. The operating cost includes only energy cost for temporary. And the capital cost is limited to belt, motor, gearbox, and carry and return idler rolls.

[1] Single drive belt conveyor - in this design capital cost is limited upto unique motor, gear box, and drive pulley while design constraints include effective transmission of pulling force, limitation of belt sag, and mechanical endurance of belt and idler rolls.

[2] Single- tandem belt conveyor – In this case, capital cost is included upto two gearboxes, two motors, two drive pulleys. While all the remaining constraints are same as in first

[3] Multi-drive belt conveyor – In it, capital cost consists of N+1 drive units, each with two motors, two gearboxes, and two drive pulleys. While the design constraints includes effective transmission of pulling force to the belt, limitation of belt sag, equalize slight side tensions of all the drive units.

5. CASE STUDY

5.1 Optimization Problems

Basically the energy model which is created after eliminating the complexity of its mechanical power equation incorporated with the efficiency of drive system is as followed.

$$f_P(V,T) = \frac{1}{\eta}\left(\theta_1 V T^2 + \theta_2 V + \theta_3 \frac{T^2}{V} + \theta_4 T + \frac{V^2 T}{3.6}\right),$$

The assumptions taken for solving the further optimization problems each with different constraints on it and the following simulation results of each problem are given below.

1. At any time, silo A has enough material to supply the belt conveyor and stockpile B always has enough capacity to store the material.

2. The time delay associated with the material from silo A to stockpile B is ignored.
3. The dynamic energy consumption associated with start-up and stop of the belt conveyor is not taken into account.

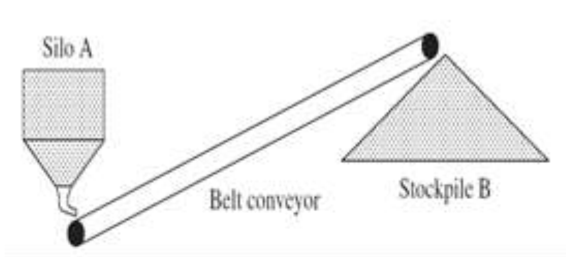


Fig 5.1 Block Diagram of Belt Conveyor

Optimization Problem 1 – Optimization problem 1 is dedicated to the reduced feed rate to minimize the energy consumption. Hence the belt speed and unit mass within their feasible domain are the constraints in it. Hence, optimization problem one is formulated as follows.

$$\begin{aligned} \min \quad & J_P(V) = f_P(V, T_{RED}), \\ \text{subject to} \quad & T = T_{RED}, \\ & 0 \leqslant V \leqslant V_{MAX}, \\ & 0 \leqslant Q_G \leqslant Q_{G\_MAX}. \end{aligned}$$

The optimal solution to this problem is the optimal belt speed V according to the given reduced feed rate Tred. The reduction in power consumption with the reduced feed rate is proved from the simulation result.

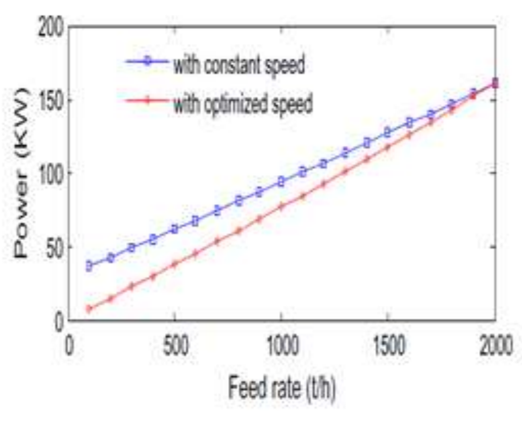


Fig. 7. Energy saving through operation efficiency optimization.

consumption is taken as the objective for minimization. Three variables, belt speed, feed rate, and working time denoted by tw will be optimized to minimize the total energy consumption. The constraints taken in account are belt speed [V], unit mass [Q], total production and working time all within their feasible domain. This problem is formulated as below.

$$\begin{aligned} \min \quad & J_P(V, T, t_w) = f_P(V, T)t_w, \\ \text{subject to} \quad & 0 \leqslant V \leqslant V_{MAX}, \\ & 0 \leqslant Q_G \leqslant Q_{G\_MAX}, \\ & T \cdot t_w \geqslant T_{SUM} \\ & 0 \leqslant t_w \leqslant (t_f - t_0). \end{aligned}$$

The solution to this problem is the optimal operational instruction, which schedules the belt speed, feed rate, and working time of the belt conveyor optimally to minimize the energy consumption.

Optimization Problem 3 - This problem considers the energy cost of belt conveyor subjected to TOU [Time of Use] tariff. Optimization problem 3 shares the first two constraints of problem 2 and third constraint is the total production. Now the problem three is formulated in the following way.

$$\begin{aligned} \min \quad & J_C(V_j, T_j : 1 \leqslant j \leqslant N) = \sum_{j=1}^{N} f_P(V_j, T_j)p_j t_s, \\ \text{subject to} \quad & 0 \leqslant V_j \leqslant V_{MAX}, \\ & 0 \leqslant Q_{G\_j} \leqslant Q_{G\_MAX}, \\ & \sum_{j=1}^{N} T_j t_s \geqslant T_{SUM}. \end{aligned}$$

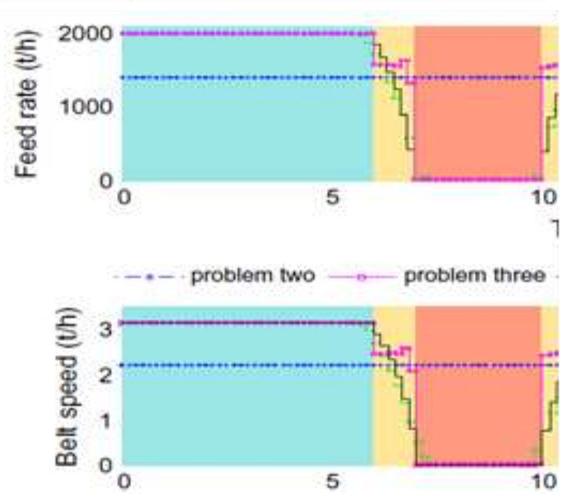


Fig 5.3 Simulation Results

The Operational Efficiency Optimization Of Problem 2 and 3is given by the above simulation results.

5.2 Design Considerations

The effective and efficient material handling system which increases the productivity and minimize the cost take the following in account

A] Dimension, capacity and speed B] Roller diameter C] Belt power and tension D] Idler spacing E] Pulley Diameter F] Motor

5.2.1 Belt dimension, Capacity and Speed

The magnitude of the belt speed can be determined either from the equations given or the catalogue for standard belts. Belt speed depends on loading, discharge and transfer arrangements, maintenance standards, lump size. Belt length is dependent on the pulley diameters and the centre distances. The value of belt capacity is determined from second equation which further determines the lump size.

1] $V = d \times$ 1] $V = d \times \Pi$

Where V= Belt speed

d= diameters of rollers

2] $B.C = 3.6 \times A \times \rho \times V$

Where A=belt sectional area

ρ = material density and

V= belt speed

3] Mass of material is given by the following equation

$$Mm = \frac{c}{3.6 \times V}$$

Where Mm = mass of material

C = Conveyor capacity V = Belt speed

5.2.2 Roller Diameter, Belt Power and Tensions

The roller supports belt and facilitates easy as well as let the belt conveyor rotate freely in all directions. The proper roller diameter can be calculated by the equation no 4. In case of power consumed by the conveyor longer the conveyor length, higher the power required .The power at drive pulley drum is given by equation no 5. The belt tension must be great enough to avoid the slippage between the drive pulley and the belt which is given by equation 6.

4] The length of a belt on roll is given as

$$L = \left(d + \left(\frac{D-d}{2} \right) \times \pi \times N \right)$$

Where D = Outside diameter of roller

d = Inside diameter of roller

N = No of wraps of belt

5] The power Pp at drive pulley is given as

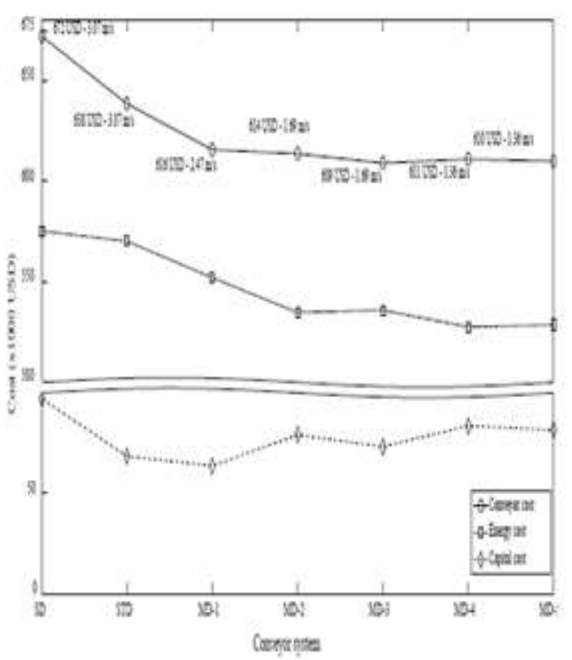
$$P_p = \frac{F_u \times V}{1000}$$

Where Fu = Total tangential force at the periphery of drive pulley

V= Belt speed

5.3 Benefits of Multi-drive Conveyor System

The simulation results in which SD represents single drive unit, STD represents single tandem drive unit and MD represents multi-drive unit displaying EAC [Equivalent annual cost] of conveyor as function of conveyor speed and system configuration. From the practical results like percentage of power consumption, particulate emission and water consumption shown below confirms it that multi-drive conveyor with 3 units i.e MD-3 saves 63,120 USD and 29,475 USD over the single drive and single-tandem drive conveyor



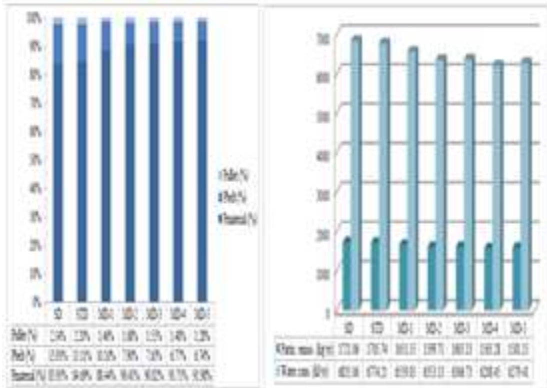


Fig 5.5 Bar Graph Of Conveyor Consumptions

In the figures above, the relative particulate emissions and the specific water consumption due to electricity generation are evaluated at 0.35 kg/MWh. From the research carried on conveyor systems as mentioned it is shown that implementation of MD-3 belt conveyor will reduce the total particulate emissions per year by 117.92 kg [6.85 %] an 102.60 kg [6.02%] with respect to single drive and single tandem drive belt conveyors. Annual savings on water consumption of 468.33 kl and 407.48 kl will also be achieved.

6. APPLICATIONS

The importance of belt conveyor systems is different in distinct industries as per the belt required. The usage of this system is mentioned below as per the type of belt used.

1. Filter belts- Industries may use filter belts to drain excess fluids or to filter out toxins. Water treatment companies often use these conveyor systems during water treatment processes.
2. Woven metal belts- Businesses commonly use woven belts to facilitate drying, cooling, and heating processes in food, electronics, and glass-working industries.
3. Hinged belts- Companies use hinged belts for small product, scrap and recycling applications. Metal hinged belts are durable and can withstand upto rigorous use.
4. Plastic interlocking belts - This types of belts are often used in food handling, packaging processes or in the automotive industry. Mainly these are used in applications that require frequent cleaning and belt replacement .

7. CONCLUSIONS

1. The practical conveyor systems having imperfect results can be optimized with the help of various optimization techniques and tools or performance indicators like energy cost or energy consumption.
2. Using the design values from the proper input data utilized in formulas the belt conveyor system can be designed with high degree of automation, loading, movement, and unloading efficiency.
3. The usage of optimal multi-drive belt conveyor systems can establish the significant cost-savings potential for a specific application along with the environmental benefits.

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