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ENERGY EFFICIENCIES OF END-USE DEVICES IN AN ELECTRO-METALLURGICAL INDUSTRY: A CRITICAL STUDY

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Abstract—The inefficient use of energy in a large number of industries is slowly developing into a major energy crisis in the already power-starved Karnataka State, India. This study attempts to bring out the present inefficient pattern of energy use in an electro-metallurgical industry. It also brings out the considerable scope for energy conservation, especially by increasing the efficiency of the end-use devices used. This concept, when extended to other industries, wherein increasing efficiency of the end-use devices would provide the desired end results with small energy input. This, in turn, would result in a slower rate of energy growth as well as saving in energy use.

Energy efficiency   End-use devices

INTRODUCTION

Energy plays a vital role in our society. Its role in economic and industrial development needs no emphasis. The fast depletion of non-renewable sources of primary energy has necessitated examining the possibility of more efficient use of energy. Conservation of energy is becoming essential for sustained development. Most of the energy consuming facilities and processes currently in use in the industrial sector were designed and imported in an era of inexpensive energy sources. However, with rapid increases in fuel costs in the late 1970s, with changes in fuel availability, and with the present ecological situation, there is a need for critical re-examination of accepted practices adopted so far. Hence, a key element of the present energy management processes is to identify and analyse the possible energy conservation procedures now available with the development of energy conservation techniques.

There are also certain obvious economic incentives which will accrue because of conservation measures. They are:

(1) The savings realized by the reduction in the existing levels of energy use.
(2) The economic losses that can be prevented by avoiding loss of production in case the fuel supply is curtailed (in case of fuel crisis).

This study was conducted to look at the utilization of energy in many industrial processes which constitute a major component of the energy problem. This study reveals the possibility of better efficiency of energy use which would provide desired end results with a smaller quantity of energy inputs.

ENERGY USE IN KARNATAKA STATE: PRESENT SITUATION

In Karnataka State, India, both commercial (coal, oil and electricity) and non-commercial (fuel wood, cow dung and agrowastes) sources of energy are being used almost equally. Sectoral energy consumption indicates that 44% of the total commercial energy is consumed in the industrial sector followed by transport (24.4%) and domestic sectors (18.1%) [1]. The gradual increase in energy consumption in the agricultural sector is noticed in the late 1970s due to its mechanization—both for land preparation (use of tractors, tillers) and for lift irrigation (use of

173

centrifugal pump sets). The industrial sector continues to be one of the single largest commercial energy consuming sectors and is most often highly energy intensive, with consumption of 1.96 t of coal replacement for every Rs. 1000/– of output compared to 0.162 t of coal replacement for the household sector, 0.05 t of coal replacement for the agricultural sector and 3.35 t of coal replacement for the transport sector. In Karnataka, electrical energy generation from hydro and thermal power plants accounted for 10,644 million (mkWh) units (during 1987–1988). More than 70% of this went to the industrial sector. Next to the industrial sector comes the domestic sector [mostly comprising of AEH (all electric homes)] wherein most of this energy is used inefficiently to obtain low quality heat (e.g. bath water heating). The bulk of the non-commercial energy consumption is in the domestic or household sector, used mostly for cooking, predominantly in rural households. The dependence of rural households on fire wood is often as high as 90%. Earlier studies [2] have revealed that, in Karnataka, 41.29% of the total annual energy consumption is from firewood (11.208 MTCR), while cow dung and agrowastes meet about 10.22% (2.79 MTCR) of the total domestic energy requirement.

The situation is fast changing and to meet the energy needs of a growing population, it is necessary to maintain an adequate supply of energy. Demand for electrical energy in the industrial as well as urban household sectors has been increasing so rapidly that the delays in the completion of power projects have created enormous shortages and increased power-cuts during long periods. This has become a yearly, but unwelcome, phenomenon. Karnataka State mainly depends on hydro resources for the production of electricity. It is becoming increasingly necessary to supplement the installed hydro generation by thermal electricity and use of renewable sources of energy. The conflict between the energy demand and environmental quality goals can be solved by an integrated approach with a view to minimizing the consumption of non-renewable resources and maximizing the efficiency of end-use devices. We should also understand that energy consumption is not an end in itself. Vast possibilities exist for improvements in end-use efficiencies in all sectors. The improvements in the efficiencies of energy use permit significant improvements in the physical quality of life without an increase in the amount of primary energy which has to be supplied. When a particular energy carrier is being used very inefficiently, its much more efficient use, or a shift to a more efficient energy carrier, results in the release of hitherto inefficiently used sources for alternative purposes.

OBJECTIVES

The main objectives of this study are to (a) look at the energy consumption pattern in an electro-metallurgical industry and (b) study the efficiency of operation of various end-use devices/equipment.

METHODOLOGY

An industry manufacturing the high-technology equipment required for moving men and material was chosen for this study. The main products manufactured are heavy duty transportation trailers, heavy earth moving equipment like bulldozers, scrapers, graders, dumpers, loaders and rail coaches.

First, the power distribution and requirements in this industry are studied. Next, the efficiencies of the connected load, viz. heating, welding, machinery and lighting, are calculated based on measurements systematically for each and every process.

This study is to examine all loads in a electro-metallurgical industry. The types of machines used are shearing machines, press brakes, cranes, welding machines, diesel generating sets. In all the calculations, both input and output are expressed in power units of kW or in energy units of kilowatt hours (kWh), as the case may be.

The efficiency calculation methods are:

(a) Diesel generating sets

Input:

fuel (high speed diesel) consumption $= VD(C_v)\text{kCal} = (VDC_v) \times 1.16 \times 10^{-3}\,\text{kWh}$

where

V = volume of diesel used by diesel engine in litres
D = density of diesel = 0.82 kg/l
C_v = 10,200 kCal/kg (for high speed diesel)

Output = generator output in kWh.

$$\text{Efficiency} = \frac{\text{output}}{(VDC_v \times 1.16 \times 10^{-3})} \times 100\%.$$

(b) Shearing machine

The shearing machine is driven by an electric motor which is connected to the main shaft by means of a belt drive. The electrical power input to the motor is measured by a watt meter. The material output is calculated by the work done to shear metal sheet. The work done is the product of the shearing force and the distance travelled by the shearer. The distance travelled is half the thickness of material since no effort is required to cut the remaining half. The output power is work done per unit time.

Shearing force = (shear stress × area of the sheet sheared) kgf

Work done = (shearing force × distance travelled in metres) kg m

Output power = [(work done/time in seconds) × 0.0098] kW (since 1 kW = 102 kg m/s).

(c) Press brake

Here, the main drive is an electric motor coupled to the shaft by means of a belt. Input power is measured by a watt meter. Output is the tonnage required to bend the sheet, which is calculated. Thus,

$$\text{Tonnage} = T = (KLSt^2/W)\,\text{t}$$

where

K = a constant (depends on the type of material bent)
L = length of plate to be bent (mm)
S = ultimate shearing strength [kg/mm^2 or (10^{-3})t/mm^2]
W = width of the die (mm)
t = thickness of the plate to be bent (mm).

The bending moment is given by

$$M_b = Tb^2/W \text{ kg m}$$

where b = half the width of the die (mm) and W = width of the die (mm).

$$\text{Work done} = 2(M_b\Theta) \times 9.81 \text{ J}$$

where Θ = half the angle of the bend in radians.

Power is work done per unit time

$$\text{Output} = (\text{work done/time})\text{W}.$$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} \times 100 = \frac{(2M_b\Theta)/\text{time}}{\text{input}} \times 100\%.$$

(d) Furnace

The furnace used is an electrically heated induction type. When an alternating voltage is applied to the coil, a pulsating flux is set up. Due to the rate of change of flux, eddy currents flow in the metal. The direction of the flux is along the axis of the coil. The induced voltage in the metal (to be heated) on account of the rate of change of the flux is in a plane at right angles to the flux. The metal core, therefore, provides a closed path at right angles to the flux. The power in the form of the eddy current losses in the charge produces heat.

An induction heating furnace constitutes an electrical load with a low lagging power factor. Hence, both the energy loss and power drawn are more. Due to the power cut imposed by the State Electricity Board, this furnace is operated only during night shifts, when there are no other heavy loads on the system.

$$\text{Input} = \sqrt{3}VI\cos\phi \times 10^{-3}\,\text{kW}$$

where V = voltage, I = current, $\cos\phi$ = power factor.

$$\text{Output (heat)} = MS(t_2 - t_1) \times 1.16 \times 10^{-3}\,\text{kWh}$$

where

M = mass of material (aluminium wire) heated in kgs
S = specific heat of material in kCal/kg °C [for aluminium ($S = 0.216$ kCal/kg °C)]
1 kCal = 1.16×10^{-3} kWh
T = time taken to attain the required temperature (h)
t_1 = room temperature (°C)
t_2 = temperature to which mass is heated (°C)

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} \times 100 = \frac{\left[\dfrac{MS(t_2 - t_1)}{T}\right] \times 1.16 \times 10^{-3}}{\sqrt{3}VI\cos\phi} \times 100\%.$$

(e) Cranes

Here, the efficiency is computed separately for (i) the hoist motor used for lifting and dropping of load and, (ii) the long travel motor used to lift and move the material.

(i) Hoist motor

Here, the electrical input to the motor in kW is measured by a watt meter and the output is given by

$$\text{the potential energy} = mgh\ \text{J}$$

$$\text{Output} = \frac{mgh}{t}\,\text{kW}$$

where

m = mass (kg)
g = acceleration due to gravity (m/s^2)
h = height to which material is lifted (m)
t = time (s).

(ii) Long travel motor

Here, the energy efficiency is calculated considering both operations, viz. lift and move operations. Here, the input is measured by a watt meter.

$$\text{Output} = \frac{\text{(potential energy need for lift operations + kinetic energy needed for move operations)}}{\text{time}}$$

$$\text{(in kW)} = (mgh + \tfrac{1}{2}mv^2)/t_1\ \text{kW}$$

where

m = mass (kg)
g = acceleration due to gravity (m/s^2)
h = height through which the materials are lifted (m)
v = velocity of the movement of crane

$$= \frac{\text{distance travelled}}{\text{time taken in seconds to travel}} = \frac{D}{t_2}\,\text{m/s}$$

t_1 = time for total operation (s)
t_2 = time for move operation (s).

(f) Welding sets

Arc welding and foil roll welding are the main types of welding used in this industry. Most of the welding sets are of the portable type, using transformer–rectifier sets or motor–generator sets.

$$\text{Input} = (W_1 T_1 + W_2 T_2)\text{kW s}$$

W_1 = watt meter reading while welding
T_1 = time of welding
W_2 = watt meter reading on no-load
T_2 = time for which motor is on no-load.

$$\text{Output} = \text{heat required to melt metal, flux and electrode} = (Q_e + Q_f + Q_m)\text{kCal} = (Q_e + Q_f + Q_m) \times 1.16 \times 10^{-3}\,\text{kWh}$$

where

Q_e = heat required to melt electrode $= [(m_e \times s_e \times t_e) + (m_e \times L_e)]$kCal
S_e = specific heat in kCal/kg °C
L_e = latent heat of fusion
t_e = melting points of electrode

where

m_e = mass of electrode = (volume × density) of electrode $= V_e \times d_e = A_e l_e d_e$

where

A_e = area of electrode (m^2)
l_e = length of electrode (m)
d_e = density of electrode (kg/m^3)
Q_m = heat required to melt the material $= [(m_m \times s_m \times t_m) + (m_m \times L_m)]$kCal

where

$m_m = V_m$ × density of the metal
V_m = volume $= l_m \times b_m \times t_m$

where

l_m = length
b_m = breadth
t_m = thickness of metal portion melted.

The assumptions made in this calculation are: (1) the welding is uniform and beads formed are of the same cross section, and (2) the metal melted is rectangular throughout the length (curvature is neglected).

Q_f = quantity of heat required to melt flux $= [(m_f \times s_f \times t_f) + (m_f \times L_f)]$kCal

where

m_f = mass of flux (kg) = volume of flux × density of flux
s_f = specific heat (kCal/kg °C)
L_f = latent heat of fusion.

In submerged arc welding, the mass is found directly, while in foil roll welding, no flux is used, hence $Q_f = 0$.

$$\text{Thus, efficiency (\%)} = \frac{(Q_e + Q_f + Q_m) \times 1.16 \times 10^{-3}}{(W_1 T_1 + W_2 T_2)}.$$

Table 1. Plant use factor details of generators

Generator	Capacity (kVA)	Hours	Energy	Plant use factor
G_1	350	18.25	3110	0.60
G_2	350	16.75	3010	0.64
G_3	500	21.00	6110	0.72
G_4	500	21.00	6240	0.74

Table 2. Nature of connected loads and their capacities

Sl. No.	Nature of connected load	Capacity (h.p.)	% of total
1	Welding	9350.0	49.65
2	Machinery	7118.5	37.80
3	Lighting	1160.0	6.15
4	Heating	1009.0	5.35
5	Rectifiers	195.0	1.05
	Total	18,832.5	100.00

EXPERIMENTAL RESULTS AND DISCUSSION

Energy Consumption Pattern Study

The power supply by the State Electricity Board to this industry is through two 11 kV feeder lines. Two 500 kVA and two 350 kVA capacity diesel engine generator sets are installed to generate its own captive power when needed, especially during power cuts. Currently, there are four diesel engine generator sets being run with a total capacity of 1700 kVA.

The operation of the captive diesel station at the factory was investigated by analysing the statistical data available of fuel consumption, energy produced and the duration of operation of each generator. The "plant use factor" for each generator on a particular day is given in Table 1. It is observed that the energy supplied through the captive generating sets constitutes nearly 34.7% of the total energy requirement of the industry.

The cost of the energy generated using the diesel sets, taking into account depreciation and maintenance, is approximately four times that supplied by the State Electricity Board (Table 7).

The power factor of this industry is maintained at 0.9 by the use of static capacitor banks with a total capacity of 1825 kVAR.

A schematic of the connected loads is shown in Fig. 1, and their capacities are given in Table 2.

Computation of Energy Efficiency

The energy efficiency of the different categories of connected loads are computed by the procedures indicated in the previous sections. The results are tabulated in Tables 3–6. The manufacturing details of the respective generators are given in the Appendix (Section A1).

(a) Energy efficiency of diesel engine–generator sets

It is clear from Table 7 that the cost of generation is about 4 times that of the energy supplied by KEB. This would highlight the necessity of improving the efficiency of the captive power station

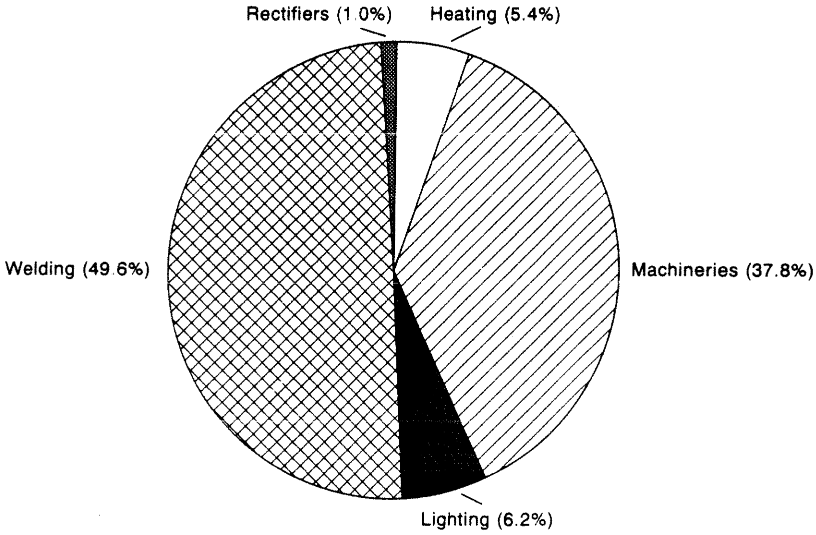

Fig. 1. Connected load details in an industry.

Table 3. The energy efficiencies of the 350 kVA diesel engine–generator set

Sl. No.	Time for which the set is run (h)	HSD consumed (l.)	Heat input (kWh)	Output (kWh)	Efficiency (%)
1	18.5	1070	10,381.14	3370	32.46
2	16.5	900	8731.80	2810	32.18
3	20.75	1160	11,254.32	3670	32.61
4	17	980	9507.96	3150	33.13
5	18	920	8925.84	2860	32.04
6	16.5	990	9604.98	3200	33.32
7	13.25	800	7761.60	2530	32.6
8	12.5	690	6694.30	2300	34.35

Table 4. Computation of energy efficiency of 350 kVA diesel generator (generator 2)

Sl. No.	Time for which the set is run (h)	HSD consumed (l.)	Heat input (kWh)	Output (kWh)	Efficiency (%)
1	17	1020	9896.04	3290	33.24
2	15	850	8246.70	2850	34.56
3	18	1030	9993.06	3350	33.52
4	15.75	920	8925.84	3130	35.06
5	16.5	950	9216.90	3220	34.93
6	14.5	950	9216.90	3490	37.86
7	15.25	910	7858.62	2950	37.54
8	12.5	710	6888.42	2410	34.98

Table 5. Computation of energy efficiency of 500 kVA diesel generator (generator 3)

Sl. No.	Time for which the set is run (h)	HSD consumed (l.)	Heat input (kWh)	Output (kWh)	Efficiency (%)
1	21.00	1620	15,717.24	5820	37.05
2	21.00	1680	16,299.32	5830	35.77
3	21.50	1720	16,687.36	6170	36.97
4	20.50	1580	15,329.16	5820	37.97
5	21.00	1680	16,299.36	6010	36.87
6	11.25	680	6597.36	2760	41.83

Table 6. Computation of energy efficiency of 500 kVA diesel generator (generator 4)

Sl. No.	Time for which the set is run (h)	HSD consumed (l.)	Heat input (kWh)	Output (kWh)	Efficiency (%)
1	20.75	1600	15,523.2	5830	37.55
2	21.50	1720	16,687.4	6190	37.09
3	20.75	1580	15,329.16	5940	38.75
4	21.00	1680	16,294.36	5920	36.32
5	21.00	1700	16,493.4	6240	37.83
6	20.75	1640	15,911.28	5910	37.14
7	21.00	1680	16,299.36	6150	37.73

Table 7. Economics of cost of generation vs energy supplied by Electricity Board

	No. of units/yr	Amount (Rs.)	Cost/unit
KEB supply	4.7×10^6	2.303×10^6	0.49
Captive generation	1.63×10^6	3.35×10^6	2.06

Table 8. Efficiency calculation of guillotine shear

Machine 1							
Input							
No load	While shearing	Test specimen job details	Shear stress (kgf/mm^2)	Shear force (kgf)	Work done (kgm)	Power output (kW)	Efficiency (%)
2 kW	4.2 kW	M.S. sheet length = 900 mm Thickness = 2.5 mm cross-sectional area = 900 × 2.5 mm	50	112,500	140.625	1.39875	33.03

and running the plant at the highest possible efficiency of operation. An increase of efficiency by 1% would, for instance, save around Rs. 45,000/yr in the total energy cost.

(b) Energy efficiency of shearing machines

Depending on the thickness of metal cut, shearing machines are grouped into two categories. They are: (1) sheet metal machines which are capable of cutting metal of 10 gauge thickness and (2) plate shearers which are capable of shearing metal with thickness greater than 10 gauge. Common sheet metal shearers are the foot shearing shearers, the punch and the notches. Both the foot shearing shears and notches operate by the use of a straight blade. The shearing is carried out without creating clips or waste products. The basic shearing operation involves cutting a sheet of metal to final size by trimming, notching and piercing.

The energy efficiencies of the shearing machines are shown in Table 8. The manufacturing details for each machine are given in the Appendix (Section A2).

(c) Energy efficiency of press brake

The press brake has a set of dies, a stationary jaw and a movable jaw. The die is used to perform simple tasks of hand operations such as bending, flanging, wire edging, hammering, etc. The prime mover of the press brake is an electric motor whose efficiency is calculated by the procedure used earlier. The results are shown in Tables 10 and 11. The manufacturing details of each machine are given in the Appendix (Section A3).

(d) Furnace

There are, in all, eight furnaces, four electric furnaces and four oil furnaces. The electrically heated furnaces are of the induction type, two of 150 kW capacity each and the other two of 200

Table 9. Efficiency calculation for shearing machines 2 and 3

Machine 2							
Input							
No load (kW)	While shearing (kW)	Test specimen Job details	Shearing stress (kgf/mm^2)	Shearing force (kgf)	Time (s)	Output (kW)	Efficiency (%)
2.25	19.5	type = M.S. L = 2800 mm t = 3.15 mm	50	44,100	1	6.9	35.4
2.25	5.5	Type = aluminium sheet L = 3000 mm t = 3 mm	50	450,006	0.5	1.90	33.14
Machine 3							
Input							
No load (kW)	While shearing (kW)	Test specimen Job details	Shearing stress (kgf/mm^2)	Shearing force (kgf)	Time (s)	Output (kW)	Efficiency (%)
6	11.5	type = M.S L = 168 mm t = 10 mm	50	84,000	1	4.1776	36.42

Table 10. Efficiency calculation of a press brake (No. 1)

Machine 1							
Input		Output calculations					
No load (kW)	While on load (kW)	Job details (mm)	Tonnage (t)	Bending moment (M_b) (kg m)	Work done $2(M_b\theta)$ (J)	Output power (kW)	Efficiency (%)
8.5	21	$l = 795$ $w = 18$ $t = 2.6$	12.4	$M_b = 55.8$	952	1.904	9.066

Table 11. Efficiency calculation of a press brake (No. 2)

Machine 2							
Input		Output calculations					
No load (kW)	While on load (kW)	Job details (mm)	Tonnage (t)	Bending moment (m_b) (kg m)	Work done $2(M_b\theta)$ (J)	Output power (kW)	Efficiency (%)
Specimen 1							
6	9	$L = 110$ $w = 50$ $t = 6$	4.11	41.1	633.3	1.266	14.06
Specimen 2							
6	8.5	$l = 58.1$ $w = 79$ $t = 3.15$	6.616	66.16	1019.49	2.039	24

and 100 kW capacity, respectively. These furnaces are used for hardening, tampering and stress relieving of materials like L.S. beam, die blocks, bushes, washers, eyebolts, caps, wires, etc. The efficiency of an electric furnace is computed as shown below (Table 12). The manufacturing details of the machine are also given in the Appendix (Section A4).

(e) Cranes

Cranes are used for lifting loads and moving them from one place to another. A crane consists of four motors: (a) hoist motor—to lift and drop the load; (b) long travel motors—two motors are fixed at the end of movement; (c) cross travel motor—one motor for cross travel.

The efficiency is calculated separately for each of these four motors performing different operations and is shown in Table 13 (for the hoist motor), while Table 14 gives the energy efficiency calculations for combined operation (for the long travel motor). The manufacturing details of the machine are given in the Appendix (Section A5).

(f) Welding

Welding is a process of joining similar metals by application of heat with or without application of pressure.

Arc welding and foil roll welding are the two main types of welding used in this industry. Most of the welding sets used are portable except in the case of submerged arc welding and foil welding. The portable welding sets are either transformer–rectifier sets or motor–generator sets.

Table 12. Energy efficiency calculation of an electric furnace

Heat output	Input	Average value of energy efficiency
M.S. $(t_2 - t_1)$	$\sqrt{3}\ VI \cos\phi \times 1\ h$	10.84%
7560 kCal	where	
	$V = 415$ V	
8.76 kWh in 1.5 h	$I = 150$ A	
	$\cos\phi = PF = 0.5$	
	time = 1 h	
∴ energy output/h = 5.846 kWh (average)	∴ input $= \sqrt{3} \times 415 \times 150 \times 0.5 \times 1$	

Table 13. Energy efficiency calculation of a crane

(i) Hoist motor (when the material is lifted or moved up)

Input (kW)	Output (mgh/t)	Efficiency (%)
4.25	m = mass lifted 2132.36 kg $g = 9.81$ m/s^2 h = height = 5 m $t = 32$ s output = 3.26 kW	76.89

(ii) Hoist motor (when material is moved down)

Input (kW)	Output (kW) ($t = 18$ s)	Efficiency (%)
8.75	5.81	66.5

Table 14. Long travel motor (when carrying the operation of lifting and moving)

Input (kW)	Output (kW)	Efficiency (%)
Input power = 8.5 kW	(a) h = height to which is lifted = 2 m, t = 36 s, mass m = 2132.326 kg Energy required to lift to this height in the time interval of 20 s = 2091.81 W	
	(b) Distance travelled = 25 m $mgh + \frac{1}{2}mv^2$ Mass = 2132.326 kg Time = 36 s	24.82
	Therefore power required for moving the load = 14.28 W	
	Total = $a + b$ = 2116.082 W = 2.116 kW	

Types of filler metal and flux used

Here, welding rods or electrodes are used as filler material. For ferrous metals, steel rods coated with flux are generally used. Copper coated mild steel electrodes are used in submerged arc welding. The electrodes normally used in this industry are supercito or over cord-S. The specifications for these electrodes are as follows:

(1) Supercito: manufactured by Advani Oerlikon

Classification	AWS: E7018		BS: E 601 JH	IS: M 601389 JH		
Diameter of welding rod (mm)	6.3		5	4		3.15
Welding current (A)	270–360		200–240	150–200		100–140
	C	Mn	Si	S	P	
Weld metal analysis (%)	0.08	0.95	0.45	0.03	0.03	

(2) Over cord-S: manufactured by Advani Oerlikon Ltd

Classification	AWS: E6013		BO: E 307	IS: M 307275		
Diameter of welding rod (mm)	5		4	3.15	2.5	2
Welding current (A)	180–250		140–190	100–140	60–90	40–60
	C	Mn	Si	S	P	
Weld metal analysis (%)	0.07	0.50	0.20	0.03	0.03	

The work done in the welding process is the welding of the joint. The welding of the joint involves: (a) metal to be welded, (b) electrode used as filler material and (c) flux used in the process which forms the slag.

Calculation of energy efficiency

Input to the welding sets is electrical in nature. Output will be in the form of heat at the welded joints. Once the process starts, the power is supplied continuously to the welding set. The work done is intermittent or discontinuous. The total time spent includes: (a) replacing the electrodes, (b) removing slag, (c) moving of welding rod from one joint to another and (d) sometimes deliberate delays on the part of the workers handling the welding set increases the idle running time of the welding set and consequent energy losses.

The total electrical input to the welding set consists of: (i) W_1 when sets are on no load for the period T_1s and (ii) W_2 when on load for T_2 s. Hence, input = $W_1T_1 + W_2T_2$.

The specimen calculation to find out the energy efficiency of the welding process is as follows:

Welding set: Indarc Silicon Rectifier

[The manufacturing details of the machine are given in the Appendix (Section A6)].

Input: T = total time of operation = 55 min = 3300 s, $T_1 = 1826$ s, $T_2 = 1474$ s, $W_1 = 32$ kW, $W_2 = 12$ kW, input = $W_1T_1 + W_2T_2 = 76{,}120$ kW s.

Output: flux of density = 3003.92 kg/m^3, $L_f = 9.369$ m, area = 1.76×10^{-5} m^2, V_f = volume = 1.6523×10^{-4} m^3, m_f = mass of flux = 0.4963 kg.

Electrode: type: Over card-S. d_e = diameter of the electrode = 4 mm, number of electrodes used = 25, length of each electrode = 0.445 m, length of electrode (total) = 11.125 m, length of electrode used = 9.369 m, volume of electrode = 1.1773×10^{-4} m^3.

Metal: d_m = density = 7860 kg/m^3, L_m = length of metal melted = 7.46 m, b_m = breadth = 0.004 m, t_m = thickness = 0.002 m, volume of metal = $L_m \times b_m \times t_m = 5.968 \times 10^{-5}$ m^3, mass of metal = $d_m \times V_m = 5.968 \times 10^{-5} \times 7860 = 0.4691$ kg.

Due to the non-availability of the specification for the electrode, only Qf and Qm were computed as explained in the methodology, and the efficiency of the welding process is found to vary between 14 and 18% for the motor–generator sets and that for the transformer–rectifier sets is found to lie between 24 and 32%. It is also observed that the losses in the welding process are enormous due to the fact that the machine runs idle for nearly half the total operation period. It is noticed that cutting down the idle time by instructing the operator to carry out continuous operation and cutdown deliberate delays, the efficiency of the welding process shot up to 28% as against 14% in the motor–generator set, while, in the case of the rectifier sets, the improvement in efficiency is 16% (that is from 24 to 40%). Thus, providing automatic control switches (by using CNC machines) leads to optimal resource and energy utilization.

In this industry, motor–generator welding sets outnumber the transformer–rectifier sets. Since the motor–generator sets work at lower power factor and higher losses when on no load, the power consumed by the motor–generator sets is higher. By replacing these sets with transformer–rectifier sets, the power factor of the system could be improved. The advanced instrumentation and control machines will further reduce energy and wastage.

Electroplating

Electroplating constitutes a major component of any electro-metallurgical industry. Electroplating is electrodeposition of metals on metals, alloys and non-metals. The electroplating is normally carried out (i) to change the surface properties of metals and non-metals, (ii) to improve resistance to corrosion, chemical attack and wear, and (iii) to obtain increased surface hardness.

The different electroplating processes used in this industry are

(a) Zinc bath: 350 A, 7–8 V, operation 12 h/day
(b) Zinc barrel: 300 A, 15 V, operation 8 h/day
(c) Anodizing plant: 600 A, 12 V, operation 10 h/day
(d) Chromium plant: 500 A, 12 V, operation 8 h/day

(heating of bath for 2 h in all cases).

Calculation of energy efficiency

Impurities in the electrolyte cause secondary reactions. Due to these reactions, the voltage required across the electrodes is higher than the theoretical value. Thus, the energy consumed

183

Table 15. Calculation of rectifier plant efficiency. Make: Hind Rectifier Ltd, a.c. = 380/440 V, 3-phase, 50 Hz. Rectifier output = 12 V, ambient temperature = 45°C, electrodes used = mild steel rods

Number of specimens = 5

Sl. No.	Input (kW)	Output			
		Current (A)	Voltage (V)	Area (ft^2)	Efficiency (%)
1	8.50	360	9.0	7	38
2	5.50	300	7.0	7	41
3	3.40	260	6.0	7	44
4	1.75	200	4.5	7	51
5	1.40	100	3.0	7	21

Number of specimens = 9

Input (kW)	Output			
	Current (A)	Voltage (V)	Area (ft^2)	Efficiency (%)
7	250	9	3.5	31
4.25	200	7.5	3.5	35
2.75	160	6	3.5	36
1.8	120	4.5	3.5	30
1.6	60	3	3.5	11

is actually higher than the theoretically estimated value. Hence, the energy efficiency is defined as [3]

$$\text{Energy efficiency} = \frac{\text{theoretical value}}{\text{actual consumption}}.$$

Specimen calculation: electrode used = M.S., cross-section area = (23 × 75) cm^2, thickness = 3.5 cm, No. of electrodes used = 2.

	Electrode 1	Electrode 2
Initial mass of specimen (g)	426	431.9
Final mass of specimen (g)	430	435.9

Mass of zinc coated with each electrode = 4 g, total mass of zinc deposited = 4 × 2 = 8 g, power input = 1.25 kW, rectifier voltage = 4.5 V, let current = I A, time = 39 min or 0.65 h.

According to Faraday's first law of electrolysis mass of zinc deposited $\propto Q$ (quantity of electricity passed through it)

$$\propto It$$

$$= ZIt$$

where Z = electrochemical equivalent for zinc 0.3370 units. Therefore, I = rectifier current

$$I_c = \frac{M}{Zt} = \frac{8}{0.3370 \times 0.65} = 36.52 \text{ A}.$$

Therefore, the theoretical value of the power output = $EI = 4.5 \times 36.52 \times 10^{-3} = 0.1643$ kW

$$\text{Efficiency} = \frac{0.1643}{1.25} \times 100 = 13.45\%.$$

CONCLUSIONS

This study shows that there is a potential for energy saving in the industry sector and gives the extent of ineffective utilization of energy (as in the case of welding sets, motors etc.).

(1) The cost of generation using captive diesel generating sets is about 4 times that of energy supplied by the Karnataka State Electricity Board. This would necessitate improvement in the efficiency of operation of the diesel sets. It is estimated that an increase in efficiency by 1% would save about Rs. 45,000/yr in the total energy costs.

(2) The efficiency of the captive power generating units varies from 3.15 to 4.80 units l. The latest diesel captive sets are operating at a higher efficiency of 4.5–5.5 units/l. Switching over to the latest units saves HSD.

(3) Motors for conveyors, drives, compressors, etc. consume about two-thirds of the electricity used in industry. Replacing the conventional electro-mechanical motor starters with microprocessor based induction motor controllers provides a smooth start with reduced voltage and current, and these controllers control the voltage applied to the motor to that required to meet the varying load conditions without reducing speed or torque, resulting in a reduced power consumption and also an improvement in the power factor (details are in the Appendix, Section A7) and consequent reduction in power bills. Also, the motor is protected against stalling, overload and single phasing. The payback period can vary from 9 to 30 months (details in Appendix, Section A8) depending upon the size of the motor, load condition and total period of working per year.

(4) A careful examination of the production process, schedules and operating practices can result in more efficient utilization of machinery. Other improvements in plant efficiency can be achieved through:

(a) Rearranging schedules to utilize process equipment for continuous periods of operation in order to avoid numerous short runs and minimize heat-up losses.

(b) Scheduling process operations during off-peak periods in order to level electrical demands and conserve energy during peak demand periods. Thus, expenditures on captive generation and, hence, dependence on oil could be brought down.

(c) Utilization of waste heat and energy cascading, in which the energy is used as its highest quality first and then at lower qualities in other associated processes, until the energy is of such low quality that it is no longer useful.

(5) Energy efficiency can be improved by improving maintenance of energy consuming devices like machinery and by changing such operational procedures as turning off lights and equipment and changing thermostat settings during non-use. Maintenance of machines plays an important role in enhancing the life of machinery, cutting down energy loss and production delays.

(6) The motors and drives consume a large percentage of the electrical energy used in the industrial sector. The high efficiency motors (85.5–95%) currently available in the market are now competitive with the conventional type of motors, considering the cost of motor losses.

(7) The losses in the welding sets are due to the fact that the machine runs idle for nearly half the total operation period. Power is consumed even during this 'non-use' period. This could be avoided by having microprocessor based numerical controllers which automatically switch off the welding generator set when it remains idle for more than a preset time interval (which is selectable). Touching the electrode to the job resets the controller, and welding can be carried out instantly.

Scope for saving energy: in a welding generator set of 25 kVA, the no load power consumption is about 800 W. Generally, in an 8 h shift, the continuous welding period is less than 4.5 h. The saving will be about 3.6 units/shift. The saving per year on two shifts, 300 working days would be around 2200 units.

(8) As the major welding loads in this industry are motor–generator sets, switching over to recent transformer–rectifier sets with microprocessor based numeric controllers would further boost the saving in energy.

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APPENDIX

A1. Diesel Engine Generator Sets

(1) Engine make: Cummins Engine Co. Ltd, b.h.p. = 425, speed = 1500 r.p.m.; generator make: Stanford – H type, kVA/volts = 350/415, speed = 1500, power factor (PF) = 0.8, frequency = 50 Hz, model: 486-A, ambient temperature: 40°C, rotation clockwise, excitation current: 1.63 A, phase sequence: ABC.

(2) Engine make: Cummins Engine Co. Ltd, b.h.p. = 425, speed = 1500 r.p.m.; generator make: Stanford – H type, kVA volts: 350/415, speed: 1500 r.p.m., power factor (PF): 0.8, number of phases: 3, frequency: 50 Hz, rotation: clockwise, phase sequence: ABC.

(3) Engine make: Kirloskar Cummins Pump Ltd, b.h.p.: 610, speed = 1500 r.p.m.; generator make: KEC, Bangalore, kVA/volts = 500/415, speed = 1500 r.p.m., power factor (PF) = 0.8, number of phases: 3, frequency = 50 Hz, ambient temperature: 40°C, excitation current: 2 A, excitation voltage: 40 V, rotation: clockwise, phase sequence: ABC.

(4) Engine make: Kirloskar Cummins Pump Ltd, b.h.p.: 610 Speed 1500 r.p.m.; generator make: KEC, Bangalore, kVA/volts: 500/415, speed: 1500 r.p.m., power factor (PF) = 0.8, number of phases: 3, frequency: 0.8, ambient temperatue: 40°C, excitation current: 2 A, excitation voltage: 30 V, rotation: clockwise, phase sequence: ABC.

A2. Shearing Machines

(1) Make: Fischer Schweiss Konstruktion. Working length: 1000 mm, depth of throat: 250 mm, speed: 1400 r.p.m., number of strokes: 60/min, motor: 29 h.p., capacity: 3 mm on 50 kg/mm^2, 3.5 mm on 37 kg/mm^2.

(2) Make: Godrej & Boyce Manufacturing Co. Capacity = 3 mm, length = 3000 mm. Motor: Crompton Greaves 3-phase, 380/420 V, 1550 r.p.m., 5 h.p., current: 8/8.15 A.

(3) Make: Karleugen Fischer (other manufacturing details were not available as key plate was missing).

A3. Press Brake

(1) Name plate details: Type: HMT VERSON, capacity: 120 U.S. tons/tonnes, stroke: 127 mm, stroke/min: 30, shut height (bed to ram): 437 mm, ram adjustment = 127 mm, ram size = LP 3660, FB = 76 mm. Motor details: SIEMENS–SCHOKGRT Delta/Y = 420 V, 122.6 A, 11.5 kW, power factor (PF): 0.8, r.p.m. = 1405 units/min, frequency: 50 cycles/s, 3-phase.

(2) Name plate details: Type Godrej Sl No./yr: 6/1963, capacity = 80 tonnes, stroke: 0.76 mm, shut height: 300 mm, ram adjustment = 152 mm, main motor (h.p./r.p.m.) = 10/1450, strokes/min = 35, insulation = Class E.

A4. Furnace

(1) Make: Electro therm private Ltd, Voltage: 440 V, numer of phases = 3, kW = 100, max. temperature = 1100°C.

Specimen details: Material heated is aluminium wire, mass $M = 125$ kg, t_2 = temperature to which mass is heated = 300°C, t_1 = 20°C (ambient temperature). Specific heat of aluminium = S = 0.216 kcal/kg °C. Time required to attain this temperature = 90 min or 1.5 h.

A5. Cranes

(1) Name plate details: Make: Jossep Company Ltd (AEI), Capacity: 5 tonnes, span: 30 m. Motor details: Hoist motor—induction motor 10 h.p., 19 A, 440 V, 720 r.p.m. Long travel motor = 5 h.p., cross travel motor = 2 h.p.

A6. Welding

(1) Name plate details: Make: Indian Oxygen Ltd. a.c. input: supply voltage = 380–440 V, d.c. output: O.C.V. range = 59–68V, phase = 3, current range = 40–500 A, frequency = 50 Hz, max. continuous hand weld current (rated output) = 400 A, primary current 45 A (at rated output), kVA (at rated output) = 31 kVA, max. automatic continuous welding current = 280 A.

A7. Saving with Controller in a 7.5 h.p., 50 Hz, 3-Phase Induction Motor

						Savings	
Load point	Voltage (V)	Current (A)	Input (W)	Input VARs	PF	Watts (W)	VARs
No load	400 (170)	5.5 (1.0)	450 (240)	3783 (170)	0.11 (0.81)	210	3613
1425 W load point	400 (300)	6.0 (5.0)	1770 (1620)	3761 (2031)	0.45 (0.82)	210	1730
2825 W load point	300 (340)	8.0 (7.0)	3420 (330)	4361 (2470)	0.61 (0.80)	120	1890

Data without controller and with controller (in parentheses)

A8

	Power consumption in units/h		Saving	
Equipment	without	with controller	per year (Rs.)	Payback period
Blower fan 20 h.p (5000/h/yr)	7.24	6.25	7070 (cost/kWh: Rs. 1.40 average)	18