RELIABILITY ANALYSIS AND PROFIT OPTIMIZATION OF BRIQUETTE MACHINE BY CONSIDERING NEGLECTED FAULTS

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Abstract

Sustainable energy plays a significant role in socio-economic advancement by raising the standard of living of all human beings. Briquetting is the process of compaction of biomass residues into solid fuels in order to increase the effectiveness of thermal capacity, combustion rate, calorific value to name a few. In this paper, we consider not only the occurrence of minor/ major faults but also the other neglected faults such as abnormal sound, overheating of the motor unit, vibration, etc. Such neglected faults may not affect the working of the system at a time but their ignorance may convert into major faults in the future. An ordinary repairman can easily rectify all machine faults except some major faults for which an expert repairman is required. Moreover, we analyse the availability of the system and optimize system profit by using the Artificial Bee Colony optimization algorithm. Furthermore, a graphical study of these parameters is presented.

Keywords: Briquette machine, Profit, Base state, Transition probability, Regenerative Point Graphical Technique (RPGT).

I. Introduction

Ongoing international efforts to reduce CO2 emission from the consumption of energy lead us towards renewable energy sources. Production of biomass helps us in achieving a neutral CO2 emission which balances the rate of growth of biomass. Sharma et al. [20] discussed varying contents of carbon, oxygen, and hydrogen provide us various effects on the conversion process of energy. Cellulose, hemicellulose, and lignin are the three main polymers of biomass.

The process of heating biomass up to approximately 200-300 degrees Celsius is sometimes known as Torre-faction (roasting, slow pyrolysis). Nowadays, Torre-faction becomes a widely discussed technology because of its potential to enable the use of extra biomass resources and make it one of the main energy sources of the present time. One of the main purposes of the Torrefaction process is to produce biomass that resembles coal mostly in terms of its properties as a solid fuel. Due to such reasons terrified biomass is often called bio-coal. Many authors published their works on describing several parameters which are necessary for its use as solid fuel and introduced bio coal into the energy market [21].

Briquetting or densification is the process of pressurizing loose biomass into a compacted fuel known as briquettes. It helps us to produce an energy content with a smaller amount of dampness.

Briquettes are consistent in shape which results in smooth utilization and storage equipment lessening the handling, storage space, and transport expenses. Sawdust, cotton stalk, edible nutshell, coconut shell, paper and coconut mixture cocoa shell, and a lot more are the samples of biomass investigations so far [18]. Raju et al. [15] analysed that such biomass briquettes can be utilized not only for housing purposes like cooking, warming, and barbequing but for agriculture and food industries also. Nowadays, as the necessity for an alternative energy source is high, we should focus on developing new biomass briquettes using biomass wastes [17,19].

Okwu and Omonigho [14] used saw dust and water hyacinth plant along with cassava starch as binder for the production of solid briquettes by developing a movable and light weighted briquette machine. Obtained parameters were better performing as compared to the traditional energy sources in terms of profit, high calorific value, less moisture content etc. Fikri and Sartika [4] constituted a bio-charcoal briquette obtained from organic wastes, they used simple random sampling method in order to obtain different compositions of organic wastes for comparative analysis.

Lubwama et al. [13] developed a bio-composite briquette from coffee and rice husks with proportionate groundnut shells and studied its several attributes. This briquette performs better over other single constituent briquettes. Kumar et al. [10] compared biomass briquette and charcoal briquette in order to find that which briquette has higher calorific value and also the effect of the addition of binder. Senchi & Kofa [22] investigated the intrinsic properties of corncob as well as un-carbonized rice husk base briquettes to check their fuel efficiencies. They concluded that briquette produces from corncob is far better than the rice husk briquette in terms of low moisture content, moderate ash content, and high viability. Garg and Garg [24] analysed the reliability parameters of a briquette machine with deviation in demand. Aliyu et al. [1] developed a composite briquette using corn cobs and orange peels which are easily available in some parts of Niger state, Nigeria to overcome the issue of lack of electricity supply. Obtained results give a strong hope of the development of such briquettes in those areas where there is less electricity supply or no electricity supply at all. Rane and Narvel [16] redesign the organisation based on Blockchain-IoT integrated architecture to improve the agility in their routine operations. In order to monitor its operations, they installed a sensor based industrial pump and suggested predictive measures for the management of such assets. They concluded that the new technology increases the decentralisation capacity and allowed autonomous coordination among devices. Asni and Andiappan [25] discussed Fuzzy Multi-Objective Optimal Design of a Biomass Combined Power and Heat System Considering System Reliability, Cost, and Flexibility.

Singh et al. [23] developed a mathematical model and evaluated reliability measures of power generation system by using the Boolean function technique in which lengthy calculations are involved. Garg et al. [5] utilized RPGT technique to analysed the performance parameter of a single unit briquetting system. Also, Barak et al. [3] used RPGT successfully to find reliability measures of a milk plant. So, we calculate various measures such as busy period, machine availability, mean time to system failure (MTSF), expected number of ordinary/expert repairman visits, and profit for the developed system quickly by using RPGT [12]. Moreover, we optimize profit by utilizing Artificial Bee Colony (ABC) [7,8]. Step by step working algorithm is also presented for ABC.

Generally, we consider two kinds of faults in the operation of a briquette-making machine: Minor and Major [6]. Minor faults are responsible for the degradation of the whole operating unit but major faults lead towards the complete failure of the unit. Apart from those two faults, some other faults sometimes may convert into major faults if ignored. Vibrations of the machine, overheating, unusual sounds are some examples of such faults [11]. We usually neglect such faults but their ignorance may lead to complete failure of the operating unit. Various faults necessitate the use of different repair facilities, since an ordinary repairman is unable to adequately address all major faults [2]. None of the researchers considered above discussed faults simultaneously. To fill this gap, we present a system consisting of minor, major as well as neglected faults for the development of a briquette machine.

This paper is structured as follows: A detailed introduction of the related topic is presented in Section I. Assumptions and notations are discussed thoroughly in Sections II and III, respectively. In Sections IV and V, we developed a state transition diagram and a research methodology flowchart, respectively. Calculation of all transition probabilities as well as mean Sojourn times for each state of the transition diagram are estimated in Section VI. Different measures are calculated and optimized by using various algorithms in order to find maximum profit in Section VII. In Section VIII, detailed analyses along with graphical representations of obtained results are discussed. Section IX concludes our work with future scope.

II. Assumptions

- Inspection/Failures/Repairs are analytically independent.
- All Faults are self-announcing.
- The Faults are exponentially distributed and repair rate are arbitrary.
- Once the system has failed, no more failures can occur.

III. Notations

$\lambda/\gamma/\lambda 2$: Machine complete/neglected failure rate
O/On: Operative/Operative under neglected fault
Fi: Machine failed & under inspection
Frm: Minor Fault & under repair
FiM: Major Fault & under inspection
FrO/FrE: Machine under repair by ordinary/expert repairmen
a/b: Minor/Major Fault Probabilities
p/q: Major fault repair Probability
i(t)/I(t): fault inspection time p.d.f/c.d.f
h(t)/H(t): major fault inspection time p.d.f/c.d.f
g1(t)/G1(t): Minor fault repair-time by ordinary repairmen p.d.f/c.d.f
g2(t)/G2(t): Major fault repair-time by Ordinary repairmen p.d.f/c.d.f
g3(t)/G3(t): Major fault repair-time by Expert repairmen p.d.f/c.d.f

IV. State Transition diagrams

The state S_0, S_1 are the available-states, S_2, S_3, S_4, S_5, and S_6 are failed states as shown in Figure 1. We assume that S_0 is the base state.

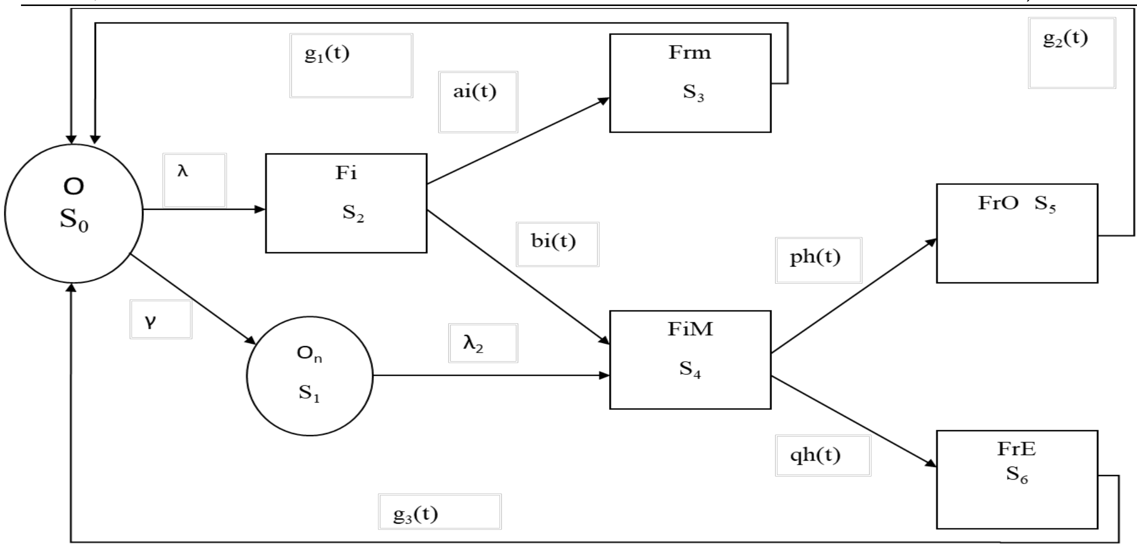

Figure 1: *State transition diagram*

V. Research Methodology Flowchart

The flowchart of the proposed methodology is shown in fig. 2

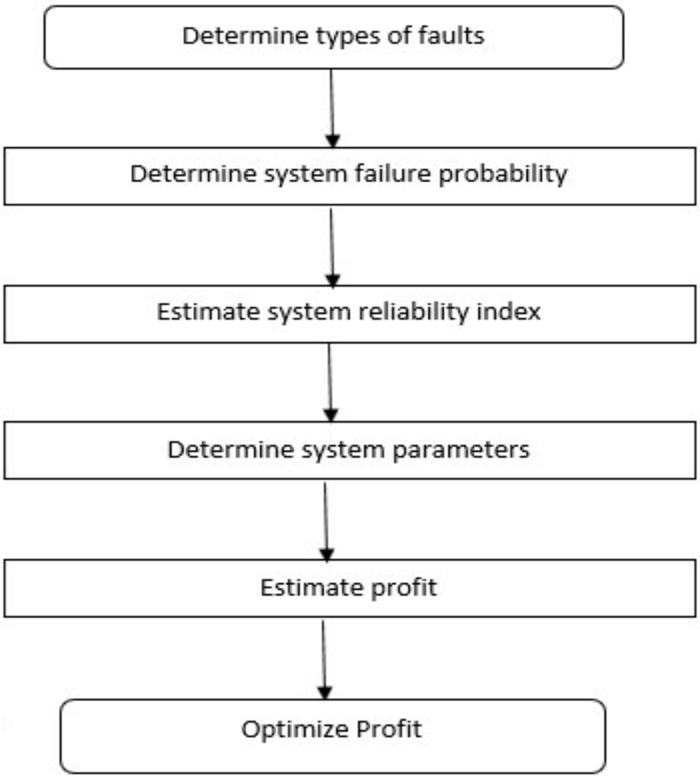

Figure 2: *Research Methodology Flowchart*

VI. Research Methodology Flowchart

In this section, all transition probabilities and mean sojourn times are shown in Table 1 and Table 2, respectively.

$q_{i,j}(t)$: probability distribution function from regenerative state *i* to *j*.

$p_{i,j}(t)$: State transition probability from regenerative state *i* to *j*.

$p_{i,j}(t) = q_{i,j}*(0)$

where * stand for Laplace transform

Table 1: Transition Probabilities

$\boldsymbol{q_{i,j}(t)}$	$\boldsymbol{p_{i,j} = q_{i,j} * (0)}$
$\boldsymbol{q_{0,1} = \gamma e^{-(\lambda+\gamma)t}}$	$p_{0,1} = \gamma/(\lambda+\gamma)$
$\boldsymbol{q_{0,2} = \lambda e^{-(\lambda+\gamma)t}}$	$p_{0,2} = \lambda/(\lambda+\gamma)$
$\boldsymbol{q_{1,4} = \lambda_2 e^{-(\lambda_2)t}}$	$p_{1,4} = 1$
$\boldsymbol{q_{2,3} = ai(t)}$	$p_{2,3} = ai*(0)$
$\boldsymbol{q_{2,4} = bi(t)}$	$p_{2,4} = bi*(0)$
$\boldsymbol{q_{3,0} = g_1(t)}$	$p_{3,0} = g_1*(0)$
$\boldsymbol{q_{4,5} = ph(t)}$	$p_{4,5} = ph*(0)$
$\boldsymbol{q_{4,6} = qh(t)}$	$p_{4,6} = qh*(0)$
$\boldsymbol{q_{5,0} = g_2(t)}$	$p_{5,0} = g_2*(0)$
$\boldsymbol{q_{6,0} = g_3(t)}$	$p_{6,0} = g_3*(0)$

$$p_{01} + p_{02} = 1, p_{23} + p_{24} = 1, p_{45} + p_{46} = 1,$$

Mean sojourn time can be calculated as follows:

$$\mu_i = \int_0^\infty R_i(t)dt = R_i^*(0)$$

Where, $R_i(t)$ is the reliability of system at time t.

Table 2: Mean Sojourn Times

$\boldsymbol{R_i(t)}$	$\mu_i = \boldsymbol{R_i * (0)}$
$R_0 = e^{-(\lambda+\gamma)t}$	$\mu_0 = 1/(\lambda+\gamma)$
$R_1 = e^{-(\lambda_2)t}$	$\mu_1 = 1/\lambda_2$
$R_2 = I(t)$	$\mu_2 = -i*'(0)$
$R_3 = G_1(t)$	$\mu_3 = -g_1*'(0)$
$R_4 = H(t)$	$\mu_4 = -h*'(0)$
$R_5 = G_2(t)$	$\mu_5 = -g_2*'(0)$
$R_6 = G_3(t)$	$\mu_6 = -g_3*'(0)$
$\boldsymbol{q_{6,0} = g_3(t)}$	$p_{6,0} = g_3*(0)$

Now, transition probability factors are given as:

$V_{0,1} = \frac{\gamma}{\lambda+\gamma}$, $V_{0,2} = \frac{\gamma}{\lambda+\gamma}$, $V_{0,3} = \frac{\lambda}{\lambda+\gamma} a$,

$V_{0,4} = \frac{1}{\lambda+\gamma} b$, $V_{0,5} = \frac{1}{\lambda+\gamma}[p\gamma + bp\lambda]$, $V_{0,6} = \frac{1}{\lambda+\gamma}[q\gamma + bq\lambda]$

VII. Measures of System Effectiveness

Briquetting Machine Parameters are evaluated by utilizing RPGT and "0" as a base state.

I. Mean time to system-failure

MTSF is the average time predicted until a system fails for the first time. By fig. 1, S_0 and S_1 are the only operative states that can be transited before reaching the Failed State. MTSF per unit time is represented in Table 3.

$$MTSF = V_{0,0}\mu_0 + V_{0,1}\mu_1 = \frac{1}{\lambda+\gamma} + \frac{\gamma}{\lambda+\gamma}\left(\frac{1}{\lambda_2}\right) = \frac{1}{\lambda+\gamma}\left[1 + \frac{1}{\lambda_2}\right]$$

Table 3: Effect of λ_1, γ & λ_2 on MTSF

λ	γ=0.001, λ_2=0.025	γ=0.003, λ_2=0.025	γ=0.003, λ_2=0.025	γ=0.001, λ_2=0.005
0.005	233.3333	275	300	200
0.01	127.2727	169.2308	200	109.0909
0.015	87.5	122.2222	150	75
0.02	66.66667	95.65217	120	57.14286
0.025	53.84615	78.57143	100	46.15385
0.03	45.16129	66.66667	85.71429	38.70968
0.035	38.88889	57.89474	75	33.33333
0.04	34.14634	51.16279	66.66667	29.26829
0.045	30.43478	45.83333	60	26.08696
0.05	27.45098	41.50943	54.54545	23.52941

II. Machine Availability

Let A be the probability that the unit in is working state at time t. Here, S0 and S1 are only operative states and all states are regenerative states. Using regenerative point graphical technique, the proportion of steady-state machine availability is given by

$$A = \frac{V_{0,0}\mu_0 + V_{0,1}\mu_1}{\sum_{i=0}^{6} V_{0,i}\mu_i}$$

$$A = \frac{N}{D}$$

$$N = \frac{1}{\lambda+\gamma}\left[1 + \frac{\gamma}{\lambda_2}\right]$$

$$D = V_{0,0}\mu_0 + V_{0,1}\mu_1 + V_{0,2}\mu_2 + V_{0,3}\mu_3 + V_{0,4}\mu_4 + V_{0,5}\mu_5 + V_{0,6}\mu_6$$

$$= \frac{1}{\lambda+\gamma} + \frac{\gamma}{\lambda+\gamma}\left(\frac{1}{\lambda_2}\right) + \frac{\lambda}{\lambda+\gamma}\left(\frac{1}{\alpha}\right) + \frac{\lambda}{\lambda+\gamma}\left(\frac{1}{\alpha_1}\right) + \frac{[\gamma+b\lambda]}{\lambda+\gamma}\left(\frac{1}{\beta}\right) + \frac{[p\gamma+bp\lambda]}{\lambda+\gamma}\left(\frac{1}{\alpha_2}\right) + \frac{[q\gamma+bq\lambda]}{\lambda+\gamma}\left(\frac{1}{\alpha_3}\right)$$

$$= \frac{1}{\lambda+\gamma}\left[1 + \left(\frac{\gamma}{\lambda_2}\right) + \left(\frac{\lambda}{\alpha}\right) + \left(\frac{\lambda a}{\alpha_1}\right) + \frac{[\gamma+b\lambda]}{\beta} + \frac{[p\gamma+bp\lambda]}{\alpha_2} + \frac{[qr+bq\lambda]}{\alpha_3}\right]$$

Machine availability values of the given system are shown in Table 4:

Table 4: Machine availability

λ	α=0.8, β=0.8	α=0.8, β=0.0.9	α=0.9, β=0.8	α=0.9, β=0.9
0.005	0.289917598	0.289969009	0.289665715	0.2897171
0.01	0.293154824	0.29325821	0.29273926	0.29284256
0.015	0.296354714	0.296510608	0.295778765	0.295934484
0.02	0.29951791	0.299726819	0.298784793	0.298993409
0.025	0.30264504	0.302907442	0.301757893	0.30201986
0.03	0.305736716	0.306053066	0.304698604	0.305014351
0.035	0.308793539	0.309164264	0.307607452	0.307977387
0.04	0.311816095	0.312241599	0.310484952	0.310909461
0.045	0.314804956	0.315285621	0.313331609	0.313811054
0.05	0.317760683	0.318296867	0.316147915	0.318296867

III. Busy Period

Let B be the likelihood that the repairmen are occupied with fixing the unit caused to failure at time t. From the state Transition Diagram, the repairmen busy at states j=2, 3, 4, 5 & 6. For base state ‘0’, the busy period is given in Table 5.

$$B = \frac{N2}{D}$$

$$N_2 = V_{0,2}\mu_2 + V_{0,3}\mu_3 + V_{0,4}\mu_4 + V_{0,5}\mu_5 + V_{0,6}\mu_6$$

$$= \frac{\lambda}{\lambda+\gamma}\left(\frac{1}{\alpha}\right) + \frac{\lambda}{\lambda+\gamma}\left(\frac{a}{\alpha_1}\right) + \frac{1[\gamma+b\lambda]}{\lambda+\gamma}\left(\frac{1}{\beta}\right) + \frac{1[p\gamma+bp\lambda]}{\lambda+\gamma}\left(\frac{1}{\alpha_2}\right) + \frac{1[q\gamma+bq\lambda]}{\lambda+\gamma}\left(\frac{1}{\alpha_3}\right)$$

$$= \frac{1}{\lambda+\gamma}[\left(\frac{\gamma}{\lambda_2}\right) + \left(\frac{\lambda a}{\alpha_1}\right) + \frac{[\gamma+b\lambda]}{\beta} + \frac{[p\gamma+bp\lambda]}{\alpha_2} + \frac{[q\gamma+bq\lambda]}{\alpha_3}$$

Table 5: Busy period

λ	α=0.8, β=0.8	α=0.8, β=0.0.9	α=0.9, β=0.8	α=0.9, β=0.9
0.005	0.99287427	0.993050337	0.993226466	0.993402658
0.01	0.987115457	0.987463579	0.987695796	0.988044328
0.015	0.981423063	0.98193933	0.98222638	0.982743492
0.02	0.975795946	0.976476547	0.976817204	0.977499231
0.025	0.970232988	0.97107421	0.971467279	0.972310643
0.03	0.964733099	0.96573132	0.966175637	0.967176847
0.035	0.959295212	0.960446902	0.96094133	0.962096979
0.04	0.953918284	0.955220001	0.955763432	0.957070193
0.045	0.948601297	0.950049684	0.950641036	0.952095663
0.05	0.943343253	0.944935036	0.945573254	0.947172577

IV. Expected visits by repairmen

let V be the number of repairmen visits for repair in time (0, t]. From the state Transition Diagram, the repairmen visit anew for repair at j=2. For base state ‘0’, the expected visits by repairmen are given in Table 6.

$$V = \frac{V_{0,2}}{\sum_{i=0}^{6} V_{0,i}\mu_i}$$

$$= \frac{\lambda}{\lambda+\gamma} \div \frac{1}{\lambda+\gamma}[1 + \left(\frac{\gamma}{\lambda_2}\right) + \left(\frac{\lambda}{\alpha}\right) + \left(\frac{\lambda a}{\alpha_1}\right) + \frac{[\gamma+b\lambda]}{\beta} + \frac{[p\gamma+bp\lambda]}{\alpha_2} + \frac{[qr+bq\lambda]}{\alpha_3}$$

Table 6: Repairmen visits

λ	α=0.8, β=0.8	α=0.8, β=0.0.9	α=0.9, β=0.8	α=0.9, β=0.9
0.005	0.007091959	0.007093217	0.007094475	0.007095733
0.01	0.011986402	0.011990629	0.011993449	0.011997681
0.015	0.016824395	0.016833246	0.016838167	0.016847031
0.02	0.02160691	0.021621981	0.021629524	0.021644626
0.025	0.026334895	0.026357729	0.026368398	0.026391289
0.03	0.031009278	0.031041364	0.031055645	0.031087827
0.035	0.035630965	0.035673742	0.035692107	0.035735031
0.04	0.040200842	0.0402557	0.040278602	0.040333672
0.045	0.044719775	0.044788057	0.044815935	0.04488451
0.05	0.049188612	0.049271613	0.049304891	0.049271613

V. Profit

we consider particular case and function for analysing the system profit\
g1(t) = α1e-α1t, g2(t) = α2e-a2t, g3(t) = α3e-α3t, i(t) = αe-α t, h(t) = βe-β t
and P = P1 A0 – P2 B0- pP3 V0- qP4 V0- P5
Where
P1 = Revenue per unit time while the system is in up-state
P2 = Loss due to busy period of repairmen
P3 = Price of ordinary repairmen involved in the repair
P4 = Price of Expert repairmen involved in the repair
P5 = Downstate reduction & other costs
The System profit is shown in table 7:

Table 7: Profit

λ	α=0.8, β=0.8	α=0.8, β=0.0.9	α=0.9, β=0.8	α=0.9, β=0.9
0.005	29499.44914	29510.0002	29520.64369	29531.20225
0.01	29152.74694	29173.60808	29187.67066	29208.55639
0.015	28810.04339	28840.97977	28858.38534	28889.37249
0.02	28471.26972	28512.05245	28532.7268	28573.59516
0.025	28136.3587	28186.7647	28210.63546	28261.17012
0.03	27805.24465	27865.05644	27892.05302	27952.0443
0.035	27477.86337	27546.86892	27576.92246	27646.16569
0.04	27154.15209	27232.14464	27265.18797	27343.48341
0.045	26834.04943	26920.82739	26956.79495	27043.94761
0.05	26517.4954	26612.86212	26651.68996	26747.1146

VI. ABC Algorithm

Step-1: Formulate the fitness function and randomly initialize the honey bee.

Step-2: Find an applicant food source position for each utilized honey bee and estimate the nectar amount fitness function of food sources.

Step-3: Calculate the pi (probability Values) for the solution.

Step-4: for each onlooker, the bee chooses a food source depending on a pi and generates an applicant solution.

Step-5: select the better food source position.

Step-6: Memorize the best solution found so far.

Step-7: Locate the surrendered food sources and produce new situations for depleted food sources

Step-8: Repeat steps 2 onwards till the end criterion is met.

All constraints limits are reflected in Table 8.

Table 8: Repair, inspection and failure rate parameter constraints limits

Parameters	λ	γ	λ_2	α	β	α_1	α_2	α_3
Min	0.001	0.002	0.005	0	0	0.1	0.2	0.2
Max	0.05	0.1	0.05	0.9	0.9	0.9	0.9	0.9

Table 9 shows ABC's optimal profit function values for various repair and failure rates.

Table 8: Constraints limits

ABC Results (Profit)	λ	γ	λ_2	α	β	α_1	α_2	α_3
29637.091	0.002	0.003	0.019	0.87	0.0878	0.0892	0.9	0.889
29668.051	0.002	0.002	0.047	0.731	0.878	0.463	0.895	0.894
29589.136	0.006	0.003	0.05	0.891	0.895	0.871	0.89	0.883
29504.176	0.002	0.004	0.006	0.9	0.9	0.871	0.851	0.806
29640.821	0.015	0.002	0.047	0.891	0.894	0.879	0.895	0.845
29745.041	0.001	0.002	0.01	0.9	0.883	0.578	0.9	0.9
29702.85	0.002	0.002	0.005	0.753	0.752	0.844	0.9	0.9
29719.59	0.003	0.002	0.044	0.88	0.849	0.9	0.9	0.9
29747.066	0.001	0.002	0.005	0.829	0.898	0.597	0.9	0.739
29762.308	**0.001**	**0.002**	**0.005**	**0.852**	**0.9**	**0.872**	**0.9**	**0.9**

VIII. Results and Discussion

In this section, different graphs for MTSF, availability, and profit are drawn by considering the particular cases. Fig. 3 represents the reciprocate of MTSF with respect to the failure rate. In Fig. 4, a graph of availability versus failure rate is shown. It is easy to check that availability decreases with the increase in failure rate and increases with the higher value of inspection rate. Fig. 5 reflects the graphs between profit and failure rates. Profit goes down with an increase in failure rate but depicts the same behaviour as the inspection rate. The validation of the proposed work is ensured by the expected trends on the following graphs.

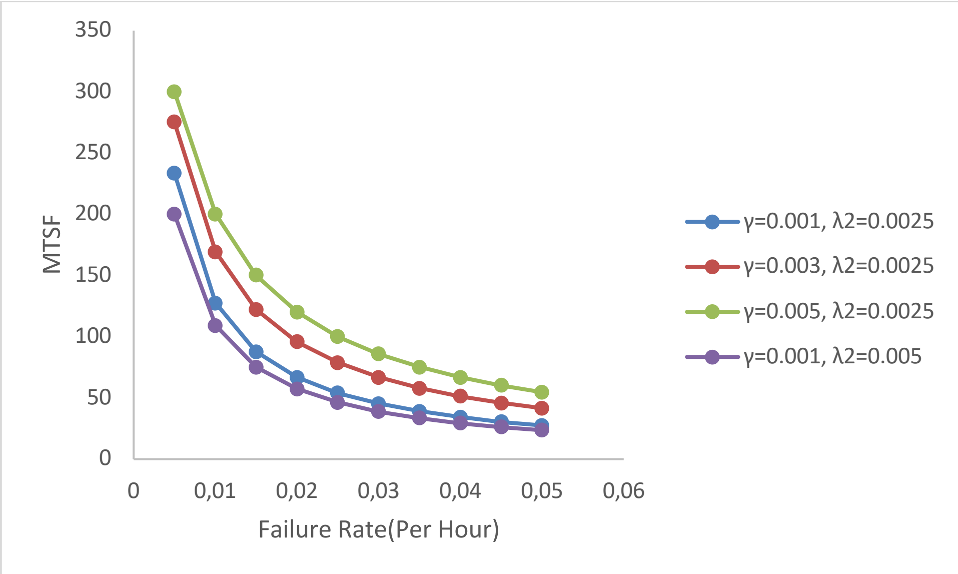

Figure 3- *Effect of different parameters on MTSF*

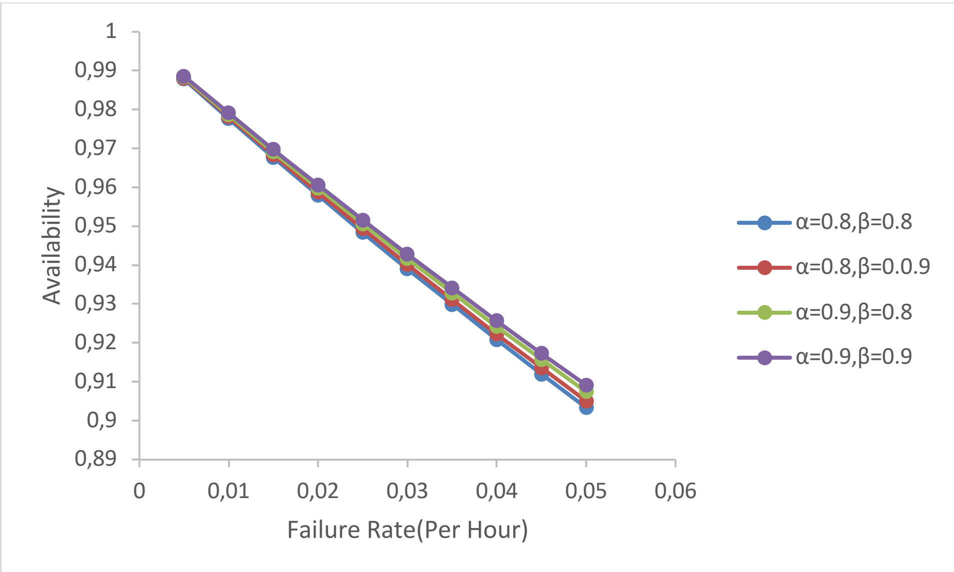

Figure 4- *Availability Vs Failure Rate*

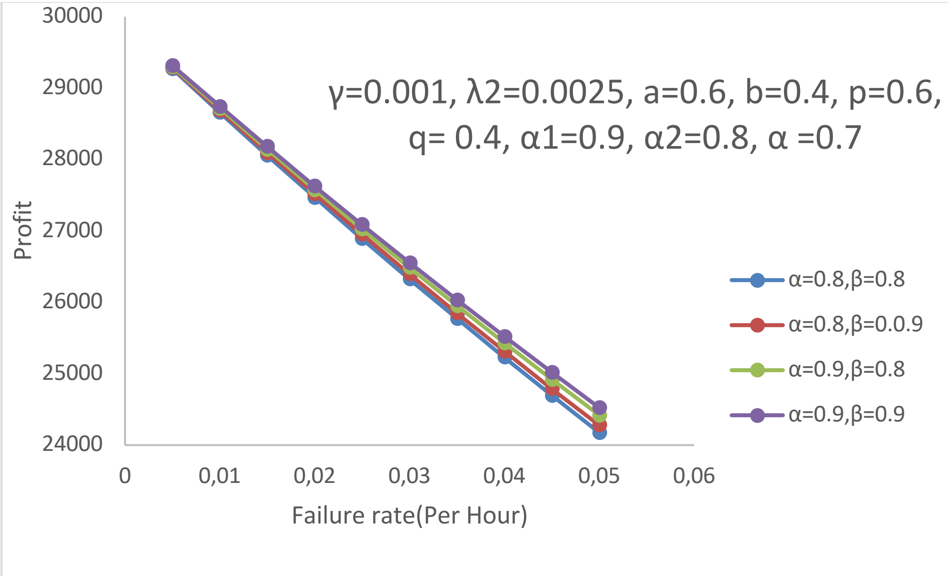

Figure 5- ***Profit Vs Failure Rate***

Biomass is one of the easily available energy sources which can be used for bioenergy to generate electricity, heat, and various other forms of energy. Biomass briquettes produced by a piston press are less expensive than coal. It also has a higher burning capacity and lowers ash concentration than coal and wood. Industries using such briquettes are more profitable as compare to traditional energy sources. Briquettes are environment friendly due to its less carbon emission nature.

IX. Conclusion and future scope

Neglected faults along with different faults in the bio-coal briquette machine have been analysed and formulated. All three parameters MTSF, availability, and profit drop as the failure rate increases and rise as the inspection rate increases. Artificial Bee colony optimization algorithm is effectively applied to organize simultaneously repair, inspection, and failure rate parameters for an ideal degree of system profit. The optimum value for Profit by ABC algorithm for repair and failure rate parameters (λ, γ, λ_2, α, β, α_1, α_2, α_3) is 29762·308. That means the briquetting machine is quite profitable. Therefore, Biomass briquettes are of practical significance in any apparatus intended for the combustion of coal or wood. Some adjustments to the operating parameters are required to achieve maximum profit. Also, a preventive maintenance policy or periodic rest which will help practitioners to avoid such conversion of neglected faults into major faults.

The Briquetting system tends to fail when neglected faults are ignored. The concept of preventive maintenance was not taken care of in this manuscript. In future, we wish to work on the profit optimization of two-unit briquetting system considering neglected Faults with Preventive Maintenance.

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