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Mechanistic models for predicting specific energy consumption and throughput of palm nut–pulp separator

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ABSTRACT

Prediction models for specific energy consumption and throughput of palm nut–pulp separator were developed using mechanistic modeling technique. These models facilitate the easy production of different sizes of this machine in line with the budgets of the oil palm fruit processors. It also accounts for all the operational parameters of this machine as well as relevant properties of processed materials, digested palm fruit mash, palm nut and pulp. Experimental results indicated over 99% prediction accuracy of the models, while the prediction error of the specific energy consumption and throughput models are within the range of −0.014 to 0.076% and −0.005 to 0.003% respectively.

1. Introduction

Palm nut–pulp separator is a unit operational stand-alone machine developed specifically based on a modified palm oil and nut extraction process which involves separating the digested palm fruit mash into palm nuts and pulp before pressing only the pulp for palm oil. Records showed that the introduction of this machine in a semi-mechanized palm fruit processing sector improved the quality and quantity of palm oil and kernel extracted and also eliminated nut breakage during pressing [1]. This improvement in products extraction as well as drudgery reduction called for mass production of different sizes of this machine in line with the budgets of palm fruit processors. Thus, the need for prediction models of the two most important characteristic performance indicators of the separator- specific energy consumption and throughput. Specific energy consumption is the amount of energy utilised by the machine in separating a unit mass of digested palm fruit mash while throughput is the mass of digested palm fruit mash processed per unit time.

Development of energy saving equipment/processes is one of the major international trend for production cost reduction in industries over the decades because a machine/system may be very efficient in operation, but the application may not be economical if its specific energy consumption is not relatively small with respect to its throughput. Thus, processes and equipment with minimum specific energy consumption remain the outstanding targets of present day researchers and designers of engineering systems [2,3]. This outstanding importance of specific energy consumption relative to throughput in the operation of engineering systems led to the optimization of these responses along with the separation efficiency of a palm nut–pulp separator using response surface modeling approach by Nwankwojike et al. [4]. Separation efficiency is the

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Nomenclature

A	cross sectional area of belt, m^2
v	belt speed, m/s
m	mass per unit length of belt, kg/m
T_i	tight side tension of belt, N
T_j	slack side tension of belt, N
$T_{\max}$	maximum allowable tension of belt, N
T_c	centrifugal tension of the belt, N
σ	maximum safe stress of belt, N
μ	coefficient of friction of belt and pulley,
θ	angle of lap of belt on the smaller pulley, ^{o}
β	groove angle of pulley, ^{o}
D_1	diameter of the driving pulley, m
D_2	diameter of the driven pulley, m
C	center distance between adjacent drive pulleys, m
T	torque on the transmission shaft, Nm
Q	volumetric throughput of the auger running 100% full with the bulk material moving axially without relative rotation, m^3/s
ρ	bulk density of material transported by the auger kg/m^3
C_a	palm nut discharge rate of the auger, kg/s
C_p	digested pulp discharge rate of the auger, kg/s
M_b	maximum bending moment of the drive shaft, Nm
M_t	maximum twisting moment of the drive shaft, Nm
N	angular velocity of the shafts, rpm
Q_t	maximum theoretical palm nut volumetric throughput of the auger, m^3/s
η_v	maximum theoretical volumetric efficiency
D	Auger screw diameter, m
D_c	Auger membrane diameter, m
T_s	Auger blade thickness, m
P_a	Auger pitch, m
C_r	radial clearance of the auger, m
α_e	effective helix angle of the auger, °
ϕ_s	angle of repose of pulp on the auger surface, °
h_{av}	average height of materials on the auger, m
L_a	length of the auger shaft, m
N_a	angular velocity of the auger shaft, rpm
ω	angular velocity of the auger, rad./s
v_a	linear velocity of the auger, m/s
x	number of auger shaft revolutions required to process a given mass of digested palm fruit mash
D_{ap1}	diameter of the driving pulley on the auger shaft, m
D_{ap2}	diameter of auger shaft driven pulley, m
D_{mp}	diameter of the pulley on the prime mover, m
b	distance between auger shaft driving pulley and first bearing support on the shaft, m
a_a	distance between the two bearing supports of auger shaft, m
W_a	weight of auger shaft, N
W_{p2}	weight of cake breaker driving pulley, N
W_{p3}	weight of auger driven pulley, N
σ_a	maximum safe stress of the belt in the prime mover/auger drive, N/m^2
T_1	tight side tension of the belt in the auger/cake breaker drive, N
T_2	slack side tension of the belt in the auger/cake breaker drive, N
T_3	tight side tension of the belt in the motor/auger drive, N
T_4	slack side tension of the belt in the motor/auger drive, N
A_a	cross sectional area of the belt in the prime mover/auger drive m^2
M_a	mass per unit length of the belt in the motor/auger drive, kg/m
μ_a	coefficient of friction between motor/auger drive belt and pulleys
θ_a	angle of lap of the belt on the auger driven pulley, °
β_a	groove angle of the auger driven pulley, °
M_{ta}	maximum twisting moment of the auger shaft, Nm