DETERMINATION OF TECHNO-ECONOMIC VIABILITY, RELIABILITY AND DURABILITY OF A CHARCOAL RETORT PROTOTYPE

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ABSTRACT

The paper briefly describes a charcoal retort model designed to improve efficiency of charcoal production and recovery of by-products. The design is technically sound. However the initial prototype with 4.5 m^3 retort chamber capacity is not economically viable. A 10 m^3 capacity retort chamber increased the profit margin with a corresponding 18% increase in the rate of return on investment. The rate is further increased by 30% if the crude pyroligneous liquor and tar was to be sold to a central processing distillery plant. The reliability and durability of the retort prototype is also reported.

INTRODUCTION

In attempting to improve on the method of production of charcoal, theoretical and experimental work has been undertaken aimed at designing, constructing and testing a charcoal retort model. The model (Yamba 1983) consists of a retort chamber and furnace connected by five stainless steel tubes (Figure 1) and includes a heat exchanger for recovery of by-products in the form of pyroligneous liquor.

The model has been extensively evaluated to establish optimum operating conditions and determine techno-economic viability, reliability and durability. The findings are reported in this paper.

TECHNO-ECONOMIC EVALUATION

The charcoal retort prototype has been extensively tested over more than 3000 hours of actual operation over a period of five years. The model has proved to be technically sound in as far as charcoal production and recovery of by-products is concerned.

Factors affecting the production rate, ie conversion efficiency, include initiation reaction temperature, and carbonisation and stabilisation times (Yamba 1984). Highest conversion efficiency (35%) was achieved at a carbonisation temperature of 350°C, and stabilisation and carbonisation times of 5 and 9 hours respectively. Under these conditions there was a higher recovery of the by-products in the form of pyroligneous liquor and tar.

Data obtained from the design specifications of the retort model constructed, such as steel, refractory bricks, electric motor, etc, were used to determine the total investment requirement of the project. The retort chamber of the retort model was determined as 0.25 m^3. To arrive at an economically viable project two retort chamber capacities of 4.5 m^3 and 10 m^3 were selected based on dimensional analysis. Since the size of the retort chamber in the former and latter cases increased three and four times respectively to that of the model, the material cost for the retort chamber increased three, nine and 27-fold for the 4.5 m^3 retort chamber capacity, and four, 16 and 64-fold for the 10 m^3 retort chamber capacity per unit metre, mass and volume respectively. The total capital investment also included the cost of construction and assembly of the plant.

The materials required for the construction of the furnace, increased by a quarter, and a half for a 4.5m³ and 10m³ capacity respectively. To obtain the required heat for sustaining a continuous operation of nine hours, a blower with twice the capacity of that used in the model was recommended.

Data, such as, amount of waste fuel and electricity consumed, for determining the operating costs was obtained from various tests undertaken on the retort model. The data were then extrapolated to obtain the operating costs required for the 4.5 m³ and 10 m³ retort chamber capacities. To determine the total production cost, the cost of maintenance estimated at an average annual rate of 5% of the capital investment and labour were added to the operating costs.

A comparison of the investment and performance in the first year of operation of charcoal retorts of three different capacities is shown on Table 1. This analysis suggests that the prototype model is not economically viable. The situation slightly improves in the 4.5 m³ retort chamber capacity but only marginally as the rate of investment is only 2.0% and 11.0% from the sales of charcoal alone, and charcoal and the crude by-product respectively. The profit margin increases significantly using a 10m³ capacity charcoal retort prototype. There is a corresponding increase in the rate of return on investment of 16.2 and 31.7% from the sales of charcoal only, and charcoal and the crude by-product.

Performance can be further improved if a market for the by-products is identified. For this reason, it is recommended that a central distillery be set up for processing the by-products into products such as wood tar, acetic acid, acetone and methyl alcohol.

DETERMINATION OF RELIABILITY AND DURABILITY OF THE CHARCOAL RETORT PROTOTYPE

To determine eliability and durability of the system, it is important to consider separately its various components: namely retort chamber, furnace, piping, blower assembly and heat exchanger. The criteria for determining the various economic indices of reliability and durability must also be defined.

The most important criterion of reliability is the probability of non-failure, intensity of failure and average down time. For the charcoal prototype, the probability of non-failure can be measured by the probability (P) of non failure of the various identified components as follows:

$$P = P_r \, P_f \, P_b \, P_p \, P_{he} \qquad (1)$$

where P is probability on non-failure of the charcoal prototype; P_r of retort chamber, P_f of furnace; P_b of blower assembly; P_p of piping system; P_{he} of heat exchanger. The most vulnerable of all the components is the furnace which is subjected to high temperatures.

The intensity of failure of the prototype can be defined as the ratio of the number of failures of the whole plant during a given time interval to the average number of failures of its different components as given below.

$$\lambda = \frac{n}{N_{av} \Delta L} \qquad (2)$$

where λ is intensity of failures of the plant; N_{av} is average number of not failed components of the plants; ΔL is given operating time interval.

With the help of equation 2, the probability on non-failure can be determined, using the following equation:

$$P = e^{-\lambda L} \quad (3)$$

where e is natural logarithm.

The mean down time (To) of the prototype can be determined from:

$$To = \frac{\sum^{n} t_i}{n} \quad (4)$$

where t_i is average length of time between two consecutive failures in a given operating time, and n is number of failures in a given operating time.

Durability is an economic analysis index which can be used to determine the economic life of the charcoal plant. It largely depends on operating costs for maintenance and repair and its armotisation rate over a given service life. The economic service life can be determined by the minimum point on a graph showing the two losses against operating time.

The service life of the charcoal prototype according to results from the model is estimated at 10 years. The most critical component which has been identified from the intensive testing is the furnace. According to available data, the furnace, in particular the refractory bricks, will have to be replaced approximately once in every two years. Another critical component requiring frequent replacement within the same order of time is the stainless steel furnace hood and its associated piping which are subjected to high thermal stresses.

During the pilot plant commissioning stage, all the various economic indices which have been identified must be determined and monitored.

CONCLUSIONS

The techno-economic evaluation which has been undertaken in this work has shown that the 10 m^3 retort chamber capacity offers the best investment. A pilot plant based on such a capacity must be constructed for further testing and commissioning prior to commercial production of the design.

During desting of the pilot plant, all attempts should be made to collect data for determining the reliability and durability of the pilot plant.

REFERENCES

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TABLE 1: Investment performance in Kwacha at first year of operation of a charcoal retort of three different capacities

	Capacity (m^3)		
	0.24	**4.5**	**10.0**
Capital requirement	5000	70,000	95,000
Net sales from charcoal only *	1000	24,000	52,000
Net sales from charcoal and by products +	1350	33,000	73,000
Costs (raw material operational cost, overheads, etc)	8000	22,000	30,000
Net profit(loss) before tax +	(-6650)	11,000	43,000
Income tax *	-	600	6600
Income tax +	-	3300	12,900
Net profit(loss) after tax *	-	1400	15,400
Net profit(loss) after tax +	-	7700	30,100
Annual rate on capital *	-	2%	16.2%
Annual rate on capital +	-	11%	31.7%

* Yamba 1983; + Yamba 1984

FIGURE 1: Charcoal retort model