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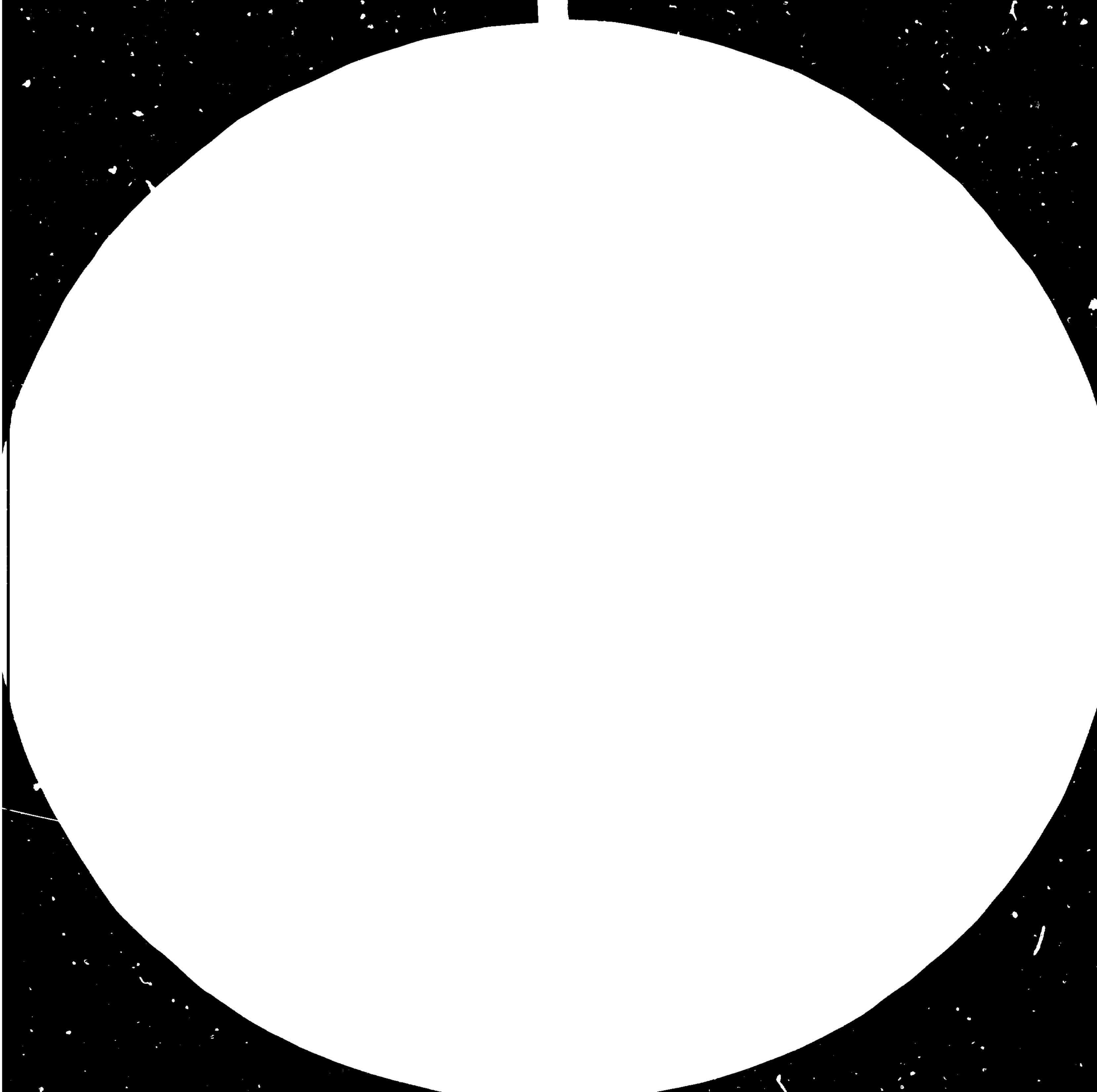

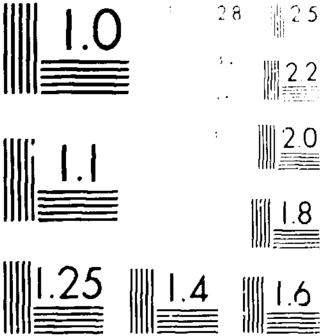
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ENERGY AND MATERIAL FLOWS IN THE MANUFACTURE OF SELECTED CERAMIC PRODUCTS

by: J. Müller

Table of Contents

1. Introduction

In general the energy and material balances are application of the Material and Energy Conservation Law in a manufacturing process. They are applied particularly in chemical and some other industries and also in ceramics. They are usefull and unsurpassed aid to everybody who is concerned with economy of production and each desing or project of a ceramic factory is based on them. In the following lecture we will discuss the material and energy balances from the point of view of a technologist who applies them for control of the economical run of a certain ceramic manufacture.
We will not pay special attention to measurment techniques which are applied in connection with the study of both the energy and materials balances since they themselves pose many questions transcending the subject of this lecture. We will use "SI" system of physical units consistently.

2. Fundamental Terminology

As mentioned above, the essence of the material and energy balances is based on the energy and material conservation law how it is expressed in classical parts of physics and how Lavoisier and Helmholtz set down it some two hudred years ago. In order to understand each other better, we will discuss the energy and material balances seperately.

2.1. Fundamental Terminology in Material Balances

The fundamental law, which affects the material balances seys : "The weight of masses of a separated system before chemical reaction equals to the weight of masses after the reaction". As Lavoisier said : "Rien ne se crée, rien ne se perd, tout se transforme".

If there are no chemical reaction and only physical processes like phase transitions take place, the above mentioned conservation principle is obviously valid as well.

As a separated system we consider the whole plant where the observed production runs. While elaborating balance tables or diagrams /these techniques we will discuss in chapters 3 and 4/, it is important not to forget any material item belonging to the system. Quantity of these items we express in units of SI system i.e. in kilograms or metric tons.

2.2. Fundamental Terminology in Energy Balances

While elaborating the energy balances, we are primarily concerned about the heat energy spent on drying and firing. Further sort of energy we are concerned about is that of the electric power spent on driving machines and equipment e.g. mills, presses, different sorts of fans, pumps, stirrers, blungers etc. It must be emphasized that first rate object of the interest of a technologist or a power engineer should be the heat energy since we have practically no influence upon power consumption of machines and equipment built-in in a production line.

There are numerous problems concerning the heat consumption when driers and kilns are projected in the ceramics. But in case of elaborating energy balances, a plainer theoretical apparatus will do. In solving this problem we only need to compare theoretical consumption of the heat, which can be determined at least by approximate calculation, with the practical consumption indicated on appropriate gauges. In tis way we can find loss of heat energy and by its analysis we can take corrective measures.

2.2.1. Heat Consumption for Drying

Drying process is nothing but the evaporation of water from ceramic body at a certain temperature. Theoretical consumption of heat will be the simple sum of the heat spent on bringing the body to a temperature of drying, the heat spent on bringing water to a temperature of drying and the heat spent on evaporation of water from ceramic body at that drying temperature.

Heat consumption either theoretical or practical we always relate to one kilogram of evaporated water and call as "Specific Heat Consumption of a Drier".

Consequently, amount of the heat spent on evaporating one kilogram of water at a certain temperature consists of the heat needed for bringing water to a temperature at which evaporation begins and the evaporating heat of water at a considered temperature. The amount of evaporating heat depends on the temperature as shown in the following table where the heats spent on transforming one kilogram water with the initial temperature of 0°C into vapour at different temperatures of evaporation can be seen.

Temperature of evaporation °C	Evaporating heat kJ/kg
0	2,487.1
10	2,464.5
20	2,442.4
30	2,419.8
40	2,397.2
50	2,374.2
60	2,351.2
70	2,327.4
80	2,304.0
90	2,279.4
100	2,254.7

Theoretical heat consumption during drying is not the really spent heat. This really spent heat in a drier is only that heat which is spent on removal of mechanically bound water. The heat stored in dried ware could be regained and utilized /at least theoretically/ for different ends but it is not done in practice since the temperature of the dried ware is usually not high enough. Strictly speaking even the heat accumulated in vapour could be utilized after its condensation. For this reason the really spent heat in the drier would be only a fiction and in fact it would be necessary to ascribe it to the account of the losses. However, with regard to the low temperature of vapour after drying and to its implausible contamination, this heat is not utilized in industrial practice.

The amount of heat Q needed for bringing matter weighing m to a temperature T_2 from a temperature T_1 is derived from the formula /1/ :

/1/ $Q = mc/T_2 - T_1/$ where,

Q ....heat /kJ/

m ....weight /kg/

T_1, T_2 ...... temperatures /deg°C/

c ....specific heat /J/kgdeg/

Specific heat c, as known from physics, varies with the temperature. In case of the energy balance calculation, we need not take into account these changes and we only consider its average in a given interval of temperatures. Specific heat of ceramic materials fluctuates approximately from 0.9 to 1.0 kJ/kgdeg.

The accurate amount of the specific heat and itsdependance on temperatures must be assessed in concrete cases experimentally. However it is possible to say that influence of microstructure on the specific heat is negligible but influence of polymorphic transformations is greater.

2.2.2. Heat Consumption at Firing

The above mentioned formula /1/ used for calculation of heat consumption in case of drying is valid for firing as well. The amount of the spent heat which is calculated according to this formula must be added to the amount of the heat spent on removal of chemically bound water and on possible decomposition of limestone or on other chemical reactions. Here is to say that for practical calculation only the heat spent on removal of chemically bound water and decomposition of limestone is taken into consideration. Since we lack accurate data for determining the amount of heat spent on other chemical reactions and since this amount of heat compared with that of the above-mentioned /i.e. on removal of chemically bound water and decomposition of limestone/ is negligible, we do not consider it at calculation. This calculated heat, i.e. heat according to the formula /1/ plus heat spent on removal of chemically bound water and on limestone decomposition, iscalled theoretical heat consumption at firing. At the end of firing all chemical reactions and removal of water are finished but the product contains the heat which was spent on the bringing this product to the temperature of firing. This accumulated heat is not really spent since we can regain it by cooling the product to its initial temperature, e.g. by means of air. The really spent heat is only that heat spent on the removal of chemically and mechanically bound water and on the accomplishment of all the chemical reactions. A part of the heat accumulated in products and kiln furniture or kiln cars can be really used for drying, etc. Some 20 % of heat brought to the kiln could be usually utilized in this way.

2.2.3. Heat Losses

There are heat losses in kilns, driers and other thermal equipments. They equals to the difference between the amount of the heat put in a thermal equipment and the amount of the really spent heat /both for chemical reactions and physical processes/. Heat losses usually climb over 50 % . Even if we made use of residual heat from kilns /e.g. in driers/, the effect will be scarcely essentially better. The principal kinds of heat losses in ceramics are as follows :

- the flue loss
- the heat contained in goods and kiln furniture
- the heat contained in linings of kiln cars
- the heat passing through walls and ceiling of the heat equipments.

2.2.4. Fuels

The source of heat energy in ceramic industry are different kinds of fuel, either gasseous, liquid or solid. A sort of fuel is chosen in the preparatory phase of an investment decision according to local conditions. Heat equipments and their parts /e.g. driers, kilns, burners e.t.c./ correspond to that choice. For the comput ation of anenergy balance, the matter of paramount importance is the calorific value of fuel. The values of both the calorific value and those of the combustion heat are given in Tables. The combustion heat is that heat which is yielded by burning up fuel to gasseous carbon dioxide, nitrogen, sulphur dioxide and liquid water respectively, on the other hand the calorific value is the heat released by burning up fuel to gasseous carbon dioxide, sulphur dioxide, nitrogen and water vapour. As liquid water has never been generated in industrial burning, we can consider only the calorific value when we calculate an energy balance. Both the calorific value and the combustion heat are given in kJ/kg or kJ/Nm^3 according to physical states of considered fuel - either liquid, solid or gasseous one. The calorific value depends on the content and composition of flammable parts and frequently is not fixed within the same kind of fuel, therefore, it must be periodically checked.

2.3. Course of Calculation of Material and Energy Flow Balances

An usual way of assembling material and energy flow balance is as follows :

- a flow chart is drawn,
- presupossitions are put down,
- a base of calculation is chosen.

The flow chart should be simplified to a maximum. Only technology blocks which are submitted to a change concerning the balance should be drawn. The blocks are drawn without technology details and are frequently performed as rectangles. Oriented arrows indicate inputs and outputs. Systems considered should include all the inputs and outputs influencing the final result. The flow chart should also show what is known about the given problem, what shall be solved, eventually which are the possibilities of the solution.

As mentioned above, in order to simlify calculation some presuppositions are taken into account /e.g. negligence of small reaction heats, application of approximate values of specific heats and calorific values respectively, e.t.c./. Mutual compatibility of partial results must be ensured when balances are plotted. Consequently, a base or unit is being chosen the calculation relates to. It is usually mass of output concerning a certain balancing spell /e.g. net annual production/.

Data concerning the material flows are put down directly into the flow charts but data concerning the energy consumptions are frequently put down into separate tables or into so called Senkey´s diagrams. This way is not usually sufficiently detailed but the energy flows in separated phases of the technology process are easy to survey. Sankey´s diagrams are used in ceramic practice in case of the material flows as well and here they are usually applied to the whole technological process. The Sankey´s diagrams display the energy or material consumption by means of the width of the area /a corresponding scale per kJ or kg, ton etc. must be chosen/, which is branched off into individual outputs or inputs as will be shown in the next chapter.

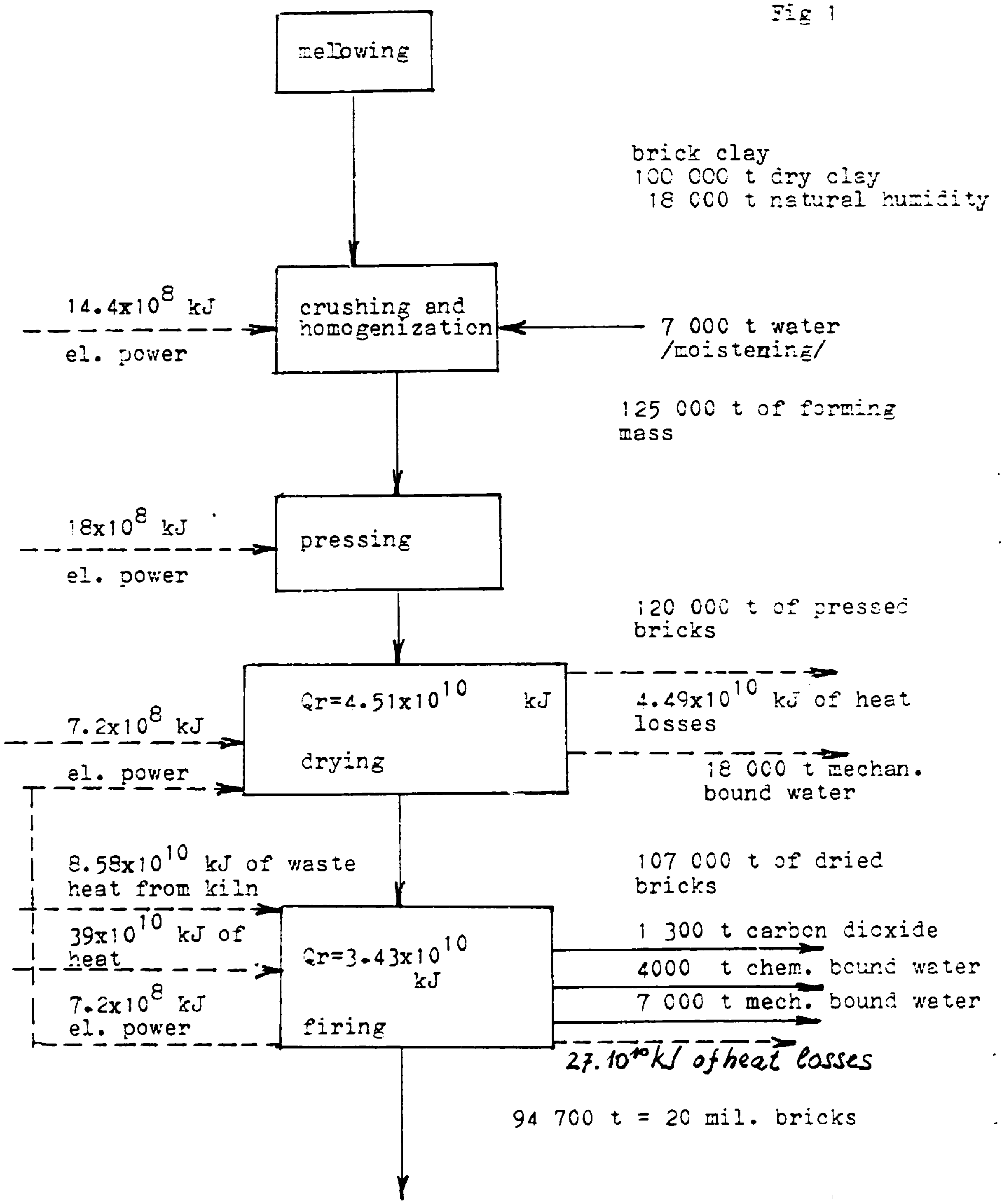
3. Case Study on Material and Energy Balance in the Red Brick Manufacture

The following case study of calculation the energy and material balances in the red brick manufacture shall give you a better outlook concerning the problems related.

A decision of making 20 milions solid bricks per year close to the deposit has been taken. There is a sufficient supply of appropriate brick clay in the given locality and the local brickworks can buy a tunnel kiln heated by gas of the same annual capacity under favourable conditions. Geological survey and laboratory tests has proved the average natural humidity of the brick-clay being 15 % and content of chemically bound water and calcium carbonate being 4 % and 3 % respectively. /The percentage relates to dry brick-clay/. Since a brick-moulding press shall be implemented, it is reckoned on moistening dug and mellowed clay in order to reach water content 20 %. A box feeder, rollers for crushing and fine grinding and a batch mill for homogenization are anticipated for implementation. Pressed bricks shall be dried in a tunnel drier heated by residual heat from the kiln. The producer of the kiln and drier declares that the specific heat consumption for firing 1000 bricks is 1.95×10^7 kJ and the approximate heat consumption per 1 kg of evaporated water in the drier amounts to 5000 kJ. It has been calculated that 1.000 bricks weighing 4.7 tons will consume 3.3 m. cub. of the clay weighing 5.9 tons.

The material and energy flow is displayed in the following flow chart.

Fig 1


mellowing
brick clay
100 000 t dry clay
18 000 t natural humidity
$14.4x10^{8}$ kJ
el. power
crushing and homogenization
7 000 t water /moistening/
125 000 t of forming mass
$18x10^{8}$ kJ
el. power
pressing
120 000 t of pressed bricks
$Qr=4.51x10^{10}$ kJ
drying
$7.2x10^{8}$ kJ
el. power
$4.49x10^{10}$ kJ of heat losses
18 000 t mechan. bound water
$8.58x10^{10}$ kJ of waste heat from kiln
$39x10^{10}$ kJ of heat
$7.2x10^{8}$ kJ
el. power
107 000 t of dried bricks
$Qr=3.43x10^{10}$ kJ
firing
1 300 t carbon dioxide
4000 t chem. bound water
7 000 t mech. bound water
27.10^{10} kJ of heat losses
94 700 t = 20 mil. bricks

There is an experience in the brick - making /similar data can be found in special handbooks as well /that the electric power consumption will amount to approx. 65 kWh /1.000 bricks in the case of the equipment considered in our example. One third of the total consumption is spent on driving equipment for crushing and homogenization, the second third drives the brick - moulding press and the drier and the kiln consume the rest. There is also known that about 22 % waste heat from the kiln can be utilized for drying. According to these presuppositions, the inputs of energy in separated phases of the production has been assesed and calculated with respect to the annual production /dashed lines in diagram 1/. Inputs of heat energy into the drier and the kiln have been calculated from data given by the equipment producer.

3.1. Heat Consumption for Drying

18 000 tons of mechanically bound water are evaporated from 125 000 tons of crude pressed bricks. Bricks entering the drier with temperature 15°C are dried at 40°C. 7 000 tons of water still remains in dried bricks. This residual moisture will be removed during firing.

According to the above - mentiond producer's data, the practical heat consumption should be :

$$Q = 18\ 000\ 000 \text{ kg times } 5\ 000 \text{ kJ/kg} = 9 \times 10^{10} \text{ kJ}$$

But actual heat consumption Q_r needed for evaporating 18 000 tons of mechanically bound water equals to

$$Q_r = 18\ 000\ 000 \times /2\ 567.8 - 62.7/\text{kJ/kg} = 4.51 \times 10^{10} \text{ kJ}$$

The value 2 567.8 kJ/kg represent so called total evaporating heat of water at <u>40°C</u>, i.e. the heat which is necessery for evaporating 1 kg water at 40°C by heating this water from 0°C. The value 62.7 kJ/kg is the heat content in 1 kg of water at 15°C. 8.58 x 10^{10} kJ of residual heat from the kiln will be utilized in the drier, consequently only 0.42 x 10^{10} kJ of fresh heat energy will have to be needed here. Presupposed losses in the drier Q_1 are equal to the difference between the practical heat consumption and the actual heat consumption, i.e.

$$Q_1 = Q - Q_r = \underline{4.49 \times 10^{10} \text{ kJ}}$$

3.2. Heat Consumption for Firing

107 000 tons of dried bricks with temperature 15°C, which contain 7 000 tons of mechanically bound water, are put into the kiln and are fired at the maximum temperature 1 000°C. In addition to it, there are 4 % of chemically bound water and 3 % of calcium carbonate in bricks before firing which represent 4 000 tons and . 3 000 tons respectively. For removal of 1 kg of chemically bound water, 2 671 kJ are approximately needed and for decom position of calcium carbonate, 1 756.5 kJ are spent. We can calculate the actual heat consumption Q_r for firing as follows :

Decomposition of calcium carbonate :
$3\ 000\ 000 \times 1\ 776.5 = 0.53 \times 10^{10}$ kJ
Removal of chemically bound water :
$4\ 000\ 000 \times 2\ 671 = 1.07 \times 10^{10}$ kJ
Removal of mechanically bound water :
$7\ 000\ 000 \times /2\ 672 - 63/ = 1.83 \times 10^{10}$ kJ

$$Q_r = /0.53 + 1.07 + 1.83/ \times 10^{10} \text{ kJ} = \\ = 3.43 \times 10^{10} \text{ kJ}$$

Practical heat consumption according to the statement of the kiln producer is to be

$$Q = 1.95 \times 10^{7} \text{ kJ} \cdot 20\ 000 = 39 \times 10^{10} \text{ kJ};$$

22 % of heat input is to be consumed in the drier

$$0.22 \times 39 \times 10^{10} \text{ kJ} = 8.58 \times 10^{10} \text{ kJ};$$

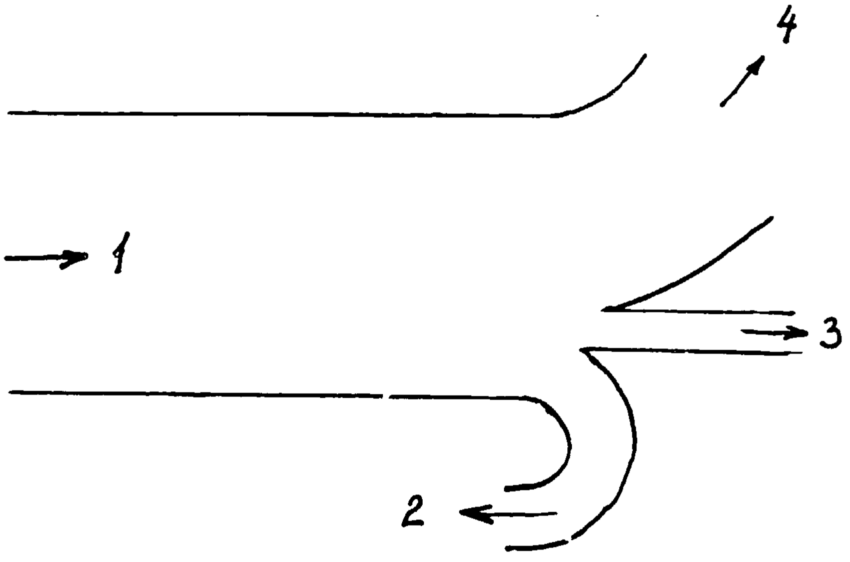
Consequently heat losses in the kiln are equal to

$$Q_l = Q - /Q_r + 8.58 \times 10^{10} kJ/ = 27 \ . \ 10^{10} \ kJ$$

As mentioned above, Sankey's diagrams are frequent way of displaying material and energy flows in ceramics. Fig.2 shows a Sankey's diagram concerning the material flow from the flow chart /fig.1/.

Fig. 3

Fig. 3 represents the S. diagram of heat flows in the kiln during firing.

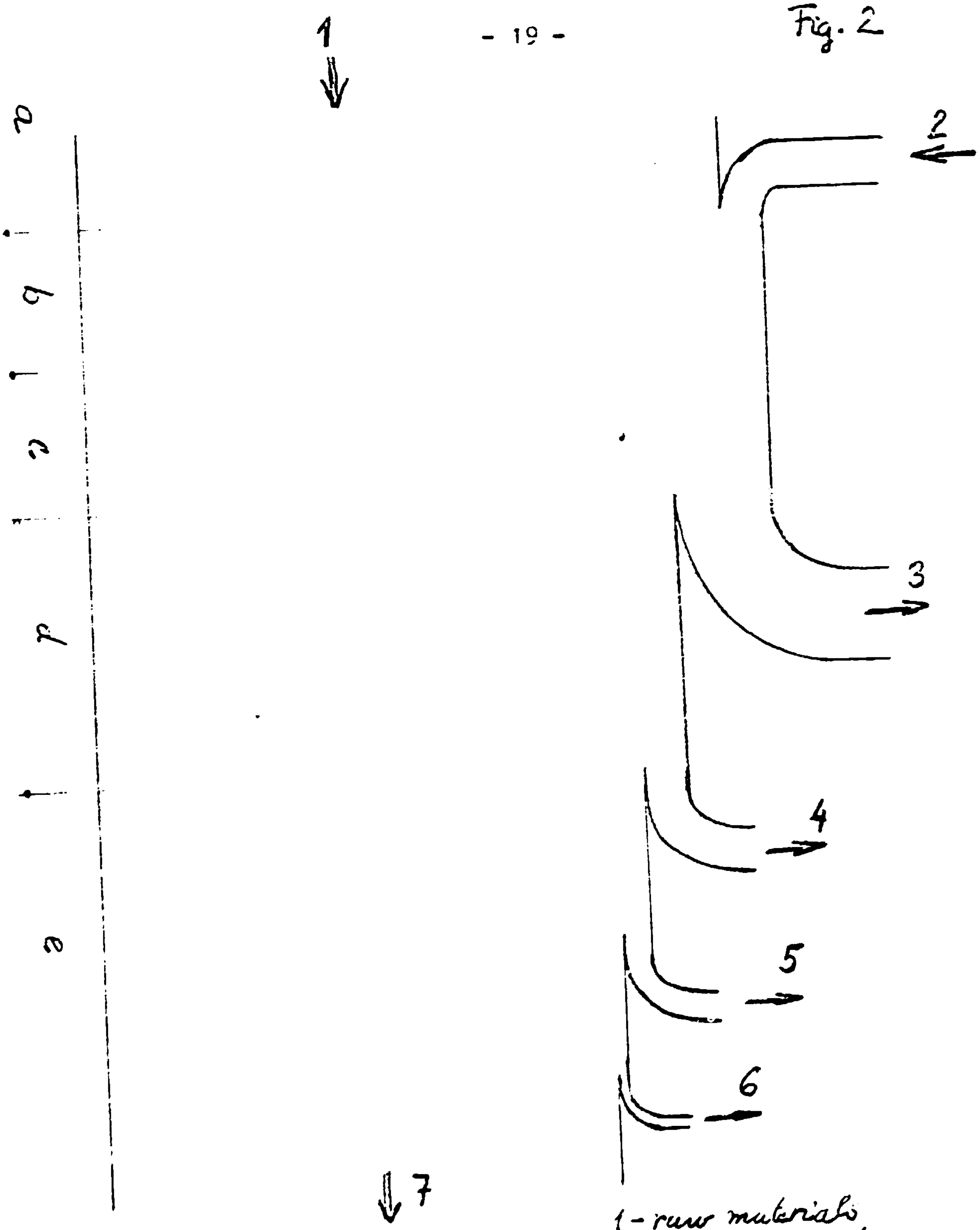


Scale: $1mm = 10^{10} kJ$

1 - heat input
2 - heat for drying
3 - really spent heat Q_r
4 - heat losses

Scale : 1mm = 1000 t

Fig. 2



a - mellowing
b - crushing and homogenization
c - forming
d - drying
e - firing

1 - raw materials
2 - moistening water
3 - mech. bound water (drying)
4 - mech. bound water (firing)
5 - chem. bound water (firing)
6 - CO_2 from $CaCO_3$ (firing)
7 - fired bricks

4. Energy and Material Flows in the Manufacture of Ceramic Products

This chapter contains data arranged into tables which enable approximate calculation of material and energy flows in the manufacture of refractories, wall tiles, unglazed floor tiles, household china, earthenware and red bricks.

We have arranged data into tables deliberately since technologies of the individual products can differ from each other considerably and consequently flow charts or Sankey´s diagrams also differ in the individual cases. The data are arranged in accordance with the sequence of the technological processes.

The information concerning the equipment, moisture content, consumption of electric power and heat for drying or firing is always attached to the appropriate process shown in the table.

The moisture content is expressed in percentage by weight, consumption of electric power in kWh/1t. Consumption of heat in kJ/kg at firing and in kJ/1kg H_2O at drying (quantity of heat spent at firing is related to 1 kg of fired products and quantity of heat spent at drying is related to 1kg H_2O evaporated from the green product). The moisture content is always related to the weight of final product and consuption of electric power is related to the weight of the material entering the appropriate process.

4.1. Material and Energy Flow in the Manufacture of Fireclay Bricks

Fireclay bricks are made from refractory clays, which serve as raw material for making both grog and bond. The moisture of refractory clays is usually in the range up to 15 % wt. Similarly the moisture of schistose clay usually amounts to 2 % wt. Raw materials with the moisture over 15 % wt. cannot be often utilized directly in a manufacturing process and must be predried e.g. in the open air. Loss on ignition of most of refractory clays varies in the range 11 to 15 % wt. whereas in Case of schistose clays in 0.5 to 2 % wt. range. Grog made by firing of refractory or schistose clays is mixed with ceramic bond in the range 50 - 70 % wt. grog and 50 - 30 % wt. ceramic bond. In tables I and II data concerning the manufacture of grog are given. Tables III and IV contain information about the manufacture of fireclay bricks by means of plastic extrusion and semidry pressing respectively.

Portion of rejects which arise during drying and firing reaches in common 5 %. If the whole consumption of electric power is to be calculated, quantity of electric power spent on transport must be added.

4.2. Material and Energy Flow in the Manufacture of Wall Tiles and Nonglazed Floor Tiles

Technologies of wall tiles and floor tiles manufacture differ substantially from each other. Consequently the specific energy consumptions in the individual stages of production process show also considerable differencesin different cases.Nevertheless it must be said that nowadays there is a prevailing tendency consisting in simplyfying of the technological process and removing the delicate operations within the framework of the whole manufacture. This is accomplished mainly by introduction of the wet milling and of subsequent spray drying of the slip. In earlier times the filterpresses were constantly used for this purpose but modern factories do not almost applied them.
Body composition varies also in a bro ad range. Besides "classical" raw materials like kaolins, earthenware clays, kaolin grogs, limestone or dolomite in case of wall tiles and stoneware clays, kaolin slips, feldspare pegmatities in case of floor tiles now e.g. calcareous marls draw attention with respect to their application in manufacture.

The moisture content of plastic and Semiplastic raw materials is usually in the range 10 to 25 % wt. and their loss on ignition reaches values of 12 - 15 % wt. The producers of the wall tiles try to choose the body composition in such a way so that the sizing of the tiles can be removed.

Considerable changes occured also in the firing of tiles. The design and quality of the kiln furniture has also substantially changed during recent times not to speak of the kiln cons_truction in itself. Classical kilns with the large crosssections have been replaced step by step by the ones having their crosssections much more smaller. Such kilns allow to accomplish the shortening of the firing process to several hours or even bellow an hour. In many countries electric tunnel kilns are used for firing of tiles which enable us to decrease the specific heat consumption.

It seems to be obvious that it is impossible to give an exhaustive and unified picture of the material and energy flows in the manufacture of tiles. For this reason date in tables V and VI are related to the standard contemporary production containing both filter presses and spray driers.

4.3. Material and Energy Flow in the Manufacture of Household China

The technology of the household china is stabilized enough in most of factories and therefore comparative studies can be relatively easily made. In older enterprises where small quantities of rich decorated goods have been made, hand forming has been utilized as well as the firing in the multiple-story round kilns. In modern factories both the jiggering and slip casting is automatized and tunnel kilns for firing are commonly used. Raw materials consumption for the manufacture of 1 ton of household china is approximately as follows :

body /kg/	
kaolin	560
plastic clays	65
pegmatite	310
sand	315

glaze /kg/	
glaze pegmatite	25
dolomite	5
limestone	11
zinc oxide	1,5
kaolin	17
sand	40,5

The consumption of water in an average household china plant is approximately in the range 780 to 950 kg per 1 t of final product. Moreover a small quantity of deflocculants /several tenths of the total weight of the slip/ e.g. soda and water glass are also needed. Total specific heat consumption in round kilns is approximately twice as much as in tunnel kilns.

Data from Table VII can be also used for the manufacture of earthenware product. Since both biscue firing and glost firing are accomplished at the lower temperatures, the specific consumption amounts approximately to 38 500 kJ/kg and 34 500 kJ/kg respectively provided that the ordinary tunnel kiln is utilized. Thermal endurance of the kiln furniture is approximately in one third higher than in case of household china.

Typical consumption of raw materials for the manufacture of 1 t of the final product is as follows :

body /kg/		glaze /kg/	
kaolin	350	sand	21
earthenware clays	350	glaze pegmatite	32
sand	410	boric compounds	16
pegmatite	13	minium	12
grog	47	soda	9

Quality control and Material and Energy flow in Manufacture of Ceramic Products

Quite obviously, portion of rejects results always in increase of material and energy consumptions during the manufacture process. The ratio rejects/good products varies in the course of time and is dependent on the whole manifold of the individual factors. Especially the changes in the quality of the raw materials cause often many difficulties in the plant. The most delicate process is usually the shrinkage during drying and firing. Nonuniform distribution of pores in the body and of temperatures in dhe drier or kiln can cause serious large scale defects. Newly built plants suffer often from high portions of rejects and the main task of the technologist is to reduce them to the minimum values. Despite this, when we bring together the diagrams or tables concerning the material and energy flows, we must always take into our consideration that the average portion of rejects can be us follows :

product	portion of rejects /%/
fireclay bricks	5
tiles	5 - 10
household china	15 - 20
earthenware	15 - 20
red bricks	2 - 3

The part of rejects can be after crushing sometimes used also as grog etc.

Table I

Grog Fired in Shaft Kiln

fabrication process	equipment	moisture content / % /	electric power consumption kWh/t	specific heat consumption kJ/kg /1/ firing kJ/kgH_2O /2/ drying
crushing and disintegration	clay shredder	12-15	1-1.5	-
drying of clay	drying drum	7-8	1-1.5	3600-4600
grinding of clay	dry pan	7-8	2-2.5	-
drying and grinding of clay +	shaft mill, pulveriser	7-8	23-25	3300-4200
moistening of clay	pug mill	16-21	1 - 2	-
extrusion of the column and cutting into clots	auger + cutter	16-21	2.5	-
drying	dryer	1-2	8-10	3200-3500
firing	shaft kiln	-	12-20	3200-3800
crushing	jaw or gyratory crusher	-	4	-
grinding	ball mill	-	3	-
	dry pan	-	4	-
screening	screens	-	0.5	-

+ in modern plants this process replaces all three preceding processes

Table II

Schistose Clays Fired in Rotary Kilns

fabrication process	equipment	moisture content %	electric power consumption kWh/t	specific heat consumption kJ/kg /1/ firing kJ/kgH_2O /2/ drying
crushing	different kinds of crushers	0.5-2	1.5-4	-
firing	rotary kiln	-	11-15	4000-4800
grinding	roller mill	-	1.5-2.5	-
screening	screens	-	0.5	-

Table III

Manufacture of Fireclay Bricks by means of the Stiff - mud Process

fabrication process	equipment	moisture content %	electric power consumption kWh/t	specific heat consumption kJ/kg /1/ firing kJ/kgH_2O /2/ drying
feeding	rotary table feeder, belt feeder	2-3	0.1	-
dry proportioning of grog and clay	mixer	2-3	1	-
wet mixing	pug mill, wet pan	16-21	1-2	-
extrusion and cutting of the column	auger + cutter	16-21	3-4	-
repressing	re-press mechine	16-21	1-2	-
drying	tunnel drier	1-2	10-12	3500-4200
firing	periodic kiln	-	12-15	4800-7000
	tunnel kiln	-	15-25	2400-4700

Table IV

Manufacture of Fireclay Bricks by means of Semidry Pressing Method

fabrication process	equipment	moisture content %	electric power consumption kWh/t	specific heat consumption kJ/kg /1/ firing kJ/kgH_2O /2/ drying
feeding	different kinds of feeders	2-3	0.1	-
dry mixing	dry pan +	8-9	5-8	-
pressure forming	different kinds of presses	8-9	6-12	-
drying	tunnel drier	1-2	10-12	3500-4200
firing	periodic kiln	-	12-15	4800-7000
	tunnel kiln	-	15-25	2400-4700

\+ in some cases /if sufficent plasticity of clays is guaranteed/ even light - weight mullers can be used so that the consumption of energy is reduced to 1.5 - 2 kWh/t.

Table V

Manufacture of Wall Tiles

fabrication process	equipment	moisture content %	electric power consumption kWh/t	specific heat consumption kJ/kg /1/ firing kJ/kgH_2O /2/ drying
body preperation with filter pressing	ball mill, filter press, drying drum, dry pen	38-42	55	3300-4600
body preparation spray drier	ball mill, spray drier	38-42	95	3300-4600
press forming	different kindsof presses	6-8	70	-
drying	tunnel drier	2	15	3500
biscue firing	tunnel kiln with big cross section	-	25-30	4050-4200
sizing +	sizing machines	-	30-35	-
glazing	glazing machines-1 kg of glaze per 1m^2	1	30	-
glost firing	tunnel furnaces of small cross section	-	20-35	4800-5200 ++
inspection		-	1-1.5	-

\+ in case of siliceous - caleareous body the process is unnecessary

++ average consumption of heat energy in electric furnaces amounts to 0.5 - 0.6 kWh/kg

Table VI

Manufacture of Unglazed Floor Tiles

fabrication process	equipment	moisture content %	electric power consumption kWh/t	specific heat consumption kJ/kg firing /1/ kJ/kgH_2O drying /2/
body preparation	bell mill, spray drier	38-42	120-150	3500-4700
press forming	different kinds of presses	6-8	80	-
drying	tunnel drier	2	20	3500
firing	tunnel kiln with big cross section	-	35	7900-8500
inspection		-	1-1.5	-

Table VII

Manufacture of Household China

fabrication process	equipment	moisture content %	electric power consumption kWh/t	specific heat consumption kJ/kg firing /1/ kJ/kgH_2O drying /2/
body preparation	blunger, ball mill, filter press, deairing auger		130-140	-
jiggering	jiggering tools and aut. jiggering equipment	23-26	35-40	-
casting	casting equipment	30-34	20-25	-
drying	different types of driers	2	20	3000-3400
bisque firing	tunnel kiln	-	70-80	7500
glazing	glazing equipment	1	35	-
glost firing	tunnel kiln	-	35-40	21000
inspection		-	5	-

The average consumption of plaster molds amounts to 5 % wt. related to the weight offinal products in case of jiggering and 10 % wt. in case of casting. The average endurance of seggars is as follous :

fireclay - 4 firings
SiC - 70 firings
cordierit - 15 firings

Table VIII

Manufacture of Red Bricks by the Soft - mud Process

fabrication process	equipment	moisture content %	electric power consumption kWh/t	specific heat consumption kJ/kg /1/ firing kJ/kgH_2O /2/ drying
crushing and desintegration	feeders, roll crushers roller mills, pen mills	12-15	10-15	-
moistening	pug mill	20-22	0.5	-
forming	auger	20-22	3-5	-
drying	different kinds of driers	2	1-2	4000-7500
firing	round kilns tunnel kilns	-	1-5	900-1200

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Lecture
on

Energy and Material flows in the Manufacture of Selected Ceramic Products - red brics, refractories, structure ceramics and fine ceramics.

by J. Müller