Journal of Harbin Engineering University Vol 45 No. 11
ISSN: 1006-7043 November 2024

Development of Mathematical Model Using Dimensional Analysis and Buckingham π Theorem for Belt Stretch of Medium-Duty Belt Conveyors

Rupali Tupkar[1*], Devesh Kumar[2] and Chandrashekhar Sakhale[3]

[1*]Research Scholar, Mechanical Engineering Department, Poornima University, Jaipur, Rajasthan, India. Pin-303905.

[2]Mechanical Engineering Department, Poornima University, Jaipur, Rajasthan, India. Pin-303905.

[3]Mechanical Engineering Department, Priyadarshini College of Engineering, Nagpur, Maharashtra, India. Pin-440019

Abstract

Belt conveyors transport materials in mining, manufacturing, and logistics. They deliver large products great distances cheaply. Changeable loading during start-up, halt, and operation causes belt strain, affecting performance and reliability. An unmanaged belt stretch can misalign, impair efficiency, and prematurely deteriorate, increasing operational expenses and downtime. This study is important because it covers medium-duty belt conveyor belt stretch under transient dynamics. We used dimensional analysis and the Buckingham π theorem to create a mathematical model to analyze the complicated interplay between belt stretch components. The dimensionless study includes belt tension, material properties, load distribution, and operational circumstances. This research aims to create a credible mathematical model for belt stretch predictions in transitory scenarios and optimize it for commercial use. Experimental and simulation results supported the model's belt stretch forecast. Belt stretch sensitivity to dimensionless groups recommends operational parameter changes to avoid issues. This study affects medium-duty belt conveyor design and maintenance. The optimized model helps engineers anticipate and reduce belt stretch, boosting conveyor reliability and lowering maintenance costs. Theory and practice are combined in this study to improve conveyor system technology and industry sustainability.

Keywords: Dimensional Analysis, Belt Conveyor Dynamics, Buckingham π Theorem Mechanical Properties, Field Data Analysis

1. Introduction

Medium-duty belt conveyors transport bulk materials and goods across large distances in modern industry[1]. These moderate-load conveyors are utilized in manufacturing, mining, agriculture, and logistics. They move grain, coal, aggregates, and packaged goods efficiently, streamlining industrial and supply networks[2]. Medium-duty belt conveyors use motorized pulleys and rollers to maintain a continuous belt loop. The motor powers the conveyor belt, gravity pulls on the material, and friction between the belt and rollers[3]. These forces control belt speed, tension, and load capacity. Transient dynamics—start-up, acceleration, deceleration, and braking—complicate conveyor operations. Dynamic forces stretch and contract the belt throughout these phases[4]. Belt stretch can cause misalignment, slippage, uneven load distribution, and belt and system component damage if not maintained[5].

Although it is vital for the functioning of medium-duty belt conveyors to be able to predict and control belt stretch, there are a number of hurdles that must be overcome as shown in figure 1. Belt stretch is influenced by a wide range of parameters, such as the characteristics of the material, such as its elasticity and tensile strength, the distribution of the load, the tension of the belt, and the design of the system[6]. Because of the dynamic nature of the interactions between these components, particularly during the start-up and braking processes, it is challenging to develop predictive models[7].

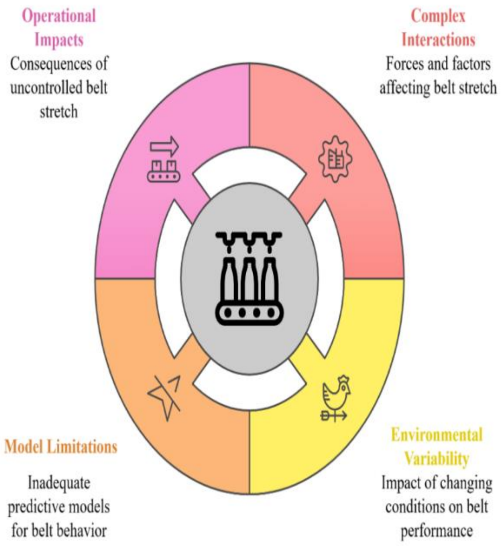


Figure 1. Belt Stretch Prediction and Conveyor Performance Challenges

Conveyor systems also work in environments where temperature, humidity, and load types are subject to change[8–10]. This not only influences the behavior of the belts but also increases the amount of stretch that occurs during dynamic conditions[11]. Conveyor dynamics models that are currently in use frequently use superficial assumptions that fail to adequately characterize the belt's transient and non-linear behavior under real-world settings[12]. Consequently, these models provide erroneous projections and poor performance. Uncontrolled belt stretch can reduce energy efficiency, raise maintenance costs, and shorten equipment lifespans[13]. Belt stretch can also affect conveyor safety, especially in high-stress industrial applications. More thorough modeling and control systems are needed[14].When managing belt stretch complexity in medium-duty conveyors, mathematical modeling works well. Formulating equations that explain system behavior in various contexts allows prediction and mitigation of transient dynamics[15]. For belt stretch parameters and their correlations, dimensional analysis is a systematic methodology[16]. The Buckingham π theorem is a crucial tool in dimensional analysis, simplifying complex systems by reducing them to dimensionless groups[17]. These groups, which represent the system's most critical properties, allow engineers to generalize their findings across many scales and configurations, which is a major benefit[18]. This work uses dimensional analysis to belt stretch to create a conveyor system model that accurately represents its underlying dynamics[19]. Both material properties and conveyor system operation will be considered during model creation[20–22]. Dimensional analysis also simplifies conveyor optimization by detecting belt stretch-affecting features. This defines important factors[23]. Since this information is available, specific changes to the system's design and operational settings can improve its dependability and efficiency[24].Dimensional analysis, especially the Buckingham π theorem, offers a valid framework for belt conveyor dynamics and stretch. To simplify complex physical systems, the Buckingham π theorem reduces variables to dimensionless groups that show their behavior. This method can explain crucial parameter interactions and generalize system configuration models.Buckingham π theorem covers belt stretch factors, including tension, elasticity, load distribution, and environmental conditions. Deriving dimensionless groups from the theorem allows systematic study of these elements' transitory behavior. This method uses empirical observations and theoretical modeling to make more accurate and useful predictions.

Due to its importance in material handling across industries, belt conveyor dynamics research continues[25]. Stable-state operations, belt tension, power requirements, and load distribution were early research topics. Transient dynamics' impact on belt performance during start-up, acceleration, deceleration, and braking become apparent over time. Studying belt elasticity, material properties, and load changes on conveyor performance has helped explain belt stretch and its operational implications[26].Several research have addressed belt stretch analysis and operating aspects such belt tension, speed, and load distribution. Dynamic forces produce belt elongation, misalignment, slippage, and wear, according to empirical and computer models. These investigations exposed conveyor belt behavior, but oversimplifying real-world circumstances impeded them.

Even with progress, conveyor dynamics research has several holes. Current models rarely predict belt stretch under transitory situations, especially when many variables interact non-linearly. Little is known about how environment and material affect belt behavior[27]. Generalized models that work across conveyor configurations without recalibration are needed.Using dimensional analysis and the Buckingham π theorem, this paper develops a comprehensive belt stretch mathematical model to address these limitations. Important conveyor dynamics features, transient behaviors, and a scalable framework for real-world applications are included in the research. This study combines theory and practice to improve medium-duty belt conveyor reliability and efficiency.

In order to precisely predict the stretch of medium-duty conveyor belts during transient dynamics, the objective of this research is to develop and perfect a mathematical model by means of optimization. This method helps engineers build and operate conveyor systems by bridging theoretical and practical knowledge. This research can improve conveyor efficiency by properly forecasting and limiting belt stretch, enhancing energy efficiency and dependability. Model insights can also reduce conveyor component wear and tear, saving money on maintenance and extending equipment life. This study optimizes conveyor performance to reduce industrial energy and material waste. This study introduces dimensional analysis and the Buckingham π theorem to improve conveyor dynamics and handle belt stretch difficulties. This research provides business solutions and deepens scientific understanding of transient dynamics in material handling systems. This research also lays the framework for the progress of conveyor system design.

2. Methodology

2.1 Field Data based Experimentation

The movement of coal from one processing area to another in coal handling plants is accomplished via belt conveyors [28]. For the purpose of loading coal onto the conveyor, automated coal hoppers or conveyor belt loaders are utilized [29]. The coal is moved further along the conveyor system, which is driven by motorized pulleys, after it has been loaded. The conveyor belt is supported and guided by idler rollers, which prevents the belt from drooping [30]. Using belt cleaners helps to maintain efficiency and prevent clogs by removing excess coal and debris from the surface of the belt [31]. A conveyor control system is responsible for regulating the speed of the belt. It was the purpose of the tour to the Khaperkheda thermal power station to locate belt conveyors that had different geometrical proportions but had the same capacity for carrying weight. In addition, to collect information on the belt conveyor, such as the head pulley, the snub pulley, the carrying idlers, the returning idlers, the length of the belt, the width of the belt, the belt take up load, the inclination, the size of the apron, the belt material, the density, the motor speed, the gear box speed ratio, the coupling. A selection of the belt conveyor characteristics of the 210 Mw coal handling plant are displayed there in Figure 2.

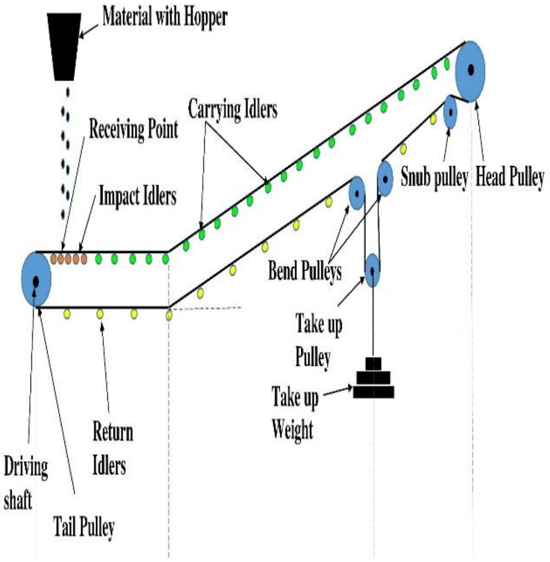


Figure 2. Specifications of belt conveyor

2.1. Dimensional Analysis

The first thing that needs to be done in this investigation is to determine the controlling parameters that have an effect on belt stretch in medium-duty belt conveyor machinery. The phenomenon of belt stretch is a consequence of the dynamic interactions that take place between physical and operational elements during transitory phases such as starting up and stopping. The following are the primary input parameter considerations:Width of Belt, Length of Belt, Weight of belt, Thickness of belt, Density of belt, Power required to drive the pulley, Velocity of belt, Angular velocity of belt, Tonnage capacity of belt, Acceleration due to gravity, Total Resistance of belt, Lift of conveying material, Ration of No of carrying idlers to return idlers, Spacing between return idlers, Total Moment of Inertia of belt Conveyor System Referred to Motor, Angle of Inclination of belt (Before bend pulley), Angle of Inclination of belt (After bend pulley), Spacing between carrying idlers, Take up weight of take up pulley, Belt angular wrap to pulley, Belt tension on tight side, Belt tension on slack side and Time. The output parameter considered for the study is Belt Stretch.

Dimensional analysis simplifies belt stretch interactions into dimensionless groupings. To do this, use the determined parameters[32]. To do this, the Buckingham π theorem is used. According to this theorem, a physical system with n variables and m fundamental dimensions (mass, length, and time) can be reduced to n−m independent dimensionless groups[33]. In belt stretch, mass (M), length (L), and time (T) are important.First, find the dimensional formula for each parameter[34]. Certain dimensional formulas create independent dimensionless groups that can represent the system[35]. After that, each group is studied to see how it represents forces, material characteristics, and operational dynamics that affect belt stretch parameters[36].This dimensional reduction simplifies the problem and provides a generic foundation for belt stretch analysis in various contexts. Because it clearly represents system behavior, it simplifies modeling and allows practical use across a variety of conveyor designs.All of the variables that are used in this investigation are presented in Table 1.

Table 1.Various variable considered in current studyand their dimensions

Symbol	*Description of variable*	*Dimensions*	*Variable type*
S	Belt Stretch (m)	$M^0L^1T^0\ \theta^0$	Dependent
b	Width of Belt(m)	$M^0L^1T^0\ \theta^0$	Independent
C_p	Spacing between carrying idlers(m)	$M^1L^1T^0\ \theta^0$	
C_I	Spacing between return idlers(m)	$M^1L^1T^0\ \theta^0$	
g	Acceleration due to gravity (m/s$^{2)}$	$M^0L^1T^{-2}\ \theta^0$	
H	Lift of conveying material (m)	$M^0L^1T^0\ \theta^0$	
I'_{EQ}	Total Moment of Inertia of belt Conveyor System Referred to Motor (Kg-m$^{2)}$	$M^1L^2T^0\ \theta^0$	
L_b	Length of Belt(m)	$M^0L^1T^0\ \theta^0$	
N	Ration of No of carrying idlers to return idlers	$M^0L^0T^0\ \theta^0$	
P	Power required to drive the pulley	$M^1L^2T^{-3}\ \theta^0$	
Q	Tonnage capacity of belt (Kg/s)	$M^1L^0T^{-1}\ \theta^0$	
R_E	Total Resistance of belt(N)	$M^1L^1T^{-2}\ \theta^0$	
T	Time (sec)	$M^0L^0T^1\ \theta^0$	

t	Thickness of belt(m)	$M^0L^1T^0\ \theta^0$	
v	Velocity of belt (m/s)	$M^0L^1T^{-1}\ \theta^0$	
W_b	Weight of belt(N)	$M^1L^1T^{-2}\ \theta^0$	
W_{tp}	Take up weight of take up pulley(N)	$M^1L^1T^{-2}\ \theta^0$	
ω	Angular velocity of belt (rad/s)	$M^0L^0T^{-1}\ \theta^0$	
ρ	Density of belt (Kg/m$^{3)}$	$M^1L^{-3}T^0\ \theta^0$	
θ	Belt angular wrap to pulley (rad)	$M^0L^0T^0\ \theta^0$	
α_1	Angle of Inclination of belt (Before bend pulley)(rad)	$M^0L^0T^0\ \theta^0$	
α_2	Angle of Inclination of belt (After bend pulley)(rad)	$M^0L^0T^0\ \theta^0$	

2.2. Development of the Mathematical Model

The next phase is a dimensionless group mathematical model from dimensional analysis[37]. This model has assumptions and boundary limitations to ensure relevance and applicability[38]. Assuming the belt material is elastic within its operating limits allows predicted tension deformation. Unless otherwise stated, weight dynamics are simplified by assuming uniform belt load distribution[39]. To analyze transient dynamic behavior, environmental conditions like temperature, which impact belt material properties, are constant during short time periods. Using linear frictional forces at the rollers and belt tension, operation resistance forces can be easily modeled. Belt stretch transient dynamics mathematical equations are designed around these assumptions to balance model soundness and computing feasibility[40]. The belt stretch of a coal conveying using belt conveyor can be expressed as follows:

$S = f\,(L_b, b, t, W_b, E, P, v, \omega, Q, g, R_E, H, I'_{EQ}, N, C_1, C_2, \alpha_1, \alpha_2, W_{tp}, T_1, T_2, \theta, t)$ (1)

In order to generate Pi Terms, each and every remaining parameter is utilized. A list of the Pi Terms for independent parameters is presented in Table 2.

Table 2.Independent parameters (Pi Terms)

S.N	Description of Variables	Group of terms
1	Geometric variables of belt	$\pi_4 = \left(\frac{(b)^{\frac{7}{2}}(g)^{\frac{3}{2}}\rho}{P}\right)$; $\pi_3 = \left(\frac{W_b\sqrt{b\times g}}{P}\right)$;$\pi_2 = \left(\frac{t}{b}\right)$;$\pi_1 = \left(\frac{L_b}{b}\right)$
2	Power rating and speed	$\pi_7 = \left(\frac{b.g.Q}{P}\right)$; $\pi_6 = \left(\sqrt{\frac{b}{g}}\omega\right)$;$\pi_5 = \left(\frac{v}{\sqrt{b\times g}}\right)$
3	Lift	$\pi_9 = \left(\frac{H}{b}\right)$
4	Resistance of belt	$\pi_8 = \left(\frac{R_E\sqrt{b\times g}}{P}\right)$
5	Idlers Geometric variables	$\pi_{13} = \left(\frac{C_I}{b}\right)$; $\pi_{12} = \left(\frac{C_p}{b}\right)$;$\pi_{11} = (N)$;$\pi_{10} = \left(\frac{g^{\frac{3}{2}}I'_{EQ}}{b^{\frac{3}{2}}.P}\right)$
6	Pulleyvariables	$\pi_{17} = (\theta)$; $\pi_{16} = \left(\frac{W_{to}\sqrt{b\times g}}{P}\right)$;$\pi_{15} = (\alpha_2)$;$\pi_{14} = (\alpha_1)$
7	Belt Tensionvariables	$\pi_{19} = \left(\frac{T_2\sqrt{b\times g}}{P}\right)$; $\pi_{18} = \left(\frac{T_1\sqrt{b\times g}}{P}\right)$
8	Elongation timevariables	$\pi_{20} = \left(\sqrt{\frac{g}{b}}t\right)$
9	Belt Stretch (S) (Dependent or Response Variable)	$\pi_{01} = \left(\frac{S}{b}\right)$

2.3Independent VariablesReduction

Many simple methods can simplify an operational plan test without compromising control or generality[41]. Most popular and spectacular is dimensional analysis[42]. Dimensional analysis stacked experimental variables. Fluid mechanics and thermal engineering benefited from this device. Most noteworthy experiments in these places were coordinated with its help[43].This idea improves modern experiment efficiency and length. This mathematical state is scientifically defined by the focussed model. Applying Buckingham's π theorem yields this result [44]. The theorem states that the number of π terms in a system with n independent variables is (n-4) times the primary dimensions (L, M, T). The π terms yield a dimensionless number showing a π term.

The Dependent Variable and the Independent Variable in Their Final Relationships for
Belt Stretch (S)

$$(\pi_{01}) = f\{(\pi_1) \text{ to } (\pi_8)\} \quad (2)$$

$$\left[\frac{S}{b}\right] = f1\left\{\left[\frac{v.\omega.b.Q}{P}\right]\left[\frac{L_b.t.W_b.b.g.\rho}{P^2}\right]\left[\frac{H}{b}\right]\left[\frac{R_E\sqrt{b\times g}}{P}\right]\left[\left(\frac{W_{to}\sqrt{b\times g}}{P}\right)(\alpha_1)(\alpha_2)(\theta)\right]\left[\left(\frac{T_1.T_2.b.g}{P^2}\right)\right]\left[\sqrt{\frac{g}{b}}\,t\right]\left[\left(\frac{g^{\frac{3}{2}}I'_{EQ}}{b^{\frac{7}{2}}.P}\right)(N)(C_p)(C_I)\right]\right\} \quad (3)$$

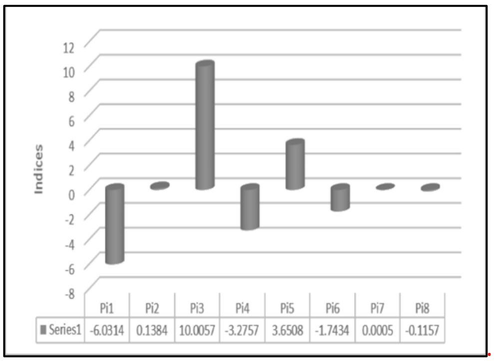
By substituting values of individual variables in independent and dependent π term and using Rayleigh's method, we get following correlation.

$$\boldsymbol{\pi_{01}} = \left[\frac{S}{b}\right] = \mathbf{1680737925.708} \times \left\{\begin{array}{c} \left[\frac{v.\omega.b.Q}{P}\right]^{0.1384}\left[\frac{L_b.t.W_b.b.g.\rho}{P^2}\right]^{-6.0314}\left[\frac{R_E\sqrt{b\times g}}{P}\right]^{10.0057} \\ \left[\left(\frac{g^{\frac{3}{2}}I'_{EQ}}{b^{\frac{7}{2}}.P}\right)(N)(C_p)(C_I)\right]^{3.6508}\left[\frac{H}{b}\right]^{-3.2757} \\ \left[\left(\frac{W_{to}\sqrt{b\times g}}{P}\right)(\alpha_1)(\alpha_2)(\theta)\right]^{-1.7434}\left[\sqrt{\frac{g}{b}}\,t\right]^{-0.1157}\left[\left(\frac{T_1.T_2.b.g}{P^2}\right)\right]^{0.0005} \end{array}\right\} \quad (4)$$

3. Result and Discussion

3.1 Analysis from indices of the models of multiple regression model

The key results that are shown below appear to be supported by the model equation and figure 3 that were presented earlier.



	Pi1	Pi2	Pi3	Pi4	Pi5	Pi6	Pi7	Pi8
■ Series1	-6.0314	0.1384	10.0057	-3.2757	3.6508	-1.7434	0.0005	-0.1157

Figure 3: Dependent Pi term- π_{01}ModelIndices

Among the terms in Π 01, the term π 7 holds the lowest position, as its absolute index is 0.0005. This indicates that it is the least densely packed term. Out of all the variables that are associated with belt tension, the variable π 7 has the least influence on the model being considered. On the other hand, the absolute index of π3, which is linked to geometric variables and belt resistance, is the most significant, with a measurement of 10.0057. Based on this, it can be concluded that the most significant impact is observed within the range of Π 01. Furthermore, the fact that the belt stretch value is positive demonstrates that geometric variables have a significant influence on the belt resistance that occurs during coal handling operations in belt conveyors. This is demonstrated by the fact that the belt stretch value is positive. In addition to being positive and greater than 1, the constant value of 1,680,737,926 is also greater than 1, which intensifies the effect that is created by the product of the model terms. This is because the constant value is greater than 1. In the meantime, the negative indices of π 1, π 4, π 6, and π 8 (where π 1 is equal to −6.0314, π 4 is equal to 2.750, π 6 is equal to 1.7434, π 6 is equal to 1.7434, and π 8 is equal to -0.1157 π 8 8 = −0.1157) are associated with the lifting capability of the material conveying system, the geometry of the pulley, and the passage of time. The presence of these negative signals, which bring to light regions that demand extra development and optimization opportunities, acts as a representation of an inverse variation.

3.3 Model Optimization

For the objective of the investigation, mathematical models have been built using several mathematical techniques. Not only is the development of the models one of the most important objectives of this activity, but also the determination of the best possible collection of independent variables that will lead to the maximizing or reduction of the target function is also one of the most important aims. Within the context of this particular case, there is a single distinct model that is connected to the belt stretch (S). Since this is the case, these models are related with a single objective function that may be found in the literature. It is recommended that the aim of the belt stretch for the belt conveyor, which is required for the coal handling activity, be decreased to the greatest extent practicable. For the purpose of making optimization more manageable, it is important to convert the models from their nonlinear structure into a linear form for the purpose of optimization. In order to achieve this goal, it is possible to make use of the logarithm of both components of the model. Specifically, the linear programming method, which will be explored in further detail in the following paragraphs, is applied in this implementation.

The solution to the equation can be obtained by taking the logarithm of both sides of the equation.

$$\mathrm{Log}(S)=\log(1680737925.708)+\log(b)-6.0314.\log.\left[\frac{L_b.t.W_b.b.g.\rho}{P^2}\right]+0.1384.\log\left[\frac{v.\omega.b.Q}{P}\right]+10.0057.\log\left[\frac{R_E\sqrt{b\times g}}{P}\right]-3.2757.\log\left[\frac{H}{b}\right]+3.6508.\log\left[\left(\frac{g^{\frac{3}{2}}I'_{EQ}}{b^{\frac{7}{2}}.P}\right)(N)(C_p)(C_I)\right]-1.7434.\log\left[\left(\frac{W_{to}\sqrt{b\times g}}{P}\right)(\alpha_1)(\alpha_2)(\theta)\right]+0.0005.\log\left[\left(\frac{T_1.T_2.b.g}{P^2}\right)\right]-0.1157.\log\left[\sqrt{\frac{g}{b}}t\right] \quad (5)$$

Z (Belt Stretch:Π₀₁ min) = $Z=9.42962-0.1157.\log(\pi_8)+0.0005.\log(\pi_7)-1.7434.\log(\pi_6)+3.6508.\log(\pi_5)-3.2757.\log(\pi_4)+10.0057.\log(\pi_3)+0.1384.\log(\pi_2)-6.0314.\log(\pi_1)$ (6)

Equation above is subjected to following constraints:

$X_1 \geq 7.30;\ X_1 \leq 10.72;\quad X_2 \geq 3.19;\ X_2 \leq 5.22; X_3 \geq 2.84;\ X_3 \leq 4.49;$

$X_4 \geq 0.57;\ X_4 \leq 1.27;\quad X_5 \geq 3.21;\ X_5 \leq 5.95; X_6 \geq 2.86;\ X_6 \leq 4.48$

$X_7 \geq 5.20;\ X_7 \leq 9.34; X_8 \geq 0.50; X_8 \leq 1.95$

The following numbers are acquired by using the Microsoft Solver to solve the problem that was discussed earlier: X1, to X8, and Z. As a result, the value of Π01min is equal to the antilog of Z, and the values of the independent pi terms are obtained from the antilog of X1, to X8, and Z, which correspond to this value of Π01max. The optimal values of the response variables for belt stretch are presented in Table 3.

Table 3: Optimize response variable values belt stretch

	S (Belt Stretch): Π_{01} min	
	Antilog of π terms	Log values of π terms
X_8	90.01519	1.954316
X_7	159945.1	5.203971
X_6	30768.25	4.488103
X_5	1641.872	3.215339
X_4	18.75	1.273001
X_3	706.6967	2.849233
X_2	1583.658	3.199661
X_1	5.35E+10	10.72866
Z	1.56E-27	-26.8073

4. Conclusions

During this test, the belt stretch of a PVC-based belt conveyor at a thermal power station that is used for coal handling ranges from 0.13 meters to 5.7 meters. During this field evaluation, test points and envelopes were established, and then the mathematical model for belt stretch on the belt conveyor was defined. Due to the fact that the experimental and mathematical models produce different dependent pi terms, it can be inferred that mathematical models have the ability to generate dependent pi terms for a specific arrangement of independent pi terms based on the percentage of error estimations it produces.

The data for this study came from experiments conducted in the field. All things considered, the outcomes of the current study accurately reflect the interplay of independent variables. The procedures that were utilized in this field-based investigation made it possible for this to occur. There are extremely few standard errors associated with the predictions and estimates of the dependant factor. Validation has been performed on the mathematical model, the log linear model, and the root mean square.

References

[1] Tupkar R, Kumar D, Sakhale C. Material selection and parametric evaluation for medium duty belt conveyor: A review on current status and future directions. Mater Today Proc 2024. https://doi.org/10.1016/j.matpr.2024.04.021.

[2] Schulz G, Schneider F. Further investigations on belt dynamics in horizontal curves of belt conveyors. Bulk Solids Handl 1996;16:183–6.

[3] Gerdemeli I, Kurt S, Dayan ET. Belt Conveyor Design and Analysis. Sci Proc Xi Int Congr "Machines, Technologies, Mater 2014;1:49–52.

[4] Santos LS, Macêdo EN, Ribeiro Filho PRCF, Cunha APA, Cheung N. Belt Rotation in Pipe Conveyors: Failure Mode Analysis and Overlap Stability Assessment. Sustainability 2023;15. https://doi.org/10.3390/su151411312.

[5] Zrnić N, Đorđević M, Gašić V. Historical Background and Evolution of Belt Conveyors. Found Sci 2024;29:225–55. https://doi.org/10.1007/s10699-022-09894-6.

[6] Luo J, Huang W, Zhang S. Energy cost optimal operation of belt conveyors using model predictive control methodology. J Clean Prod 2015;105:196–205.

[7] He D, Liu X, Zhong B. Sustainable belt conveyor operation by active speed control. Measurement 2020;154:107458. https://doi.org/https://doi.org/10.1016/j.measurement.2019.107458.

[8] Soudagar MEM, Ramesh S, Khan TMY, Almakayeel N, Ramesh R, Ghazali NNN, et al. An overview of the existing and future state of the art advancement of hybrid energy systems based on PV-solar and wind. Int J Low-Carbon Technol 2024;19:207–16. https://doi.org/10.1093/ijlct/ctad123.

[9] Gupta A, Kumar R, Maurya A, Ahmadi MH, Ongar B, Yegzekova A, et al. A comparative study of the impact on combustion and emission characteristics of nanoparticle-based fuel additives in the internal combustion engine. Energy Sci Eng 2023. https://doi.org/10.1002/ese3.1614.

[10] Kumar R, Lalnundiki V, Shelare SD, Abhishek GJ, Sharma S, Sharma D, et al. An investigation of the environmental implications of bioplastics: Recent advancements on the development of environmentally friendly bioplastics solutions. Environ Res 2024;244:117707. https://doi.org/10.1016/j.envres.2023.117707.

[11] Belkhode P, Giripunje M, Dhande M, Gajbhiye T, Waghmare S, Tupkar R, et al. Nanomaterials applications in solar energy: Exploring future prospects and challenges. Mater Today Proc 2024. https://doi.org/10.1016/j.matpr.2024.04.035.

[12] Ganvir V, Belkhode P, Kurve A, Shelare S, Maheshwary P, Sharma S, et al. Green energy using oscillatory baffled reactors: advances in biodiesel production from high free fatty acid karanja oil. Int J Chem React Eng 2024;22:1107–22. https://doi.org/10.1515/ijcre-2024-0051.

[13] Chandrakant Nikam K, Jathar L, Shelare SD, Shahapurkar K, Dambhare S, Soudagar MEM, et al. Parametric analysis and optimization of 660 MW supercritical power plant. Energy 2023;280:128165. https://doi.org/10.1016/j.energy.2023.128165.

[14] Ghatole S, Kadam A, Tupkar R, Ramteke P. An Effluent Treatment Plant's Procedure Improved by Employing the Kaizen Approach. MATEC Web Conf 2024;405:01004. https://doi.org/10.1051/matecconf/202440501004.

[15] Belkhode PN, Afsar A, Shelare S, Borkar K, Washimkar P. Investigation of two stroke engine to improve the brake power and thermal efficiency through the mathematical modeling approach. AIP Conf Proc 2023;2800:20152.

https://doi.org/10.1063/5.0163007.

[16] Waghmare SN, Shelare SD, Mungle NP, Aglawe KR. Development of IOT-Based Hybrid Helium Drone for Flight Time Enhancement. In: Vasudevan H, Kottur VKN, Raina AA, editors. Proc. Int. Conf. Intell. Manuf. Autom. Lect. Notes Mech. Eng., Singapore: Springer Nature Singapore; 2023, p. 329–39. https://doi.org/10.1007/978-981-19-7971-2_32.

[17] Belkhode P, Modak JP, Vidyasagar V, Shelare S. Procedure of Collecting Field Data: Causes, Extraneous Variables, and Effects. Math. Model. Simul., Boca Raton: CRC Press; 2021, p. 33–47. https://doi.org/10.1201/9781003132127-5.

[18] Shelare SD, Waghmare SN, Yenurkar MM, Jodh GR. Experimental Analysis of Sprayer for Horticulture and Orchards. In: Vasudevan H, Kottur VKN, Raina AA, editors. Proc. Int. Conf. Intell. Manuf. Autom. Lect. Notes Mech. Eng. Springer, Singapore: Springer Nature Singapore; 2023, p. 651–60. https://doi.org/10.1007/978-981-19-7971-2_64.

[19] Waghmare S, Shelare S, Mungle N, Sakhare V, Dhande M. Development of Paddy Transplanter Machine Using Low-Cost Materials. In: Sachdeva A, Goyal KK, Garg RK, Davim JP, editors. Recent Adv. Oper. Manag. Optim. CPIE 2023. Lect. Notes Mech. Eng., Singapore: Springer Nature Singapore; 2024, p. 59–73. https://doi.org/10.1007/978-981-99-7445-0_6.

[20] Gajbhiye TS, Waghmare S, Dhande M, Gondane R, Giripunje M, Shelare S, et al. Polymer composite additive manufacturing: Applications, challenges and opportunities. Mater Today Proc 2024. https://doi.org/10.1016/j.matpr.2024.06.013.

[21] Shelare SD, Aglawe KR, Giri SS, Waghmare SN. Additive Manufacturing of Polymer Composites : Applications , Challenges and opportunities. Indian J Eng Mater Sci 2023;30:872–81. https://doi.org/10.56042/ijems.v30i6.4490.

[22] Ambade S, Kataria R, Tembhurkar C, Meshram D. Experimental and finite element analysis of temperature distribution in 409 M ferritic stainless steel by TIG, MIG and SMAW welding processes. Adv Mater Process Technol 2022:1–16. https://doi.org/10.1080/2374068X.2022.2100127.

[23] Mungle NP, Mate DM, Mankar SH, Tale VT, Vairagade VS, Shelare SD. Applications of computational intelligence for predictive modeling of properties of blended cement sustainable concrete incorporating various industrial byproducts towards sustainable construction. Asian J Civ Eng 2024. https://doi.org/10.1007/s42107-024-01155-0.

[24] Shelare S, Aglawe K, Dhande M, Wagmare S, Giripunje M, Sirsat P. Battery Thermal Management System: A Review on Recent Progress, Challenges and Limitations. MATEC Web Conf 2024;405:02004. https://doi.org/10.1051/matecconf/202440502004.

[25] Ambade SP, Tembhurkar CK, Patil A, Tidke A V, Shelare SD, Prakash C, et al. Microstructure, mechanical properties and sensitization of ultra-low nickel Cr–Mn austenitic stainless steels. J Mater Res Technol 2024;30:4353–65. https://doi.org/https://doi.org/10.1016/j.jmrt.2024.04.127.

[26] Meshram DB, Gohil V, Puri YM, Ambade S. Implementation of multi-objective Jaya optimization for performance improvement in machining curve hole in P20 mold steel by sinking EDM. World J Eng 2022;19:381–94. https://doi.org/10.1108/WJE-11-2020-0568.

[27] Ambade S, Khan F, Dahikar A, Bhonde Y, Shelare S, Tembhurkar C, et al. Dissimilar welding of austenitic SS and ferritic SS in last decades. Mater Today Proc 2023. https://doi.org/10.1016/j.matpr.2023.04.533.

[28] Masaki MS, Zhang L, Xia X. A comparative study on the cost-effective belt conveyors for bulk material handling. Energy Procedia 2017;142:2754–60.

[29] Kumar N, Sharma HK. Design of Material Handling Systems. In: Sharma HK, Kumar N, editors. Agro-Processing Food Eng., Singapore: Springer Singapore; 2022, p. 111–46. https://doi.org/10.1007/978-981-16-7289-7_4.

[30] Yang G. Dynamics analysis and modeling of rubber belt in large mine belt conveyors. Sensors & Transducers 2014;181:210.

[31] He D, Pang Y, Lodewijks G. Speed control of belt conveyors during transient operation. Powder Technol 2016;301:622–31.

https://doi.org/10.1016/j.powtec.2016.07.004.

[32] Waghmare SN, Sakhale CN, Tembhurkar CK, Shelare SD. Assessment of Average Resistive Torque for Human-Powered Stirrup Making Process. Adv. Intell. Syst. Comput., vol. 1025, 2020, p. 845–53. https://doi.org/10.1007/978-981-32-9515-5_79.

[33] Khope PB, Shelare SD. Prediction of Torque and Cutting Speed of Pedal Operated Chopper for Silage Making. Adv. Ind. Mach. Mech. Lect. Notes Mech. Eng., Springer; 2021, p. 243–9. https://doi.org/10.1007/978-981-16-1769-0_22.

[34] Shelare S, Kumar R, Khope P. Assessment of Physical, Frictional and Aerodynamic Properties of Charoli (buchanania Lanzan Spreng) Nut as Potentials for Development of Processing Machines. Carpathian J Food Sci Technol 2021;13:174–91. https://doi.org/10.34302/crpjfst/2021.13.2.16.

[35] Ramteke AL, Waghmare SN, Shelare SD, Sirsat PM. Development of Sheet Metal Die by Using CAD and Simulation Technology to Improvement of Quality BT - Proceedings of the International Conference on Industrial and Manufacturing Systems (CIMS-2020). In: Pratap Singh R, Tyagi DM, Panchal D, Davim JP, editors., Cham: Springer International Publishing; 2022, p. 687–701.

[36] Belkhode PN, Mehta GD, Shelare SD, Pachpor AA, Roy R. Conditioning Monitoring of a Flexible Coupling Using Experimental Data Based Modelling. Rom J Acoust Vib 2021;18:93–103.

[37] Dhutekar P, Mehta G, Modak J, Shelare S, Belkhode P. Establishment of mathematical model for minimization of human energy in a plastic moulding operation. Mater Today Proc 2021;47:4502–7. https://doi.org/10.1016/j.matpr.2021.05.330.

[38] Shelare SD, Kumar R, Khope PB. Formulation of a mathematical model for quantity of deshelled nut in charoli nut deshelling machine. Adv. Metrol. Meas. ofEngineering Surfaces, Lect. Notes Mech. Eng., 2021, p. 89–97. https://doi.org/10.1007/978-981-15-5151-2_9.

[39] Waghmare SN, Shelare SD, Bahl S, Mungle N, Kumar Bagha A, Chandmal Sharma R. Structural design and its analysis of two station notching tool for industrial die. Mater Today Proc 2022;68:1335–41. https://doi.org/10.1016/j.matpr.2022.06.360.

[40] Shelare SD, Kumar R, Khope PB. Flywheel Energy Application in Commercial and Agricultural Field: A Typical Review. Lect. Notes Mech. Eng., Springer; 2021, p. 177–86. https://doi.org/10.1007/978-981-16-1079-0_19.

[41] Ambade SP, Tembhurkar CK, Shelare S, Gupta S. Application of ANN and Taguchi Technique for Material Removal Rate by Abrasive Jet Machining with Special Abrasive Materials. Evol. Optim. Mater. Remov. Process., Boca Raton: CRC Press; 2022, p. 97–128. https://doi.org/10.1201/9781003258421-7.

[42] Belkhode PN, Joshi MP, Gondane SM, Maheswary PB, Shelare S, Kanfade J. Design and Development of Bamboo Link Mechanism using Synthesize Adhesive at Bamboo Joints. Indian J Eng Mater Sci 2023;30:833–7. https://doi.org/10.56042/ijems.v30i6.4562.

[43] Mowade S, Waghmare S, Shelare S, Tembhurkar C. Mathematical Model for Convective Heat Transfer Coefficient During Solar Drying Process of Green Herbs. Adv. Intell. Syst. Comput., vol. 1025, 2020, p. 867–77. https://doi.org/10.1007/978-981-32-9515-5_81.

[44] Aglawe KR, Yadav RK, Thool SB. Development of a mathematical model for prediction of heat transfer coefficient in micro-channel heat sink. Mater Today Proc 2022;54:753–7. https://doi.org/10.1016/j.matpr.2021.11.070.