# Bulk Mechanical Properties of Waterhyacinth[1]

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## ABSTRACT

Bulk samples (0.16 m³) of fresh intact waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) were compressed to determine physical and mechanical properties. Mean initial density was 167 kg/m³. Compression to 400 kg/m³ required 7 kPa pressure and 2.4 W•h/t energy; compression to 800 kg/m³ required 64 kPa and 7.8 W•h/t.

## INTRODUCTION

Capacities of mechanical management systems for aquatic plants are usually limited by the volume of the plant material that must be handled, transported and stored. Chopping and compacting have been proposed as means of reducing volume or increasing density. Stewart (5) found that chopping increased the density of waterhyacinth to 670 kg/m³ and required as little as 380 W•h/Mt. Bagnall (unpublished data) reported that chopping increased the density of waterhyacinth to 260 kg/m³. Bulk density and compression characteristics of waterhyacinth are needed to determine the feasibility of compaction as a means of volume reduction and for rational design of compaction, handling, transportation and storage systems.

Koegel, et al. (4) reported physical-mechanical properties of Eurasian watermilfoil (*Myriophyllum spicatum* L.), and Cifuentes and Bagnall (2, 3) determined properties of waterhyacinth. They worked on small, intensively-treated samples at high pressures, but the techniques and analysis procedures are adaptable to low pressures. Bagnall (1) determined bulk properties of hydrilla, and the techniques and equipment developed in those tests have been adapted for the bulk tests on waterhyacinth.

The objective of the work reported here was to determine the pressure and energy required to compress bulk intact waterhyacinth. Secondary objectives were to determine the undisturbed bulk density of the intact plants, the losses incurred during low pressure compression, and the effects of plant size on physical-mechanical properties.

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## METHODS AND MATERIALS

A bulk press (Figure 1), consisting of a 61 cm diameter by 61 cm deep cylinder with a platen, loading beam and perforated base, was built to apply loads up to 80 kN. Loads up to 2 kN were applied by a calibrated deadweight-lever system. Higher loads were applied by a hydraulic cylinder and measured by a pressure gauge. Displacements during light loading were measured with a meter stick at four locations on the platen periphery. When the hydraulic system was used, displacement was measured on the calibrated piston rod.

Waterhyacinth was harvested on dates and at locations shown in Table 1. The plant heights, from water surface to the tip of the tallest leaves, were relatively uniform. Root systems, except those of the decayed plants, were small,

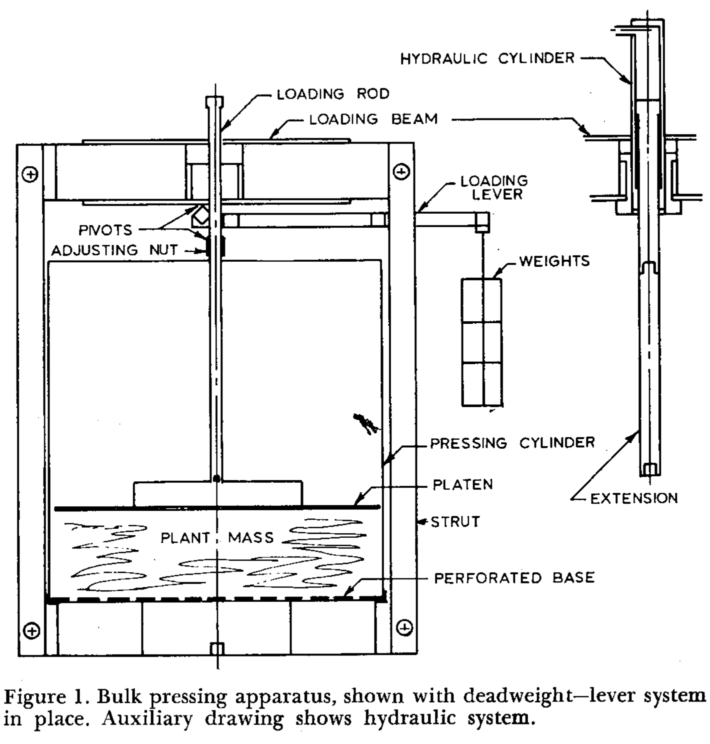


Figure 1. Bulk pressing apparatus, shown with deadweight—lever system in place. Auxiliary drawing shows hydraulic system.

because the plants were grown in wastewater. Most of the plants were pressed on site, and so were fresh. The waterhyacinth was placed in a 76 l garbage can, weighed and placed in the pressing cylinder. Two samples from the supply surplus were canned for oven drying. After levelling, the plants were loaded with the press platen, followed by the deadweight-lever system, then the hydraulic system. Depth of sample was observed at specified loadings. If the platen tipped excessively, it was removed, the charge redistributed and the platen replaced. All data were recorded orally on a continuously-running cassette recorder, which provided the time base for transcribing the data. Each pressing cycle required 20 ± 4 min (95% confidence interval on mean). Juice samples were collected in beakers placed below the perforated base. After each test, the residue was weighed and sampled.

TABLE 1. SOURCES, HARVESTING TIMES AND PROCESSING DELAYS IN COMPACTION TESTS OF WATERHYACINTH.

| Size (cm) | Source | Date (month/yr) | Mean delay (min) |
|---|---|---|---|
| decayed | Paynes Prairie, Gainesville | 3/78 | 80 |
| 18 | Paynes Prairie, Gainesville | 6/78 | 36 |
| 25 | Duda Farm, Belle Glade | 3/78 | 5 |
| 38 | Plant City Water Pollution Control Plant | 4/78 | 15 |
| 75 | Plant City Water Pollution Control Plant | 5/78 | 67 |
| 100 | Plant City Water Pollution Control Plant | 6/78 | 45 |

After examination of several alternative models, the pressure-volume data were regressed to the form

$$\frac{V - V_e}{V_o - V_e} = e^{b\, p^a},$$

where

$V$ = apparent specific volume, $m^3/kg$,
$V_e$ = equilibrium apparent specific volume, $m^3/kg$,
$V_o$ = initial specific volume, $m^3/kg$,
$b$ = constant (negative),
$p$ = pressure, kPa,
$a$ = constant.

Apparent specific volume is the ratio of volume to initial mass and neglects the effect of mass loss due to the expression of fluid.

## RESULTS AND DISCUSSION

Pressure required to compress bulk intact waterhyacinth is shown in Figures 2 and 3. Pressure increased as plant size increased, and curves for the largest (100 cm) and smallest (18 cm) plants tested are indicated. Because the range of pressures observed was wide, relative accuracy in the low range was not as great as in the high range, so the data below 7 kPa was regressed and plotted in greater detail in Figure 3. Regression and correlation coefficients for both full range and low range are listed in Table 2. All results are based on at least three samples within each size, and the regressions were found to be not significantly different ($P > 0.05$) within size and significantly different ($P < 0.01$) between sizes, by covariance analysis.

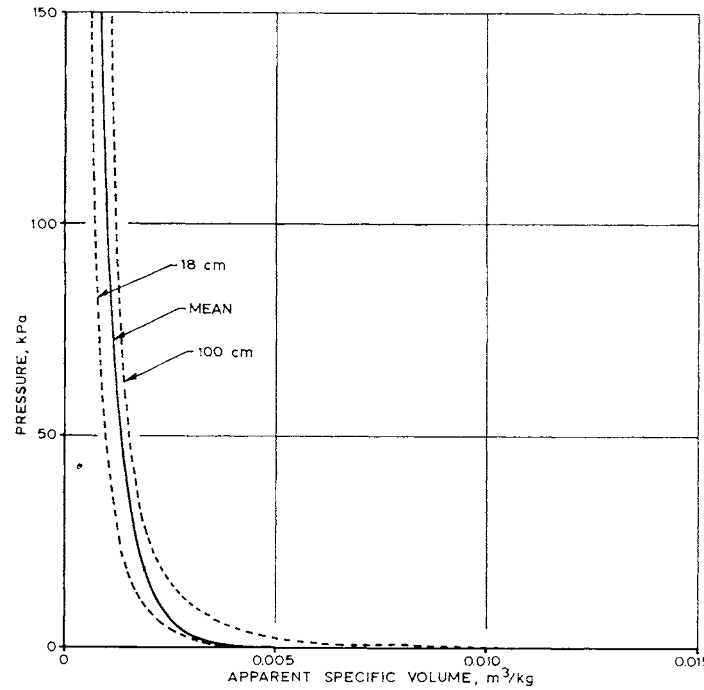


Figure 2. Full range pressure-volume relationship for intact bulk waterhyacinth; smallest (18 cm), largest (100 cm) and mean of all plants tests.

Energy required to compress waterhyacinth, based on numerical integration of the pressure-volume data, is presented in Figures 4 and 5. Energy requirement increased at an increasing rate as the sample was compressed, but even the highest levels observed were lower than that required for chopping.

It follows from the pressure-volume relationships that as intact waterhyacinth is stacked, the density near the

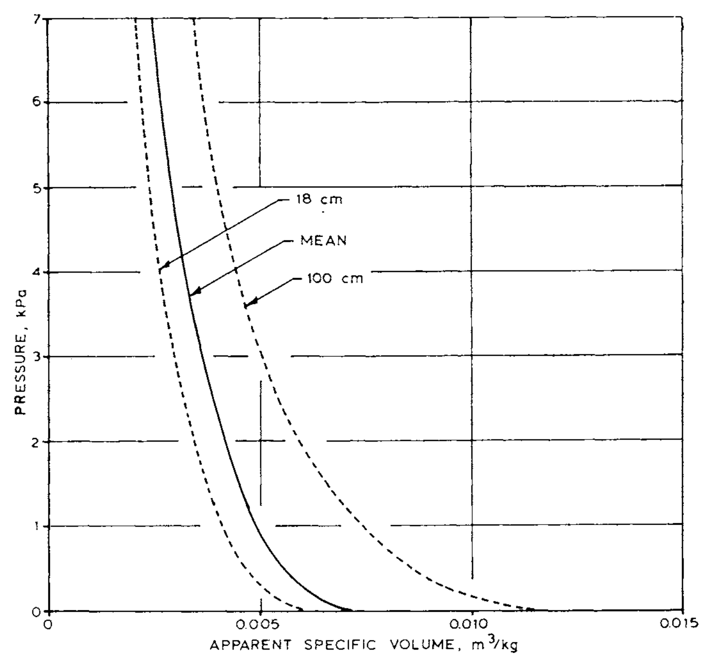


Figure 3. Low range (up to 7 kPa) pressure-volume relationship for intact bulk waterhyacinth; smallest (18 cm), largest (100 cm) and mean of all plants tested.

TABLE 2. COEFFICIENTS OF PRESSURE-VOLUME REGRESSION FOR WATERHYACINTHS

$$\frac{V - V_e}{V_o - V_e} = e^{b\,p^a}$$

(Volume = apparent specific volume, $m^3$/kg; Pressure in kPa) From Compaction Test on 0.16 $m^3$ Samples.

| | Initial volume ($m^3$/kg) | Equilibrium volume ($m^3$/kg) | b | a | Correlation coefficient |
|---|---|---|---|---|---|
| Full range | | | | | |
| Mean | 0.00714 | 0.000000 | −0.669 | 0.230 | 0.957 |
| decayed | 0.00395 | 0.000121 | −0.537 | 0.264 | 0.977 |
| 18 cm | 0.00620 | 0.000594 | −0.636 | 0.357 | 0.995 |
| 25 cm | 0.00705 | 0.000845 | −0.561 | 0.418 | 0.998 |
| 38 cm | 0.00849 | 0.000826 | −0.659 | 0.364 | 0.994 |
| 75 cm | 0.00995 | 0.000933 | −0.580 | 0.425 | 0.996 |
| 100 cm | 0.0114 | 0.000974 | −0.673 | 0.377 | 0.995 |
| Low range | | | | | |
| Mean | 0.00714 | 0.000000 | −0.363 | 0.553 | 0.865 |
| decayed | 0.00395 | 0.000000 | −0.296 | 0.720 | 0.904 |
| 18 cm | 0.00620 | 0.000788 | −0.487 | 0.572 | 0.997 |
| 25 cm | 0.00705 | 0.00152 | −0.499 | 0.630 | 0.996 |
| 38 cm | 0.00849 | 0.00951 | −0.463 | 0.598 | 0.992 |
| 75 cm | 0.00995 | 0.00205 | −0.418 | 0.811 | 0.996 |
| 100 cm | 0.0114 | 0.00246 | −0.589 | 0.679 | 0.996 |

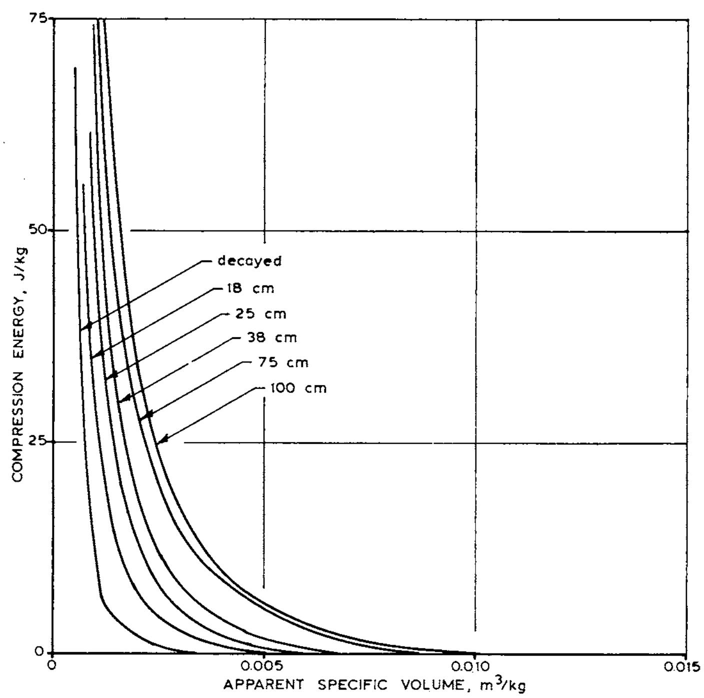


Figure 4. Energy required to compress bulk intact waterhyacinth through the full range of pressures tested as affected by plant size (height above water, cm).

bottom of the stack is greater than that near the top and that the average density in a deep stack is greater than that in a small stack. Numerical integration of the regressions leads to the depth-density relationships shown in Figures 6 and 7 and the mass-depth relationships in Figure 8.

Mean initial unloaded bulk density of waterhyacinth was 167 ± 34 kg/$m^3$. Density decreased as plant size increased:

$$\rho = 428\,h^{-0.343} \qquad r = 0.954$$

where

$\rho$ = initial bulk density, kg/$m^3$,
h = plant height, cm,
r = correlation coefficient on transformed data.

Initial density of decayed plants was 263 ± 52 kg/$m^3$.

Mean initial dry matter content of the waterhyacinth was 5.3 ± 1.8%.

Expression losses during compression of the samples are shown in Table 3. Mass, primarily water, loss decreased as plant size increased because the more rigid plant structure protected the fluids:

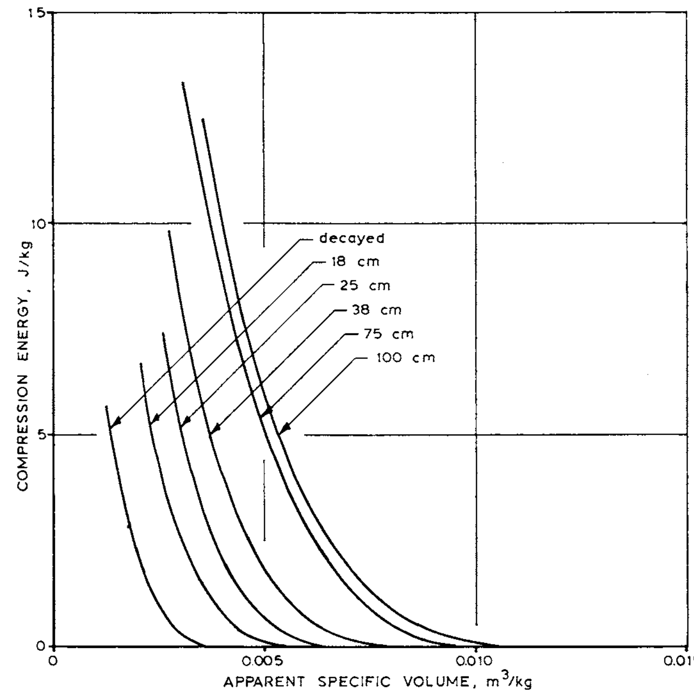


Figure 5. Energy required to compress bulk intact waterhyacinth through the low pressure (below 7 kPa) range as affected by plant size.

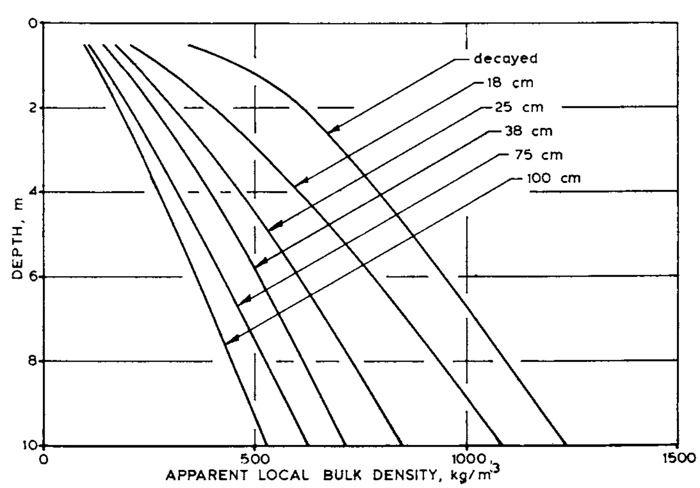


Figure 6. Local density of waterhyacinth in columnar stacks as affected by plant size.

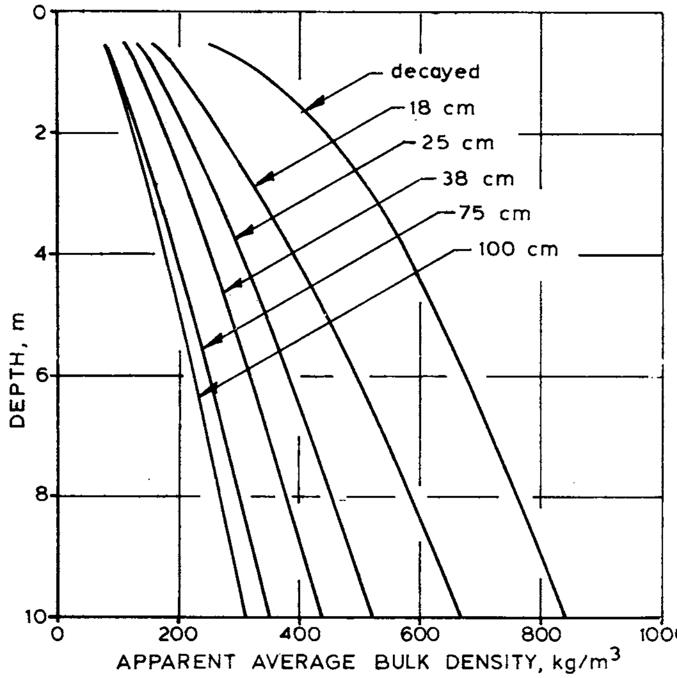


Figure 7. Average density of intact waterhyacinth in columnar stacks as affected by plant size.

$$L = 37.5 - 0.219\,h \qquad r = 0.864$$

where

L = mass loss, % of total initial mass,
h = plant height, cm.

Solids content, fixed solids content, nitrogen content and phosphorous content of the expressed fluid increased with plant size for no apparent reason. Mass loss, though appreciably higher than from hydrilla (1), was much less than that from screw-pressing. The quality of the expressed fluid was similar to that from hydrilla, clearly not potable, but not as polluted as that from screw-pressing.

TABLE 3. EXPRESSION LOSS AND FLUID COMPOSITION FROM BULK INTACT WATERHYACINTH DURING COMPACTION TESTS.

| | Mass loss[1] | Total solids (%) | Fixed solids[2] | Total kjehldahl nitrogen (mg/l) | $PO_4$-P (mg/l) |
|---|---|---|---|---|---|
| decayed | 40 | — | — | — | — |
| 18 cm | 33 | — | — | — | — |
| 25 cm | 35 | — | — | — | — |
| 38 cm | 27 | 0.11 | 52 | 31 | 5.2 |
| 75 cm | 22 | 0.13 | 63 | 29 | 5.1 |
| 100 cm | 16 | 0.14 | 62 | 36 | 9.8 |

[1]Percent of initial mass.
[2]Percent of total solids.

## APPLICATION

A typical state-of-the-art harvester, with a pickup unit capable of harvesting 0.4 ha/h and a 25 m³ hold, can carry 4200 kg of harvested waterhyacinth. It must, therefore, be unloaded every 0.013 ha or 2.0 min. If the same harvester were equipped with a light-weight compactor capable of applying 64 kPa to the waterhyacinth, carrying capacity would be increased to 20,000 kg and the harveter would need to unload only every 0.064 ha or 9.4 min. The increased hold mass capacity should improve system capacity and reduce transportation cost. The additional power required to operate the compactor would be 1.0 kW or 2.4 kW•h/ha which should be recoverable in reduction of transportation energy.

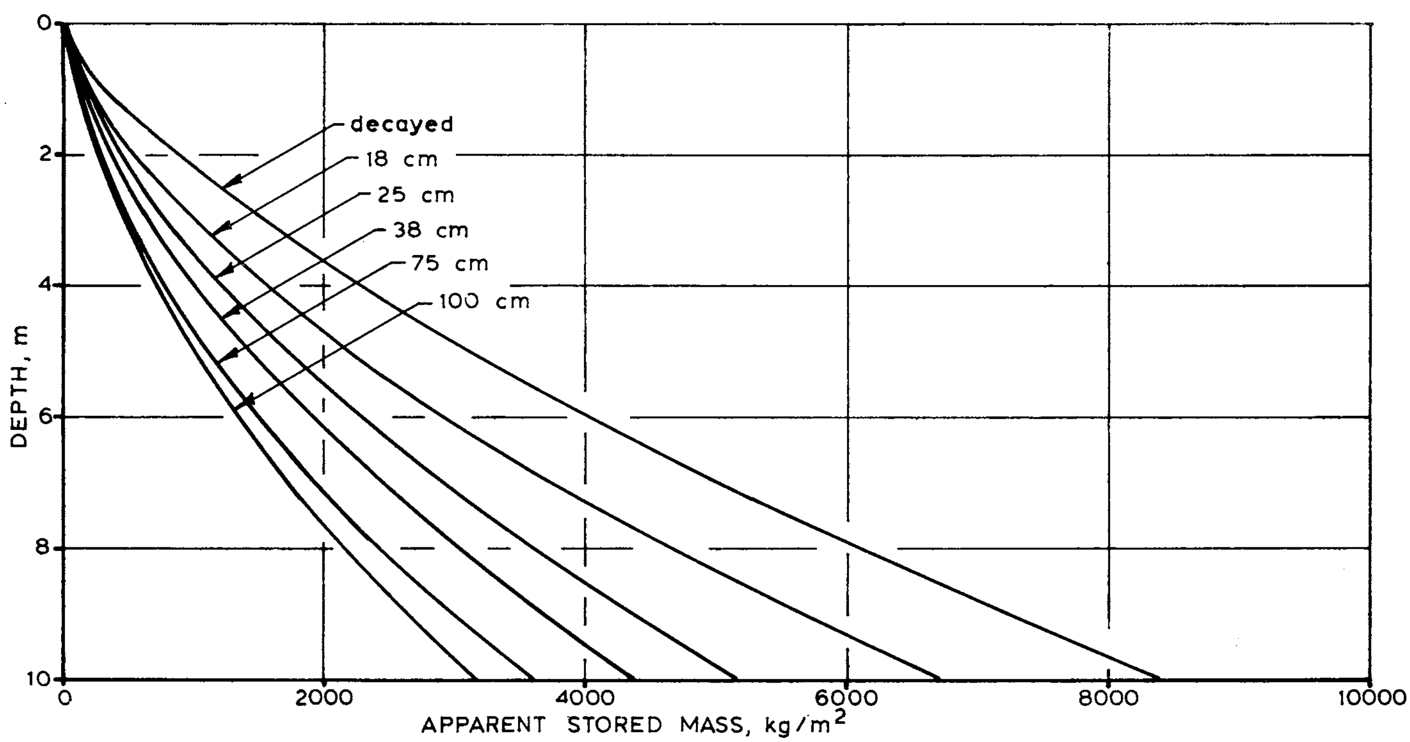


Figure 8. Mass of waterhyacinth stored in a columnar stack.

## APPENDIX

Conversions – SI metric to "English" units

length

1 m = 3.28 ft

1 cm = 0.394 in.

volume

1 $m^3$ = 35.3 $ft^3$

1 l = 0.264 gal.

mass

1 kg = 2.20 lbm

1 Mg = 1.10 T

force

1 kN = 0.225 lbf

density – specific volume

1 $kg/m^3$ = 0.0624 $lbm/ft^3$

1 $m^3/kg$ = 16.0 $ft^3/lbm$

pressure

1 kPa = 0.145 $lbf/in^2$

specific energy

1 W•h/t = 0.00122 hp•h/T

1 J/kg = 0.335 ft•lbf/lbm

1 J/kg = 0.000338 hp•h/T

1 kW•h/ha = 0.543 hp•h/A

power

1 kW = 1.34 hp

area

1 ha = 2.47 A

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