Bagasse as an Alternate Fuel to Coal for Industrial Uses – A Comparative Study

V. Rama Krishna [1] and Dr. B.V. Babu [2#]
Birla Institute of Technology & Science
Pilani – 333 031 (Rajasthan) India

The need of the hour in today's world is to globally phase out coal as a fuel source due to its high pollution potential. The results of our earlier study indicating improved theoretical thermal efficiency of bagasse when mixed with waste oil (BWO mix) in the ratio 4:1 are considered and the related technical aspects are compared with that of coal and bagasse. It is found that bagasse cannot replace coal as an effective fuel, but wherever it is abundantly available it can serve as an alternative. The optimum BWO mix works out to be a better fuel in terms of techno-economic aspects with respect to bagasse alone. Though the BWO mix is slightly expensive when compared even with F grade coal, its usage is strongly recommended as an alternative to coal in view of increasing demand for coal and its limited sources of availability. The results of the present study are flexible to incorporate several factors in future pertaining to bagasse and coal, for assessing the net savings.

Introduction

The usage of coal as a fuel in industries result in the generation of gaseous emissions (Peavy *et.al*, 1985). The total coal reserves (as on 1-1-1998) have been assessed by Ministry of Coal (MOC) at 206.24 billion tonnes but bulk of these (87%) reserves are non-coking coals of inferior grade (TEDDY, 1998). The Ministry of Environment & Forests (MOEF) has imposed restrictions on the usage of non-coking coal with high ash contents in view of huge fly ash generation. Belgium, France, Japan and United Kingdom have already reduced their usage of coal and many other countries reduced subsidies as well on coal (PTI, 1999). The need of the hour in today's world is to globally phase-out coal as a fuel source. Since the deficit of coal consumption over its availability is expected to continue and much of the available coal is of inferior grade and likely to find restricted use in the future due to the MOEF regulations, it would be desirable to choose a suitable fuel to substitute coal. The alternate fuel should have advantages in terms of utility, financial savings, less pollution loads etc. The various substitute materials currently being utilized are fuel oil, locally available cheaper agro-residues such as bagasse, husk, briquettes, wood etc.

However, their efficiency judged from the above factors needs to be reviewed. In the present study, bagasse is considered and its effectiveness to substitute coal is presented.

Bagasse is a by-product/waste in the sugar industry. Its use as a fuel is restricted because of its low Calorific Value (CV). However, the results of our earlier studies (Babu and Krishna, 1998) reveal that, theoretically the thermal efficiency of bagasse can be improved when mixed with waste oil in the optimum ratio of 4:1. This optimum ratio was arrived at such that, the prescribed minimum stack height (30m) attached to the boiler is not altered.

The present study is oriented towards:

- Exploring the feasibility of using bagasse as an alternate fuel to coal and its comparison *vis-à-vis* coal with respect to both technical and economical aspects
- Incorporating provision for any future changes in the inputs used for cost analysis

Problem Formulation and Results

The properties of coal, bagasse and Bagasse-Waste Oil (BWO) mix; cost factors for coal, bagasse, steam utilisation etc. are collected from literature (Patil, 1996; Babu and Krishna, 1998; Douglas, 1988; Perry and Green, 1984; Peters and Timmerhaus, 1981). Ministry of Coal (MOC) has classified the non-coking coal into A, B, C, D, E and F grades based on its useful CV. The useful CV in Kcal/kg according to the MOC classification (TEDDY, 1996) is defined by the formula:

8900 – 138(% ash content +% moisture content)

In the case of coal having a moisture less than 2% and a volatile content less than 19%, the useful CV shall be the value arrived at as above reduced by 150 Kcal/kg for each reduction in volatile content below 19% fraction pro-rata (TEDDY, 1996).

Pollutant emissions: The emission rates of coal and bagasse are found out for direct firing of these fuels such that, the stack height for the emission do not exceed the stipulated minimum stack height 30 m calculated by the formula reported (ISPC, 1995). The assumptions made in the calculation of pollutant

---

1 Lecturer, Civil Engineering Dept., E-mail:vrama@bits-pilani.ac.in
2 Head, Engineering Technology Dept., E-mail: bvbabu@bits-pilani.ac.in
Associate Professor, Chemical Engineering Dept.
Corresponding Author; Fax: +91-1596-44183; Ph: +91-1596-45073 (205)

emissions are: **(1)** No pollution control equipment is needed for the minimum stack height of 30 m. **(2)** Fly ash generation from bagasse is 0.081 kg per each kg of bagasse fired (Mall and Kumar, 1997) while that of the coal is 75% of coal's ash content. **(3)** The ash contents mentioned in the literature (Patil, 1996) are applicable for calculating the coal inputs. **(4)** The only emissions generated and discharged through the stack are due to the fuel firing.

With the above assumptions, the minimum fuel inputs are back calculated and are given in Table-1. The three types of coal selected from literature (Patil, 1996) with ash and moisture contents 43.12% & 3.84%, 34.38% & 6.04% and 25.19% & 6.0 % respectively are designated as C1, C2, & C3 types for the purpose of present study. As per the MOC classification of non-coking coals, the above-designated C1 & C2 types of coals come under the category of F grade while C3 type coal comes under D grade.

Table-1 *Particulate emissions from coal and bagasse*

Fuel	QPE KPH	Bagasse used KPH	Coal used KPH
Bagasse	35	432	--
C1 type Coal	35	--	108
C2 type Coal	35	--	135
C3 type Coal	35	--	185

QPE = Quantity of Particulate Emissions; KPH = Kilograms per hour

Steam generation: The characteristics and the CV of bagasse and optimum BWO mix are collected from literature (Babu and Krishna, 1998). The expected steam generation is found out using the net CV of optimum BWO mix, bagasse alone and for coal respectively and given in Table-2. This data is utilised in understanding the economics of the options considered in the present study.

Table-2 *Steam generation from fuels*

Fuel	Calorific Value kJ/kg	Steam generation kg/kg
Bagasse	8,021	3.12
Optimum BWO mix (4:1)	14,924	5.80
C1 type Coal	18,426	7.18
C2 type Coal	20,970	8.16
C3 type Coal	23,669	9.21

Economics: The economic returns involved in the alternative usage of optimum BWO as fuel for coal and/or bagasse alone are compared. The utilization cost of steam (Douglas, 1988; Perry and Green, 1984; Peters and Timmerhaus, 1981) from the fuels attempted for the study is calculated @ 2.5 US $ or Rs. 108.60 (Rs. 43.44 per US $ as on 14.10.1999) per 1000 kg of steam and is shown in Table-3. The purchase costs of bagasse, D-, & F-grade coals are taken as Rs. 150 per 1000 kg (Babu and Krishna, 1998), Rs. 594 and Rs. 415 (TEDDY, 1996) respectively. Using this information, the Net Utility Value (NUV) of the fuels attempted is calculated as the difference of its steam utility value (SUV) and purchase costs.

Table-3 *Net utility value of various fuels*

Fuel	QOF KPH	PC Rs.	SUV Rs.	NUV, Rs. (SUV-PC)
Bagasse	432	64.80	338.83	274.03
Optimum BWO mix (4:1)*	346	51.90	629.88	577.98
C1 type Coal	108	44.82	779.75	734.93
C2 type Coal	135	56.03	886.18	830.15
C3 type Coal	185	110.00	1000.21	890.21

* 0.8 x 0.432 ; QOF: Quantity Of Fuel; PC: Purchase Cost; SUV: Steam Utility value.

Analysis of Results and Discussion

From Table-3, it can be noticed that, there is a considerable saving (+ 110.92%) when optimum BWO mix is used in place of bagasse alone. This can be understood from the fact that, the CV of optimum BWO mix and hence its utility value is improved.

The details pertaining to various BWO mix ratios ranging from 1:1 to 10:1 are collected from literature (Babu and Krishna, 1998) and the NUV for the same are calculated. The NUV for few additional BWO mix ratios (up to 17:1) are also calculated using the same procedure. Using this data, the variation of NUV for the chosen BWO mix ratios is given in Fig. 1. From the Figure, it can be noticed that, the variation of NUV with respect to BWO mix ratios is non-linear and is gradually decreasing exponentially with the increase in bagasse fraction of BWO mix. It can also be observed that, the intervals of NUV variation are approaching closer to each other beyond the BWO mix ratio of 4:1. However for BWO mix ratio less than 4:1, the intervals of NUV variation are relatively larger, though they are reducing in magnitude. The BWO mix of 4:1 can thus be categorized as optimum mix with respect to NUV. It may be noted that, the BWO mix ratio of 4:1 is earlier reported (Babu and Krishna, 1998) to be the optimum mix with respect to air pollution considerations. Hence, the BWO mix of 4:1 can be categorized as *optimum mix* with respect to both the net utility cost and pollution considerations.

Fig. 2 shows the comparison of net expenditure on usage of fuel per 1000 kg firing per hour with respect to bagasse alone and optimum BWO mix. As can be seen from the Figure, the net expenditure that is to be incurred by using C1 type coal with respect to bagasse alone and with respect to optimum BWO mix are Rs. 461 and Rs. 157 respectively. It implies that, the net savings that can be made by using C1 type coal in place of BWO mix is the difference between the above two net expenditures, which is equal to Rs. 304 and is shown in the Fig. 2(a). Similarly, the net savings for the other two grades of coal are calculated as Rs. 304 and Rs. 414 respectively and shown in Figs. 2(b) & 2(c).

It is to be noticed that, in Figs. 2(a), 2(b) & 2(c), the net expenditure of C1, C2 & C3 types of coal are compared with bagasse alone and with optimum BWO mix respectively. However in Fig. 2(d), the net expenditure of bagasse alone is compared to that with bagasse alone and optimum BWO mix respectively. This resulted in a net expenditure of Rs. 0 (zero) and Rs. 304 respectively, yielding a net savings of Rs. 304.

The comparison of NUV with the quantity of fuel fired is given in Fig. 3. The three types of coal (C1, C2 & C3), bagasse alone and optimum BWO mix (4:1) are considered as fuels for this comparative study. BWO mix fuel with ratios of 1:1, 2:1 and 5:1 are also considered for comparison. From the Figure, it can be noticed that, the NUV of coal is quite high (Rs. 734.93 to Rs. 890.21) even though the quantity of its firing as fuel is very low (0.108 to 0.185 TPH). This can be attributed to their high CVs and hence higher steam generation potential.

On the other hand, the quantity of bagasse (alone) fired is 0.432 TPH resulting in a NUV of only Rs. 274. 03, due to its low CV as can be seen from Fig. 3. However, the trends of the BWO mix fuels (for the different ratios considered) show that, the NUV can be as high as Rs. 1034.05 for a BWO mix ratio of 1:1 (see Fig.1) at a fuel firing rate of 0.216 TPH (as is evident from Fig.3). The quantity of BWO mix fuel (ratio 1:1) fired is in excess of 0.031 TPH and 0.108 TPH over the C3 and C1 types of coal fired respectively. This resulted in the Net Utility Savings (NUS) of Rs. 143.84 and Rs. 299.12 respectively for the BWO mix fuel (ratio 1:1) over the C3 and C1 types of coal respectively (see Fig.3). Though the above advantages of the BWO mix (ratio 1:1) are attractive, the optimum BWO mix of 4:1 (Fig.1) decides the limiting ratio of BWO mix. Hence the additional expenditure to be incurred for usage of C1 type of coal in place of optimum BWO mix can be calculated from Fig. 3 as Rs. 157. This value is exactly the same as that arrived at in Fig. 2.

Considering the above results, the monthly saving/expenditure on the attempted fuel for the user is calculated with the assumption of 21 working hours a day and 30 working days per month. The results are: **(1)** The usage of optimum BWO mix as fuel in place of bagasse result in a net saving of **Rs. 1.915 lakhs** per month or Rs. **22.98 lakhs** per annum. **(2)** The financial loss to the user due to the non-usage of bagasse as fuel is **Rs. 1.726 lakhs** per month or Rs. **20.716 lakhs** per annum. **(3)** If the user purchases C1 grade coal despite the availability of bagasse, the net expenditure incurred is **Rs. 2.904 lakhs** per month or Rs. **34.85 lakhs** per annum. This is under the assumption that, the available bagasse is not used as a fuel.

Though the BWO mix is slightly expensive when compared even with C1 type coal, its usage is strongly recommended as an alternative to coal in view of increasing demand for coal and its limited availability of its limited resources. In addition, the need of the hour is to globally phase out the usage of coal as a fuel resource. (PTI, 1999). However, certain assumptions and justified simplifications are made in the present study while finding out the financial benefits as derived and depicted in Fig. 2. Few more aspects are observed to cause significant changes in the monetary benefits as arrived at in the present study and are summarised below:

Characteristics of fuel: The benefits calculated are based on the characteristics of the fuel, especially coal, collected from literature for the purpose. The purchase cost of non-coking coal depends on the MOC classification of categorizing them into different grades based on their characteristics i.e., proximate analysis. The monetary benefits may change if there is any specific deviation in the purchase cost of coal.

Efficiency of firing: This affects both the ash and fly ash generation. The quantity of the fuel input may vary accordingly.

Quality of waste oil: The CV for the contaminated waste oil may be less than that quoted in the text and the gaseous emissions may also vary. It is strongly recommended that waste oil be recovered at the source of generation itself where the probable degree of contamination is low.

Steam capture: Steam utilisation costs are based on effective steam conversion and steam capture.

Leak-proof duct arrangement leading to stack: This may permit less quantity of pollutants to be disposed off through the stack and hence the economics of fuel firing may be altered.

Market price of fuel: This affects the net savings and hence the decision of the user on the usage of a cost-effective fuel.

Summary and Conclusions

Due to the high pollution potential in the usage of coal as fuel, the need of the hour in today's world is a gradual changeover to an alternate fuel. In an attempt to find a fuel to substitute coal, bagasse is considered and the various technical aspects involved with respect to fuel firing including stack height, expected steam generation *vis-à-vis* CV of the fuel are worked out. The results of our earlier study indicating improved theoretical thermal efficiency of bagasse when mixed with waste oil in the ratio 4:1 are considered and the related technical aspects are compared with that of coal and bagasse in the present study. It is found that,

- Effective utilization of bagasse generated can only be achieved subjected to its mixing with waste oil in the ratio of 4:1. However, purchase of bagasse for commercial C1 type (F grade) coal is not economical.
- Bagasse cannot replace coal as an effective fuel, but wherever it is abundantly available, it can serve as an alternative. The optimum BWO mix works out to be a better fuel in terms of techno-economic aspects with respect to bagasse. The usage of optimum BWO mix as fuel in place of bagasse result in a net saving of **Rs. 1.915 lakhs** per month or **Rs. 22.98 lakhs** per annum.
- Though the BWO mix is slightly expensive when compared even with C1 type coal, its usage is strongly recommended as an alternative to coal in view of increasing demand for coal and the availability of its limited resources.

The present study is carried out for assessing the economic returns when there are no pollution control equipment attached to the stack and the only emissions generated are due to the fuel firing. The results of the present study are flexible to incorporate several factors in future pertaining to bagasse and coal, for assessing the net savings.

Nomenclature

BWO	Bagasse-Waste Oil mix
C1, C2, & C3	Types of coal designated for present study having different ash and moisture contents.
CV	Calorific Value, kJ/kg
F & D	Grades of coal as per MOC classification
MOC	Ministry Of Coal
MOEF	Ministry Of Environment and Forests
NUS	Net Utility Savings, Rs.
NUV	Net Utility Value, Rs.
KPH	Kilograms Per Hour

References

Babu B.V. and V. Rama Krishna (1998). "Optimum utilization of waste oil for improved thermal efficiency of bagasse", Journal of Indian Association for Environmental Management, Vol.25, pp. 59-65.

Douglas J.M. (1988). *Conceptual design of chemical processes*, McGraw Hill Book Company, New York (International edition), pp 36-37.

ISPC (1995). *Industrial safety and pollution control handbook*, 2nd edition, 2nd reprint, A joint publication of National Safety Council and Associate (Data) Publishers Pvt. Ltd., Hyderabad, pp. 430.

Mall I.D. and Vivek Kumar (1997). "Removal of organic matter from distillery effluent using low cost adsorbents", Chemical Engineering World, Vol. XXXII, No.7, pp. 89-96.

Patil M.A. (1996). "Industrial pollution in urban areas and possible solutions – a case study of boilers", Energy Environment and Monitor, Vol.12, No.2, Tata Energy Research Institute, New Delhi, pp. 79-87.

Peavy H.S., Donald R.R. and G. Tchobanoglous (1985). *Environmental Engineering*, McGraw Hill International Edition, Civil Engineering Series, McGraw Hill Book Company, Singapore.

Perry R.H. and D.W.Green (1984). *Perry's Chemical Engineers' Handbook,* 6th edition, McGraw Hill Book Company, New York, Chapter-9 pp. 18.

Peters M.S. and K.D. Timmerhaus (1981). *Plant design and economics for Chemical Engineers*, 3rd edition, (3rd printing), International student edition, McGraw Hill International Book Company, Tokyo, pp. 160-161 & 881.

PTI (1999). "Delhi pollution equals 1952 London smog" Times of India, New Delhi edition, dated 13.09.1999.

TEDDY (1996). *Teri Energy Data Directory & Yearbook, 1996/97*, Tata Energy Research Institute, New Delhi, pp. 121, 196-198, 46,47.

TEDDY (1998). *Teri Energy Data Directory & Yearbook, 1998/99*, Tata Energy Research Institute, New Delhi, pp. 9-13, 23-27.

LIST OF FIGURES