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NON-CONVENTIONAL USE OF SMALL DIESEL ENGINES: CASE STUDIES

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ABSTRACT

Small diesel engines are widely used for producing mechanical or electrical power all over Bangladesh. Apart from conventional use in irrigation, electrical power generation and river transportation, such engines are now having many alternative applications. Because of their huge number they constitute a significant proportion of the consumption of diesel fuel, which needs to be imported. With increasing living costs, the cost of human work force is rising and that has recently opened up some new fields of application of such engines in Bangladesh. Since there is almost no reported formal study of such uses, three such fields have been case studied. These include – Brick-Crushing, Concrete-Mixing and Sugarcane Processing. A number of samples in each category were studied, which included – the engine specification, drive arrangement of the hardware, fuel consumption rate and system transportability. The maximum torque requirement was investigated against the engine capacity. The capital, running and maintenance cost have been analyzed to estimate the economic feasibility of such applications. The sensitivity of prime parameters, on the economic feasibility of replacing each human powered system, have been characterized.

Keywords: Diesel Engines, Non-Conventional Use, Alternative Use, Human Powered Systems.

1. INTRODUCTION

Small diesel engines, typically producing less than 25 hp, are widely used all over Bangladesh. Although there is no accurate survey, the number of small diesel engine in operation is estimated to be about 0.7 million [1]. Introduced in late 70's such engines are now used in a number of sectors. Diesel fuel is the largest imported energy resource for Bangladesh. Presently about 2.4 million metric tons of Diesel is used every year in Bangladesh. High fuel price, uncertainty of availability of fuel and the question of energy security – requires Bangladesh to justify its use of diesel fuels. Although small consumption per unit, the huge number of the engines create a significant share of the total consumption. About 1 million ton of diesel consumption can be related to small diesel engines in the applications mentioned above [1].

The most important use is in irrigation for driving Low Lift pumps (LLP) and shallow tube wells (STW) in rural Bangladesh. Many of such engines are used for standby power generation to cope up with the frequent failure of main electrical power, as a small community solution. Although electricity have reached in about 60% villages, still more that 2/3rd of the irrigation devices are still run on diesel [1]. Diesel engines have reached wide application in many of about 0.9 million country boats. A large proportion of which is run by diesel now-a-days [1]. In the current decade the cost of human labor has increased, as the cost of living is increasing all across the country. In a number of non-conventional applications small diesel engines are being used now-a-days, as carrying out the operation with engines replacing human workforce is becoming more productive as well as cost effective. Recently engines have found applications in 'Stone/Brick Crushing' and 'Concrete Mixing' in construction industry; 'Crushing of Rice and Sugarcane' in food industry. Thousands of locally built 3-wheelers are propelled by such engines, which are mostly used in rural transportation. Most of the engines used now are imported from china, but lots of small industries have developed locally which manufacture many spare parts of these engines, creating further employments. As a whole these engines are playing an important role in the overall economy.

Very few studies have been reported regarding the operation of diesel engines in such non-conventional applications. The present work makes group studies of three such applications – Crushing of Sugarcane, Crushing of Bricks and Concrete Mixing machines all run by small diesel engines. The study focuses on the - Engine Specification, Drive Mechanism, Overall Engine Performance and Economic feasibility of the operation. A number of engines used for the particular purpose were visited at different places around Dhaka city. Specification data were collected from the name plate attached to the engines. Information regarding the performance was physically observed for a short period and long-term data were collected from the end users.

For making the cost analysis, average of data collected from a number of selected users was used for each case.

2. CASE-1: SMALL DIESEL ENGINES USED IN CRUSHING SUGER CANE

Now-a-days small diesel engines are widely being used for crushing sugarcane for roadside juice vendors. Traditionally this was done using manual labor, now it is being cost effective to drive the crushing mechanism [2] with small diesel engines. Both stationary of 3-wheeler van mounted mechanisms are popular. The device typically consists of a small - single cylinder, water cooled, diesel engine driving a sugarcane crushing mechanism via a pulley-Vbelt speed reduction drive. The engine torque is further increased in the speed reduction gears in the crushing mechanism, where the conveniently sized sugarcane sticks are crushed between mating rollers to squeeze the juice out of them, which is collected in a container.

Fig 1. A 3-wheeler cycle-van mounted sugarcane crushing system used by roadside juice vendors

A number of such sugarcane crushing machines were visited at different places around Dhaka city, however reasonably reliable information could be collected from only 6 samples. The technical specification of a typical system is given below in table-1. Small Diesels engines generally of nearly 3kW capacity and 2600 rpm rated speed, 210 cc displacement volume, manufactured in China were used to drive the crushing mechanism (commonly called the roller mill) using a V-belt and Pulley drive with an effective speed reduction of around 4:1. The drive pulley diameter was found to be 3.5 inch in all samples, but the driven larger pulley diameter was found to range from 13.5 – 17.5 inch with the 14.5 inch size more common. The crushing mechanism had a further speed reduction for which two variants of the mechanisms were found to be in use. Type-I consisted of total four gears in the train with gear teeth ratio of 18:98, resulting about 5.4 times speed reduction. Type-II consisted of total six gears in the train with gear teeth ratio of 38:73 and 26:90, resulting about 6.4 times speed reduction. Both spur and helical gears were found to be in use.

Fig 2a. Sugarcane Crushing Mechanism, Type-I

Fig 2b. Sugarcane crushing mechanism, Type-II

Table-1: Typical Specification of Sugarcane Crushers

Engine Rating	2.98 kW, 2600 rpm 240 cc
Pulley-VBelt Drive Diameter Ratio Speed Reduction	 3.5 : 14.5 (13.5-17.5) inch 4.14 : 1 (3.85-5 : 1)
Crush Mechanism TYPE-I : Teeth Ratios Gear Reduction TYPE-II : Teeth Ratios Gear Reduction	 (18:98) x (37:37) 5.44 (38:73) x (26:90) x (24:24) 6.65
Main Crushing Rollers	Teeth ratio = 37:37 or 24 : 24 Speed ratio = 1: -1
Overall Torque Amplification / Speed Reduction	Type-I = 22.5 times, 115 rpm Type-II = 25.6 times, 102 rpm
Typical Fuel Consumption	2.5 liters/ 12 hours

Finally a pair of 37 teeth (in Type-I) or 24 teeth (in Type-II) gears were used to rotate the main rollers in opposite direction to create the crushing as well as feed motion of the suitably sized sugarcanes (about 2-3 feet in length), extracting the juice. Overall speed reduction achieved is about 23:1 increasing the torque applied significantly, sufficient to extract most of the juice from the sugar cane in 2/3 feeds. The crushing rollers only rotate about 100 rev/min, creating a roller feed rate of about 1.5 feet/sec. The crushing mechanisms are locally made with mild steel gears and the main two 4 inch diameter crushing rollers are made of stainless steel. Figure-2 shows a closer view of the crushing mechanism.

Due to the increased cost of manual labor, the engine driven system is getting more popular. The engine driven system was reported to be more efficient in juice production as well, enhancing its feasibility. For attaining the same juice production rate of the engine driven system one additional worker needed to be employed. A typical engine costs about 11,500-13,000 Taka, the Crushing Mechanism (Ball Mill) costs about 18,000 Taka and incase of a cycle-van mounted system the van costs additional 5,000 Taka. In addition for such capital investment, the fuel consumption was reported to be about 2.5 liters in every 12 hours (effectively 1 day) costing 110 Taka. The lubricating oil and small maintenance cost was about 1000 Taka per month. On the other hand the wage of an additional worker is about 250 Taka/day, which is needed by the owner in order to maintain the level of productivity. The engine driven system could be operated by the owner/employer alone. Table-2 shows the comparison of the cost and additional profit margin per month of an employer using the typical engine driven system. The engine depreciation value was considered as 40% of the purchase cost at the end of one year of operation. For comparison the costing of Sugar Cane, costing for the Crushing Mechanism (Ball Mill) and Cycle-Van, Daily cost/rent for the roadside possession (reported to be 50-60 Taka/day) were considered equal for both cases.

Table-2: Typical monthly cost reduction of an owner per month, using a diesel engine driven system.

Engine Depreciation Per month @5% of 12,500 Tk	625 Tk.
Lubricating Oil & Maintenance	1000 Tk
Fuel Cost : Diesel 44 Taka/Liter 2.5 liters (12 hr day) x 30 x 44 Tk	3300 Tk
Additional cost per month for Diesel engine driven system	4925 Tk
Cost for an additional Labor with a wage of 250 Taka/day	7500 Tk
Cost Reduction (Increase in Profit) per month	2575 Tk
Percentage increase in profit	12 %

The table shows that if a owner/employer have sufficient customers, using the diesel engine driven system instead of the traditional manual labor operated sugarcane crushing mechanism would increase the monthly profit by more than two thousand and five hundred taka per month, which significant at this level. This could ensure high productivity, but require more investment. Compared to this the manually operated system could be operated by the owner himself only with a limited productivity. Which means his total investment would be only about 13,000 taka less, but the income would be nearly half. The engine driven systems ensures about double productivity without an additional labor. More over it has the advantage that if the business is not so well in few days of the month, the fuel cost would come down accordingly, where the additional labor needs be paid on a flat day/month basis. However one observation was concerning, the diesel exhaust often is blown by a strong wind across the sugar cane, this may degrade the juice quality to some extent, which may need a different sort of investigation.

3. CASE-2: SMALL DIESEL ENGINES USED IN BRICK CRUSHING

Conventionally brick was broken down to brick chips manually using a hammer in Bangladesh. In recent years portable brick crushing machines driven by small diesel engines are getting wide popularity. High productivity, uniformity of the chips formed and high labor costs are making its use popular. Typically the entire setup is fitted on a locally built 3-wheeled steel chassis, so that it can be moved (generally using manual labor) to different construction sites. The setup consists of a single cylinder, water cooled Diesel engine, a Belt-Pulley drive for transmitting power at reduced speed, the core crushing mechanism of bricks and accessories for brick feedings and chip collection. The technical specification of a typical system is given below in table-3. Figure-3a shows the typical arrangement mounted on a 3-wheeled chassis.

Table-3: Typical Specification of a Brick Crushers

Engine Rating	13.5 kW, 2200 rpm 1000 cc
Pulley-VBelt Drive Diameter Ratios – Flywheel - Transfer Shaft Transfer Shaft - Crusher	 6 : 9 inch 9: 22 inch
Crush Mechanism	Eccentric Crushing Teeth
Overall Torque Amplification / Speed Reduction	3.67 : 1
Typical Brick Crushing Rate	1500 Bricks/hour
Typical Fuel Consumption	10 liters/ 8 hour shift

The Diesel engine typically has a rated capacity of producing 13-14.5 kW power at 2200 rpm. Here all the speed reductions are done using V-belts and four pulleys of different diameters, no gears are used in the transmission. A double grooved pulley of 6 inch diameter is attached with the engine flywheel. This drives a 9 inch diameter pulley fitted at one of the in the transfer shaft. Another pulley of 9 inch diameter is fitted at the other end of the transfer shaft which belt drives a 22 inch diameter fourth pulley mounted on the main drive shaft of the brick crushing mechanism. This creates an overall speed reduction and torque amplification of about 3.67

times. Bricks are manually fed at the top of the crusher 4-6 inserted at a time. An Eccentric metal mass is attached with the drive shaft of the crusher which impacts the bricks against the jaw tooth. The high impact force initially crushes the bricks to several parts first, with vibration it falls down the crusher where a set of loosely meshing gears crush them into smaller pieces [3]. A metal net at the bottom separates the chips from the brick dust and both are collected separately.

Fig 3a. Diesel engine run brick crusher

Fig 3b. Mechanism of a Brick Crusher

Table-4: Typical monthly cost reduction of an owner per month, using a diesel engine driven system.

Engine Depreciation per month @10% of 25,000 Tk	2500 Tk.
Crusher & Chassis Depreciation per month @5% of 130,000 Tk	6500 Tk
Lubricating Oil @200 Tk/liter	1600 Tk
Cost of Investment per month	1500 Tk
Engine Maintenance	5000 Tk
Fuel Cost : Diesel 44 Taka/Liter 10 liters (8 hr day) x 30 x 44 Tk	13200 Tk
Labor Cost per month, 4 person	36000 Tk
Cost of crushing with Diesel run	66300 Tk
No. of Bricks Crushed	360000
Amount of Brick-chips Produced	32000 cft
Chip production cost per 100 cft	185 Tk
Cost Reduction /100 cft brick-chip	915 Tk

Everyday typically the machine is used in 8 hour shifts crushing about 12000 standard bricks. This produces about 1060 cubic feet (cft) of brick chips. Manual labor cost for producing 100 cubic feet of brick-chip is about 1100 Taka. The cost of producing 100 cft of brick-chip with Diesel run system is about Taka 185. This allows a cost-reduction or profit-increase up to about 900 Taka per 100 cft of chips. Table-4 the components of the monthly cost analysis based on average value of the data collected.

4. CASE-3: USE OF SMALL DIESEL ENGINES IN CONCRETE MIXING

Concrete mixing is an essential operation of modern construction work. Traditionally mixing of cement with brick/stone chips and sand was done manually using hand tools. In recent years concrete mixing machines have been deployed for this operation, which were run from electric mains supply. However the frequent power failures and unavailability of electricity in some construction sites is making diesel run versions of such machines very popular. In small diesel engine run machines the mixing operation do not depend on unreliable electric supply, which often hampers the mixing process and compromise the quality of the concrete mix due to frequent power failure. Typically the entire setup is fitted on a locally built 4-wheeled steel chassis, so that it can be moved (generally using manual labor) to different construction sites. The single cylinder, water cooled, Diesel engine replaces the electric motor and a belt-pulley drive transmits power at reduced speed to the mixing mechanism. The technical specification of a typical system is given below in table-5. Figure-4a shows the typical arrangement mounted on a 4-wheeled chassis. Some machines are fitted with a feeding hopper.

Fig 4a. Diesel engine run concrete mixer

Fig 4b. Drive mechanism of a concrete mixer

Table-5: Typical Specification of a Concrete Mixer

Engine Rating	5.6 kW, 2000 rpm 430 cc
Pulley-VBelt Drive Diameter Ratios – Flywheel – Drive Bevel	3.5 : 16.5 inch
Bevel Ratio	13 : 106
Overall Torque Amplification / Speed Reduction	43 : 1 Drum at 45 rpm
Typical Mixing Rate	1000 cft/ 8 hour shift
Typical Fuel Consumption	16 liters/ 8 hour shift

A pulley-V belt drive is used to transmit the power from the 5.6kW single cylinder diesel engine to the mixing mechanism. A 3.5 inch diameter pulley fitted with the engine flywheel drives a 16.5 inch diameter pulley on the shaft driving the 13 teeth bevel gear. The bevel gear drives the 106 teeth ring gear which finally rotates the mixing drum about a perpendicular axis at about 45 rpm. Speed is reduced 6.7 times in the belt drive and 8.2 times in the bevel gear-train. Typically about 1000 cubic feet of concrete mix is produced in a 8 hour shift, consuming about 16 liters of diesel. In the cost analysis the difference in costing is compared with same mixing machine driven by an electric motor on a month basis. So the costs associated with the – engine, fuel, accessories are compared to the motor and electricity charge. The cost elements are detailed in table-6.

Table-6: Typical monthly cost reduction of an owner per month, using a diesel engine driven system.

Engine Depreciation per month @10% of 15,000 Tk	1500 Tk.
Cost of Investment per month	150 Tk
Lubricating Oil@ 200 Tk/liter	1400 Tk
Engine Maintenance	1000 Tk
Fuel Cost : Diesel 44 Taka/Liter 16 liters (8 hr day) x 30 x 44 Tk	21120 Tk
Cost of mixing with Diesel engine	25170 Tk
Amount of Concrete-Mix Produced	30000 cft
Electricity Consumption / 8 hr shift	48 kWh
Cost of Electricity @6Tk/kWh	8640 Tk
Motor Depreciation per month @5% of 15,000 Tk	750 Tk
Cost of mixing with Elect. Motor	9390 Tk
Difference in cost per month	14380 Tk
Cost increase /100 cft mix with diesel	53 Tk
% of Cost Increase / 100 cft of mix.	20 %

The cost components are comparatively estimated considering the same concrete mixing machine is driven with a small diesel engine replacing an electric motor. Hence the cost involved for the mixing machine would be same in both cases and difference in the cost components for driving the concrete mixer will show the variation of cost. On a monthly basis the cost of driving the mixer with diesel was estimated to be 23,770 Taka, while it would be about 9,390 Taka with an electric motor. This results in an increase of about 48 Taka per 100 cubic feet of concrete mixture.

5. DISCUSSION

In the first case, where small diesel engine are used for crushing sugarcane, the process was found to be cost-effective. Using the engine could eliminate the need of one additional worker, with the same level of Juice productivity. The system with a 3 kW engine required only about 2.5 liters of diesel on a typical (12 hour) day. Observation of the engine exhausts indicated that the engine was frequently subjected to high loads as the bundle of sugarcane is squeezed between the rollers. It reduced the production cost by about 2500 Taka per month, which can be considered as a profit increase also if the same selling price is maintained. Typically it is about 12% rise in the monthly profit. It should be also considered that if the customer demand reduces in several days of the month, or in parts of a day, the fuel and maintenance costs will also reduce to some extent accordingly, however the daily/monthly wage the additional worker needs to be paid at a flat rate. The tri-cycle mounted version has the advantage of changing the location of operation and do not need to pay the fixed rental charges, rather the business is shifted to convenient locations according to customer demand (eg. near the Saheed Minar in the month of February). Cost of manual labor (eg. wage of the worker) is the main parameter influencing the economic feasibility of the diesel run system. Although the economic benefit is making such systems popular, it was observed that often the food materials were exposed to diesel exhaust as a wind blows. The level of food contamination by diesel exhaust could be investigated, to determine the risk of health hazards.

In the second case, where small diesel engines are used for crushing bricks in to chips, the process was found to be very cost-effective. It also reduces the dependency on the labor skill to produce uniformity of the chips produced. The investment cost of the entire setup along with the engine was about 1,55,000 taka. Every 1000 bricks would produce about 85 cubic feet of brick chips, pricing about 1100 taka if done manually. The crushing cost using the diesel run crusher is only abut 200 taka per 100 of brick-chip, which can reduce the costing or increase the profit margin very significantly, if the product price is kept the same. Cost of fuel is the main parameter influencing the economic feasibility of the diesel run system, as increase in wage will effect both systems. However to ensure this high economic advantage brick-crushing works must be available throughout the years, the chassis mounted system with wheels helps in this aspect. Although a 15 kW engine was used, the fuel consumption was typically found to be only about 10 liters per 8 hours shift. This indicates although the machine running continuously, it is only subjected to high loads for a fraction of the time, typically during the initial crushing of the bricks in between the crushing tooth. Only for this part the full strength of the relatively larger engine is actually used. The strength of the brick chips made manually and by the engine driven system was reported to be have similar strength [4].

In the third case, where small diesel engines are used for driving a concrete machine by replacing the electric motor, the process itself was not found to be cost-effective. The production cost of the concrete mix was found to be less compared to the Diesel engine run system. The production cost per 100 cubic feet of concrete mix would increase by 58 Taka, if a diesel engine is used to drive the mixing machine. However the reliability of the electric power supply is of utmost importance in this case, since the quality of the entire lot of the concrete mixture can get compromised if the ongoing process is interrupted for a while. Hence the unreliability of mains electric power, rather than the running cost is making the use of small diesel engines popular in Bangladesh. Reliability of electric supply is the main parameter influencing the economic feasibility of the diesel run system. Another thing to be noticed here is that, although a 5.6 kW engine is used the fuel consumption rate is about 16 liters per 8 hour shift, which is much higher compared to case-2. This indicates the engine is more loaded for most of its operation time, other than loading and unloading. The chassis mounted system with wheels facilitates easier transportability of the system.

6. CONCLUSION

Three cases of non-conventional use of small Diesel engines in Bangladesh were investigated. In the first case of crushing sugarcane for producing juice and the second case of crushing bricks to produce brick-chips, the engines are used to replace human manual labor. While in the third case the engines replace the electric motors. For each case 10-15 systems were physically studied first, then specification and performance data were collected from selective apparently more reliable users. In all the three cases it was found that same level of productivity could be maintained with much less manpower involvement. Although the initial investment was more but for crushing of sugarcane and brick-chips the same productivity could be attained at a much lower cost. In the case of concrete mixing the process cost would increase considerably using diesel, provided reliable electric supply is available. However non-reliability of electric power supply is making the use diesel engine run concrete mixers popular. The small diesel engines are already used in huge numbers is areas like – irrigation, standby power generation and river transportation. Further use of such engines in a number non-conventional areas are getting more popular, increasing their cumulative contribution to the overall economy.

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