Maximization of Power Through Metaheuristic Technique in the Design of a Jacketed Vessel Mixing Solid-Liquid Phases

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ABSTRACT: *This study aims to improve power for stirrer vessel equipment by involving the parameters like diameter of solid particles; tank diameter, height, and density of slurry are varied with weight percentage. The above parameters affect Zwietering's mass ratio, the kinematic viscosity of the slurry, Reynolds' number, Froude's number, impeller diameter, and just suspension speed. In the metaheuristic technique, the Ant Colony Algorithm is among the best algorithms for solving nonlinear problems. From ACO among propeller, Paddle, and Rushton impeller, the Rushton impeller has more power value of 8856.70W. In sensitivity analysis keeping ants constant by varying iterations and by keeping iterations constant varying ants the Rushton impeller has a higher power value when compared with the propeller impeller and paddle impeller.*

KEYWORDS: *Metaheuristic technique; Solid phase and liquid phase mixing; Maximization of Power requirement; Jacketed vessel.*

INTRODUCTION

Coal is a fossil-based fuel that mostly meets the world's energy needs and is converted into heat and electricity by various technologies. Clean Coal Technology (CCT), Integrated Gasification Combined Cycle (IGCC), Pressurized Fluidized Bed Combustor (PFBC), Pulverized Coal Injection (PCI), etc., are among them. Around 70% of the energy produced in India is generated from coal, which has potential and reaches a supply level of about 60% for industrial and residential loads [1]. Numerous experimental studies on small-scale gasifiers with different procedures using various grades of coals have been conducted. [2, 3]. To create a connection between a laboratory and commercial gasifier, small-scale entrained flow coal gasifiers are acceptable. [4]. The difficulty the process of gasifying coal involves combustion, energy absorption, two-phase flow characteristics, and gasification. A process diagram of oxygen blown entrained flow coal gasifier is shown in Fig. 1. From the literature, extensive studies have been observed particularly on coal gasification, liquefaction, and combustion. Feeding the direct

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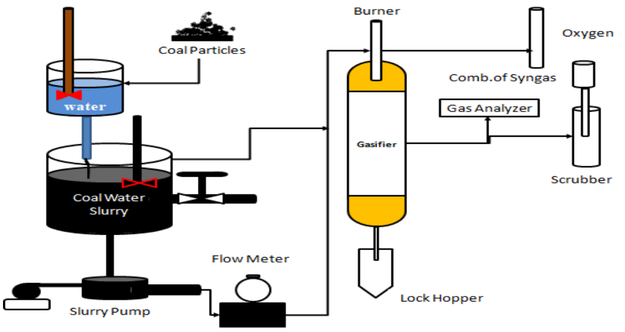


***Fig. 1: Schematic diagram of the oxygen-blown entrained flow coal gasifier* [4]**

coal into the gasifier causes damage to the environment by increasing the pollution [5].

To reduce the effects of dry coal the researchers focused on the preparation of coal slurries with oil and water. Limitations like the free flow of coal oil slurry failures have been noted over the last two decades, either from the failure of holding back surface impoundments or when underground storage areas are breached[6]. Coal Water Slurry (CWS) is a type of novel fuel preparation using a physical method to make the liquefaction of coal, and it is a highly loaded suspension of coal particles in water. When coal water slurry is sent into a high-temperature gasifier, the coal particles are quickly heated, and the moisture content in the slurry is evaporated due to a series of chemical and physical changes [5, 6]. Hence, the quality of the coal water slurry will be monitored to get better gasification by feeding the inputs like air or oxygen, steam, and coal.

The slurry that is used to feed should be initially heated before entering into the gasifier to maintain the efficiency of the gasifier [7]. Coal slurry viscosity is one of the important factors in slurry feed-type gasification. If the slurry concentration is too low, the reaction temperature inside the gasifier will be decreased which causes carbon conversion to decrease. Therefore, it is important to maintain high slurry concentration but this is difficult due to the high viscosity of coal slurry. The characteristics of coal slurry should be considered in order to prepare highly concentrated coal water slurry while simultaneously maintaining low viscosity and ideal rheological properties. [6,7]. The coal water slurry is formed by the mixing of two distinct phases, such as solid and liquid. Therefore, agitation is required for two phases will require more power to prepare slurry with uniform mixing without settling solid particles at the bottom of the liquid.

The process agitation means the mixing of phases that can be accomplished and by which mass and heat transfer can be enhanced between phases or with external surfaces. Agitated vessels like stirred tanks, that involve mechanical mixing, consist of a vessel, that can be heated or cooled using an external jacket or internal coils. The temperature evolution of the contents depends on the heat transfer, fluid temperature, stirrer speed, and apparent viscosity [8]. It relies on the impeller's balancing energy being transferred into speed in order to raise the coarse elements which are settled in a tank at the bottom-most as shown in Fig. 2. Regular and certain uniform mixing of solids in liquids like natural processes, continuous flow of solid particles in a liquid, paper pulp, coal water slurry in power plants, etc are widely used in different industries.

The intensity of heat transfer during the mixing of different phases depends on the type of agitator, the design of the vessel, and the mixing phenomena. When designing an agitated vessel, the impeller, vessel geometry, and baffles should give the degree of mixing that the process demands. In the same manner, proper design and optimization of mixing systems requires a detailed knowledge of the flow hydrodynamics, conditions of operation of the reactor, and its relation with the various relevant geometrical parameters, such as tank geometry, impeller type and size and number of impellers [7, 8, 9]. To improve the uniform mixing of solid particles motor power plays an important role in agitation. In solid-liquid phase mixing the particles of solid have more density and settle down at the bottom of the tank easily. This causes uneven heat and mass transfer flow between the two phases.

In the industrial world, problem-solving through optimization is critical. Designers must use optimization methods to solve complex problems in less time and with greater efficiency. In this work, the optimization method is used to maximize the power of the agitator based on the parameters of the agitation equipment. Metaheuristic optimization algorithms have become a popular choice for solving complex problems that are difficult to solve by conventional methods especially with incomplete or imperfect information are limited computational capacity. However, many researchers have proposed this metaheuristic technique to solve for obtaining better results [10].

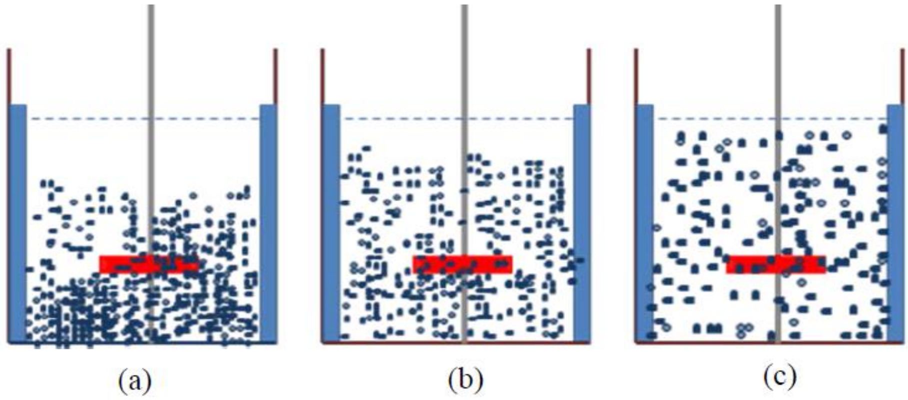


Fig.2: Different suspensions (a) Partial Suspension, (b) Complete Suspension, (c) Uniform Suspension [8]

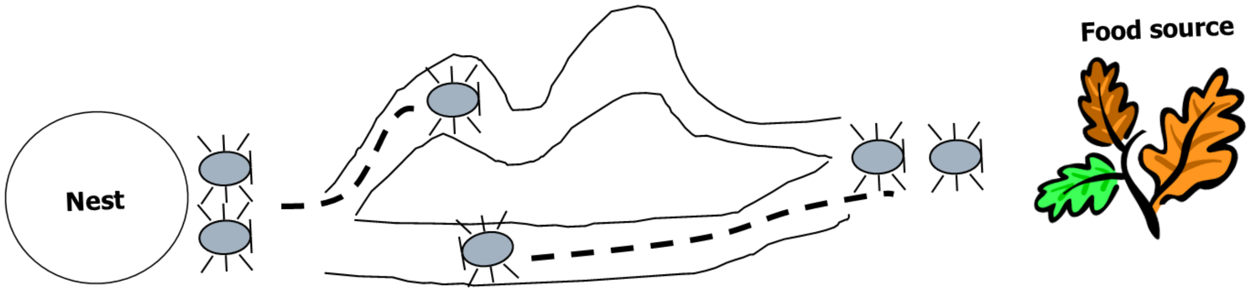


Fig. 3: Ant moving towards to food source from nest vice-versa to show optimum path [12]

In metaheuristic there are different optimization methods like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) etc. [11]. From the literature survey, GA and PSO have been shown some draw backs like time consuming and many numbers of iterations required to find the better solution when compared with the ACO [12]. ACO has shown better optimal solutions in both maximization and in minimization problems in different design applications [10, 11]

In this work, the application of ACO to design agitation equipment for mixing solid-liquid phases has been adopted. The process parameters like impeller diameter to tank diameter ratio, impeller speed, particle diameter, two-phase mixture density, and changing the percentage weight of two phases have been considered to maximize the objective function.

THEORETICAL SECTION

Introduction to ant colony algorithm

Ant Colony Optimization's algorithm is capable of solving a wide range of issues, including minimization and maximization. Nodes and undirected areas are the two main metrics used in this. These two sites are crucial for building paths to solve minimization or maximization issues, at the source node and destination node. These points will serve as the initial and final destination for this optimization strategy [10, 11]. Ants will create loops to design the solution, and it will be appealing by changing the pheromone [10].

Real ant behavior

Ant behavior is considered in three steps related to optimization for getting possible solutions. In the first step, it should be biased using pheromone trails by updating without forwarding. In the second step, the backward-moving path is eliminated and the fresh pheromone will be updated. In the final step based on the pheromones deposit the quality will be assessed. This is also known as evaporating pheromones with time. Forward mode and backward mode are two working modes which are shown in Fig. 3.

One of the working modes is forward which affects the ants moving from nest to food, and another mode is backward from food to nest. When the ant reaches to food means destination it will start backward mode immediately. When ant moves in forward direction it will choose by nearer node of other ant probabilistically based

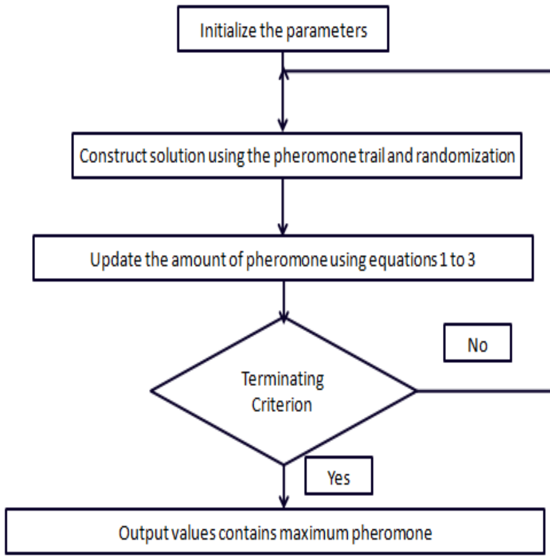


Fig. 4: Methodology of ACO

on the pheromones released by ant in backward direct mode. It will help for avoiding loops by depositing pheromone in backward mode. For destination node the memory of ants allows to create for retracing path for searching by improving overall system like elimination of loop when its starts to backward mode based on the memorized path stored in ants. The pheromone leaves by ants are based on the traversed areas. Based on the cost of the path evaluated by ants, by depositing the pheromones it modulates so that it will help to get better solutions by reducing the poor quality.

Working of optimization

Each ant begins by building a solution from a beginning node close to the source, utilizing a step-by-step decision-making process as shown in Fig. 4. The information is stored in each node, enabling ants to read it quickly and choose data probabilistically as they advance step by step toward their target. The search strategy starts with a set number of pheromones in each area at the beginning of the operation. It is at node ant, and k determines the following node at random for choosing j using a pheromone trail:

$$p_{ij}^{k}(t)=\begin{cases}\dfrac{\left[\tau_{ij}(t)\right]^{\alpha}\left[\eta_{ij}\right]^{\beta}}{\sum\limits_{l\in J_k(i)}\left[\tau_{il}(t)\right]^{\alpha}\left[\eta_{il}\right]^{\beta}} & if\;\; j\in J_k(i)\\ 0 & if\;\; j\notin J_k(i)\end{cases} \tag{1}$$

When the i^{th} node is taken into account, $J_k(i)$ is close to k(ant). The variable is used to demonstrate the significance of the pheromones. The remaining neighboring nodes that are connected directly make up the i^{th} node. As a result, there will be fewer ants returning to the same node before my node arrives. Node i's predecessor is contained in J_k if $J_k(i)$ is empty, which equates to a dead end in the graph. Before arriving at the destination node, an ant travels from node to node.

Ants tracing creates a new path

Ants will start to erase the loops they generated while searching for the destination node when they begin migrating to their source node, which is known as the reverse mode. Only by applying the scanning technique is it capable. The order of elimination determines whether it is required to remove the longest loop. The k^{th} ant leaves pheromone deposits in the areas it has visited when it begins to return. The pheromone value steadily changes as(i, j) is traversed as follows:

$$\tau_{il} \longleftarrow \tau_{il} + \Delta\tau^{k} \tag{2}$$

This rule increases the probability that ants will go through these areas:

Evaporation of pheromone

It is helpful to look for different paths in the entire procedure if the pheromone strength gradually decreases. By lowering the number of undesirable possibilities, helps in path selection. It is also helpful for locating pheromone trails with the greatest value. Pheromones attempt to dissipate when every atom of k is transported to the neighboring node using the following formula:

$$\tau_{ij} \longleftarrow (1-\rho)\,\tau_{ij}\,,¥(i,j)€A \tag{3}$$

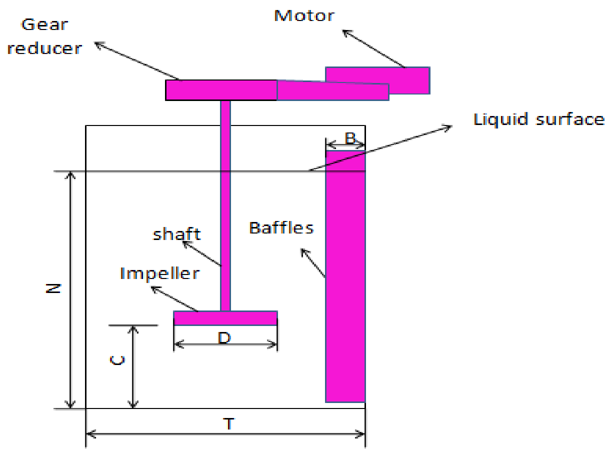
Where $p€(0,1]$is a parameter, Iteration is a completer cycle involving ant's movement, pheromone evaporation, and pheromone deposit.

Problem formulation

Fig. 5 shows a basic model diagram of agitation equipment. The primary factor affecting both the impeller region's characteristics and those of the rest of the tank is the rate of energy dissipation. [14-17]. The methodology of work is to predict the maximum power by varying

Table 1: Np values considered for impellers [9]

S.No	Type of Impeller	N_p (Base on impeller Power Number varies)
1	Propeller	Less than or equal to 0.75
2	Paddle /Pitched	Less than or equal to 3
3	Rushton	Less than or equal to 6



Nomenclature of Equipment parameters

D	Diameter of the impeller
C	Distance of impeller from bottom of tank
T	Diameter of tank
N	Height of the liquid or slurry
B	Width of Baffle Plates

Fig. 5: Parameters of Jacketed vessel [14]

different conditions that give the best result in less time and are more accurate comparatively based on the objective function, which affects the exchange of heat and mass between two phases. Best variables are also found to design the tank diameter (T), impeller diameter (D), density of solid-liquid phases, and power number based on the selection of impellers.

The precise mode equation is

$$\text{Maximize of Power} = N_p * \rho_{slurry} * Q^3 * D^5 \quad (4)$$

The power used by the agitators is estimated using a power number, which is a Newton number. In this work, three types of impellers were used to estimate the power consumption of different impellers shown in Table 1 for various applications. In this case, the solids must be lifted and maintained in suspension by an external force. The just suspension speed (N_{JS}) of solid particles must be lower than the speed of the impeller for uniform suspension in the liquid inside the tank [19]. The major constraint is impeller speed should be greater than just the suspension speed of the particles. The formulation of constraint and Just suspension speed is shown in Equations (5) and (6).

$$G_1 = Q > N_{js} \quad (5)$$

$$Nj_s = s.\vartheta^{0.1}.\ (g.\ \frac{\Delta p}{\rho_L}).X^{0.13}.d_p^{0.2}.D^{-0.85} \quad (6)$$

Where,

Njs	= Just suspension speed for particles
s	= Shape factor called Zwietering's constant
ϑ	= liquid kinematic viscosity
g	= acceleration due to gravity
Δp	= solids-liquids density difference
ρL	= Liquid Density
X	= is solids concentration by weight
dp	= diameter of solid particle
D	= diameter of Impeller
Q	= Speed of the Impeller

The Parameters are considered for agitation equipment are ratio of impeller diameter to tank diameter is 0.2 to 0.5(Y_1), particle diameter from 0.00001mm to 0.0001mm (Y_2), the percentage of coal in coal water slurry is 50 to 80 (Y_3) and impeller speed varies from 100 to 2000 in rpm (Y_4).

RESULTS AND DISCUSSIONS

The ACO was used by switching the impeller type; the power number values are taken from Table 1, parameters which are considered Y_1, Y_2, Y_3, and discussed in the above section. In this program, maximum ants and maximum iterations are 100 and 250, respectively. The parameter of trail value is 1, and the rate of evaporation is 0.8.

Table 2 indicates the optimal variables for the propeller, pitched/paddle, and Rushton impellers. Among the three impellers, the Rushton impeller has the maximum power output value when compared with the other two. Based on the result for agitation equipment the motor power can be considered the power value of Rushton impeller. In Fig. 6 for the propeller impeller, the output value increases from 1-50 iterations, 50-150 iterations the value is increased, and for 150 - 200 up to a certain stage is constant after 200-250 there is a sudden change increase in output. From Fig. 7 the power value increases gradually between 1-50 iterations, there is an increase in value from 50-100 iterations, and between 100 - 250 iterations the power value is constant. Fig. 8 shows the power value is gradually increased between 1-100 iterations from 100 to 250 iterations the value is stead. From all three impellers after 250 iterations, there is no change in power value.

Table 2: Optimal values of parameters are evaluated three impellers

Impeller Type	Obj Function	Y_1	Y_2(mm)	Y_3(%)	Y_4(rpm)	G_1(rpm)
propeller	1175.80	0.5000	1.5000e-05	63	1990	1058.5
Paddle/Pitched	4408.80	0.5000	9.0000e-05	66	2000	1618.0
Ruston	8856.70	0.5000	1.0000e-04	66	1975	1604.1

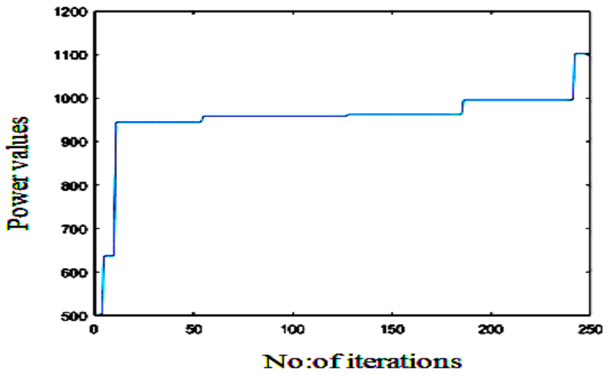


Fig. 6: Indicates propeller type power value

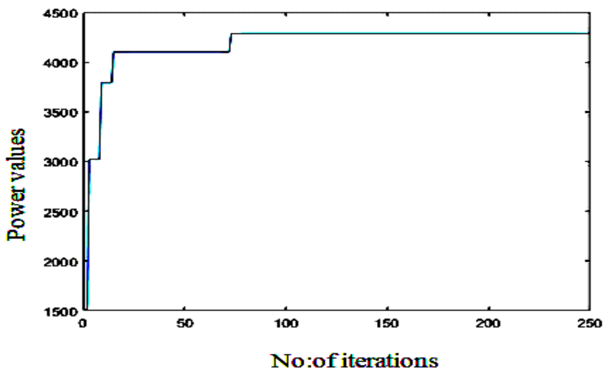


Fig. 7: Indicates paddle or pitched type power value

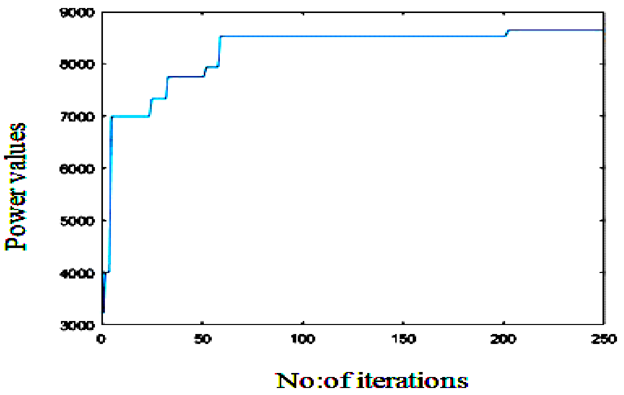


Fig. 8: Indicates Rushton type power value

Impact analysis on the output of ACO

Estimation of power holds major importance for the design of mixing equipment. Since power is closely related to flow patterns, we can draw some inferences about the state of mixing (thereby of overall performance) from the power consumption [19,20]. The distribution of the power usage in the mixing operation is of interest, and power delivered to the mixing is very important in judging the mixing performance received from the agitator.

From the above Figs. 9 to 12, by keeping ants constant and changing the iterations minimum of 100 to a maximum 250 with an increment of 50 iterations. For the propeller, paddle or pitched impeller, and Rushton the power values by keeping 25 ants, 1076.30 W, 4286.40 W, and 8249.70 W. By keeping 50 ants the power values of the propeller, paddle or pitched impeller and Rushton the power values, is 1091.2 W, 4231.1 W and 8610.2W. When 75 ants the power values are for propeller type 1169.1239 W, 4324 Watts Paddle or Pitched impeller,8648 W for Rushton impeller, and by keeping 100 ants the power values for propeller impeller is 1175.8W, for Paddle or Pitched type impeller 4408.8 W, 8856.7 Watts for Rushton type impeller.

From Fig. 13 to 16 by keeping iterations constant and changing the ants 25 to 100 with an increment of 25ants, the value of power is increased for every ants in all impellers the values given below of value of power for 100 ants by keeping 100 iterations constant 1086.10watts for propeller type impeller,4351.30Watts for Paddle or Pitched type impeller,8724.50Watts for Rushton type impeller, by keeping 150 iterations constant the power value is increased power value is 1091.2 Watts for propeller type impeller,4362.3Watts for Paddle or Pitched type impeller,8817.7Watts for impeller Rushton . For200 iterations constant the maximum power value is 1175.8 Watts for propeller type impeller, 4408.8 Watts for Paddle or Pitched type impeller, 8856.7Watts for Rushton type impeller. From the values mentioned Rushton impeller's power value is the maximum when compared to the other two impeller types.

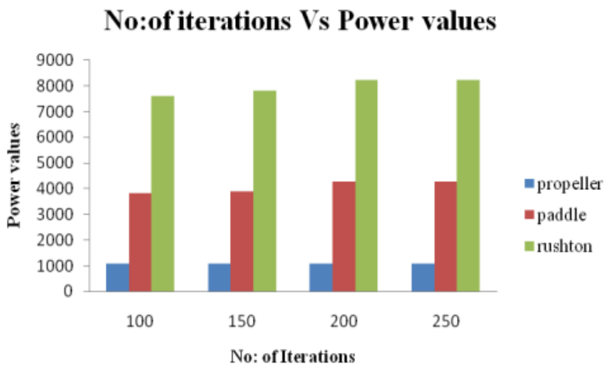


Fig. 9: 25 ants iteration Vs power value

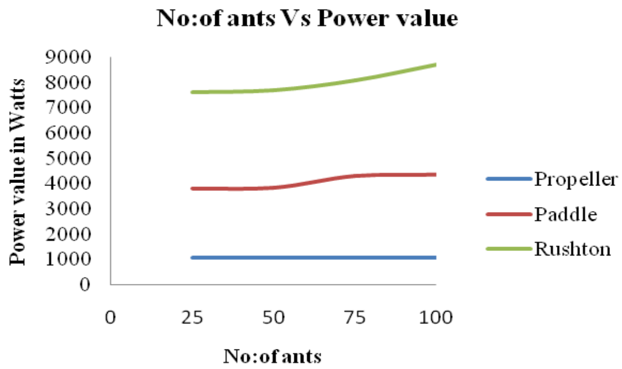


Fig. 13: For 100 iterations ants Vs power value

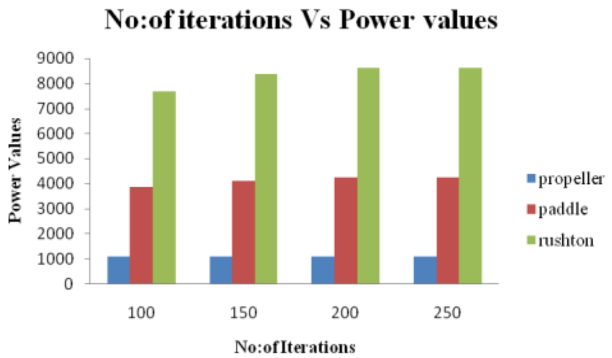


Fig. 10: 50 ants iterations Vs power value

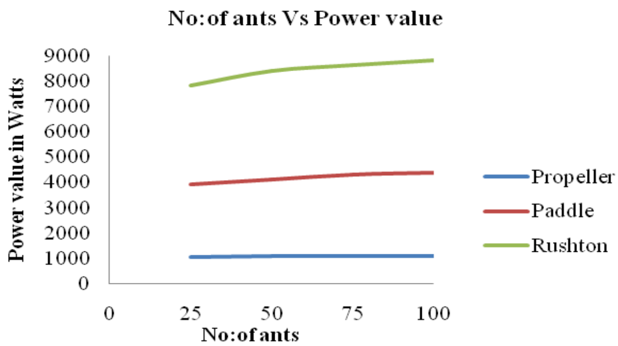


Fig. 14: For 150 iterations ants Vs power value

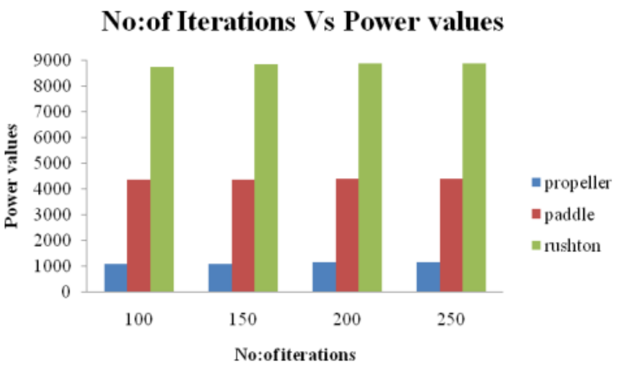


Fig. 11:75ants iteration Vs power value

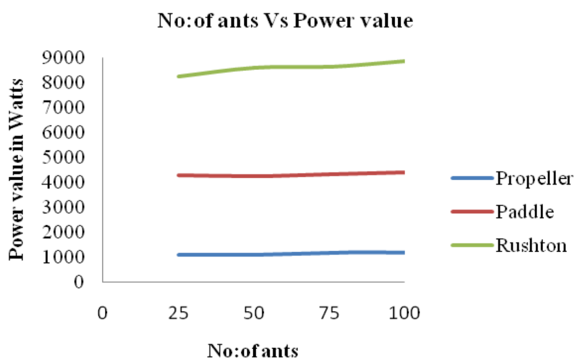


Fig. 15: For 200 iterations ants Vs power value

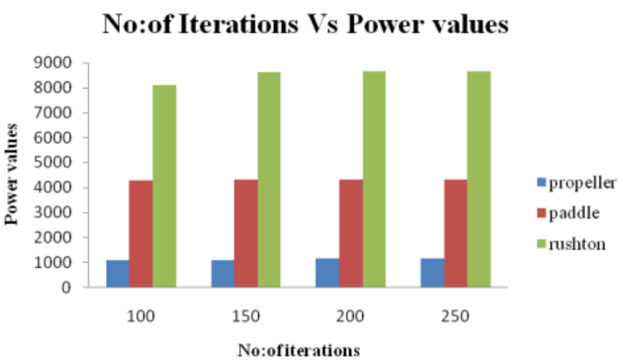


Fig. 12: 100 ants iteration Vs power value

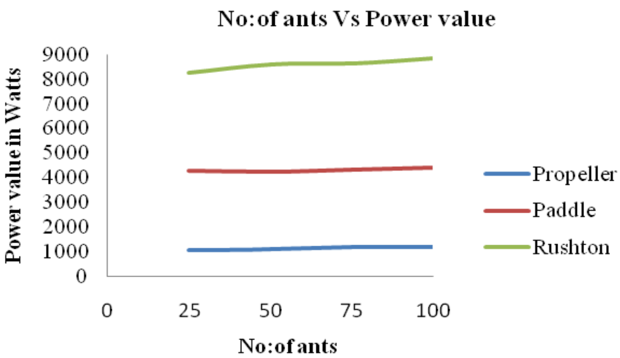


Fig. 16: For 250 iterations ants Vs power value

CONCLUSIONS

In this study, the value of power for the preparation of coal and water mixture was maximized using Ant Colony Optimization approach. The ratio of the impeller diameter to the tank diameter, the diameter of the particle, and the weight of the slurry are the design elements taken into account in the study. Propellers paddle or pitched impellers, and Rushton-type impellers can all be successfully operated using the mathematical models created using these factors. This study shows that, among the three impeller types Rushton induces high power.

- For the Propeller impeller, paddle or pitched impeller, and Rushton impeller the power values from ACO are 1175.80 W, 4408.80 W, and 8856.70 W among the three impellers Rushton impeller having more power which is considered to be design agitation equipment which is useful for uniform suspension of coal particles in liquid.
- From sensitivity analysis by keeping ants constant and varying the iterations for robustness the value of the Rushton impeller is 8856.70 W.
- The power value gradually rises to a set number of iterations, after 250 iterations the value has not changed. When evaluating power based on the parameters for mixing solid-liquid phases, large and small companies can use the methods used here.

Received : Dec. 21, 2021 ; Accepted : Apr. 24, 2023

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