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A New Approach for Optimization of Combined Heat and Power Generation in Edible Oil Plants

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Abstract: In this study, different available sources of supplying electrical energy in edible oil plants such as Combined Heat and Power Generation (CHP) in a steam plant, Diesel Generator (DG) power plant and national grid have been investigated and the energy conversion efficiencies have been measured using the suitable methods. The edible oil plant of Behshahr Agro-Industry Company in Iran was considered as a case study. The CHP system has been considered as the first choice for simultaneous thermal and electrical energy generation in the plant, due to the higher efficiency. For running on the optimum condition of the CHP system, an optimization model was developed based on the collected data of steam, edible oil production and electrical power generation in a year by using multiple regressions for having an equation between steam, edible oil and electrical power. The model was solved in GAMS software and the optimum condition of CHP with consideration of equipment characteristics and operational limitation were concluded. The results showed that on the optimum condition of CHP, 600 kW excess electrical power can be generated. This offers an excellent opportunity for the factory to generate 107,352 USD. Year^{-1} additional revenue and to reduce considerable amount of air pollutants.

Key words: Combined heat and power generation, diesel generator, energy conversion, optimization model, air pollutants

INTRODUCTION

Increasing rate of the fuels cost and tighter control of environmental aspects have forced many industries to optimize the energy systems for energy conservation (Ataei *et al*., 2009a). Electrical and thermal energy play a key role in many industries and supplying these two forms of energy is critical. Combined Heat and Power (CHP) systems are becoming main energy conversion methods in many industries because of the high energy conversion efficiency (Ataei, 2009; Descombes and Boudigues, 2009; Fumo *et al*., 2009).

Electricity cut or bad quality of electrical power from public grid can causes interruption in production, damage to some process, equipment and loss of production. Consequently, for some industries it is preferable to supply their need for electricity by implementing internal power plant instead of supplying from public grid (Ataei, 2009).

In recent years, a lot of studys about optimization of CHP's by Linear and non-linear programming, mathematical modeling, exergetic and thermo-economic analysis were published (Subbaraj *et al*., 2009; Descombes and Boudigues, 2009; Rong *et al*., 2009; Li and Wu, 2009). Savola and Fogelholm (2006) have optimized four CHP systems by nonlinear programming which improved electrical efficiency from 17-29% to 28-30% and the power to heat ratio increased from 23-48% to 45-50%. Hamed *et al*. (2006) reduced cost of electricity production in a 118 (MW) Rankine cycle based CHP by 4.3%, using the thermo-economic analysis.

The CHP optimization methods, which presented by Ataei (2009), Descombes and Boudigues (2009) and Rong (2009) did not explore the optimum condition of the CHP system regarding the historical plant data on demand side of the steam. Furthermore, in those methods, the rate of energy consumption was considered as a constraint of the optimization model. However, the steam product ratio

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should be considered as a constraint of the optimization model and the objective function required to be fitted to the power product ratio because in edible oil plants the power and steam consumption is varied. Therefore, in previous methods the cost of the optimization project cannot be minimized regarding the constant steam product ratio.

To overcome the aforementioned limitations, the new optimization model for the CHP system of the edible oil plants has been introduced in this study. The new CHP optimization technique was tested in Behshahr agro-industry plant, which was composed of two steam turbines, as an illustrative example. Related coding in GAMS optimization package (Brooke *et al*., 1998) was used for the illustrative example to get optimal values in the proposed design method computations.

MATERIALS AND METHODS

System description: Edible oil refining industries are one of the energy intensive sectors in the group of food industries. Most of processes are similar to chemical and petrochemical industries but in lower scale. Major forms of energy which use in edible oil plants are electrical and thermal energy. Electricity is mainly used in electro-motors for running pumps, separators, mixers, compressors, conveyors and fans. Thermal energy produced by burning of fossil fuel in the boiler for generation of steam and heating up the thermal fluid. The produced steam is mainly used for heating of the edible oil in refining processes and in some extents, it uses as the motive fluid in steam jet ejectors in the vacuum system and for mixing of the oil. The thermal fluid is only used for heating of the edible oil in high temperature degrees. The supplying of energy and further conversion of energy in the under studied plant is described in Fig. 1.

In this study, optimization of the energy system in Behshahr agro-industry Company was considered for maximization of power generation as an illustrative example. This study has conducted from September 2007 to March 2009. In the under studied factory, Diesel fuel is supplied to diesel generators which total installed

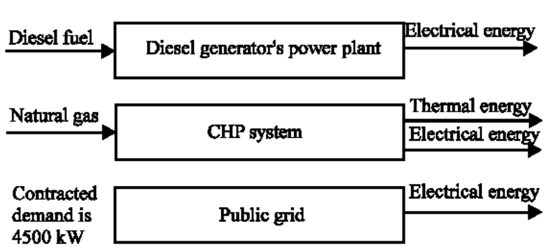

Fig. 1: Primary energy sources and conversion

capacity is 10 MW and they made by Mirrless Blackstone company. The rotational speed of two engines is 600 rpm and the others are 428 rpm. All of engines have turbo charger CHP system; consist of Babcock and Wilcox water tube boiler, which generate superheated steam in 41 (barg) and 360°C. Heat transfer area in the boiler section is 552 m^2, furnace 79 m^2, super heater 119 m^2 and economizer 428 m^2.

There are two steam turbines in this system, which operate in parallel. Steam turbine No.1 is a Single Automatic Extraction Condensing (SAXC) made by Worthington Corporation. The rotational speed of the turbine is 4250 (rpm), but it reduces to 1000 (rpm) for 2.5 (MW) electrical generation, by using a reduction gearbox. The feed steam is flowing to the turbine from the boiler at 41 (barg) and some of it extracted at 11(barg) from the turbine and enters to the main steam distribution system and the rest continues flowing to the condensing section by the automatic system. The condensate pumps to deaerator as a part of boiler feed water. The steam turbine No. 2 is a Back Pressure (non- condensing) type which made by Fincantieri. Similar to the turbine No.1, steam is flowing at 41 (barg) and extracted at 11 (barg) to the main steam distribution system. The rotational speed of the turbine is 12000 (rpm) and it reduces in gear box to 1500 (rpm) for 3 (MW) electrical generation. All of the extracted steam at 11(barg) enters to the main steam distribution system for using in the edible oil refining processes. This system continuously runs 355 days per year.

It is important to have a stable steam pressure in the steam distribution mains and this achieves by single Automatic Extraction Condensing turbine which controls steam pressure of mains. In case of increasing steam pressure from 11 (barg) in steam mains which means reduction in steam consumption of the processes, automatic system of turbine flows steam to condensing section to control steam pressure by condensing the steam without any changes in electrical power production. This turbine controls steam and electrical load independently. Schematic diagram of CHP system is presented in Fig. 2.

Electricity is supplied from electricity public grid with the contracted demand of 4500 kW by 20 kV lines.

Efficiencies: Alternative choices in supplying electrical energy as described in Fig. 1 gives flexibility, but important matter in view point of energy is conversion with maximum allowable efficiency to reduce Specific Energy Consumption (SEC) and avoid using systems with low efficiency. In order to have a benchmark for operating policy, we need to have an idea about efficiencies of these systems. Necessary measurement was done on stack by

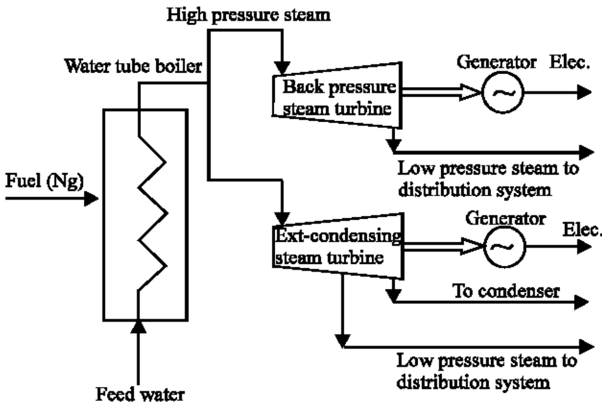

Fig. 2: Schematic diagram of the CHP system

Table 1: Composition of flue gas

Items	Amount
O_2	13.10%
CO_2	4.50%
Ambient temperature	17.8°C
Flue gas temperature	368.5°C

Table 2: Ultimate analysis of diesel fuel

Items	Amount (%)
C	82.74
O_2	1.09
S	1.05
H_2	14.94
N_2	0.18

Testo 350XL flue gas analyzer from recommended sampling point and the results are shown in Table 1.

Composition of diesel fuel based on mass fraction presented by supplier is shown in Table 2.

Necessary calculation was done and efficiency and different losses in diesel engine specified and shown in Fig. 3. Calculated efficiency for diesel engine is 42.03%.

Energy efficiency of steam boilers and turbines are playing a key role in result of the optimization. In case of low efficiency of equipment, first it is reasonable to improve the efficiency by doing necessary remedies or installing new equipment and then starting optimization of whole system to achieve a better result. Steam Boiler Losses are mainly categorized to Stack Losses, Blow-down losses and Body losses. For operating in optimum condition it is necessary to minimize these losses (Ganapathy, 2003).

In comprehensive methods which are based on British standard No. 845 (1987), all of the heat flows are calculated. Calculation of losses flows are based on measurement of necessary parameters in the defined condition in standard.

Calculation of combined heat flows and thermal efficiency: Thermal efficiency can be calculated by direct and indirect test methods. In direct method by calculation of input heat flows and output heat flows, efficiency is calculated. In indirect method, input heat flows or output heat flows (whichever is possible) and thermal losses are calculated and then efficiency can be estimated (Chattopadhyay, 2001; Rajan, 2006).

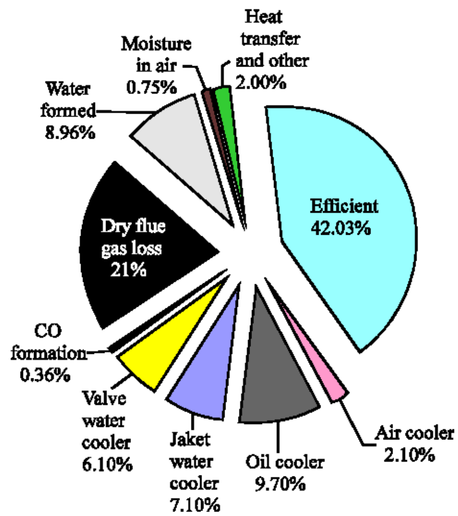

Fig. 3: Energy distribution in diesel engine

Table 3: Composition of Natural Gas

Constituent	Vol (%)
CH_4	86.14
C_2H_6	9.34
C_3H_8	3.25
C_4H_{10}	0.25
C_5H_{12}	0.55
CO_2	0.47

In the direct test when the steam flowrates and enthalpies are known:

$$G_5 = G_3 - G_4 \tag{1}$$

In the indirect test when the fuel firing rate is known;

$$G_5 = G_1 - G_2 \tag{2}$$

Calculation of thermal efficiency:

$$R_{gr} \text{ or } R_{net} = 100 \cdot \frac{G_5}{G_1} \tag{3}$$

Fuel analysis: Fuel which is uses in boiler burner is natural gas and the composition of it is shown in Table 3.

Inlet air analysis: Inlet air relative humidity was measured by Testo 625 and the amount of that was 21%. The

Table 4: Composition of flue gas

Items	Amount
O_2	5.90%
CO_2	8.60%
CO	9 ppm
NO	91 ppm
NO_2	0.9 ppm
SO_2	1 ppm
CxHy	340 ppm
Amb. Temp.	33.8°C
Flue Gas Temp.	178.4°C

Table 5: Parameters in extraction-condensing turbine

Item	Input	Gland	Condenser	Output
P (bar)	38.24	0.9	0.2	11.6
T (°C)	350.0	126.0	49.0	252.0
m (kg sec^{-1})	3.38	0.05	2.64	0.69

Table 6: Parameters in back pressure turbine

Item	Input	Gland	Output
P (bar)	39.89	0.95	11.6
T (°C)	350	149	149
m (kg sec^{-1})	10.55	0.143	10.407

atmosphere pressure was measured by Vacubrand (DVR5) and the amount of that was 881(mbar).

Flue gas analysis: The analyzing of the flue gas was done by Testo 350XL analyzer via the recommended place in standard for sampling. The results are shown in Table 4.

Calculation of heat flows:

- Heat flowrate from calorific value of gaseous fuel, F3

The measured flow rate is 0.58 kg sec^{-1}. By calculation of the gross calorific value which is Q_{gr} = 50510.77 (kj kg^{-1}) we have:

$$F_3 = 29296.25(kw) \tag{4}$$

- Heat flow rate in the unburned gas (F_{22})

$$F_{22} = 121.25(kW) \tag{5}$$

- Sensible heat flow rate in the dry flue gas (F_{23})

$$F_{23} = 30.6\cdot(t_7 - t_3)\cdot C_1\cdot\frac{100}{12\cdot\left(V_{CO_2}+V_{CO}+\sum_n V_{C_nH_m}\right)}\times\left(M_C+\frac{M_s}{2.67}-M_{CR}\right)$$

$$F_{23} = 1919.668(kW) \tag{6}$$

- Heat flow rate of the flue gas from sensible and latent heat in moisture of the fuel (F_{24})

$$F_{24} = C_1\cdot(M_E+9M_H)\times\left[4.2(39-t_3)+2409+1.88(t_7-39)\right]$$

$$F_{24} = 3160.01(kW) \tag{7}$$

- Heat flow rate added to moisture in the combustion air (F_{26})

$$F_{26} = 752.1(kW) \tag{8}$$

- Sensible heat flow rate in the gaseous fuel

$$F_{36} = 0.58\times 2.178(34.4-33.8) = 0.758(kW) \tag{9}$$

- Heat flow rate due to the mechanical energy of auxiliaries (F_{36})

$$F_{46} = 77.5(kW) \tag{10}$$

- Heat flow rate emitted by radiation, convection and conduction (F_{50})

This amount considered 0.5% based on standard recommendation.

Calculation of efficiency:

$$G_1 = F_3 + F_{36} + F_{46} = 29374.51(kw) \tag{11}$$

$$G_2 = \sum_{22}^{24} F_{ij} + F_{26} + F_{50} = 6099.53(kw) \tag{12}$$

$$G_5 = G_1 - G_2 = 23274.98(kw) \tag{13}$$

$$\eta_{gr} = \frac{G_5}{G_1} = \frac{23274.98}{29355.51} = 79.23\% \tag{14}$$

By using the comprehensive method for assessing thermal performance of boiler introduced in British standard No. 845 (1987), efficiency of boiler was concluded and it was 79.23% based on high heating value of the fuel.

Isentropic efficiency of the steam turbine is calculated after measurement of the pressure, temperature and mass flowrate which is shown in Table 5 and 6.

By calculating Isentropic efficiency of turbines are assessed and it was 53% for extraction-condensing turbine and 71.1% for back pressure turbine. Investigation shows that efficiencies of boiler and extraction condensing turbine is lower than normal range for this equipment and needs to be improved.

Problem description: Bad quality of electrical public grid such as cut, flickering, surges and other quality problem makes interruption in operating of equipments and causes damage to some processes, equipments and loss of production. A lot of waste appears during trip of equipment and start of equipments and stabilizing the condition takes some hours. In some cases especially for furnaces, cut of electricity can be a dangerous which can cause overheating of heat transfer surfaced because of stop of feed pumps and lack of water in boiler tubes and drums. Consequently, edible oil companies prefer to supply their demand for electrical power from reliable sources and internal power plant is an attractive choice for them.

Between two choices for supplying electricity by diesel power plants and steam turbines, it is reasonable by the consideration of efficiencies of this equipment to supply electrical demands as much as possible by an efficient system. In this case, simultaneous production of heat and power in CHP systems is the first choice for supplying economic energy to many plants. With consideration of process limitation, we divide all of the electrical consumers into two groups which should be on internal electricity or public grid electricity. It is better to have more consumers on reliable electricity sources to prevent and reduce interruption in trends of production.

As mentioned before, in the co-generation plant of this edible oil factory, we have two different systems for supplying steam and electrical power. Because of the mentioned problem on the electrical power, supply of it from a reliable source is the first priority in the factory. By considering different operating characteristics of CHP`s, the aim is to maximize electrical power generation in systems. Based on the edible oil production plan, an amount of steam for processes is needed to be supplied and the question is how to allocate this amount of steam between two different CHP's to have maximum power generation in the system by considering different operating characteristics?

RESULTS

In order to solve the mentioned problem, first we divide the problem into two sections; steam demand side and steam supply side. The steam demand side is the demand of production units for steam based on the production plan. In this section, we need a relation between steam and edible oil production.

The steam supply side is the supply of steam from extraction of turbines, so we need a relation between steam and electrical power generation in turbines. After definition of these two relations and consideration of some operational and technical limitations, optimum operating point should be defined.

Steam demand side: For estimation of the demand for steam, statistical data of the daily edible oil production in solid and liquid form and also the generated steam collected in one year and after investigation on data, some of them were omitted. This is because of the interruption or start up condition in production lines which caused unsteady trend for the steam consumption. Finally, 320 days data were selected for further calculation. By multiple regressions of data, a correlation for estimation of the steam demand to produced edible oil was calculated, as follow:

$$D(S_i) = 1527.78 + 0.2612 \cdot x_i - 0.1587 \cdot z_i \qquad (15)$$

The steam demand can be estimated by Eq. 15 and the production plan specifies x_i and z_i for calculation.

Steam supply side: Steam is generated in the steam boiler and then enters to steam turbines and extracted from turbines in lower pressure and temperature (Gill, 1984). In order to have a relation between power generation and steam flow in the turbo-generator set, it is necessary to have an equation. The experimental data were collected to find equations for representing relationship between the steam flow and power generation. The result concluded as follow:

For extraction condensing steam turbine we have;

$$P_1 = \frac{S_1 - b}{p_f \times 4.54} + 1000 \qquad (16)$$

where, P_1 is the power generated in the turbo-generator and S_1 is flowing steam and p_f is performance factor of the steam turbine which present performance of equipment and it is uses as a correction factor for the operating chart and consideration of the loss in efficiency during the operating life.

The performance factor was calculated for each point and the average of them was considered as performance factor which the rate amount is 93.34%. The results are shown in Table 7.

The schematic operating chart of extraction-condensing turbine and back pressure turbine have been depicted by Bloch (1995) and Gill (1984), respectively.

The actual data were collected from meters and based on these data and statistical considerations; operating chart for the back pressure steam turbine was created.

Table 7: Performance factor of extraction- condensing turbine

Performance factor	Condensate ($kg\ h^{-1}$)	Generator (kW)	Steam Input ($ton\ h^{-1}$)
0.9286	8050	1750	24.85
0.9405	7262	1700	25.50
0.9398	7710	1800	26.00
0.9405	7255	1700	25.50
0.9458	8217	1800	24.40
0.9414	9186	1500	14.42
0.9264	9719	1450	12.70
0.9280	9967	1500	12.19
0.9179	10161	1550	13.31
0.9251	10000	1450	11.25

For the back pressure steam turbine we have:

$$P_2 = \frac{S_2 - 11250}{16.7} \quad (17)$$

where, P_2 is power generated in turbo-generator and S_2 is flowing steam. Equation 16 and 17 are derived and modified from real operating data.

Constraints: There are some operating and technical limitations which affect the result of optimization and they must be considered before solving the model. For extraction condensing steam turbine, we have:

$$1000 \le P_1 \le 2500 (kW) \quad (18)$$

$$8000 \le b_1 \le 45400 (kg h^{-1}) \quad (19)$$

$$s \le 47000 (kg h^{-1}) \quad (20)$$

For

$$2000 \le P_1 \le 2500 (kW)$$

We have:

$$S_1 = 19.07 \times (P_1 - 2000) + 11800\ (kg h^{-1}) \quad (21)$$

For

$$1000 \le P_1 \le 2100 (kW)$$

We have:

$$S_1 = 19.07 \times (P_1 - 1000) + 24000\ (kg h^{-1}) \quad (22)$$

For the back pressure steam turbine, we have:

$$15000 \le S_2 \le 50000 (kg h^{-1}) \quad (23)$$

Table 8: Reduction of air pollutants emission for the illustrative example ($ton\ h^{-1}$)

Air pollutants	Values
No_x	2.74
SO_2	2.195
SO_3	0.03366
CO_2	479.135
CO	0.0042
CH	0.0822
SPM	0.2932

$$200 \le P_2 \le 3000\ (kW) \quad (24)$$

Solving the model: GAMS software was used for solving the model; the aim in this optimization is maximization of the electrical power generation in CHP systems. The amount of steam enters to the turbine is limited by the edible oil production. The important part of this solution is dividing this steam between two different turbines to achieve maximum electrical power. Based on Eq. 16 and 17 we have:

$$Max\,(P_1 + P_2) = Max\left(\frac{s_1 - b}{4.86} + 1000 + \frac{s_2 - 11250}{16.7}\right) \quad (25)$$

By solving the model based on the linear algorithm and consideration of Eq. 18 to 24, regarding the amount of steam which was estimated by Eq. 15 and the production plan equal to 73,280 ($kg\ h^{-1}$), the optimum condition can be explored through the feasible region.

The results showed that the targeted amount of production should be divided by 23,280 ($kg\ h^{-1}$) for extraction-condensing turbine to generate 2500 (kW) and 50,000 ($kg\ h^{-1}$) for back pressure turbine for generating 2321.125 (kW) electrical power, therefore the total power generation is 4821.125 (kW).

During the investigation, we recognized that the operating chart of back pressure turbines is different from manufacturer. It was revealed that because of under sizing of turbine inlet pipe, high pressure loss occurs so we lose 400 (kW). By proper sizing of this line, we were able to have this 400 (kW) so there was no need to supply it from public grid. Cost of this correction consist of pipe, valve, insulation and installation was around 10,000 (USD) and saving was 71,568 (USD) annually and pay back period was only 50 days.

Another opportunity for energy conservation could be achieved by improvement of FD and ID fan system by using VSD instead of the damper control system which saved 50 (kW). The cost of this modification was less than 10,000 (USD) but the cost of this saving was 8,946 (USD) annually.

In energy saving projects, environment costs of fossil fuels and water as well as electricity must be assessed (Ataei *et al*, 2009b; Panjeshahi and Ataei, 2008). However, internalization of externalities needs further research (Karbassi *et al*., 2008; Shafie-Pour-Motlagh and Farsiabi, 2007). As seen, applying the new CHP optimization model to this example can provide more 1050 (kW) power saving with attractive pay back period. Therefore, considerable amount of air pollutants as well as greenhouse gases will be reduced (Ataei *et al*., 2009b; Karbassi *et al*., 2008). The reduction of air pollutants emission for this example is given in Table 8.

DISCUSSION

The aim of this study was modeling and optimization of the energy system, which was composed of two steam turbines, in an edible oil plant for increasing the power heat ratio and generating the additional power. In this study, by introducing a new method, the energy system and its application were modeled based on operating charts and modified with the actual experimental data. The new proposed model was developed regarding the technical constraints and held on the operating limitations and solved in GAMS software for maximizing the power production in turbines based on the edible oil production plan.

Current procedure for the steam load distribution between steam turbines was based on percentage of the generator capacity from the total capacity. The optimum condition of the mentioned system could be achieved by solving the optimization model. Hence, the performance of the system on the existing and optimum conditions was different. By operating on the optimum mode, without applying common mentioned rule for the distribution of load, we were able to generate 600 (kW) more electrical power in two steam turbines with the same amount of the flowing steam. In addition, by proper sizing of the turbine inlet pipe and improvement of FD and ID fan of the boiler by using VSD, more 450 (kW) power could be saved. Accordingly, considerable amount of air pollutants emission would be reduced. The total cost of the power saving in this project was 187,866 (USD) annually but the investment required for these modification was less than 20,000 (USD), therefore the payback period was very short.

Such power saving which derived by the recently introduced method for optimization of energy system in the edible oil plant, can not be achieved by the previous methods which presented by Ataei (2009), Descombes and Boundignes (2009) and Rong *et al*. (2009), due to the following reasons:

- In spite of other methods, the new presented one explores the optimum condition of the CHP system regarding the historical plant data on demand side of the steam. The equation on steam demand side of the plant is a correlation between the steam, edible oil and electrical power which can be estimated by multiple regressions of the annual data
- The new presented model is not only a theoretical model but also includes the actual binary conditions. Therefore, the output of the model is basically evaluated and practical
- In the edible oil plant, the power and steam consumption is basically varied. Therefore, in the new proposed formulation, instead of the rate of energy consumption, the steam product ratio was considered as a constraint of the optimization model and the objective function was fitted to the power product ratio. Hence, the cost of the optimization project can be minimized thanks to the constant steam product ratio. Note that in the other optimization models, the demand for electrical power is normally considered as a constraint, therefore the needed cost for the project increases because of the changes on the steam production

CONCLUSIONS

Edible oil plants are one of the energy intensive sectors in the group of food industries. The energy is supplied to theses factories mainly as fuel and electricity. In addition to the growing rate of the energy cost and tighter control of environmental aspects, the bad quality of electrical national grid such as cut, flickering, surges and other quality problem, have forced these plants to supply their demand for electrical power from reliable and economic sources. In this study, different available sources of supplying electrical energy in an Iranian edible oil factory such as combined heat and power generation (CHP) in a steam plant, Diesel Generator (DG) power plant and national grid have been investigated. Efficiencies have been measured and it was 79.23% for boiler and 53 and 71% for extraction condensing and back pressure steam turbines of the CHP system. The efficiency for DG was measured 42.03%. Bad quality of national grid makes interruption in production trends and causes of losses in material and production. Consequently, a reliable source of electricity is the first choice for the edible oil factory. Two internal power plants in CHP and DG are the first choices in this case. In DG, generation of power is less efficient and more expensive than CHP, so our first choice is CHP system. Running in optimum condition is really important, so we need to investigate the optimum point of CHP. Accordingly, the model was developed based on the collected data of steam and edible oil production and also electrical power generation in a year by using multiple regressions for having an equation between steam, edible oil and electrical power. The model was solved in GAMS and optimum conditions with consideration of equipment characteristics and operational limitation were concluded. The results showed that by working in the optimum point, 600 kW more electrical power can be generated in comparison with the current condition, which the cost of this saving is 107.352 USD annually. In addition, the results showed thatmore than 2.74 ton NO_x, 2.195 ton SO_2, 0.03366 ton SO_3, 479.135 ton CO_2, 0.0042 ton CO, 0.0822 ton CH and 0.2932 ton SPM per year could be reduced.

NOMENCLATURES

G_1	=	Heat input flow rate (kW)
G_2	=	Sum of all heat losses from unit (kW)
G_3	=	Sum of useful heat flows from unit (kW)
G_4	=	Sum of heat flows in steam entering unit (kW)
G_5	=	Heat output flow rate (kW)
P_1	=	Electrical power generated by extraction-condensing turbine (kW)
P_2	=	Electrical power generated by back pressure turbine (kW)
S_1	=	Steam flowing through extraction-condensing turbine (mtonh^{-1})
S_1	=	Steam flowing through back pressure turbine (mton h^{-1})
D (S_i)	=	Estimated daily demand of steam (mton h^{-1})
x_i	=	Daily production of solid oil (mton h^{-1})
z_i	=	Daily production of liquid oil (mton h^{-1})
pf	=	Performance factor

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