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Profit estimation models of industrial and engineering brick manufacturing using UASB reactor sludge

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ABSTRACT

According to a recent report by the Iranian industrial organization, over 1700 Industrial and Engineering Brick Manufacturing (IEBM) industries are currently running in Iran, using the same method in common use worldwide. The present research study used a combination of a literature review, existing research reports, and a model of assessment among the four main kinds of IEBM industries to estimate the profit of IEBM using Wastewater Treatment Plant (WWTP) sludge as a model. Paying attention to differences in brick manufacturing practices among the many published papers, we summarized the available standard procedures and methods. Both the paired test and t-test analyses revealed a significant difference among parameters such as initial feed, employees, power, water, fuel, and land ($p_{value} \leq 0.001$) for the four main types of IEBM industries in Iran. The evaluation identified a priority hierarchy among factors: employees> land > initial feed > water > power > fuel. Therefore, automation in this industry is recommended. Next, two models were developed to estimate the profit of a WWTP and Four Main Brick Manufacturing Industries (FMBMI) using released sludge from the WWTP.

Keywords: Profit, Brick manufacturing, Wastewater sludge, Model

Introduction

Growth of the population, increasing urbanization, and changes in human life styles are interconnected with progress in technology and development, resulting in increased volume of miscellaneous solid wastes released by industrial, mining, domestic, and agricultural activities. Globally, the quantity of solid wastes produced was reported to be around 12 billion tons in 2002 and a predicted 19 billion tons annually by 2025.

The construction of water treatment plants has caused problems due to the huge quantity of dry sludge released. There are two practices in use to address this problem, disposal of the solid waste including land filling and using the dry sludge as fertilizers. However, there are some harmful materials remaining in this sludge that can cause damage to the environment.

The global generation of Incinerated Sewage Sludge Ash (ISSA) and sludge has been reported to be around 10.0×10^6, 7.0×10^6, 1.2×10^6, 0.5×10^6, and 1.2×10^8 tons/year for Europe (sludge), USA (sludge), North America (ISSA), Japan (ISSA), and Taiwan (sludge), respectively.[1] Recycling of wastes into civil engineering materials has received more attention recently, such as employing fly ash, blast furnace slag, phosphogypsum, recycled aggregates, red mud, Kraft pulp production residue, waste tea, hazardous wastes etc to form building materials.[2]

The full-scale manufacturing of bricks incorporating sludge commenced in Port Elizabeth in 1979. Brick manufacturing utilizing sludge introduced some advantages such as saving around 7 million liter of water per year for every approximately 27 million bricks produced by the industry, reducing fuel demands by up to 69%, reducing the cost of transportation because of the lighter bricks that are manufactured, and the fuel value of the sludge contained in the brick has efficiently extended the firing zone within the kiln, resulting in an increase of throughput by almost 100%, and a provision of heat for drying by

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sludge fired in the afterburner, making this a trouble-free and convenient practice of sludge disposal. Moreover, the bricks do not produce any indoor air quality difficulties. The fired flash bricks have approximately the same characteristics as standard clay bricks.[3]

According to a report published by the Iranian industries organization, around 1700 brick manufacturing industries are currently operating in Iran and there are approximately 100,000 small and micro industries in India, each manufacturing between 100,000 and 20 million bricks per year.[3,4]

A fired clay brick is made via mixing clay with water, forming the clay into the preferred shape, then by drying and firing the brick. Clays contain plasticity and are a complex product that comes in 3 main forms, surface clays, shales, and fire clays. The content of SiO_2 (ranging from 55–65 wt%) and alumina (Al_2O_3; 10–25%) along with various values of metallic oxides and other impurities create the main differences between clays. The chemical nature of clays along with different firing techniques lead to the variations in the properties of miscellaneous types of clay bricks.[5] Extensive research has been conducted on brick manufacturing practices worldwide such as Li et al.,[6] Huang et al.,[7] Lin et al.,[8] Hegazy et al.,[9] Lin,[10] Kadir,[3] Babu, and Ramana,[11] Jahagirdar et al.,[12] Mymrin et al.,[13] Devant et al.,[14] etc. The current research offers a standard procedure for IEBM as well as an explanation of the complete details of FMBMI and it also introduces two models for estimating profits.

Materials and Methods

The data related to chemical analysis of sludge were obtained from tests carried out in the laboratory and the physico-chemical properties of WWTP were extracted based on existing local WWTP in Hyderabad, India. IBM SPSS Statistic 20 software was used to analysis the data of FMBMI. In order to prioritize the existing main factors among FMBMI we used equations 1–3. The data were sorted from smallest to largest and then we used equation 1.

$$Nij=\frac{(rij\text{-}r\ minj)}{(rj\text{-}r\ minj)} \tag{1}$$

$$Z=\frac{(X\text{-}\mu)}{\alpha} \tag{2}$$

$$Znew=Zold+|Min\ Zj| \tag{3}$$

In these equations, Z, X, μ, α, Z_{new}, Z_{old}, and Min Z_j are standard numbers for each existing item in the matrix, average number of values in the particular column, standard deviation of each column, new item, obtained item from the previous step and existing minimal item in the column.[15]

Results and Discussion

The current study discussed four types of brick manufacturing industries, ceramic brick, firebrick, façade, and semi-automatic brick. Ceramic bricks contain 6 holes with nominal dimensions about 200 × 100 × 100 mm. At first, the clay must be prepared in terms of size by milling and sieving, then it is mixed with water and a filter press or extrusion process is used to form the brick frameworks. Finally, the molded bricks pass through the drying tunnel for 24 h to remove extra moisture and are then ready for burning or firing at 1000 ºC for 15 to 120 h depending on the particular clay properties. Firebrick can withstand high temperatures of up to 1700 ºC for 2 h with a maximum shrinkage percentage of only around 3%. The clay is cured after mixing it with water and some additives followed by a filter press or wind hammer. Facade bricks have a thickness around 3 cm (typical) or 4–5 cm. To generate facade bricks, approximately 28%–30% water is mixed with a fine grain clay. A variety of firing temperatures can be used to generate typical facade bricks depending on the properties of the clay. For instance, clay with high percentages of Al_2O_3 (melting point 2050 ºC) and SiO_2 (melting point 1750 ºC) needs high burning or firing temperatures and vice versa. Semi-automatic brick contains nominal dimensions around 5.5 cm×22×10.5 in thickness, length and width, 20% holes and 1.8 kg for the final weight of a fired brick. Typically wet and dried bricks are approximately 22.9×11.4×5.9 cm^3 and 22.4×10.7×5.6 cm^3, respectively. The fired semi-automatic brick withstands working pressures of at least 120 kg/cm^2. Fig. 1 and Table 1 display the brick Manufacturing operations and requirements for the FMBMI in Iran, respectively.

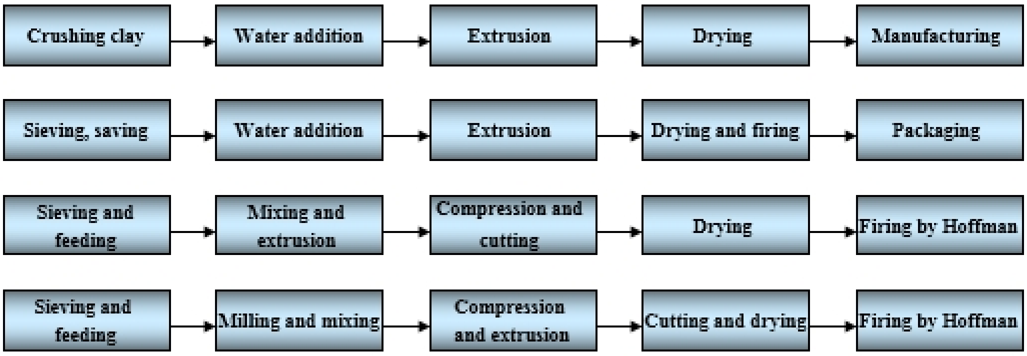

Fig. 1. Diagram of Ceramic brick, firebrick, facade and semi-automatic bricks manufacturing respectively (This study)

Table 1. Requirements of FMBMI (This study)

Industries	Ceramic brick	Fire brick	Facade brick	Semi-automatic brick
Feed box	4 m^3/h (2 No)	50 m^3 (1 No), 10 m^3 (2 No)	3 m^3 (1 No)	3 m^3 (1 No)
Conveyor	Metal and plastic types; 3 kW (4 No) 2.2 kw (4 No)	2.5 tons/h (5 No)	1.3 m/h (1 No)	1 No
Extruder	30 bar (1 No)	Compressor (4-1000 l/h, (5 No))	Two-axis (1 No)	Two-axis (1 No)
Mixer	Two-axis mixer 30-40 m^3/h (1 No)	Two –axis 30-40 m^3/h (2 No)	Initial mixer 30-40 tons/h (1 No), two-axis mixer (25 tons/h;1 No)	Initial mixer (25 tons/h; 1 No), two-axis mixer (25 tons/h;1 No)
Clay pocket	-	Carton; 47 * 23 * 13 cm); 380000 No	(30*50); 1 N0	(30*50); 1 No
Ventilator	30 kw, (2 No)	30 kw, (2 No)	30 kw, (2 No)	30 kw; (2 No)
Power Supplier	1 No	1 No	1 No	1 No
Roller miller	Waltz machine 220/170 rpm; 28 m^3/h; (1 No)	Sieve shaker; (1 No)	1 No	1 No
Furnace	Tunnel furnace; (1 N0)	Furnace 1400 °C; (1 No)	Hiffman (1 No)	Hiffman (1 No)
Cutter-crusher	Automatic cutter 8000/h; 1 No, Crusher 0.17 kW; (1 No)	Hydrolic press (2000 tons); 4 No	20 units; (1 No)	1 No

The main factors that make up the frameworks of FMBMI are listed in Table 2. The equipment cost was ignored in the present research because it is approximately the same among all FMBMI.

Table 2. Assessment matrix based on main factors of FMBMI

Industry	Initial feed (t)	Employees	Power (kw)	Water (m^3)	Fuel (Gj)	Land (m^2)	Equipment cost
Ceramic brick	38035	74	1388	21	351	17300	-
Firebrick	11000	67	663	23	104	13100	-
Façade brick	56700	62	406	77	9	13350	-
Semi-automatic brick	56700	62	406	77	9	13350	-

According to both the paired sample test and t-test analyses, a significant difference was found among parameters of initial feed, employees, power, water, fuel and land ($p_{value} \leq 0.001$). Also, for the null hypothesis using independent samples the Kruskal Wallis test revealed a significant difference of about 0.05. Performing a Pearson correlation test among the FMBMI (ceramic brick, firebrick, façade brick and semi-automatic brick) found two significantly different parameters around 0.05 and 0.01. The following values were obtained (0.5915, 1), (0, 0.4166), (0, 0.2617), (0.035, 1), (0, 0.2777), and (1, 0) for initial feed, employees, power, water, fuel, and land, respectively, using equation (1). These values can be employed to prioritize the factors as shown in Fig. 2.

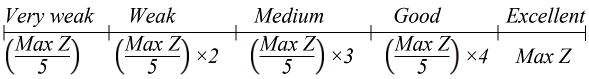

Fig. 2. Spectrum of Growth Potential Assessment

Employing equations 2 and 3 for these values resulted in amounts of (1.86, 1.88), (0, 11.6), (0, 1.54), (1.55, 1.52), (0, 0.73), and (7.605, 0). The Z max values were found to be about 1.88, 11.6, 1.54, 1.55, 0.73, and 7.605, respectively. It is worth mentioning that the industry classifies employees, land, initial feed, water demand, power and fuel consumption as their primary concerns. There was a perceived priority among these items as employees > land > initial feed > water > power > fuel. Cavallaro et al.[16] investigated the combined heat and power systems applying fuzzy Shannon entropy and fuzzy TOPSIS to prioritize the factors to produce a classification style as gas turbine > steam turbine > fuel cell > reciprocating engine > micro-turbine.

To make an industrial and engineering brick, a variety of tests are performed upon the brick specimens to ensure the material quality is sufficient for construction. Therefore, some quick physico-chemical tests for the properties of clay and sludge samples have been developed. Sludge and clay samples are dried at 105 ºC then passed through 550 ºC and are then prepared for X Ray Difraction (XRD), X Ray Florescence (XRF), Scanning Electron Microscopy (SEM), and Transmission Electron Microscopy (TEM) analysis tests. Table 3 represents the chemical analysis of allowable values (%) for making an industrial and engineering brick.

Table 3. Chemical analysis of allowable values (%) for making industrial and engineering brick

Analysis	Max and min values	Optimum ratios	Industrial soil analysis	Available values in soil
L.O.I	3.49-17.38	4.9-9.1	18.21	
SiO_2	47.38-72.6	49.2-68	33.59	40-60
Al_2O_3	7.01-21.87	10.2-19.4	11.59	9-21
$Fe_2O_3 + TiO_2$	0.8-8	2.7-3	5.13	Fe_2O_3: 3-12
CaO	0.05-17.04	0.3-16.5	16.98	Maximum 17
Mgo	0.38-5.16	0.5-2.9	4.98	4
K_2O	0.5-4.86	1.3-4	2.58	
Na_2O	0.1-1.96	0.3-1.2	0.95	

The required size distribution of elements and components for making industrial and engineering brick using clay and dry sludge encompasses SiO_2, Al_2O_3, Fe_2O_3+TiO_2, CaO, K_2O, and Na_2O, illite, montmorillonite, kaolinite, and clay. Typical physical tests to evaluate the dry sludge sample include specific gravity, bulk density, water absorption, and moisture content. There are two methods used to determine the physical properties of sludge and brick samples, either the conventional method that is explained below (Eq. 4-33) or a method using a special apparatus.

$$\text{Specific Gravity Gs}=\frac{(W2-W1)}{(W2-W1)-(W3-W4)} \quad (4)$$

$$\text{Bulk density}\left(\frac{kg}{m3}\right)=\frac{Mt-Mc}{V}*1000 \quad (5)$$

$$\text{Weight of sample}=\gamma=\frac{Mg}{V}=p*g=p*9.81*10^{-3} \quad (6)$$

$$LLn=Wn*\left\{\frac{N}{25}\right\}\text{^}0.121 \quad (7)$$

$$LLn=k*w\text{^}n \quad (8)$$

$$PI=LL-PL \quad (9)$$

$$W=\frac{M2-M3}{M3-M1}*100(\%) \quad (10)$$

$$Sd\%=\frac{Lp-Ld}{Lp}*100 \quad (11)$$

$$Sf\%=\frac{Ld-Lf}{Ld}*100 \quad (12)$$

$$St\%=\frac{Lp-Lf}{Lp}*100 \quad (13)$$

$$Ps\%=\frac{Ww-Wd}{Wd}*100 \quad (14)$$

$$\text{Weight loss on ignition}=\frac{Wa-Wb}{Wa} \quad (15)$$

$$p=\frac{(W-D)}{(W-S)}*100 \quad (16)$$

$$\text{Water absorption}=\frac{W-D}{D}*p*100 \quad (17)$$

$$\text{Water absorption coefficient, } C=\frac{M*100}{S*t^1/2} \quad (18)$$

$$V=W-S \quad (19)$$

$$\text{V of open pores}=W-D \quad (20)$$

$$\text{V of imprevious portion}=D-S \quad (21)$$

$$T=\frac{D}{(D-S)} \quad (22)$$

$$B=\frac{D}{V} \quad (23)$$

$$\text{Bulk Density}=\frac{D}{W-S}*p \quad (24)$$

$$\text{Compressive Strength}=\frac{p}{t*w} \quad (25)$$

$$RF=\frac{3PL}{BH2} \quad (26)$$

$$Q=\frac{KA\Delta T}{L} \quad (27)$$

$$K=\frac{QL}{A\Delta T} \quad (28)$$

$$Sd\%=\frac{Lp-Ld}{Lp}*100 \quad (29)$$

$$St\%=\frac{Lp-Lf}{Lp}*100 \quad (30)$$

$$\text{Volume shrinkage }\%=[1-\left(1-\frac{S}{100}\right)^3]*100 \quad (31)$$

$$\text{Shrinkage factor}=\frac{Lp}{Lf} \quad (32)$$

$$D=100-\{(W1-W2)*\frac{100}{W1}\} \quad (33)$$

Weight of bottle + sample (W_1), Weight of bottle + water (W_2), Weight of bottle + distilled water (W_3) and Weight of bottle (W_4).	(4)
Weight of cylinder + sample (M_1), Length of sample in the cylinder (I_i) and depths of both ends of the cylinder (I_2 and I_3). After extruding, weigh of cylinder (Mc). Weigh of tube + sample (Mt). After extruding (Mc).	(5 and 6)
LLn is one point of Liquid Limit (LL) for given trial, %, N is number of blows causing closure of the groove for given trial, Wn is water content for given trial, %, k is factor given in ASTM [16], ^= Symbol of second root, PI is Plasticity index, LL is liquid limit (whole number) and PL is plastic limit (whole number).	(7,8 and 9)
Weigh of container to the nearest 0.1 g (M_1), Weight of sample + container (M_2). Weigh of the container and the contents after drying at 105 ºC for minimum 12 h (M_3).	(10)
Weight of samples as dried (W_1), weight sunk in cold water for 24 h (W_2) based on arashmodous equation. Weight of samples (W_3) as soon as coming out from water, The dry contraction (Sd), firing contraction (Sf), total contraction (St) and plasticity (Ps), Lp (plasticity length= initial length), Ld (length after drying by oven) and Lf was the brick length after firing.	(11-14)
Electrical furnace was used for firing samples and recorded weights before (Wa) and after firing (Wb).	(15)
P is the apparent porosity, W is the saturated weight, D is the dry weight and S is the suspended weight of the manufactured bricks.	(16)
Archimedes' procedure; (dry weight, D), (density, p), (suspended weight, S) and soaked weight (W). M, S and t are mass in grams of water absorbed by brick from the begining of submerging, surface of submerged face (cm^2) and time of starting immersion (t=10 minutes) respectively.	(17-23)
Exterior Volume: V (cm^3), of the test specimens is obtained by subtracting the suspended weight from the saturated weight, both in grams.	(19)
Volumes of open pores and impervious portions.	(20 and 21)
Apparent specific gravity (T) of that portion of the test specimen which is impervious to boiling water.	(22)
Bulk density, B (g/cm^3) of a specimen in grams per cubic centimetre is the quotient of its dry weight divided by the exterior volume, including pores.	(23)
Bulk density by Archimedes: weights of the samples (dry weight, D) and then samples soaked in boiling water (density, p), (suspended weight, S) and soaked weight (W).	(24)
P is load on the material, W is width of the sample, t is thickness/height of the sample	(25)
RF is the flexural rupture strength (MPa), P is the maximum load introduced (kgf), L is the distance between the supports (mm), b is the width of the TS (mm), and h is the height of the TS (mm).	(26)

K, Q, A, ΔT and L define as thermal conductivity (W/mK), heat flow, surface area, temperature gradient and thickness respectively. The k value computed for primary building products mentioned to be about 1.226, 1.053, 0.807, 1.154, 1.442 for densities of asphalt, roofing 2240 kg/m^3, glass 2512 kg/m^3, brick dry and common with both density 1760 kg/m^3, concrete 2400 kg/m^3 respectively.	(27 and 28)
Sd is linear drying shrinkage, %, Lp is plastic length of test specimen, and Ld is dry length of test specimen.	(29)
St is total linear shrinkage after drying and firing, %, Lp is plastic length of test specimen, and Lf is fired length of test specimen.	(30)
S means linear shrinkage, %.	(31)
Lp means plastic length of test specimen, and Lf is fired length of test specimen.	(32)
In this test, the brick sample is weighed before introducing in the machine and then encountered to 500 revolutions and weighed again.	(33)

First, clay samples are dried at 110 ºC and after milling and passing through sieves (40 mesh: 425 µm) water addition is carried out depending on the initial moisture content of the mixture and according to the Standard Proctor test. Then the molds are cured for 7 days and subjected to firing temperatures around 1250 ºC for 2 hours.

Table 4 represents the required physical tests of the manufactured brick. In addition, a number of studies have been reported employing various wastes to make brick. Table 5 represents some studies that have been completed about using wastes to make bricks.

Table 4. Physical tests of bricks[17,18]

Test	Temperature	Descriptions	Recent methods
LL	110 ºC		Size distribution machine or casagrande apparatus
Soil mechanical tests		Porosity of clay, PI, PL, LL, plasticity length and contraction tests of clay	Manually (diagram) or modern apparatuses
Soil water concentration	105 ºC	Clay can comprise 10-15% water (dry basis) at 400 ºC	A source of high-energy neutrons (0.1 to 10 Mev) that is embedded into an AL tube in the soil.
Atterbergs Tests		Normally, 0 to 5 and 15 to 30 for a low plasticity while more than 35 is a high plasticity soil	
Compaction test		15 kN, 10 mm/min	
Brick Weight Loss on Ignition	1050 ºC	The weight loss on ignition criterion for a normal clay brick is 15%	Electrical furnaces
Brick Water Absorption		It is below 17% for first and 17 to 22% for second-class brick and for a relevant brick around 20%	
Density and bulk density of brick		1.8 to 2.0 kg/cm^3 that pertains inversely proportional to the ratio of sludge added in the mixture (1800 to 2900 kg/m^3)	
Initial rate of suction		≤7.0%	
Compressive Strength of Bricks		For engineering bricks such as A, B, damp-proof course 1 and 2 and all other around ≥70, ≥50, ≥5 and ≥5 and ≥5 respectively	
Flexion resistance strength		Class A for <2.5 MPa; Class B for 2.5 to 4.0 MPa; and Class C for >4.0 MPa	
Thermal Conductivity			Studies electrical furnace equipped to Watts clever EW 4008 Wireless energy monitor contains an energy monitor and power transmitter with a magnetic sensor clamp
Brick corrosion		To investigate HCl attack (1-4%), after 8 days of bricks age during 30 days exposure	
Firing Shrinkage		Normally a good quality brick exhibits shrinkage below than 8% at firing temperatures of 950-1050 ºC	
Brick Linear Shrinkage		Measuring the length of samples before and after the firing stage	Using a caliper with a precision of ± 0.01 mm
Brick Abrasion Resistance Test		The abrasion resistance is measured in terms of % durability via equation 33	
Durability	110 ºC	Diving bricks in sodium sulfate solution (50 g/l of sodium sulfate / water) for a period of 30 days	
Toxicity characteristics leaching procedure		Measuring Arsenic, Barium, Cadmium, Chromium, Lead and Mercury in manufactured bricks	

Table 5. Many studies previously completed about using wastes to make bricks

Additive	Optimum ratios	Ref.
Kinds of sludges / silica fume / rice husk ash (25: 50: 25%), (50: 25: 25%), and (25: 25: 50 wt%) fired at 900-1200 ºC	50% of sludge, 25% of silica fume, and 25% of rice husk ash	9
Cassava starch 0%, 4%, 6%, 10% and 12 wt%	6%	19
Hazardous laundry sludge 0-20 wt% fired at 1000-1150 ºC	10 – 20% wt*	13
Sludge of water treatment plant at 0-20 wt%; sludge-clay fired at 850-1050 ºC	5 wt%	20
Sludge and ash from the paper industry, sludge (50%), agricultural and industrial scrap (25%) and silica fume (25%)	WWTP's sludge (10 to 50 wt%)	21
Various oil industrial wastes such as spent filtration earth, spent bleaching earth, sludge from oil refining industry or sludge from pomace oil extraction industry fired at 950 ºC	Waste (10 wt %)	22
Bagasse, ash and rice husk ash (2.5-20%)	Maximum 15%	23
Sewage sludge additions ranging from 10-40 wt% (dry) dried at 150 ºC for 85 h and 150°C to a peak temperature 985 ºC over a 12-h, at 985 ºC for about 14 h	Up to 40 wt%	24
Alum (0-40%) fired at (800-1200 ºC)	Up to 20% sludge, withstand 1200 ºC, or 5% sludge at 1100 ºC	25
(5-15 wt%) of sugaecane bagasse ash + rice husk ash	5 wt%	26
Gypsum sludge	30%	27
Faecal sludge from the anaerobic pond treated with lime fired at 850-1000 ºC for 10 h	10 % – 20 % of the lime-stabilized sludge	28
Textile mill sludge 0-35 wt% fired at 800 ºC and 24 h	Up to 15%	12
Water treatment sludge + Bottom Ash fired at 1150 ºC	20 wt% bottom ash	8
Clay-water treatment sludge 0-100 wt% fired at 100 ºC for 24 h, 600 ºC for 2 h and 1000 ºC for 3 h	100 wt% of sludge	29
Sewage sludge (0-50%) Soft -mud bricks	10% sewage sludge; 40% sludge ash	30
Bodymill Sludge + dan Polishing Sludge (by ratios 0-30 Wt%)	Up to 30%	5

* Weight percentage

The WWTP was constructed in 1938 in Hyderabad. Despite using the modern technology of an Upflow Anaerobic Sludge Blanket (UASB) with an extended aeration system the treatment plant has no ability to remove phosphorus or heavy metals, which have a huge impact on the ecosystem. Also, it turns out that only the new part is in operation because there is no compatibility between the new and the old part of the treatment plant. Figure 3, Table 6 and 7 denote the flow diagram of the WWTP, existing characteristics, and chemical analysis of sludge released by WWTP effluent before the water is released into the river Musi, Amberpet, Hyderabad, India.

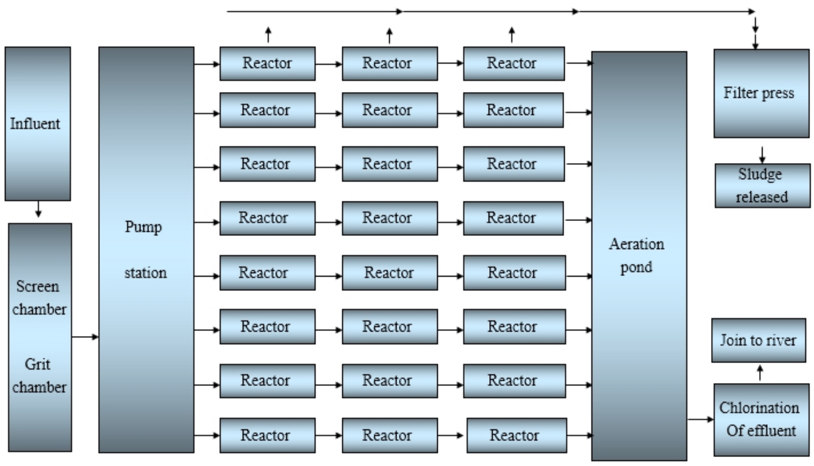

Fig. 3. WWTP in Hyderabad (This study)

Table 6. Existing characteristics of WWTP in Hyderabad, India (This study)

Parameter	Design characteristics of mixed sewage
Biological Oxygen Demand (BOD)	300 MG/L
Total Suspended Solid (TSS)	400 MG/L
Fecal coliform	$5.6*10^6$ MPN/100 ML
Chemical Oxygen Demand (COD)	550 MG/L
Screen channel	4 working, 2 standby, 2.5 m wide, liquid depth 0.8 m, head loss 0.3 m
Detritor tank	4 units, 12.25*12.25 m, liquid depth 0.7 m
Grit channel	4 units, 24*2.5 m, liquid depth 0.87 m
Pumping station	18 pumps, 2360 cum/hr, head 17 m, 160 kw or 210 HP, detention time 5 min
UASB	24 No, 32*28*5.8 m LD, feed inlet boxes 16 No, outlet per feed inlet box 14 No, solids retention time 33 days, upflow velocity during average flow 0.65 m/hr and during peak flow 1.3 m/hr,
Sludge pump	3 No, 3*2 m, capacity 160 cum/hr, head 18 m
Facultative reactor	Detention time 1 day, size 450*300*3.8 m LD,
Aerator	30 No, 50 HP
Polishing pond	Detention time 12 Hr, size 450*200*1.5 m LD
Biogas tanks	3 No, 910 KVA/625 KW, 2 No working 1 standby, gas requirement 350 cum/hr
Power generation	0.91 MW/day
Electric requirement	2.3 MW/day

Table 7. Chemical analysis of sludge released by WWTP effluent before joining river Musi, Amberpet, Hyderabad (This study)

Heavy metals (mg/kg) of sludge	Values
Zn	1199
Mn	211
Fe	14130
Cu	346
Pb	119
Cd	73
Cr	88
Ni	54
As	4
Hg	<1

Studies of economic evaluation are accomplished via empirical equations 34 to 43 and professional experiences in industries. The steps related to this aim have been explained as follows.

(1) Estimation of requirements from projects, (2) estimation of fixed and working capitals, (3) estimation of depreciation costs, maintenance, operational, and non-operational fixed annual capitals, (4) estimation of total fixed and variable manufacturing outlays, (5) estimation of total manufacturing price, (6) estimation of economic indices.

$$W=0.75(\sum e)\times A \quad (34)$$

$$C=0.005\times P \quad (35)$$

$$V = P - ((\sum)e) \times \acute{A} + F + C_f) \quad (36)$$

$$\%V = V \times {}^{100}/_{P} \quad (37)$$

$$Q_p=V-((\sum)I+L+D+S) \quad (38)$$

$$C_v={}^{C_{vd}}/_{C_p} \quad (39)$$

$$Ph=Tf/Cv-Cs \quad (40)$$

$$Cpi=Cvp+Cfp \quad (41)$$

$$Ai=Ts-Cpi \quad (42)$$

$$V_t = {}^{I_f}/_{A_i} \quad (43)$$

In equations 5 to 14, W, e, A, C, P, V, A', F, C_f, Q_p, I, L, D, S, C_v, C_{vd}, C_p, P_h, T_f, C_s, C_{pi}, C_{vp}, C_{fp}, A_i, T_s, V_t, and I_f, are the electrical energy demand, total electrical energy employed in lines, area (m^2), selling outlays, selling rate, value-added, initial materials applied, maintenance, unforeseen outlays, revenue, insurance, expenditures of interest and fees, depreciation, salary, variable outlays of commodity unit, variable project outlays, production capacity, breakeven point, total fixed outlays, selling outlay of commodity unit, manufacturing outlays, variable manufacturing outlays, fixed manufacturing outlays, annual revenue, total selling expenses, time of return on investment, and fixed capital, respectively.[31] To estimate the profit of IEBM using the released sludge of WWTP, the demolished, fixed and disassembled products must be included at an identical quantity or lower than the quantity purchased from the same product according to equation 45.

$$Li + Ai + DMi \leq Si \quad \forall i\ [1,2,3,\ldots.n \qquad (44)$$

Total profit obtained from the recycling operation is estimated based on equations 45–48.

$$TRP=TRR-(TRC+ICR) \qquad (45)$$

$$TRR=\sum_{i=1}^{n}[Ri\times\sum_{j-1}^{m}(DMij\times RPj)] \qquad (46)$$

$$TRC=\sum_{i=1}^{n}[Ri\times\sum_{j-1}^{m}(DMij\times RCij)] \qquad (47)$$

$$ICR=\sum_{i=1}^{n}[Ri\times\sum_{j-1}^{m}(DMij\times HCj)] \qquad (48)$$

Total profit obtained from the remanufacturing operation is estimated based on equations 49–52.

$$TRMP=TRMR-(TRMC+ICRM) \qquad (49)$$

$$TRMR=\textstyle\sum_{j-1}^{m}(RMi\times\text{-}RMPi) \qquad (50)$$

$$TRMC=\sum_{j-1}^{m}[RMi\times\sum_{j-1}^{m}(DMij\times DMCij)]+\sum_{j-1}^{m}[RMi\times\sum_{j-1}^{m}(DMij\times RMCij)] \qquad (51)$$

$$ICRM=\sum_{j=1}^{m}(RMi\times HCi) \qquad (52)$$

In equations 44 to 52, Li, Ai, DMi, TPR, Ri, DMij, RCij, ICR, HCj, TRMP, TRMR, TRMC, ICRM, RMi, RMPi, DMCij, RMCij, and HCi are the amounts of disposable product, amount of recycleable product, amount of dismantling product, obtained profit from the recycling operation, recyclable product rate, amount or number of available piece j from I product, outlay for recycling of the piece j from I product, outlay for product maintenance, outlay for maintenance of piece j, total revenue obtained from the remanufacturing operation, total revenue obtained from reselling, total outlay paid for remanufacturing, outlay for maintenance of product that should be remanufactured, remanufacturing rate of product, obtained profit from selling remanufactured products, outlay for assembly of piece j, cost of remanufacturing of piece j, and cost of maintenance for product I, respectively.[31, 32]

Conclusion

The survey of requirements of FMBMI confirmed that automation, new equipment, and practices can decrease the outlays. The developed models can be employed to estimate the profit of any remanufacturing and recycling materials or engineering construction project. Also, depending on the chemical analysis of the released sludge of WWTP, mixing and employing this sludge in construction materials like brick paves the way to an optimal pathway to manage the sludge as well as producing many environmental benefits.

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