Math Lab 10 MS 3

Solving Energy-Conversion Problems for Electrical Energy Convertors

For best results, print this document front-to-back and place it in a three-ring binder.
Corresponding teacher and student pages will appear on each opening.

TEACHING PATH - MATH SKILLS LAB - CLASS M

RESOURCE MATERIALS

Student Text: Math Skills Lab

CLASS GOALS

1. Review procedures for converting units in one system to the units of another system.
2. Teach students how to calculate the efficiency of a electrical energy convertor.

CLASS ACTIVITIES

1. Take five or ten minutes to go through the Student Exercises. Make sure that students understand the correct answers.
2. Complete as many activities as time permits. Students already should have read the discussion material and looked at the examples for each activity before coming to this class. (How much you accomplish will depend on the math skills your students already have.) Summarize the explanatory material for Activity 1: "Solving Energy-Conversion Problems for Electrical Energy Convertors." Then have students complete the Practice Exercises given at the end of Activity 1.
3. Supervise student progress. Have students obtain the correct answers.
4. Before the class ends, tell your students to read Lab 10*5, "Converting Energy with a Steam Engine."

Math Skills Laboratory

Lab 10 MS3

MATH ACTIVITY

Activity: ***Solving Energy-Conversion Problems for Electrical Energy Convertors***

MATH SKILLS LAB OBJECTIVES

When you complete these activities, you should be able to do the following:

1. ***Solve energy-conversion problems for electrical energy convertors.***
2. ***Substitute correct numerical values and units in energy-conversion equations. Solve the equations for an unknown numerical value with the proper units.***
3. ***Find the efficiency of electrical energy convertors.***

LEARNING PATH

1. ***Read the Math Skills Lab. Give particular attention to the Math Skills Lab Objectives.***
2. ***Study the examples.***
3. ***Work the problems.***

ACTIVITY

Solving Energy-Conversion Problems for Electrical Energy Convertors

MATERIALS

For this activity, you'll need a calculator.

In this Math Skills Lab, you'll review the important formulas for work and energy. You'll review the units used to measure work, energy and power. You'll solve problems that involve electrical energy convertors.

NOTE: Tables 1, 2, and 3 do not contain new information. They're presented here for review and for the convenience of your students who may need to refer to them while working the Math Lab exercises. Don't forget to remind students that much of this same information is contained in the *Student Resource Book*.

LET'S REVIEW FORMULAS AND UNITS!

Examine Tables 1, 2 and 3. These are the same tables included in Math Skills Labs 10MS1 and 10MS2.

Table 1 lists the important formulas for work and energy that you've already studied. Table 2 sums up common units that you'll use in energy-conversion problems. Table 3 lists some conversions between units.

You'll find these conversions helpful when you solve the problems in this activity.

TABLE 1. REVIEW OF BASIC FORMULAS FOR WORK AND ENERGY

Energy System	Formulas	Definition of Symbols
MECHANICAL		
Linear Work	$W = F \times D$	F = applied force D = distance moved
Rotational Work	$W = T \times \theta$	T = torque applied θ = angular distance rotated
Gravitational Potential Energy	$E_p = w \times h$	w = weight h = height raised above reference level
Elastic Potential Energy	$E_p = \frac{1}{2} kd^2$	k = force or spring constant d = distance spring is stretched or compressed
Linear Kinetic Energy	$E_k = \frac{1}{2} mv^2$	m = mass v = speed
Rotational Kinetic Energy	$E_k = \frac{1}{2} I\omega^2$	I = moment of inertia ω = angular speed
FLUID		
Fluid Work	$W = p \times (\Delta V)$; $W = (\Delta p) \times V$	p; Δp = pressure or pressure difference ΔV; V = volume of fluid moved
Fluid Kinetic Energy	$E_k = \frac{1}{2} (\rho V)v^2$	ρ = mass density V = volume v = speed
ELECTRICAL		
Electrical Work	$W = q \times \Delta V$	q = electrical charge moved ΔV = voltage difference
Electrical Energy	$E_{elec} = P_{elec} \times t$	P_{elec} = electrical power used t = time power is used
THERMAL		
Thermal Energy	$H = mc\Delta T$	m = mass c = specific heat ΔT = temperature difference

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TABLE 2. SUMMARY OF COMMON UNITS USED IN ENERGY CONVERSION CALCULATIONS

Quantity	Symbol	English Unit	SI Unit
Mass	m	slug or (lb·sec^2/ft)	kg
Weight	w	lb	N
Force	F	lb	N
Work	W	ft·lb	N·m or J
Kinetic Energy	E_k	ft·lb	N·m or J
Potential Energy	E_p	ft·lb	N·m or J
Power	P	(ft·lb)/sec; hp	(N·m)/sec or watt
Spring Constant	k	lb/ft; oz/in.	N/m; kgf/m *
Angular Displacement	θ	rad	rad
Angular Speed	ω	rad/sec	rad/sec
Linear Speed	v	ft/sec	m/sec
Mass Density	ρ	slug/ft^3; lbm/ft^3 **	kg/m^3
Moment of Inertia	I	slug·ft^2	kg/m^2
Pressure or Pressure Difference	p; Δp	lb/ft^2; oz/in^2	N/m^2
Electrical Charge	q	—	coulomb (C)
Torque	T	lb·ft;lb·in.	N·m
Fluid Volume	V; ΔV	ft^3	m^3
Electrical Current	I	—	ampere (A)
Electrical Voltage	V; ΔV	—	volt (V)
Electrical Resistance	R	—	ohm (Ω)
Heat Energy	H	Btu	cal
Temperature	T	°F	°C
Temperature Difference	ΔT	F°	C°
Specific Heat	c	$\frac{\text{Btu}}{\text{lb·F°}}$	$\frac{\text{kcal}}{\text{kg·C°}}$

* kgf ⇒ kilogram force
** lbm ⇒ pound mass

TABLE 3. USEFUL CONVERSIONS FOR UNITS

1 slug	=	32 pound mass (32 lbm)
1 kilogram force (kgf)	=	9.8 newtons
1 newton·meter	=	1 joule
1 volt·coulomb	=	1 joule
1 ampere·second	=	1 coulomb
1 radian	=	57.3°
1 horsepower	=	550 ft·lb/sec
1 horsepower	=	746 watts
1 watt	=	1 newton·meter per second
1 watt	=	1 joule per second
1 watt	=	1 volt·ampere
1 watt·sec	=	1 joule = 0.7376 ft·lb
1 kilowatt·hour (kWh)	=	3.6×10^6 joules
1 calorie	=	3.086 foot·pounds
1 calorie	=	4.184 joules
1 Btu	=	778 foot·pounds
1 Btu	=	1055 joules

SOLUTIONS TO FORMULA/UNIT REVIEW QUESTIONS

1. $W = q \times \Delta V$
2. $E_{elec} = P_{elec} \times t$
3. $E_k = 1/2\ I\omega^2$
4. $E_k = 1/2\ (\rho V)v^2$
5. $W = p \times \Delta V$ and $W = (\Delta p) \times V$
6. $H = mc\Delta T$
7. $kg \cdot m^2$
8. Btu/lb•F°
9. joules or watt•sec
10. a. 1054 J

    b. 1 J

    c. 1054 watt•sec
11. $\text{Eff (\%)} = \frac{E_{out}}{E_{in}} \times 100\% = \frac{1054\ \cancel{J}}{1100\ \cancel{J}} \times 100\% = 95.8\%.$

    or

    $\text{Eff (\%)} = \frac{E_{out}}{E_{in}} \times 100\% = \frac{1054\ \cancel{\text{watt}\cdot\text{sec}}}{1100\ \cancel{\text{watt}\cdot\text{sec}}} \times 100\% = 95.8\%.$
12. Energy Expended = Work Done = $q \times (\Delta V)$

    $= 5\ C \times 12\ V = 60\ V{\cdot}C = 60\ J\ (1\ V{\cdot}C = 1\ J).$
13. One kWh = 3.6×10^6 J. (Since 1 kWh = 1000 W x 3600 sec,

    1 kWh = 3.6×10^6 W•sec = 3.6×10^6 J.)
14. $\text{Eff (\%)} = \frac{E_{out}}{E_{in}} \times 100\% = \frac{3.5 \times 10^6\ \cancel{J}}{3.6 \times 10^6\ \cancel{J}} \times 100\% = \frac{3.5}{3.6} \times 100\%$

    Eff (%) = 0.970 x 100%

    Eff (%) = 97%.

Now that you've reviewed the contents of Tables 1, 2 and 3, use them to help you answer the following questions.

1. The formula for electrical work in electrical systems is: ____.
2. The formula for electrical energy used, given the electrical power and time of operation, is: ____.
3. The formula for rotational mechanical energy is: ____.
4. The formula for fluid kinetic energy is: ____.
5. The formulas for fluid work are: ____.
6. The formula for thermal energy is: ____.
7. In Question 3 and Table 2, the units of moment of inertia (I) in SI units are ____.
8. In Question 6, specific heat (c) in English units (from Table 2) is: ____.
9. In Question 2, electrical energy would be in units of ____.
10. An electrical energy convertor changes 1100 watt·sec of electrical energy into 1 Btu of heat energy.
    a. One Btu equals ____ joules.
    b. One watt·sec of heat energy equals ____ joule.
    c. One Btu equals ____ watt·sec.
11. In Question 10, the electrical energy convertor is ____ % efficient.
12. Five coulombs of charge are moved by 12 volts. All energy expended is changed to electrical work. Energy expended is ____ joules.
13. One kilowatt-hour of electrical energy is changed to 3.5×10^6 joules of mechanical energy. One kWh equals ____ joules.
14. In Question 13, the electrical energy convertor is ____ % efficient.

ENERGY-CONVERSION PROBLEMS THAT INVOLVE ELECTRICAL ENERGY CONVERTORS

Two examples of energy conversion follow. Study them, and then solve the exercises.

Example A: *Efficiency of an Electric Motor (Electrical-to-Mechanical Energy Convertor)*

Given: An electric motor converts 0.5 kWh of electrical energy into 1.56×10^6 J of rotational mechanical energy at the motor output shaft.

Find: The efficiency of the motor.

Solution: The efficiency is given as:

$$\text{Eff}(\%) = \frac{E_{OUT}}{E_{IN}} \times 100\%$$

where: $E_{OUT} = 1.56 \times 10^6$ J (output shaft mechanical energy)
$E_{IN} = 0.5$ kWh (electrical energy)

The energy values are in different units. Efficiency can't be calculated. Therefore, first change E_{IN} from kWh to joules. From Table 3, find that 1 kWh = 3.6×10^6 J.

$$E_{IN} = 0.5\ \text{kWh} \times \left[3.6 \times 10^6 \frac{\text{J}}{\text{kWh}}\right]$$

$$E_{IN} = (0.5 \times 3.6 \times 10^6)\left[\cancel{\text{kWh}} \times \frac{\text{J}}{\cancel{\text{kWh}}}\right] \qquad \text{(Cancel units.)}$$

$$E_{IN} = 1.8 \times 10^6\ \text{J}$$

Now calculate the efficiency.

$$\text{Eff}(\%) = \frac{1.56 \times 10^6\ \cancel{\text{J}}}{1.8 \times 10^6\ \cancel{\text{J}}} \times 100\% \qquad \text{(Cancel units.)}$$

$$\text{Eff}(\%) = 87\% \ \text{(rounded)}$$

SOLUTIONS TO PRACTICE EXERCISES

Problem 1: Efficiency of Electric Motor = $\frac{\text{Motor Shaft Output Energy}}{\text{Motor Input Energy}} \times 100\%$

$\text{Eff } (\%) = \frac{E_{out}}{E_{in}} \times 100\%$ where: $E_{out} = 137.5 \text{ ft·lb}$

$E_{in} = 203.5 \text{ watt·sec}$

Use Table 3 to convert watt·sec to ft·lb.

$$E_{in} = 203.5 \text{ watt·sec} \times \frac{0.7376 \text{ ft·lb}}{\text{watt·sec}}$$

E_{in} (203.5 x 0.7376) ft·lb

$E_{in} \approx 150$ ft·lb.

$$\text{Eff } (\%) = \frac{137.5 \text{ ft·lb}}{150 \text{ ft·lb}} \times 100\% = \left(\frac{137.5}{150} \times 100\%\right) \frac{\cancel{\text{ft·lb}}}{\cancel{\text{ft·lb}}}$$

Eff (%) = 0.9167 x 100%

Eff (%) = 91.67% or about 91.7%

Example B: *Efficiency of an Electric Heating Element (Electrical-to-Thermal Energy Convertor)*

Given: An electric heating element, often called a "calrod unit," is 94% efficient in changing electrical energy to thermal energy. Twenty gallons of water (167 lbm) are raised in temperature from 80°F to 105°F by the calrod unit. The specific heat of water is 1 Btu/(lbm·F°).

Find:
a. The thermal energy required to raise the water from 80°F to 105°F.
b. The electrical energy (in joules) used by the calrod unit to change the electrical energy to thermal energy.
c. The electrical energy in kWh.

Solution:
a. To find the thermal energy needed to heat the water, use the formula

$$H = mc\Delta T \qquad \text{where: } m = 167 \text{ lbm},\ c = 1 \text{ Btu/(lbm·F°)},\ \Delta T = 105°\text{F} - 80°\text{F} = 25 \text{ F°}$$

$$H = 167 \text{ lbm} \times \left(1 \frac{\text{Btu}}{\text{lbm·F°}}\right) \times 25 \text{ F°}$$

$$H = (167 \times 1 \times 25)\left[\cancel{\text{lbm}} \times \frac{\text{Btu}}{\cancel{\text{lbm}}\cdot\cancel{\text{F°}}} \times \cancel{\text{F°}}\right] \qquad \text{(Cancel units.)}$$

$$H = 4175 \text{ Btu}$$

b. To find the electrical energy input to the calrod unit, use the efficiency formula.

$$\text{Eff(\%)} = \frac{E_{OUT}}{E_{IN}} \times 100\%$$

where: Eff(%) = 94%, E_{OUT} = H = 4175 Btu, E_{IN} = electrical input energy in joules

Rearrange the equation to isolate E_{IN}.

$$E_{IN} = \frac{E_{OUT}}{\text{Eff(\%)}} \times 100\%$$

Substitute in values, converting E_{OUT} to joules. From Table 3, 1 Btu = 1055 J.

$$E_{IN} = \frac{4175 \text{ Btu} \times 1055 \frac{\text{J}}{\text{Btu}}}{94\%} \times 100\%$$

$$E_{IN} = \left(\frac{4175 \times 1055 \times 100}{94}\right)\left(\frac{\cancel{\text{Btu}} \times \text{J} \times \cancel{\%}}{\cancel{\%} \times \cancel{\text{Btu}}}\right) \qquad \text{(Cancel units.)}$$

$$E_{IN} = 4{,}685{,}771 \text{ J} \quad \text{(rounded)}$$

c. To convert the electrical energy to kWh, use the relationship, 1 kWh = 3.6×10^6 J from Table 3.

$$E_{IN} = 4{,}685{,}771 \text{ J} \times \frac{1 \text{ kWh}}{3.6 \times 10^6 \text{ J}}$$

$$E_{IN} = \left(\frac{4{,}685{,}771 \times 1}{3.6 \times 10^6}\right)\left(\frac{\cancel{\text{J}} \times \text{kWh}}{\cancel{\text{J}}}\right) \qquad \text{(Cancel units.)}$$

$$E_{IN} = 1.3 \text{ kWh} \quad \text{(rounded)}$$

Thus, the calrod unit consumed 1.3 kWh of electrical energy to heat the water.

PRACTICE EXERCISES

Problem 1: Given: An electric motor is rated at 137.5 ft·lb/sec (¼ hp) shaft output. This means the shaft has 137.5 ft·lb of energy available to do work each second. The electrical input energy to the motor is 203.5 watt·sec (about 150 ft·lb; see Table 3).

Find: The motor efficiency.

Solution:

SOLUTIONS TO PRACTICE EXERCISES, Continued

Problem 2:

$$\text{Efficiency of a Solenoid} = \frac{\text{Mech. Energy to Move Solenoid Plunger}}{\text{Elec. Energy Input to Solenoid}} \times 100\%$$

$\text{Eff}\ (\%) = \dfrac{E_{out}}{E_{in}} \times 100\%$ where: $E_{out} = 40\ \text{J}$

$E_{in} = \text{Work In} = q \times \Delta V$

$E_{in} = q \times \Delta V$ where: $\Delta V = 12\ \text{V}$

$q = 4\ \text{coulomb} = 4\ \text{C}$

$E_{in} = 4\ \text{C} \times 12\ \text{V}$

$E_{in} = 48\ \text{V}\cdot\text{C} = 48\ \text{J}$ $(1\ \text{V}\cdot\text{C} = 1\ \text{J})$

$$\text{Eff}\ (\%) = \frac{40\ \text{J}}{48\ \text{J}} \times 100\% = \left(\frac{40}{48} \times 100\%\right)\frac{\cancel{\text{J}}}{\cancel{\text{J}}}$$

$\text{Eff}\ (\%) = 0.833 \times 100\%$

$\text{Eff}\ (\%) = 83.3\%.$

Problem 3: $\text{Eff}\ (\%) = \dfrac{E_{out}}{E_{in}} \times 100\%$ where: $E_{out} = 550\ \text{N}\cdot\text{m}$ (plunger energy)

$E_{in} = q \times \Delta V$

$\text{Eff} = 90\%$

First, rearrange the efficiency equation. Solve for "E_{in}." Do this by multiplying both sides of the equation by "E_{in}/Eff." Cancel like terms and get:

$$\left(\frac{E_{in}}{\cancel{\text{Eff}\ (\%)}}\right) \cancel{\text{Eff}\%} = \left(\frac{\cancel{E_{in}}}{\text{Eff}\ (\%)}\right) \frac{E_{out}}{\cancel{E_{in}}} \times 100\%$$

$$E_{in} = \frac{E_{out}}{\text{Eff}\%} \times 100\%$$

Now, substitute "$(q \times \Delta V)$" for "E_{in}." Solve for the charge, "q." This is the charge moved in operating the solenoid.

$(q \times \Delta V) = \dfrac{E_{out}}{\text{Eff}\ (\%)} \times 100\%$ (Divide each side of the equation by "ΔV" to isolate "q." Cancel ΔV's on left.)

$$\frac{q \times \Delta V}{\Delta V} = \frac{E_{out}}{\text{Eff}\ (\%)} \times \frac{1}{\Delta V} \times 100\%$$

$$q = \frac{E_{out}}{\Delta V \times \text{Eff}\%} \times 100\%$$

$$q = \frac{550\ \text{N}\cdot\text{m}}{110\ \text{V} \times 90\%} \times 100\% = \left(\frac{550 \times 100\%}{110 \times 90\%}\right)\left(\frac{\text{N}\cdot\text{m}}{\text{V}}\right)$$

$$q = 5.55\ \frac{\text{N}\cdot\text{m}}{\text{V}} = 5.55\ \frac{\cancel{\text{V}}\cdot\text{coulomb}}{\cancel{\text{V}}} = 5.55\ \text{coulomb}\ (1\ \text{N}\cdot\text{m} = 1\ \text{V}\cdot\text{coul}).$$

(Solutions to Problems 4 and 5 continued on T-94c.)

SOLUTIONS TO PRACTICE EXERCISES, Continued

Problem 4: $\text{Eff }(\%) = \frac{P_{out}}{P_{in}} \times 100\%$

where: $P_{out} = 3 \text{ hp} \times 746 \text{ W/hp} = 2238 \text{ watts}$

$P_{in} = \Delta V \times I = 220 \text{ V} \times 12.5 \text{ A} = 2750 \text{ V}\cdot\text{A} = 2750 \text{ watts}$

$\text{Eff }(\%) = \frac{P_{out}}{P_{in}} \times 100\% = \frac{2238 \cancel{\text{watt}}}{2750 \cancel{\text{watt}}} \times 100\% = (\frac{2238}{2750} \times 100\%)$

$\text{Eff }(\%) = 81.4\%.$

SOLUTION TO STUDENT CHALLENGE PROBLEM

Problem 5: a. $H = mc\Delta T$ where: $m = 0.5 \text{ kg}$

$c = 0.113 \text{ kcal/(kg}\cdot\text{C}^\circ)$

$\Delta T = (T_f - T_c)$

$= 120^\circ\text{C} - 30^\circ\text{C} = 90\text{C}^\circ$

$H = 0.5 \text{ kg} \times 0.113 \frac{\text{kcal}}{\text{kg}\cdot\text{C}^\circ} \times 90 \text{ C}^\circ$

$H = (0.5 \times 0.113 \times 90)(\frac{\cancel{\text{kg}}\cdot\text{kcal}\cdot\cancel{\text{C}^\circ}}{\cancel{\text{kg}}\cdot\cancel{\text{C}^\circ}})$

$H = 5.085 \text{ kcal}.$

b. $\text{Eff }(\%) = \frac{E_{out}}{E_{in}} \times 100\%;$ $E_{out} = H = 5.085 \text{ kcal} = 5085 \text{ cal}$

$\text{Eff} = 75\%$

Rearrange the efficiency equation to isolate "E_{in}." This gives:

$E_{in} = \frac{E_{out}}{\text{Eff}\%} \times 100\%$

Substituting in values, the equation for "E_{in}" becomes:

$E_{in} = \frac{5085 \text{ cal}}{75\cancel{\%}} \times 100\cancel{\%} = (\frac{5085}{75} \times 100) \text{ cal}$

$E_{in} = 6780 \text{ cal}$ (electrical energy input to produce 5085 cal of heat energy).

Problem 2: Given: The solenoid in an electrical relay opens and closes electrical contacts. When twelve volts (12 V) of electricity are applied, 4 coulombs of charge move through the solenoid coil. The resulting plunger movement uses 40 joules of energy to close a set of electrical contacts.

Find: The efficiency of the solenoid.

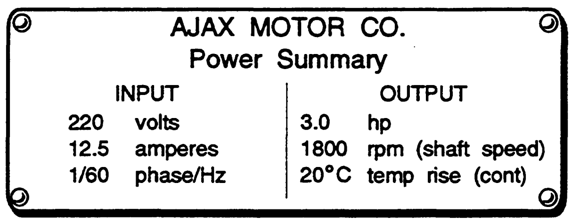
Solution: (***Hint:*** Use the relationship that 1 volt·coulomb = 1 joule.)

Problem 3: Given: A remote water-line cut-off valve located in the ceiling of a building is operated by a 110-volt solenoid. The plunger that seats the valve in the closed position is held in place by a spring. It takes 550 N·m of energy to unseat the valve by compressing the spring. The solenoid assembly is 90% efficient in changing electrical energy to the linear mechanical energy that is used to compress the spring.

Find: The charge moved in operating the solenoid.

Solution: (***Hint:*** $E_{IN} = W_{IN} = q \times \Delta V$.)

Problem 4: Given: An electrical motor has the following data plate on it:



Find: The efficiency of this motor.

Solution: (***Hint:*** The output is given in units of power. Input power can be calculated easily by $\Delta V \times I$. Therefore, use the efficiency formula involving *power*, namely $\text{Eff}(\%) = \frac{P_{OUT}}{P_{IN}} \times 100\%$.)

Student Challenge

Problem 5: An electric induction heater (an energy convertor) is used to heat the inner race (ring) of ball bearings or roller bearings. This expands the inside diameter of the inner race of the bearing, allowing a slip-fit of the bearing onto a close-tolerance shaft or axle. When the bearing cools, the inner race shrinks to its original size, fits snugly on the shaft, and doesn't slip.

Given: Bearing inner races are heated to 120°C to allow the slip-fit under normal conditions. Room temperature is 30°C. The specific heat of steel is 0.113 kcal/(kg·C°).

Find:

a. The heat energy that must be added to the inner race of a bearing of 0.5-kg mass to heat the bearing from room temperature to 120°C.

b. The electrical energy that must be supplied to the induction heater if the induction heater is 75% efficient.

Problem 6: a. $E_{in} = P_{in} \times t = V \times I \times t$

$E_{in} = 48\ V \times 0.83\ A \times 1\ sec = 48 \times 0.83 \times 1\ V{\cdot}A{\cdot}sec$

$E_{in} = 39.84\ V{\cdot}A{\cdot}sec$ (1 V•A = 1 watt; 1 watt = 1 J/sec)

$$E_{in} = 39.84\ watt{\cdot}sec = 39.84\ \frac{J{\cdot}\cancel{sec}}{\cancel{sec}} = 39.84\ J$$

$E_{in} = 39.84\ J.$

b. $E_{out} = W_{out} = T \times \theta$ where: $T = 120$ lb•in of torque

$\theta = 1.57$ rad (angle moved through)

$E_{out} = 120\ lb{\cdot}in \times 1.57\ rad$

$E_{out} = 120 \times 1.57\ lb{\cdot}in{\cdot}rad$ (Drop the "rad" unit.)

$E_{out} = 188.4\ lb{\cdot}in{\cdot}rad$

Change inches to feet. Convert "E_{out}" from "in•lb" to "ft•lb."

$$E_{out} = 188.4\ lb{\cdot}\cancel{in} \times \frac{1\ ft}{12\ \cancel{in}} = \frac{188.4}{12}\ ft{\cdot}lb$$

$E_{out} = 15.7\ ft{\cdot}lb.$

Convert "ft•lb" to joules. See Table 3. Use:

3.086 ft•lb = 1 cal = 4.184 J.

$$E_{out} = 15.7\ ft{\cdot}lb \times \frac{4.184\ J}{3.086\ ft{\cdot}lb} = \left(\frac{15.7 \times 4.184}{3.086}\right)\frac{\cancel{ft}{\cdot}\cancel{lb}{\cdot}J}{\cancel{ft}{\cdot}\cancel{lb}}$$

$E_{out} = 21.3\ J.$

c. $$\text{Eff}\ (\%) = \frac{E_{out}}{E_{in}} \times 100\% = \frac{21.3\ J}{39.84\ J} \times 100\% = \left(\frac{21.3}{39.84} \times 100\%\right)\frac{\cancel{J}}{\cancel{J}}$$

Eff (%) = 0.535 x 100%

Eff (%) = 53.5%.

Problem 6: Given: A coal-fired boiler in an electric power plant uses a draft-damper control to regulate the fire. The control motor that rotates the draft-damper has a data plate, as shown below.

SPECIALTY MOTORS, INC.	
Hercules Motor Damper, Model 120-1A	
MOTOR INPUT	SHAFT OUTPUT
48 volts DC	120 lb-in torque
0.83 amperes	SHAFT ROTATION
20°C temp rise (cont)	90/1.57 degrees/radians

Find:

a. The electrical energy converted each second into rotational mechanical energy of the output shaft. (***Hint:*** Use $E_{IN} = P_{IN} \times t = [\Delta V \times I] \times t$.)

b. The work done (energy used) each second by the output shaft while it spins at constant speed through an angle of 90° (1.57 radians). (***Hint:*** Use the formula, $W_{OUT} = E_{OUT} = T \times \theta$.)

c. The efficiency of the motor/damper unit as an energy convertor.

Solution: