10. Appendix

10.1 Design calculations and drawings

10.1.1 Floating-drum plants

Design calculation

Sizing factors	Example
Daily substrate input, Sd	= 115 l/d
Retention time, RT	= 70 days
Daily gas production, G	= 2.5 m³/d
Storage capacity,Cs	= 60%
Digester volume, Vd	= 8 m³
Gasholder volume, Vg	= 1.5 m³

Calculating formulae after Sasse, 1984

1. Vg = Cs • G

2. ha = design-dependent

3. Vg= r • p • h

4. rg =

$$\sqrt{Vg/(\pi \cdot h)}$$

5. rd = r + 0.03

6. Vd1 = p • d2 • p • h

7. Vd2 = R3 • p • 2/3

8. R =

$$\sqrt[3]{Vd2/(\pi \cdot 2/3)}$$

9. Vd3 = R2 • p • H/3

10. H = R/5

11. Vd3 = R3 • p • 1/15

12. Vd2 : Vd3 = 10 : 1

13. Vd(2+3) = 1.1 Vd2

14. Vd(2+3) = Vd - Vd1

15. hd = hg

16. hdk = hd + structurally dependent free board (0.1 . . . 0.2 m)

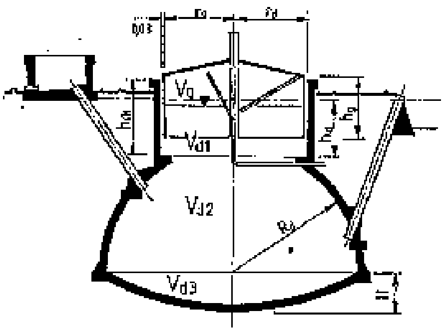

Fig. 10.1: Conceptual drawing of a floating-drum biogas plant

Vd = Vdl +Vd2 +Vd3

= digester volume

Vg = gasholder volume

Index g = gas holder

Index d = digester

Sample calculation	**Results**
1. Vg = 0.6 • 2.5	**= 1.5 m³**
hg = (specified)	**= 0.7 m**
4. r =	**= 0.82 m**

$\sqrt{1.5 / 3.14 \cdot 0.7}$	
5. r = 0.85 (chosen)	
6. Vdl = 0.852 •3.14 • 0.7	**= 1.58 m³**
14. Vd (2+3) = 8.45 - 1.58	**= 6.87 m³**
8+ 14. R = $\sqrt[3]{6.87 / (1.1 \cdot 3.14 \cdot 2 / 3)}$	**= 1.45 m**

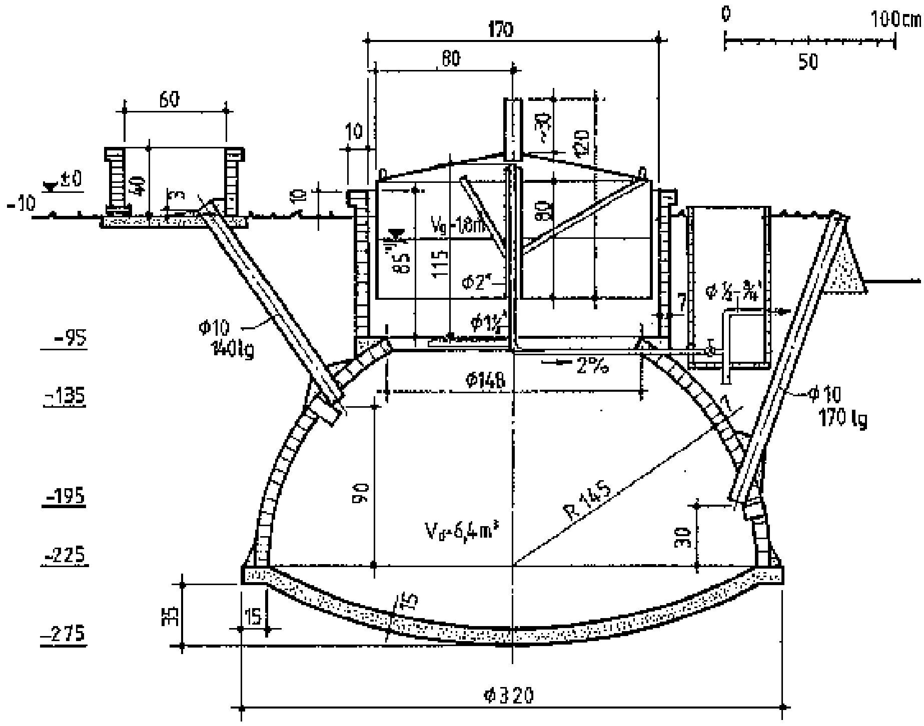

Fig. 10.2: Constructional drawing of a floating-drum plant. Vd = 6.4 m³, Vg = 1.8 m³. Material requirements: Excavation 16.0 m³, Foundation 1.6 m³, Masonry 1.1 m³, Rendered area 18.0 m², Sheet steel 5.7 m². (Source: OEKOTOP, Sasse)

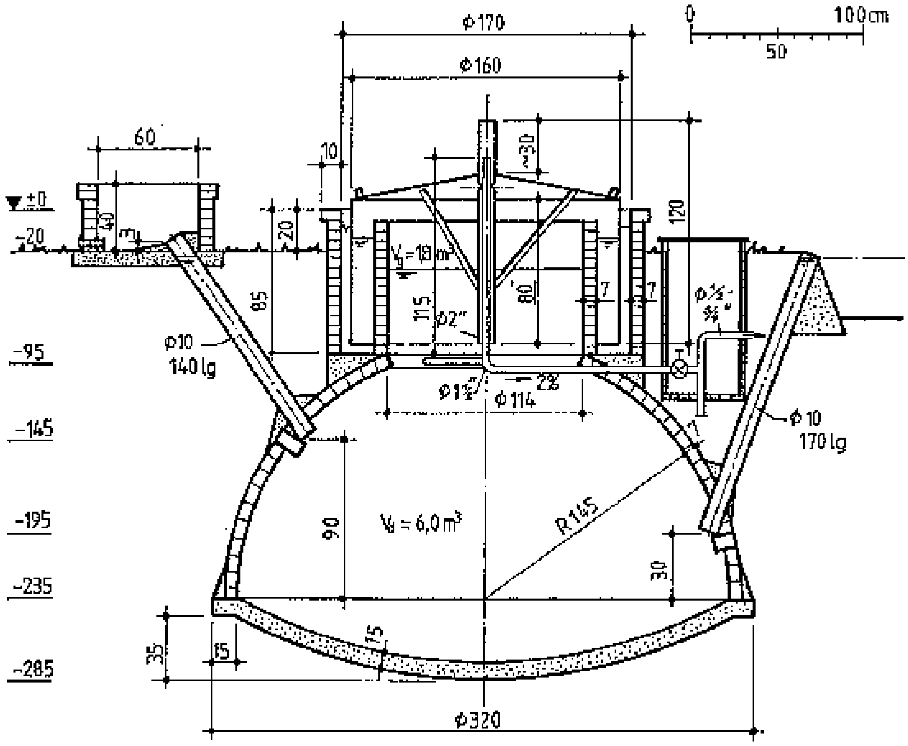

Fig. 10.3: Constructional drawing of a water-jacket plant. Vd = 6.0 m³, Vg = 1.8 m³. Material requirements: Excavation 16.0 m³, Foundation 1.6 m³, Masonry 1.6 m³, Rendered area 21 m², Sheet steel 5.7 m². (Source: OEKOTOP, Sasse)

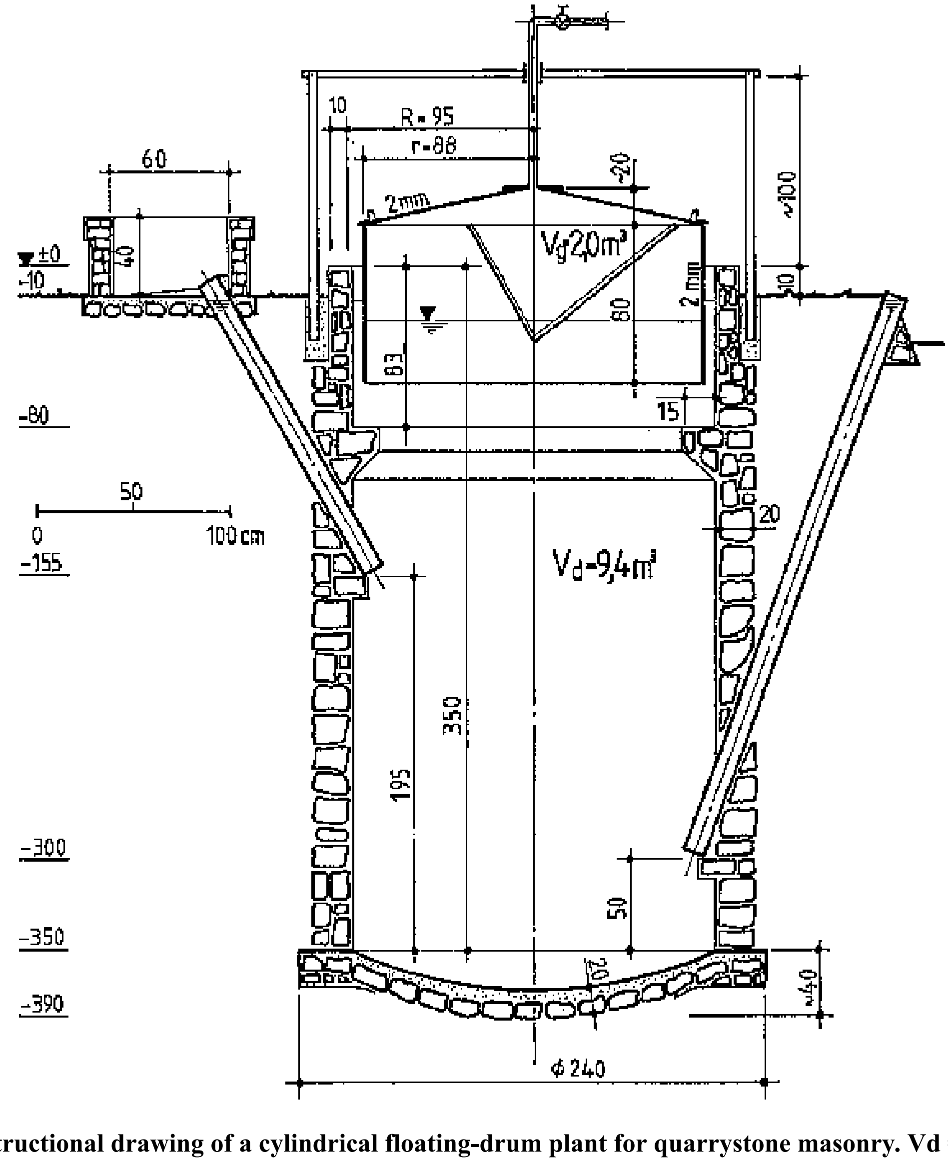

Fig. 10.4: Constructional drawing of a cylindrical floating-drum plant for quarrystone masonry. Vd = 9.4 m³, Vg =

2.5 m³. Material requirements: Excavation 21.0 m³, Foundation 1.0 m³, Masonry 5.4 m³, Rendered area 27.3 m², Sheet steel 6.4 m². (Source: OEKOTOP, KVIC)

10.1.2 Fixed dome plants

Design calculation

Sizing factors	Example	Sample calculation
Daily substrate input, Sd	= 115 l/d	R = (0.76 • 8)1/3= 1.85 m
Retention time,RT	= 70 days	r = 0.52 R= 0.96 m
Daily gas production, G	= 2.5 m³/d	h = 0.40 R= 0.72 m
Storage capacity, Cs	= 60%	p = 0.62 R= 1.14 m
Digester volume, Vd	= 8 m³	
Gasholder volume, Vg=G•Cs	= 1.5 m³	
Vd : Vg	= 5.3 : 1	

Tab. 10.1: Calculating parameters for fixed-dome biogas plant (Source: Sasse 1984.OEKOTOP)

Vg : Vd	1:5	1:6	1:8
R	(0.76 • Vd)1/3	(0.74 • Vd)1/3	(0.72 • Vd)1/3
r	0.52 R	0.49 R	0.45 R
h	0.40 R	0.37 R	0.32 R
p	0.62 R	0.59 R	0.50 R

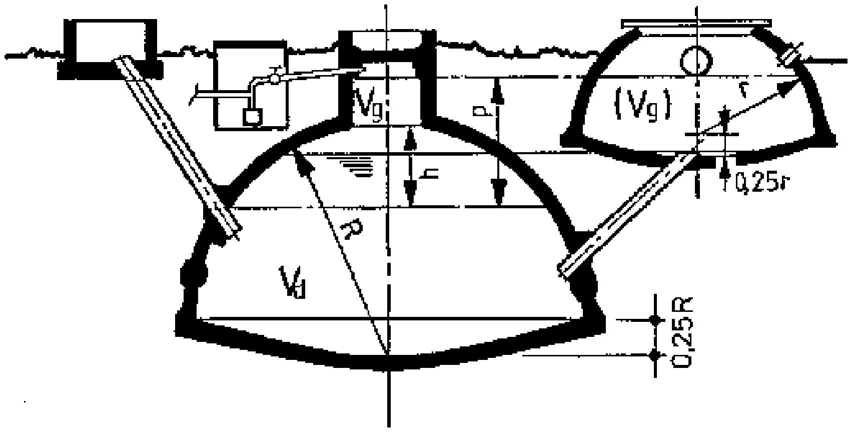

Fig. 10.5: Conceptual drawing of fixed-dome biogas plant. Vg gasholder volume, Vd digester volume. (Source: OEKOTOP, Sasse)

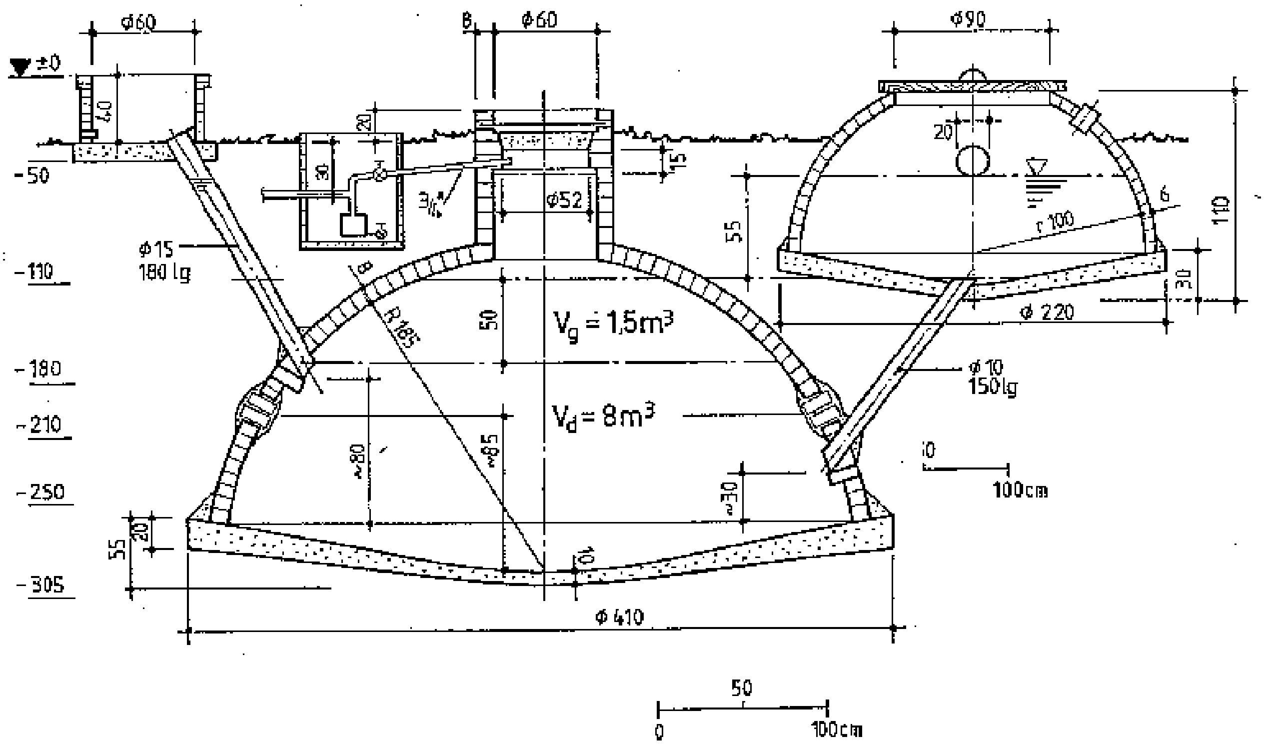

Fig. 10.6: Constructional drawing of a fixed-dome plant. Vd = 8 m³, V = 1.5 m³. Material requirements: Excavation 25 m³, Foundation 2.2 m³, Masonry 2.0 m³, Rendered area 22.0 m², Sealed area 7.0 m². (Source: OEKOTOP, Sasse, BEP Tanzania)

10.1.3 Earth pit with plastic-sheet gasholder

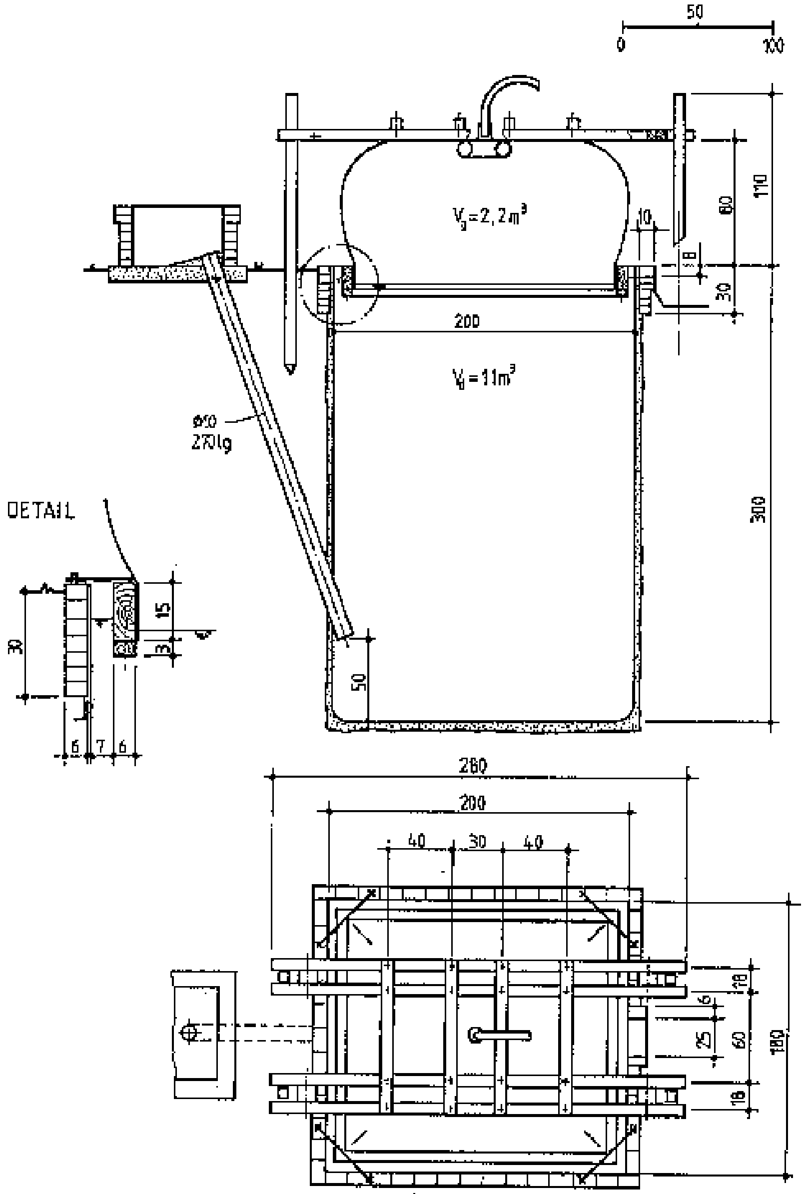

Fig. 10.7: Constructional drawing of an earth-pit biogas plant with plastic-sheet gasholder. Vd = 11 m³, Vg = 2.2 m³. Material requirements: Excavation 16 m, Rendered area 28 m², Sheeted area 10 m² (Source: OEKOTOP)

10.1.4 Estimating the earth-pressure and hydraulic forces

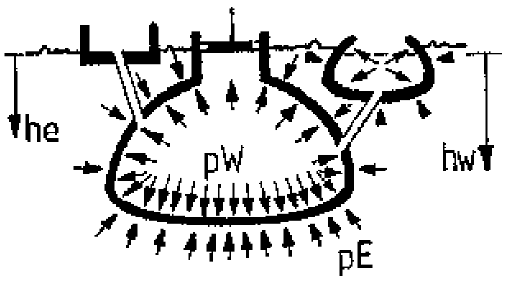

Fig. 10.8: Schematic diagram of earth-pressure and water-pressure forces

In-depth forces, h (e, w)

pW = wW • hw

pW = hydrostatic pressure at depth hw (m) wW = specific weight of water

= 1000 kp/m³ pW = 1000 • h (kp/m²)

pE = wE • ce • he

pE = active earth pressure, i.e. force of pressure of dry, previously loose but now compact column of earth on a solid vertical wall

wE = specific weight of dry backfill earth

= 1800 . . . 2 100 kp/m³

he = height of earth column (m)

ce = coefficient of earth pressure for the earth column in question

= 0.3 . . . 0.4 (-)

pE = (600 . . . 700) • h (kp/m²)

Force acting on a surface

P(E, W) = p • A (kp = (kp/m²) • m²)

Note: The above formulae are simplified and intended only for purposes of rough estimation.

10.2 Gas-law calculations

10.2.1 Calculating the pressure drop in a gas pipe

dp = FL + Ztot

dp = pressure drop (N/m²)

FL = friction losses in the gas pipe (N/m²)

Ztot = sum total of friction losses from valves, fittings, etc. (N/m²)

dp = cp l/D • D/2 v2

+ (cfl D/2 • v2 + . . . + cfn • D/2 • v2)

(approximation formula)

cp = coefficient of pipe friction (-)

l = length of pipe section (m)

D = pipe diameter(m)

g = density of biogas (1.2 kg/m³)

v = velocity of gas in the pipe (m/s)

cf = friction coefficients of valve, fittings, etc.

Q = v • A

Q = gas flow (m³/s)

v = velocity of gas in the pipe (m/s)

A = p r2 = cross-sectional area of pipe

The coefficient of pipe friction (cp = non. dimensional) is a function of:

- the pipe material and internal surface roughness

- pipe diameter

- flow parameter (Reynolds number)

For pipe diameters in the 1/2" . . . 1" range, the coefficients of friction read:

PVC tubes approx. 0.03

steel pipes approx. 0.04

Some individual friction-loss factors (cf; nondimensional)

elbow	**0.5**	**valve 3.0**
constriction	**0.02-0.1**	**water trap 3 - 5**
branch	**0.8-2.0**	

10.2.2 Calculating gas parameters

Temperature-dependent change of volume and density

D = DN • P • TN / (PN • T)

V = VN • PN • T / (P • TN)

where:

D = density of biogas (g/l)

DN = density under s.t.p. conditions (0 °C, 1013 mbar)

V = volume of biogas (m^3)

VN = volume of biogas under s.t.p. conditions

P = absolute pressure of biogas (mbar)

PN = pressure under s.t.p. conditions (1013 mbar)

T = absolute temperature of biogas (measured in ºKelvin = ºC + 273)

TN= temperature under s.t.p. conditions (0 0ºC = 273 °K)

Table 10.2: Atmospheric pressure as a function of elevation (Source: Recknagel/Sprenger, 1982)

Elevation (km)	**0**	**0.5**	**1.0**	**2**	**3**	**4**	**6**	**8**
Atm.pressure (mbar)	**1013**	**955**	**899**	**795**	**701**	**616**	**472**	**365**

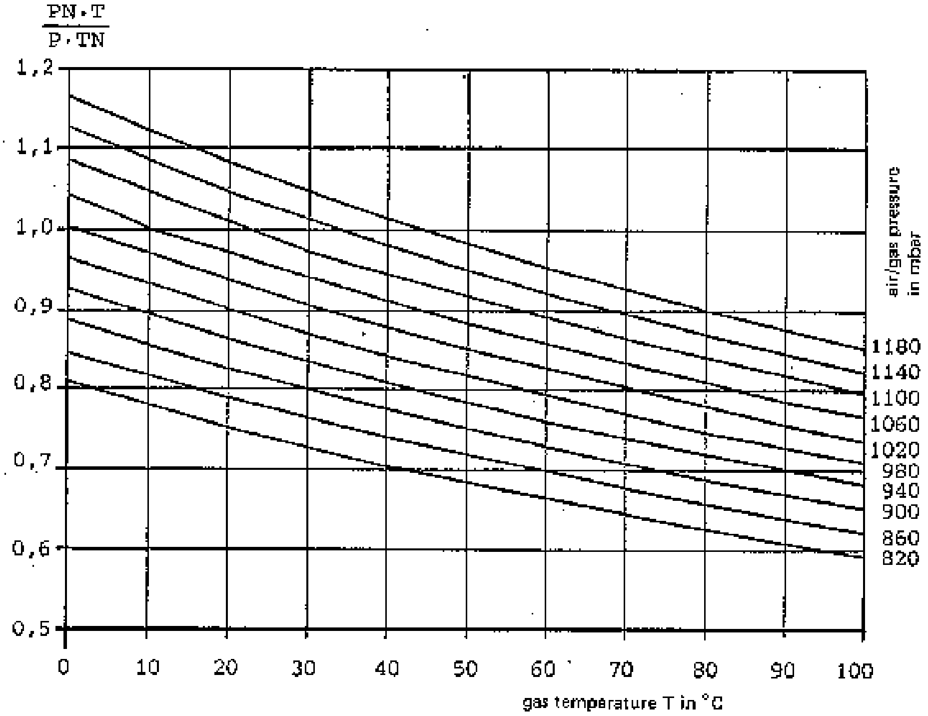

Fig. 10.9: Nomogram for correcting gas pressures/temperatures (Source: OEKOTOP)

Determining the calorific value

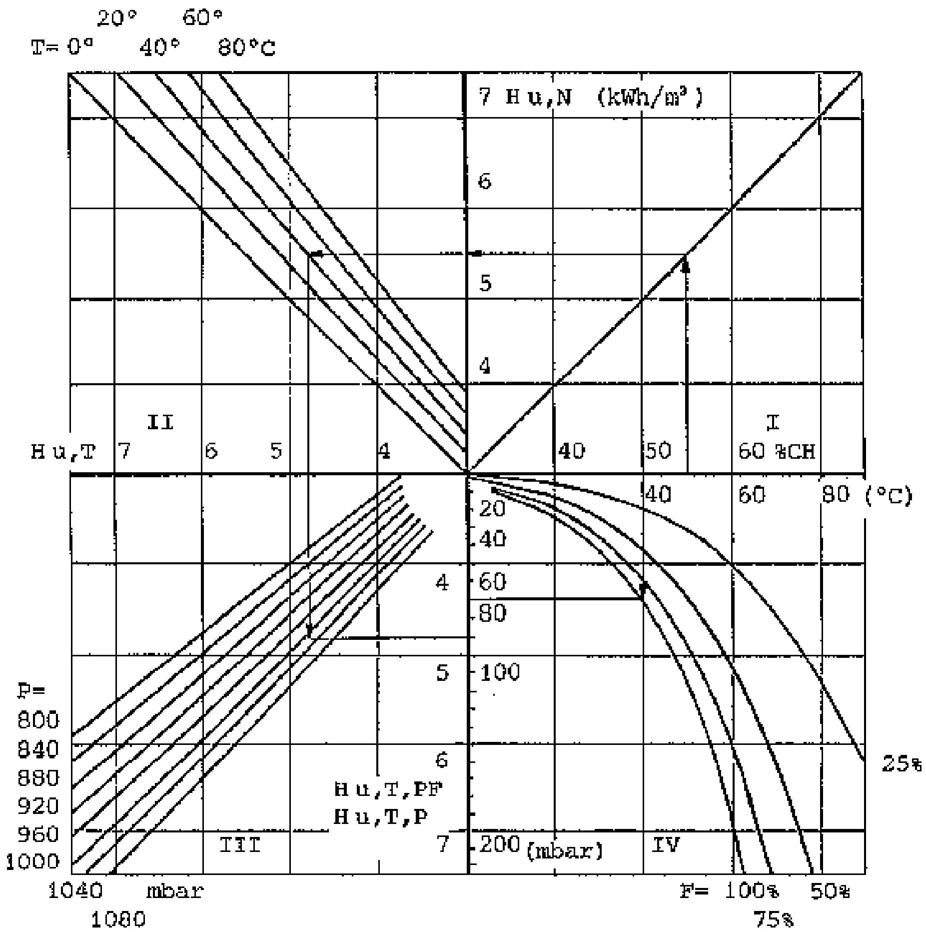

Fig. 10.10: Nomogram for finding the net calorific value of biogas as a function of temperature, pressure and moisture content. T gas temperature (°C), F relative dampness of biogas (%), Hu, N net calorific value (n.c.v.) of biogas under s.t.p. conditions (0 °C, 1013 mbar), Hu, T net calorific value (n.c.v.) at gas temperature, P gas pressure (mbar), Hu, T, P net calorific value (n.c.v.) at gas temperature and pressure, PW partial pressure of water vapor, Hu, T, PF net calorific value (n.c.v.) of biogas at gas temperature, corrected to reflect the water-vapor fraction (Source: OEKOTOP)

Using the nomogram

1. Quadrant I: Determine the net calorific value under standard conditions as a function of the CH4-fraction of the biogas

2. Quadrant II: Determine the net calorific value for a given gas temperature

3. Quadrant III: Determine the net calorific value as a function of absolute gas pressure (P)

4. Quadrant IV: Interim calculation for determining the partial water-vapor pressure as a function of gas temperature and relative dampness. This yields the gas pressure (PF) = absolute pressure (P) - partial pressure of water vapor (PW); PF = P - PW. The expanded calorific value determination with account for the moisture content occurs via quadrant III.

Sample calculation

Given:	
Biogas	**55 vol. % CH4**
Gas temperature	**T = 40 °C**
Gas dampness	**F = 100%**
Gas pressure	**P = 1030 mbar**

Results:		
Hu, N	**= f (CH4-vol. 70)**	**Quadrant I**
	= 5.5 kWh/m³	
Hu,T	**= f(T)**	**QuadrantII**
	= 4.8 kWh/m³	
Hu,T,P	**= f(T, P)**	**Quadrant III**
	= 4.6 kWh/m³	
PF	**= f(P, T)**	**Quadrant IV**

- f(PW)	Quadrant III	
	Hu, T, PF = 4.3 kWh/m³	

Table 10.3: Partial pressure of water vapor, PW, and absolute humidity, GM, at the saturation point (Source: Recknagel / Sprenger, 1982)

T (°C)	PW (mbar)	GM (g/m³)
.0	6.1	4.9
10	12.3	9.4
20	23.4	17.3
30	42.4	30.4
40	73.7	51.2
50	123.3	83.0
60	199.2	130.2
70	311.6	198.2
80	473.6	293.3
90	701.1	423.5
100	1013.3	597.7

10.3 Conversion tables

Table 10.4: SI units of calculation (selection) (Source: OEKOTOP, compiled from various sources)

Quantity	Symbol	Unit	Conversion
Length	1	m	1 m = 10 dm = 100 cm = 1000 mm

Area	**A**	**m³**	**1 m³ = 100 dm³ = 10000 cm³**
Volume	**V**	**m³**	**1 m³ = 1000 dm³ = 1 mill. cm³**
Mass	**M**	**t; kg**	**1 t = 1000 kg**
Density	**D**	**t/m³**	**1 t/m³ = 1 kg/dm³**
Force, load	**F**	**kN**	**1 kN= 1000 N ~100 kp**
Stress	**d**	**MN/m²**	**1 MN/m² = 1 N/mm² ~10 kp/cm²**
Pressure	**p**	**MN/m²**	**1 MN/m² = 1 MPa ~10 kp/cm²**
Energy	**E**	**kWh**	**1 kWh = 3.6 • 106 Ws ~3.6 • 105 kpm**
Work	**W**	**kNm**	**1 J = 1 Ws = 1 Nm 1 kNm ~ 100 kpm**
Quantity of heat	**Q**	**kWh**	**1 kWh = 3.6 X 106 Ws; 1 kcal = 4187 Ws**
Power	**P**	**kW**	**1 kW ~100 kpm/s = 1.36 PS**
Temperature	**t**	**°C, K**	**0ºK = -273 °C; 0ºC = 273 °K**
Velocity	**v**	**m/s**	**1 m/s= 3.6 km/in**
Acceleration	**b**	**m/s**	**1 m/s², acceleration due to gravity: 9.81 m/s²**

Table 10.5: Conversion of imperial measures (Source: Sasse, 1984)

Length	**1 m = 1.094 yrd**	**1 yrd = 0.914 m**
	1 cm = 0.0328 ft	**1 ft = 30.5 cm**
	1 cm = 0.394 inch	**1 inch = 2.54 cm**
Area	**1 m² = 10.76 sqft**	**1 sqft = 0.092 m²**

	1 cm² = 0.155 sq.in	1 sq.in = 6.452 cm²
	1 ha = 2.47 acre	1 acre = 0.405 ha
Volume	**1 1 = 0.220 gall.**	**1 gall. = 4.55 1**
	1 m³ = 35.32 cbft	1 cbft = 28.31
Mass	**1 kg = 2.205 lb**	**1 lb = 0.454 kg**
Pressure	**1 MN/m² = 2.05 lb/sqft**	**1 lb/sqft = 0.488 MN/m²**
	1 cm Ws = 205 lb/sqft	**1 lb/sqft = 70.3 cm Ws**
Quantity	**1 kcal = 3.969 BTU**	**1 BTU = 0.252 kcal**
of heat	**1 kWh = 3413.3 BTU**	**1000 BTU = 0.293 kcal**
	1 kcal/kg = 1799 BTU/lb	**1 BTU/lb = 0.556 kcal/kg**
Power	**1 PS = 0.986 HP**	**1 HP = 1.014 PS**
	1 kpm/s = 7.24 ft.lb/s	**1 ft.lb/s = 0.138 kpm/s**

Table 10.6: Conversion factors for work, energy and power (Source: Wendehorst, 1978)

Comparison of work units (work = power X time)

	kpm	PSh*	Ws = J	kWh	kcal
1 kpm =	1	3.70 X 10-6	9.807	2.7 X 10-6	2.342 X 10-3
1 PSh*=	270 X 103	1	2.648 X 106	0.7355	632.4
1 Ws = J =	0.102	377.7 X 10-9	1	277.8 X 10-9	239 X 10-6

1 kWh =	367.1 X 103	1.36	3.6 X 106	1	860
1 kcal =	426.9	1.58 X 10-3	4186.8	1.163 X 10-3	1

*** PS = 0.986 HP**

Table 10.7: Energy content of various fuels (Source: Kaltwasser, 1980)

Fuel	Calorific value		Unit
	MJ	kWh	
Plants	16-19	4A- 5.3	kg TS
Cow dung	18-19	5.0 - 5.3	kg TS
Chicken droppings	14-16	3.9- 4.4	kg TS
Diesel, fuel oil, gasoline	41-45	11.4-12.5	kg = 1.1 1
Hard coal (anthracite)	30-33	8.3- 9.2	kg
Wood	14-19	3.9- 5.3	kg
Producer gas	5-7	1.4 - 1.9	Nm^3
Pyrolysis gas	18-20	5.0- 5.6	Nm^3
City gas	18-20	5.0- 5.6	Nm^3
Propane	93	25.8	Nm^3
Natural gas	33-38	9.2-10.6	Nm^3
Methane	36	10.0	Nm^3
Biogas	20-25	5.6- 6.9	Nm^3

Table 10.8: Conversion factors for units of pressure (Source: Wendehorst, 1978)

	kp/m²	N/m²	pa	cm WG	mbar	at
kp/m²	1	10	10	0.1	0.1	0.0001
N/m²	0.1	1	1	0.01	0.01	10-5
pa	0.1	1	1	0.01	0.01	10-5
cm WG	10	100	100	1	1	0.001
mbar	10	100	100	1	1	0.001
at	104	105	1000	1000	1000	1

Table 10.9: Table of powers and radicals

n	n2	n3	n	n2	n3	n	n2	n3	n	n2	n3
0.60	0.36	0.22	1.10	1.21	1.33	1.60	2.56	4.10	2.10	4.41	9.26
0.65	0.42	0.27	1.15	1.32	1.53	1.65	2.72	4.49	2.15	4.62	9.94
0.70	0.49	0.34	1.20	1.44	1.73	1.70	2.89	4.91	2.20	4.84	10.65
0.75	0.56	0.42	1.25	1.56	1.95	1.75	3.06	5.36	2.25	5.06	11.39
0.80	0.64	0.51	1.30	1.69	2.20	1.80	3.24	5.83	2.30	5.29	12.17
0.85	0.72	0.61	1.35	1.82	2.46	1.85	3.42	6.33	2.35	5.52	12.98
0.90	0.81	0.73	1.40	1.96	2.74	1.90	3.61	6.86	2.40	5.76	13.82
0.95	0.90	0.86	1.45	2.10	3.05	1.95	3.80	7.41	2.45	6.00	14.71
1.00	1.00	1.00	1.50	2.25	3.38	2.00	4.00	8.00	2.50	6.25	15.63

1.05	**1.10**	**1.16**	**1.55**	**2.40**	**3.72**	**2.05**	**4.20**	**8.62**	**2.55**	**6.50**	**16.58**

n	**n1/3**	**n**	**n1/3**	**n**	**n1/3**	**n**	**n1/3**	**n**	**n1/3**	**n**	**n1/3**
0.001	**0.10**	**0.22**	**0.60**	**1.33**	**1.10**	**4.10**	**1.60**	**9.26**	**2.10**	**17.58**	**2.60**
0.003	**0.15**	**0.27**	**0.65**	**1.53**	**1.15**	**4.49**	**1.65**	**9.94**	**2.15**	**18.61**	**2.65**
0.008	**0.20**	**0.34**	**0.70**	**1.73**	**1.20**	**4.91**	**1.70**	**10.65**	**2.20**	**19.68**	**2.70**
0.016	**0.25**	**0.42**	**0.75**	**1.95**	**1.25**	**5.36**	**1.75**	**11.39**	**2.25**	**20.80**	**2.75**
0.027	**0.30**	**0.51**	**0.80**	**2.20**	**1.30**	**5.83**	**1.80**	**12.17**	**2.30**	**21.95**	**2.80**
0.043	**0.35**	**0.61**	**0.85**	**2.46**	**1.35**	**6.33**	**1.85**	**12.98**	**2.35**	**23.15**	**2.85**
0.064	**0.40**	**0.73**	**0.90**	**2.74**	**1.40**	**6.86**	**1.90**	**13.82**	**2.40**	**24.39**	**2.90**
0.091	**0.45**	**0.86**	**0.95**	**3.05**	**1.45**	**7.41**	**1.95**	**14.71**	**2.45**	**25.67**	**2.95**
0.125	**0.50**	**1.00**	**1.00**	**3.38**	**1.50**	**8.00**	**2.00**	**15.63**	**2.50**	**27.0**	**3.00**
0.166	**0.55**	**1.16**	**1.05**	**3.72**	**1.55**	**8.62**	**2.05**	**16.58**	**2.55**	**28.37**	**3.05**

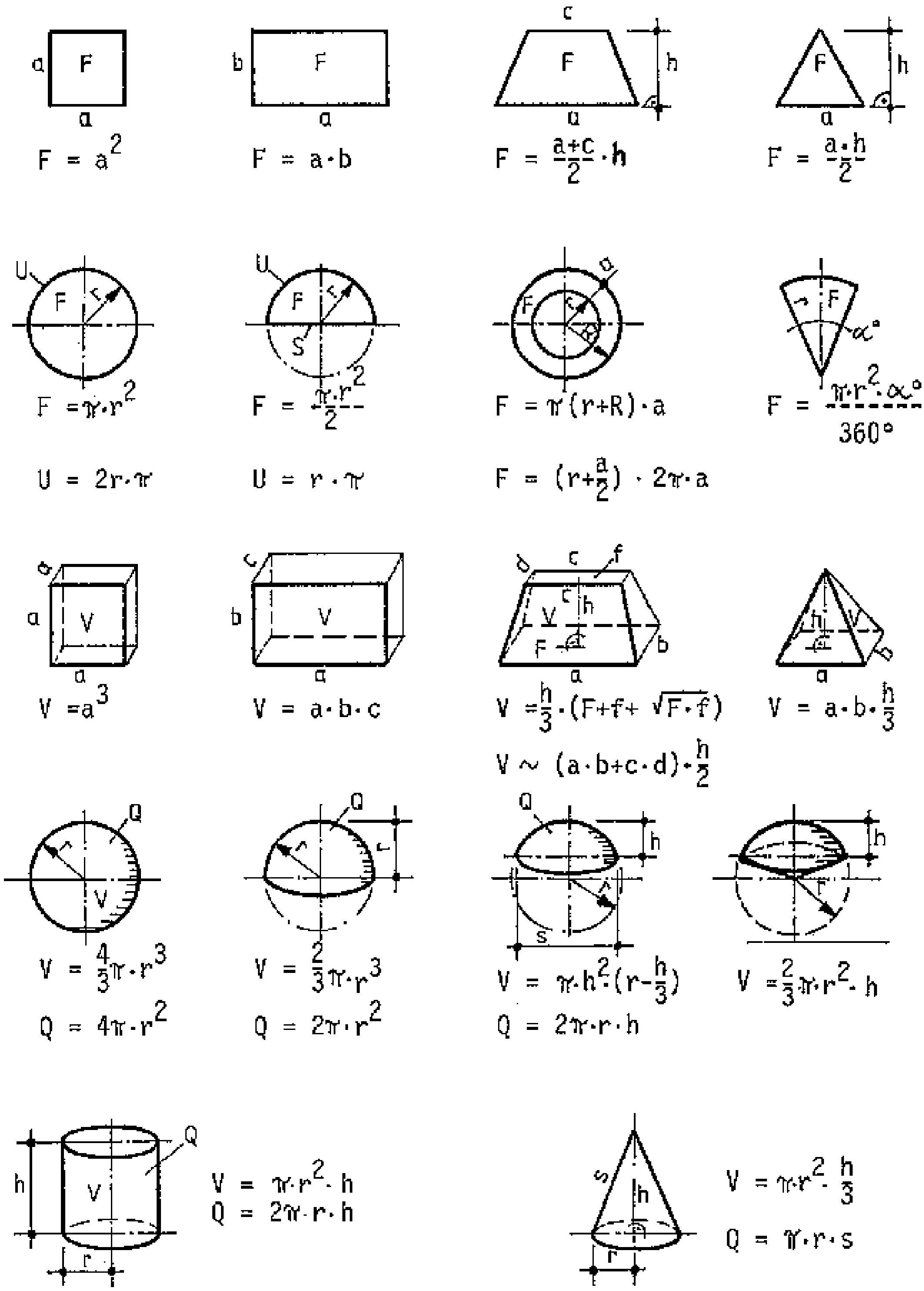

Fig. 10.11: Fundamental geometric formulae (Source: Sasse 1984)

10.4 Charts and tables for use in performing micro-economic

Notes on using the data sheet (table 10.10)

The data survey (data sheet, table 10.10) contains fictive, but nonetheless substantially realistic, data on a family-size biogas plant. Those data are reffered to for explaining and calculating the arithmetic models described in chapter 8. Such data must be ascertained separately for each project site.

Notes on the individual data-sheet items

1. In order to keep the calculations uncomplicated, an unrealistically constant annual rate of inflation is assumed. It is possible to account for different inflation rates in the various analytical procedures. For explanatory details beyond those offered in this guide, please refer to Finck/Oelert, chapter C III.

2. Calculatory interest rate, i: assumed rate of interest for evaluating the cash flows (income and expenditure) generated by a biogas plant during its technical service plant. Proceeding on the assumption that the expenditures are all the more burdensome, the earlier they fall due, while income is all the more valuable, the earlier it is earned,

all cash flows occuring in connection with the investment are compounded/discounted at an assumed rate for a fixed point in time. Please refer to chapter 8.4 for the calculation procedure.

3. Investment costs (incl. wages):

- planning

- land aquisition/leasing (as applicable)

- civil works

- building and structures/digester

- modification of animal housing

- gas appliances/aggregates

- slurry spreading implements

- assembly and commissioning

- customs, taxes, duties, fees

- transportation

4. Manpower costs for:

- feeding the plant

- spreading the digested slurry

5. Maintenance and repair:

- spare parts/materials

- wages for maintenance/repair work

6. Energy revenues

- market value of replaced energy

- energy supplied

- production induced with extra energy (market value)

7. Revenues from fertilizer:

- market value of replaced inorganic fertilizer

- revenues from sales of digested slurry

- higher cash-crop yields due to fertilizing with digested slurry

8. Time saved (real financial income only) for additional:

- wage work

- work on the farm (included additional incom)

9. Depreciation (annual for linear depreciation):

= investment costs / n (technical service life)

In this example, the technical service life of the plant is conservatively estimated at only 10 years.

10. Depreciation and capital-servicing costs (interest on loans): neither of these two factors is included as a cost factor in the dynamic models presented in chapter 8, because the cost of investment is equal to the sum of cash values from depreciation and interest (cf. Brandt, 1982, for details). In this example, it is assumed that no external capital is needed, i.e. that the biogas plant is fully financed with internal capital.

Table 10.10: Data sheet for economic analysis (Source OEKOTOP; Finck/Oelert, Table 1)

Project title:	Location:	Owner:	Type of plant/digester volume:

Technical service life:	**years**											
Item Period		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Year		**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**
1.1 General inflation rate 1)	**%**	**34**	**34**	**34**	**34**	**34**	**34**	**34**	**34**	**34**	**34**	**34**
1.2 Market interest rate, p	**%**	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**
1.3 Assumed interest rate, i 2)	**%**	**10.4**	**10.4**	**10.4**	**10.4**	**10.4**	**10.4**	**10.4**	**10.4**	**10.4**	**10.4**	**10.4**
2. Investment costs, I 3)	**CU**	**1100**										
3.1 Manpower costs 4)	**CU**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	
3.2 Maintenance and repair 5)	**CU**	**-**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**
spare-parts requirement												
4.1 Taxes and levies not linked to profit	**CU**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
4.2 Other expenditures	**CU**	**-**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**
5. Total operating costs,	**Co**		**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**
6.1 Energy-related revenues 6)	**CU**	**-**	**210**	**210**	**210**	**210**	**210**	**210**	**210**	**210**	**210**	**210**
6.2 Revenues from fertilizer 7)	**CU**	**-**	**250**	**250**	**250**	**250**	**250**	**250**	**250**	**250**	**250**	**250**
6.3 Time saved 8)	**CU**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
6.4 Other income	**CU**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
6.5 Subsidies	**CU**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

7. Total income	**CU**	**-**	**235**	**235**	**235**	**235**	**235**	**235**	**235**	**235**	**235**	**235**
8. Returns (item 7- item 5)	**CU**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**
9. Depreciation 9)	**CU**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**	**110**
10. Capital servicing costs 10)	**CU**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
11. Profit	**CU**	**-**	**90**	**90**	**90**	**90**	**90**	**90**	**90**	**90**	**90**	**90**

CU = currency unit; in local currency or DM/US $ (conversion to DM/US $ rarely advisable due to fluctuating exchange rates)

Table 10.11: Discounting factors for interest rates of i = 1 -30% and periods of t = 1 - 30 years

t\i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	.990	.980	.971	.962	.952	.943	.935	.926	.917	.909	.901	.893	.885	.877	.870
2	.980	.961	.943	.925	.907	.890	.873	.857	.842	.826	.812	.797	.783	.769	.756
3	.971	.942	.915	,889	.864	.840	.816	.794	.772	.751	.731	.712	.693	.675	.658
4	.961	.924	.888	.855	.823	.792	.763	.735	.708	.683	.659	.636	.613	.592	.572
5	.951	.906	.863	.822	.784	.747	.713	.681	.650	.621	.593	.567	.543	.519	.497
6	.942	.888	.837	.790	.746	.705	.666	.630	.596	.564	.535	.507	.480	.456	.432
7	.933	.871	.813	.760	.711	.665	.623	.583	.547	.513	.482	.452	.425	.400	.376
8	.923	.853	.789	.731	.677	.627	.582	.540	.502	.467	.434	.404	.376	.351	.327
9	.914	.837	.766	.703	.645	.592	.544	.500	.460	.424	.391	.361	.333	.308	.284
10	.905	.820	.744	.676	.614	.558	.508	.463	.422	.386	.352	.322	.295	.270	.247
11	.896	.804	.722	.650	.585	.527	.475	.429	.388	.350	.317	.287	.261	.237	.215

12	.887	.788	.701	.625	.557	.497	.444	.397	.356	.319	.286	.257	.231	.208	.187
13	.879	.773	.681	.601	.530	.469	.415	.368	.326	.290	.258	.229	.204	.182	.163
14	.870	.758	.661	.577	.505	.442	.388	.340	.299	.263	.232	.205	.181	.160	.141
15	.861	.743	.642	.555	.481	.417	.362	.315	.275	.239	.209	.183	.160	.140	.123
16	.853	.728	.623	.534	.458	.394	.339	.292	.252	.218	.188	.163	.141	.123	.107
17	.844	.714	.605	.513	.436	.371	.317	.270	.231	.198	.170	.146	.125	.108	.093
18	.836	.700	.587	.494	.416	.350	.296	.250	.212	.180	.153	.130	.111	.095	.081
19	.828	.686	.570	.475	.396	.331	.277	.232	.194	.164	.138	.116	.098	.083	.070
20	.820	.673	.554	.456	.377	.312	.258	.215	.178	.149	.124	.104	.087	.073	.061
21	.811	.660	.538	.439	.359	.294	.242	.199	.164	.135	.112	.093	.077	.064	.053
22	.803	.647	.522	.422	.342	.278	.226	.184	.150	.123	.101	.083	.068	.056	.046
23	.795	.634	.507	.406	.326	.262	.211	.170	.138	.112	.091	.074	.060	.049	.040
24	.788	.622	.492	.390	.310	.247	.197	.158	.126	.102	.082	.066	.053	.043	.035
25	.780	.610	.478	.375	.295	.233	.184	.146	.116	.092	.074	.059	.047	.038	.030
26	.772	.598	.464	.361	.281	.220	.172	.135	.106	.084	.066	.053	.042	.033	.026
27	.764	.586	.450	.347	.268	.207	.161	.125	.098	.076	.060	.047	.037	.029	.023
28	.757	.574	.437	.333	.255	.196	.150	.116	.090	.069	.054	.042	.033	.026	.020
29	.749	.563	.424	.321	.243	.185	.141	.107	.082	.063	.048	.037	.029	.022	.017
30	.742	.552	.412	.308	.231	.174	.131	.099	.075	.057	.044	.033	.026	.020	.015

t\i	16	17	18	19	20	21	22	23	24	25	26	27	28	229	30
1	.862	.855	.847	.840	.833	.826	.820	.813	.806	.800	.794	.787	.781	.775	.769
2	.743	.731	.718	.706	.694	.683	.672	.661	.650	.640	.630	.620	.610	.601	.592
3	.641	.624	.609	.593	.579	.564	.551	.537	.524	.512	.500	.488	.477	.466	.455
4	.552	.534	.516	.499	.482	.467	.451	.437	.423	.410	.397	.384	.373	.361	.350
5	.476	.456	.437	.419	.402	.386	.370	.355	.341	.328	.315	.303	.291	.280	.269
6	.410	.390	.370	.352	.335	.319	.303	.289	.275	.262	.250	.238	.227	.217	.207
7	.354	.333	.314	.296	.279	.263	.249	.235	.222	.210	.198	.188	.178	.168	.159
8	.305	.285	.266	.249	.233	.218	.204	.191	.179	.168	.157	.148	.139	.130	.123
9	.263	.243	.225	.209	.194	.180	.167	.155	.144	.134	.125	.116	.108	.101	.094
10	.227	.208	.191	.176	.162	.149	.137	.126	.116	.107	.099	.092	.085	.078	.073
11	.195	.178	.162	.148	.135	.123	.112	.103	.094	.086	.079	.072	.066	.061	.056
12	.168	.152	.137	.124	.112	.102	.092	.083	.076	.069	.062	.057	.052	.047	.043
13	.145	.130	.116	.104	.093	.084	.075	.068	.061	.055	.050	.045	.040	.037	.033
14	.125	.111	.099	.088	.078	.069	.062	.055	.049	.044	.039	.035	.032	.028	.025
15	.108	.095	.084	.074	.065	.057	.051	.045	.040	.035	.031	.028	.025	.022	.020
16	.093	.081	.071	.062	.054	.047	.042	.036	.032	.028	.025	.022	.019	.017	.015
17	.080	.069	.060	.052	.045	.039	.034	.030	.026	.023	.020	.017	.015	.013	.012
18	.069	.059	.051	.044	.038	.032	.028	.024	.021	.018	.016	.014	.012	.010	.009

19	.060	.051	.043	.037	.031	.027	.023	.020	.017	.014	.012	.011	.009	.008	.007
20	.051	.043	.037	.031	.026	.022	.019	.016	.014	.012	.010	.008	.007	.006	.005
21	.044	.037	.031	.026	.022	.018	.015	.013	.011	.009	.008	.007	.006	.005	.004
22	.038	.032	.026	.022	.018	.015	.013	.011	.009	.007	.006	.005	.004	.004	.003
23	.033	.027	.022	.018	.015	.012	.010	.009	.007	.006	.005	.004	.003	.003	.002
24	.028	.023	.019	.015	.013	.010	.008	.007	.006	.005	.004	.003	.003	.002	.002
25	.024	.020	.016	.013	.010	.009	.007	.006	.005	.004	.003	.003	.002	.002	.001
26	.021	.017	.014	.011	.009	.007	.006	.005	.004	.003	.002	.002	.002	.001	.001
27	.018	.014	.011	.009	.007	.006	.005	.004	.003	.002	.002	.002	.001	.001	.001
28	.016	.012	.010	.008	.006	.005	.004	.003	.002	.002	.002	.001	.001	.001	.001
29	.014	.011	.008	.006	.005	.004	.003	.002	.002	.002	.001	.001	.001	.001	.000
30	.012	.009	.007	.005	.004	.003	.003	.002	.002	.001	.001	.001	.001	.000	.000

10.5 List of pertinent suppliers and institutions

Plant engineering, construction and consultancy services in developing countries

AIT Asian Institute of Technology - Division for Energy Technology, P.O. Box 2754, Bangkok 10501, Thailand

AVARD Association of Voluntary Agencies for Rural Development, c/o Safdarjung Development Area, New Delhi, India

BORDA Bremen Overseas Research and Development Association, Bahnhofsplatz 13, 2800 Bremen, Federal Republic of Germany

Biogas projects: BORDA/UNDARP Poona, India

CEMAT Centro Mesamericano de Estudios sobre Tecnologia Apropiada, A.P.1160, Guatemala-City, Guatemala

GATE/GTZ German Appropriate Technology Exchange/Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Postfach 5180, 6236 Eschborn, Federal Republic of Germany

GATE/GTZ Biogas Extension Program Projects:

Projecto de Biogas c/o ENPRA, km 11.5 vieja a Leon, A.P.4772 Managua, Nicaragua

Biogas Extension Service c/o CAMARTEC, P.O. Box 764, Arusha, Tanzania Projet Biogaz Cankuzo, D/S 148, Bujumbura, Burundi

CDB/GATE Biogas Team c/o CDB, P.O. Box 407, Wildey St. Michael, Barbados

Proyeto Biogas PAAC-UMMS-GATE, Casilla 4740, Cochabamba Bolivia

Special Energy Program biogas projects (GTZ-Div.34) GTZ Special Energy Program, P.O. Box 41607, Nairobi, Kenya Projet Special de l'Energie, c/o I.V.E., B.P. 5321 Ouagadougou, Burkina Faso

KVIC Khadi and Village Industries Commission, Gobar Gas Scheme, Ivla Rees, Vila Parle, Bombay 400 056, India

Maya Farms Angona, Rizal, Philippines

OEKOTOP Gesellschaft fur AngepaÃŸte Technologien in Entwicklungsgebieten, Bingerstr. 25a, 1000 Berlin 33, Federal Republic of Germany

Biogas projects (by order of GTZ): Projet Biogaz c/o SODEPRA Ferkessedougou, Cote d'Ivoire Proyecto Biogas Colombo-Aleman c/o CVC, Apto. A2366, Cali, Colombia

RED-Latino Americana de Biogas, Emprater, W3 Norte Q515, Brazilia, Brazil

Equipment producers / suppliers

Elster AG, Postfach 129,6500 Mainz, Federal Republic of Germany

Products: gasmeters

Kromschroder AG, Postfach 2809,4500 Osnabruck, Federal Republic of Germany

Products: full range of gas valves

Metallurgica Jackwal Ltd., Rua Braz Cardoso 674, Vila Nova Canceicao, Sao Paulo, Brazil

Products: lamps, burners, reducing valves

OEKOTOP GmbH, Berlin

Product: portable biogas measuring set

Patel Gas Crafters Ltd., Shree Sai Bazar, Mahatma Gandhi Road, Bombay 400 054, India

Products: lamps, burners

Saron Vdyog, Shanghai, PR China

Products: gasmeters, lamps, burners

Service Centre for Development on New Energy, NO. 33 Fugiun Skeet, Shijiazkuang, PR

China

Products: burners, motors

Shanghai Bioenergy, Shanghai, PR China

Products: gasmeters, lamps, burners, motors

T.A. Schiller, Postfach 1224, 2072 Bargteheide, Federal Republic of Germany

Products: lamps, burners, motors

Producers of biogas-fueled engines

Ford AG, Edsel-Ford-Str., 5000 Cologne 71, Federal Republic of Germany

- Type 2274 E, 15-25 kW, 1500 - 3000 min-1, 4-cylinder, water-cooled, spark ignition

Henkelhausen, Postfach 9149, 4150 Krefeld 12, Federal Republic of Germany

- Series GFL 912, 19~0 kW, 1500-2300 min-1, 3-, 4-, 5-, 6-cylinder, air-cooled, spark ignition

- Series GFL 413, 55 - 140 kW, 1500 - 2300 min-1, 5-, 6-, 8-, 10-, 12-cylinder, air-cooled, spark ignition

Kirloska, India, German representative: Schule Co., Postfach 260620, 2000 Hamburg 26,

Federal Republic of Germany

- Series AVG, TVG, CAG, TAG, 5 - 12 kW, 1200 - 2000 min-1, 1-, 2-cylinder, air-cooled or water-cooled, dual-fuel

MWM AG, Carl-Benz-Str., 6800 Mannheim, Federal Republic of Germany

- Series G 227, 18 - 40 kW, 1500 - 2200 min-1, 3-, 4-, 6-cylinder, water-cooled, spark ignition

10.6 Selected literature

Biotechnical fundamentals and plant engineering

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Memento de l'agronome, Republique Francaise, Ministere de la Cooperation, 1984

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Williamson, G./Payne, W.J.A., An Introduction to Animal Husbandry in the Tropics, London/New York 1977

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Brandt, H., Projektplanung in der kleinbauerlichen Produktion, Berlin 1982

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10.7 Lists and indexes

10.7.1 Illustrations

10.7.2 Tables

10.7.3 Abbreviations

A	**area**
a	**inflation rate**
a	**year (per annum)**
at	**atmosphere**
B	**biomass**
B.D.C.	**bottom dead center**

BEP	**GATE/GTZ Biogas Extension Program**
BOD	**biochemical oxygen demand**
C	**carbon**
C	**circumference**
CaO	**calcium oxide**
cd	**candela (candle power)**
ce	**coefficient of earth pressure**
cf	**coefficient of friction**
CH4	**methane**
cmWG	**cm water gage**
C/N	**carbon/nitrogen ratio**
CO2	**carbon dioxide**
COD	**chemical oxygen demand**
cp	**coefficient of pipe friction**
cP	**heat capacity**
CS	**crankshaft**
Cs	**storage capacity**
D	**density of biogas**

D	**energy demand**
D, d	**pipe diameters**
d	**day**
d	**stoichiometric air ratio**
DN	**density of biogas under normal (s.t.p.) conditions**
dp	**pressure drop**
Dr	**digestion rate**
E	**illuminance**
E	**compression ratio**
E	**energy**
Ee	**energy input**
Es	**specific illuminance**
F	**luminous flux**
F	**relative dampness of biogas**
Fe(OH)3	**ferric hydrate**
FL	**friction losses**
G	**gas production**
gc, max	**max. gas consumption per hour**
GM	**moisture content of gas**

Gp	**specific gas production**
GRP	**glass-reinforced plastic**
Gy	**gas yield**
H, h	**height**
H2	**hydrogen**
he	**height of earth column**
hp	**horsepower**
hph	**horsepower-hour**
H2S	**hydrogen sulfide**
I	**luminous intensity**
i	**discounting factors/calculatory (assumed) interest rate**
Io	**initial investment**
J	**joule**
K	**potassium**
KA	**average capital invested (per time interval)**
kcal	**kilocalorie**
K2O	**potassium oxide**
kWh	**kilowatt hour**
L	**latent heat of evaporation**

I	length of pipe
Ld	digester loading
lrn	lumen
mbar	millibar
MgO	magnesium oxide (magnesia)
mWG	meter water gage
N	nitrogen
N	burner efficiency
N	Newton
n.c.v.	net calorific value (in diagrams: n.c.v. = Hu)
NP	net profit
P	pressure/gas pressure
P	phosphorus
p	market rate of interest
p	biogas/energy production
pa	Pascal
PE	polyethylene
pE	active earth pressure

PN	**normal pressure**
P2O5	**phosphorus pentoxide**
PVC	**polyvinyl chloride**
PW	**partial pressure of water vapor**
pw	**hydrostatic pressure**
Q	**gas flow**
QW	**quantity of heated water**
R, r	**radius**
Re	**luminous efficiency**
ROI	**return on investment (profitability)**
RT	**retention time**
Sd	**daily substrate input**
T, t	**temperature**
tc, max	**maximum consumption time**
T,D.C.	**top dead center**
tz, max	**maximum period of zero consumption**
TN	**temperature under normal (s.t.p.) conditions**
TS	**total solids content**
V	**volume**

v	**velocity/speed**
vc	**maximum gas consumption**
Vd	**digester volume**
Vg	**gasholder volume**
Vh	**compression volume**
VN	**volume of biogas under normal (s.t.p.) conditions**
Vn	**swept volume**
VS	**volatile solids content**
Vtot	**total volume of a cylinder**
W	**water**
W	**watt**
Wd	**daily water input**
wE	**weight of dry earth**
Wl	**water loss (leak testing)**
wW	**weight of water**
Ztot	**sum total of friction losses**