Optimal Power Generation from Bagasse in a Sugarcane Plant using PSO Algorithm Compared to SQP Algorithm

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ABSTRACT:
Due to the high amounts of sugarcane residue or bagasse which was produced by sugarcane plants in Iran, this study was aimed to optimize power generation from bagasse biomass in sugarcane plants using Particle Swarm Optimization (PSO) algorithm by data obtained from several case studies which had been simulated with SQP (Sequential quadratic programming) algorithm. In these studies, bagasse containing 50% moisture content (MC) alone or with fossil fuels, as well as bagasse with a moisture content of 40% and 30% with fossil fuels were used. Optimization values showed that 20% decrease in bagasse's MC caused 55.6% increase in power generation efficiency, 36.3% reduction in gas emissions as well as 100% bagasse saving. PSO showed similar results to SQP and it seems that it is a proper algorithm than SQP. Therefore, if the bagasse is more dried by solar energy to lower MC, the greater efficiency of power generation is obtained.

KEYWORDS: Bagasse, Power Generation, PSO Algorithm, Optimization.

1. INTRODUCTION

Regarding rising in energy demand due to rapid urbanization, the sugar industry which is located in the vicinity of urban regions, plays an important role to manage this energy challenge using supply significant part of this demand. Sugar factories as power generation plants can be used to meet the community needs for energy via processing biomass feeds such as sugarcane bagasse [1]. Bagasse or residue of sugarcane stems is a byproduct in sugar factories which has become a valuable fuel due to technology advances in using co-generation systems [2]. Studies have shown that the efficiency of bagasse to power generation is greater than bioethanol production and it is more advantageous to use it for electricity generation [3]. An energy surplus up to 33 MW can be obtained using bagasse which can be sold to national electricity grid [4]. In Iran, Mazut and natural gas are the main fuels used to generate energy in Agro-industry complex. Due to expensive and pollutant fossil fuels as well as high availability of bagasse, it is possible to replace the fossil fuels with bagasse in power generation plants.

2. LITERATURE REVIEW

Different studies on optimization of power generation from various biomasses have suggested that bagasse has been successfully used in the process of electricity and heat cogeneration in sugar factories [5-7]. According to an optimization study which has been performed by the Sequential Quadratic Programming (SQP) algorithm [7], bagasse can be used in combination with other energy sources as an alternative fuel for sugar production as well as power generation in the sugarcane plants. In the mentioned study, different combinations of bagasse, coal and other biomasses along with solar energy were evaluated in order to bagasse saving and minimization of carbonic pollutants emissions since the use of bagasse causes gas emissions during power generation [7]. In another simulation, dryer bagasse was found to be more efficient for power generation with a lower emission [8]. In fact, in the process of power generation from bagasse in a power plant, the operators are forced to reduce emissions of pollutants due to their adverse effects on environment [7, 9-11]. Therefore, considering this issue is also necessary in the optimization problems.

Although several studies have shown that Iran has a significant potential to use biomass as a biofuel, bagasse application has not been optimized. Therefore, in the present study, an optimization problem was solved using Particle Swarm Optimization (PSO) algorithm for generating power and reducing environmental pollutants according to the previous data [7] and regarding the various parameters such as different combinations of bagasse with fossil fuels, as well as different moisture content of bagasse.

3. MODELLING AND OPTIMIZATION

In this study, the data was obtained from a case study in a sugarcane factory consuming 10,000 tons of sugar cane per day [7]. Since the aim of this study was to optimize power generation from bagasse using PSO algorithm, and also regarding no availability of the original data from the reference case study, the approximation method was first used for simulation using MATLAB.

The main objective of the problem was to minimize the consumed amount of bagasse and emitted pollutants during cogeneration as well as, to obtain the optimal amount of generated power using solar energy. The objective functions were the bagasse weight and emission amount.

The bagasse weight "$F_W(P_{g1})$ was obtained in tons per hectare using curve fitting method (Equation 1).

$$F_w\left(P_{gI}\right)=aP_{gI}^3+bP_{gI}^2+cP_{gI}+d \tag{1}$$

Where, a, b, c and d coefficients are the weight coefficients for bagasse fuel and "P_{g1}" is the actual output of powered generated by bagasse fuel.

Major emitted pollutants in a thermal power plant using bagasse, coal and biomass are CO_2, SO_2 and NO_2 [7, 8]. The equation for general emission of gases " $F_e(P_{gi})$" (kilograms per hectare) was produced due to the combustion of a combination of bagasse, other biomass and coal in a boiler, can be shown as follows:

$$F_e\left(P_{gi}\right)= \sum_{i=1,2,3} \alpha_i P_{gi}^3+ \beta_i P_{gi}^2+ \gamma_i P_{gi}+ \delta_i \tag{2}$$

$$i=\begin{cases} 1 \text{ for bagasse} \\ 2 \text{ for coal} \\ 3 \text{ for biomass} \end{cases}$$

α_i, β_i, γ_i and δ_i coefficients are the emission coefficients for ith fuel which was used.

Total demand "$\left(P_D^t\right)$" includes the amount of power required for the sugar factory performance "P_p"and the power provided for the electricity grid "P_g".

The electricity power obtained from sunlight varies and so can be considered as a variable load. Therefore, this power "$\left(P_D^t\right)$" was deducted from the total demand. The net actual demand was represented as:

$$P_D^a=p_D^t-P_s \tag{3}$$

Thus, the optimization problem can be summed up as follows:

$$\text{Minimize } \left(F_W\left(P_{gI}\right),F_e\left(P_{gi}\right)\right) \tag{4}$$

In this way, the optimization problem was solved with the given constraints using MATLAB. Afterwards, the optimization values were obtained and the related diagrams were drawn.

The total objective function was considered as the sum of F_w and F_e functions and loss function was zero, for optimization. Then, using the data from Tables 1 and 2 [7], the convergence diagrams were plotted. The convergence diagrams represent the best cost in terms of iteration. So that, 5-8 equations were used.

$$(F=a_p^3+b_p^2+c_p=d \tag{5}$$

$$E=a_{1_p}^3+b_{1_p}^2+c_{1_p}=d_1 \tag{6}$$

$$P_{d_1}=P_d+P_L \tag{7}$$

$$P_L=0 \tag{8}$$

Table 1. The bagasse weight coefficients.

Moisture content (%)	a	b	c	d
50	7×10^{-6}	-2.8×10^{-3}	0.7065	13.341
40	4×10^{-6}	-1.8×10^{-3}	0.5733	13.341
30	2×10^{-6}	-2.2×10^{-3}	0.8062	13.341

Table 2. The emission coefficients.

Fuel	α	β	γ	δ
Bagasse (MC:50%)	1×10^{-5}	-5×10^{-3}	1.20	22.04
Bagasse (MC:40%)	6×10^{-6}	-3×10^{-3}	0.95	22.04
Bagasse (MC:30%)	1×10^{-5}	-2.2×10^{-3}	0.81	22.04
Coal	1×10^{-7}	-2×10^{-4}	0.51	28.39
Biomass	3×10^{-8}	-1×10^{-4}	0.59	0.62

The objective function was defined as follows:

$$F = F_{cost} + E_{mi} \tag{9}$$

The constraints of the problem are as follows:

$$P_{d_1}=P_d+P_L$$
$$P_L=0$$

$$P_{min} \le P \le P_{max}$$
$$P_1 \le 0.1P_{d_1} \text{ for solar energy}$$
$$P_2 \le 0.3P_{d_1} \text{ for coal}$$
$$P_3 \le 0.2P_{d_1} \text{ for biomass}$$

The number of populations or "n_{pop}" was 30 as well as the number of iterations, "$P_{d_{min}}$" and "$P_{d_{max}}$" were considered as 500, 50 and 150, respectively. The upper and lower limits of power outputs of the generator were assumed to be:

$$50\ \text{MW} \le \sum_{i=1,2,3} P_{gi} \le 150\ \text{MW} \quad (10)$$

4. RESULTS AND DISCUSSION

Usually, bagasse contains 50% moisture which decreased the high calorie value of bagasse. Hence, the use of bagasse for power generation and its emissions is high. When using Bagasse alone as fuel, the weight (W) of bagasse which was used and its emission (E) varied with energy demand (MW) (Fig. 1a). Accordingly, 90kg of emissions release due to generation of 100 megawatts of electricity by firing 60 tons of bagasse per hour. The diagram showed a reduction trend for objective function with the approach to optimal solution for each iteration of PSO algorithm with an optimal value of 71.7725 (Fig. 1, b).

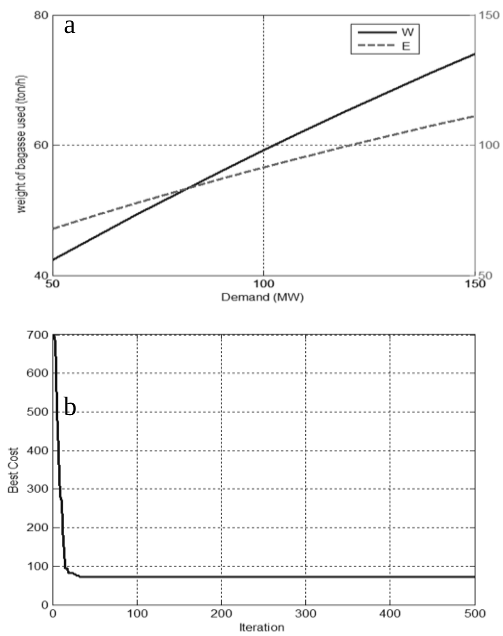

Fig. 1. (a) Variations in bagasse weight and emission along with the electricity demand for bagasse with a moisture content of 50% (MC = 50%) alone; **(b)** reduction trend for the objective function with the approach to the optimal solution for each iteration of PSO algorithm for bagasse with a moisture content of 50% (MC = 50%) alone.

In each case study, "W_a", "W_b" and "W_c" were considered as the amount of bagasse used (tons per hour) as well as "E_a", E_b" and" E_c " as the amounts of released gas (kilograms per hour).

In the first case study, bagasse did not dry up, and hence the amount of fired bagasse containing approximately 50% moisture (MC = 50%) and the amount of emissions regarding the power demand were obtained (Fig. 2, a). Moreover, the reduction trend for objective function with the approach to optimal solution for each iteration of PSO algorithm with an optimal value of 51.2655 was obtained (Fig. 2, b).

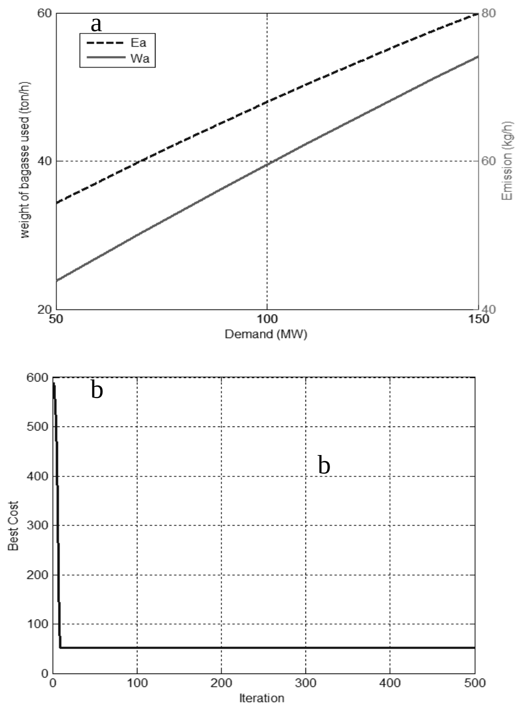

Fig. 2. (a) Variations in bagasse weight and emission along with the electricity demand for bagasse with a moisture content of 50% (MC = 50%) along with fossil fuels; **(b)** reduction trend for the objective function with the approach to the optimal solution for each iteration of PSO algorithm for bagasse with a moisture content of 50% (MC = 50%) along with fossil fuels.

In cases 2 and 3, dried bagasse by solar energy along with coal and biomass were burnt in the boiler. Thus, the bagasse moisture content had been decreased as it was about 40% and 30%, in cases 2 and 3, respectively. The changes in the weight of bagasse which had been fired and the amount of emissions during power generation in the cases of 2 and 3 are shown, respectively (Figs. 3. a and 4.a). For a 100 megawatts power output, 40, 38 and 30 tons per hour bagasse was burned in the cases of 1, 2 and 3 and the gas emissions were 70, 59 and 52 kg per hour, respectively.

For the cases of 2 and 3, the reduction trends for objective function with the approach to optimal solution for each iteration of PSO algorithm (Figs. 3.b and 4.b) with optimal values of 46.9795 and 38.8207 were obtained, respectively.

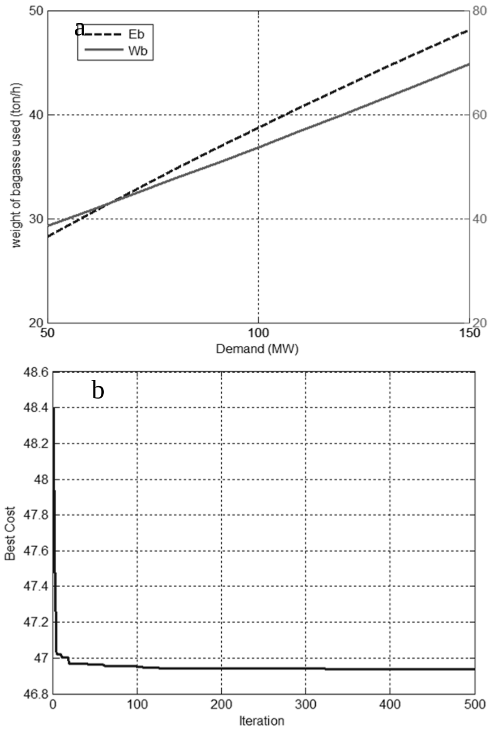

Fig. 3. (a) Variations in bagasse weight and emission along with the electricity demand for bagasse with a moisture content of 40% (MC = 40%) combined with fossil fuels; **(b)** reduction trend for the objective function with the approach to the optimal solution for each iteration of PSO algorithm for bagasse with a moisture content of 40% (MC = 40%) combined with fossil fuels.

The changes in weight of fired bagasse (% ΔW) and amount of emissions (% ΔE) (Fig. 5) represent that with reduction in moisture content (MC) of bagasse, the amount of consumed bagasse decreased, bagasse saving increased as well as emissions decreased. The percentage of fired bagasse and reduction in emissions were related as: $\%\Delta W_a < \%\Delta W_b < \%\Delta W_c$ and $\%\Delta E_a < \%\Delta E_b < \%\Delta E_c$ (a: 30%MC, b: 40% MC, c: 50% MC).

The optimization results showed that when the moisture content of bagasse was decreased from 50% to 30% (20% reduction), optimization value increased for 24.3%. It means that, the efficiency of power generation was optimized. Using 35 tons per hours of bagasse with moisture content of 50% and 30%, 90 and 140 megawatts of power output was obtained, respectively. It represents 55.6% increase in power generation efficiency with 20% reduction in bagasse moisture.

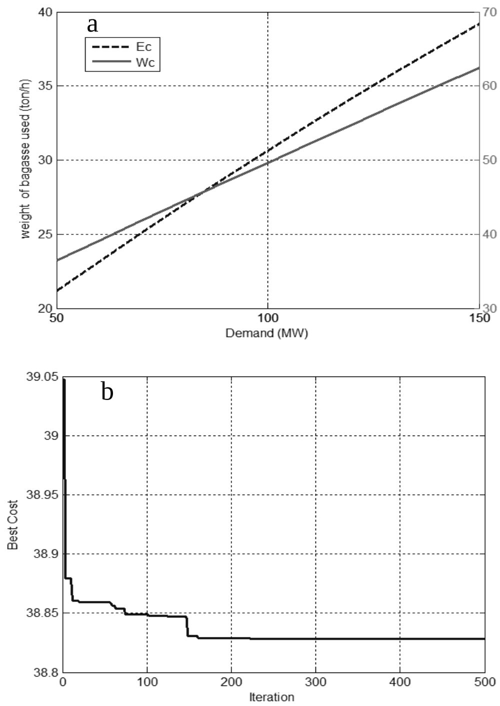

Fig. 4. (a) Variations in bagasse weight and emission along with the electricity demand for bagasse with a moisture content of 30% (MC = 30%) combined with fossil fuels; **(b)** reduction trend for the objective function with the approach to the optimal solution for each iteration of PSO algorithm for bagasse with a moisture content of 30% (MC = 30%) combined with fossil fuels.

Furthermore, regarding (% ΔE) and (% ΔW) values, 20% reduction in bagasse moisture content caused 36.3% reduction in gas emissions and 100% bagasse saving (reduction in bagasse consumption).

The results obtained from this study were compared to similar study [7] which is suggested that in sugarcane factories and other industries consuming bagasse as fuel in boilers, solar energy and cogeneration are used to increase efficiency of power generation. A solar drying system reduces moisture content of bagasse before its burning in a boiler. Such systems can be designed with minimal energy consumption [7, 8]. Therefore, the use of combined fuels is recommended due to bagasse saving and decrease in emissions.

In this study, the results obtained from PSO algorithm were compared to a similar study which was carried out using SQP algorithm [8]. This comparison indicated that bagasse weight required for power generation using PSO algorithm was lower than SQP algorithm, except for bagasse containing 50% and 40%

moisture plus fossil fuels (cases 1 and 2) (Table 3). Moreover, in all cases, the emissions amounts estimated using PSO algorithm were less than the amounts estimated by SQP algorithm. Therefore, it seems that PSO to be a more appropriate algorithm than SQP algorithm to solve this optimization problem. Based on the results of the present study, the lowest consumption of bagasse and the lowest amount of emissions were obtained using bagasse containing 30% moisture which is consistent with the results of the previous study.

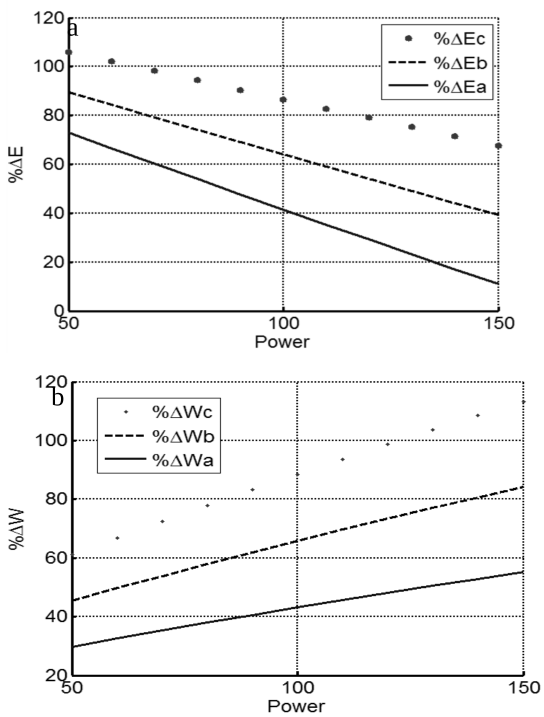

Fig. 5. (a) Change in ΔE (% ΔE) with power demand amount and **(b)** change in ΔW (% ΔW) with power demand amount.

Table 3. Comparison of the results with previous study (W: Weight of used bagasse, E: amount of emitted gas), power output (100 MW).

	PSO algorithm			SQP algorithm	
Moisture content	W (th^{-1})	E (th^{-1})	Optimization value	W (th^{-1})	E (th^{-1})
50%	60	90	71.7725	62	101
50% plus fossil fuels	40	70	51.2655	37	90
40% plus fossil fuels	38	59	46.9795	32	90
30% plus fossil fuels	30	52	38.8207	30	70

In the previous study using SQP algorithm, optimization was not done. So, in the present study, there was a novelty to solve an optimization problem on the data obtained from the previous research (the results were summarized in Table 3). The lowest optimization value was obtained from bagasse with a moisture content of 30%, which suggested more optimized power generation in 30% moisture content. This finding is consistent with the results obtained from previous research [7] which indicated higher power generation using 30% moisture content of bagasse.

With SQP algorithm, for generation of 100 MW using bagasse containing 50% and 30% moisture combined with fossil fuels, bagasse saving was 42% and 52%, respectively; while with PSO algorithm bagasse saving was 40% and 82%, respectively. In addition, the emissions reduction from bagasse with 50% and 30% moisture content using SQP algorithm was 43% and 53%, respectively; while using PSO algorithm it was 42% and 85%, respectively. These results indicate that the PSO method is more appropriate than the SQP method.

5. CONCLUSION

In the present optimization, various case studies which were reported in a previous study were considered. In the case studies, combinations of bagasse with other biomasses and coal were burnt in a boiler to generate electricity as cogeneration system. Moreover, solar energy was used to dry bagasse before burning in the boiler which caused different moisture content of bagasse including 50%, 40% and 30%. The results of optimization using PSO algorithm showed that 40-50% moisture content in bagasse decreased the efficiency of power generation in sugarcane factories. Therefore, if the bagasse is more dried by solar energy containing less moisture content, the efficiency of electricity generated in a cogeneration system is increased. According to the results of the present study, decreasing the moisture content of bagasse by 20% caused increasing of optimal value by 24.3% and increasing efficiency of power generation by 55.6%. In addition, 20% reduction in moisture content of bagasse caused 36.3% reduction in gas emissions (% ΔE) and 100% bagasse saving (% ΔW). Comparison of the results of PSO algorithm with SQP algorithm indicated that bagasse weight required for power generation using PSO algorithm was lower than SQP algorithm, except for bagasse containing 50% and 40% moisture plus fossil fuels. Furthermore, in all cases, the emissions amounts estimated using PSO algorithm were less than the amounts estimated by SQP algorithm. Therefore, it seems that PSO to be a more appropriate algorithm than SQP algorithm to solve this optimization problem.

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