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PRODUCTION TECHNOLOGY

WINNING, PREPARATION AND SHAPING OF CLAY [1]

by

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SUMMARY

The origin and composition of clays for brick and tile manufacture is treated in a general way, common impurities identified and ways in which they may be removed, or their effects treated, described. No attempt is made to deal with specific raw materials since even within the African Continent there is a wide range available. The way in which different types of raw material affect the process, and the appropriate plant for these, is, however, described. Consideration is given to production control procedures for raw materials and the quality control tests necessary.

The factors affecting the method of winning are outlined and the methods and equipment available described and their characteristics discussed. The important factors in deciding upon a method of haulage are listed and then various methods indicated.

The section on clay preparation is subdivided into primary and secondary preparation and also into dry methods and plastic preparation. The important topic of storage, both bulk storage, weathering and blending of raw materials and intermediate storage and souring of prepared clay is considered as is the problem of blending clays and additives.

Shaping is considered under the headings of the five basic processes which, in order of decreasing moisture content are, hand-made; soft mud; extrusion; stiff plastic; and semi-dry pressed. Roofing tile manufacture is also described.

Monetary cost data are not suitable for comparisons between different countries, but the basic unit of a man-hour is used to compare processes. Labour figures are given for various operations of winning and haulage and for simple and more complex clay preparation and shaping methods.

Finally some suggestions are made for the first stages in the mechanisation of the processes of winning and haulage and clay preparation and shaping which may be suitable for application in developing countries.

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WINNING, PREPARATION AND SHAPING OF CLAY

by H.W.H.WEST

INTRODUCTION

This paper deals with that part of the brick and roofing tile manufacturing process up to and including the shaping of the green piece. It is based on experience in developed countries, but an attempt is made to indicate areas of special interest to developing nations. No attempt is made to deal with specific raw materials since even within the African Continent there is a wide range available. The way in which different types of raw material affect the process, and the appropriate plant for these is however described.

Monetary cost data are not suitable for comparisons between different countries, but the basic unit of a man-hour is used to compare processes. This does enable meaningful comparisons to be made between different countries, and the insertion of the local wage rate not only provides direct cost data but also gives a figure of capital worth spending on mechanised plant to replace a given amount of labour.

Developed countries have passed through an era of industrialisation and their brick industries have developed from craft workshops to complex brick factories. The plant and processes which have survived are the best and most economic. This experience may be helpful to those developing nations who have yet to establish a wide spread, efficient and profitable clay building materials industry.

2. RAW MATERIALS

2.1 Origin and Composition

The raw materials of the brick and roofing tile industries are usually buff or red-burning clays, heterogeneous in composition and often containing impurities of various kinds. In hand-winning it is possible to select the best clays for manufacture, or even different seams for different products, but in mechanised plants the material must be won as a whole, and it thus becomes important to ensure that the clay resources are satisfactory before a works is established.

Clays are sedimentary rocks formed by the breakdown of igneous rocks under the chemical and mechanical agencies of surface weathering and subterranean attack by chemically active solutions and gases. Primary clay deposits, for example, kaolin, are found in association with the original igneous rock, while secondary clays have been transported by the action of wind, water or ice. Brick and tile clays are usually secondary and their properties are determined by their geological history, especially the depositional environment.

The chief transporting agent is water which carries the finer particles in suspension and rolls the coarser ones along the stream bed thus providing a sorting effect. As the stream slows down progressively finer particles are deposited, until by the time it reaches the sea only the finest particles remain in suspension.

The movement of glaciers grinds away the rocks over which they pass, but besides a large quantity of fine material some bigger pieces are picked up so that the glacial clays deposited when the ice melts tend to be fine grained but to contain stones and some large rock fragments.

Clays laid down in water are consolidated by succeeding sediments, and may be turned into shales or even slates by earth movements. Secondary minerals, calcareous and ferruginous nodules may be formed and eventually uplift and denudation make the deposit available at or near the surface.

The purer clays, such as ball clays, may be uniformly fine grained, but brick clays have a range of particle sizes from quartz grains several millimetres in diameter to clay minerals of sub-micron size. The very fine particles impart plasticity. Although the size fraction less than two microns is referred to as "clay" it contains, besides clay minerals, fine particles of the constitutents found in coarser sizes, notably silica flour and micas.

The chemical composition of clay is a combination of the compositions of its constituent minerals. Typical examples of British heavy clays are shown in Table 1.

In all heavy clay deposits variation is to be expected both laterally and vertically. The nature and proportion of the clay mineral affect the properties of the clay markedly as do subsidiary constituents the more important of which are:-

Iron oxides: haematite, limonite, goethite, magnetite
Carbonates: calcite, dolomite, siderite
Sulphates: gypsum, barytes
Sulphides: marcasite, pyrites, chalcopyrites
Carbonaceous material: coal, lignite, etc.

All these subsidiary constituents may be deleterious if present in sufficient quantity or size.

2.2 Common impurities and their treatment

The raw material for bricks must be inexpensive, commonly less than 5/- per ton delivered into the works, so that although constant quality is desirable beneficiation to remove impurities is not economic. Indeed the most effective beneficiation is not to win contaminated areas or to strip and discard unsuitable material.

The commonest contaminant is sand, occurring as massive sandstone layers which have to be removed by blasting, or as alternating bands or pockets of loose sand. Some proportion of sand added to very plastic clay improves the drying and firing characteristics but too much makes shaping difficult and reduces the strength of the fired product. Often the layers of sand and clay

Table 1

Chemical analyses of different types of clay (After Keeling (1))

	1 Coal Measure Fireclay	2 Coal Measure Shale	3 Etruria Marl (Non-calcareous)	4 Etruria Marl (Calcareous)	5 Keuper Marl (Illitic)	6 Keuper Marl (Sepiolitic)	7 Oxford Clay	8 Weald Clay	9 London Clay
SiO_2	64.5	53.69	58.12	51.39	42.74	55.85	43.96	54.98	57.13
TiO_2	1.2	0.20	1.35	1.27	0.95	0.54	0.30	1.01	1.08
Al_2O_3	20.6	20.50	22.40	23.10	16.32	10.26	17.51	18.43	17.18
Fe_2O_3	2.8	Fe_2O_3 6.95 FeO 0.86	7.55	10.02	6.55	3.83	Fe_2O_3 2.76 FeS_2 2.60	10.37	7.98
CaO	0.7	0.30	0.40	2.00	9.46	5.66	8.14	2.66	2.41
MgO	0.8	2.41	1.28	0.96	6.23	11.30	1.59	0.91	2.82
K_2O	1.7	2.73	1.65	1.79	3.57	3.01	2.66	3.25	3.27
Na_2O	0.1	0.62	0.14	0.10	0.83	0.19	0.72	0.46	0.27
Li_2O	n.d.	n.d.	n.d.	n.d.	n.d.	0.03	n.d.	n.d.	n.d.
SO_3	0.3	0.37	n.d.	n.d.	n.d.	n.d.	1.30	n.d.	n.d.
Loss	7.3	11.14	7.40	9.09	13.58	9.62	18.46	7.71	8.00
CO_2 from carbonate	1.0	n.d.	0.1	1.3	n.d.	3.9	5.92	n.d.	2.1

n.d. = not determined

occur in roughly the right proportions and are won together, but for adequate quality control of the product they should be won separately and recombined in the correct predetermined amounts.

Pebbles occur in glacial clays, where some are so large as to cause damage to the plant if not removed. When ground up the pebbles act as a diluent so that a large proportion reduces the plasticity in the same way as sand, while if not properly broken down trouble may arise in drying and firing due to localised differential thermal expansion and contraction.

"Lime" includes all forms of calcium carbonate, limestone, chalk, calcite nodules and crystals and fossils, as well as the mixed carbonates dolomite and ankerite. During firing the carbonate breaks down and the calcium oxide formed may cause "lime blowing" in work. Finely divided lime is a flux and may cause the ware to slump out of shape during firing. It may also modify the fired colour and is added to make yellow bricks.

Siderite (iron carbonate) occurs in clay ironstone bands and concretions and in ironstone nodules. It may lead to "blows" like calcite or give iron spots on the face like pyrites. In work, the ferrous residue left after firing is soluble in acid rain water and may cause brown stains on the brickwork especially the mortar joints.

Calcium sulphate occurs as varieties of gypsum and anhydrite. It breaks down at high temperatures, but any residual sulphate can give rise to efflorescence or mortar decay due to reaction with the tricalcium aluminate in cement.

The iron sulphides, pyrites and marcasite, are the most common, but copper, lead and zinc sulphides may also be found. Pyrites is oxidised during firing to form sulphurous oxides which react with the clay to form the soluble sodium, potassium, magnesium and calcium sulphates which give rise to efflorescence in work. Pyrites may also cause bloating during firing.

Sodium and potassium chlorides and nitrates arise in many countries through the use of fertilisers, but also occur in quantity in the soil of certain countries, and can give rise to efflorescence.

Carbon occurs as roots in recent surface clays, as beds of peat, as lignite and coal both disseminated and in seams, and finely dispersed throughout the material as in carbonaceous shales and oil shales. Its presence is often helpful as a fuel but difficulty arises when it varies in quality and quantity. When present in large amounts the rate of firing must be reduced to allow it to be completely oxidised. Where appearance is unimportant the black cored or bloated product which results from faster firing may be acceptable.

The removal of unwanted material presents considerable problems. When clays are won in a relatively dry condition stones, roots etc. may be picked out by hand as the material passes by on a conveyor, but wet clay tends to coat these impurities so that they are less readily seen. Stone-separating rolls may be used, however, or pugs with a perforated barrel section, in which the clay extrudes through the holes while the stones and roots remain behind.

In wash-mills brick earth is mixed with a large quantity of water and slowly stirred to make a thin slurry, which is pumped out through a grid, fine enough to retain any stones or roots. The slurry is allowed to settle and dry out in pits before being rewon as a soft mud suitable for hand-making.

When mechanical digging methods are used tramp iron is inevitable. The discarded bolts or digger teeth may be picked out by hand or removed by a magnetic head pulley on the conveyor, an overhead magnet over the conveyor or a magnetic chute.

While large impurities can be removed by the methods described small pieces will get through and reliance must be placed on fine grinding to distribute them evenly throughout the mix. Even finely ground lime may cause blowing and common salt (sodium chloride) additions are sometimes made to cope with this. Soluble sulphates in any case remain and may be treated by the addition of barium carbonate. This only removes the sulphates present in the raw clay and has no effect on those subsequently produced in firing by the reaction of sulphur gases with the clay. The most effective way of minimising soluble salts in the finished product is to fire to as high a temperature as the clay will allow.

2.3 Production characteristics of clays

The characteristics of clays which affect the production technology employed may be graded according to their place in the geological column. Table 2 shows the technologies usually employed for each of the different strata in U.K.

Table 2

GEOLOGICAL COLUMN IN U.K.

GEOLOGICAL AGE	TYPE OF RAW MATERIAL	Age of base of formation (million years)	Usual method of brick manufacture	Type of Roofing Tile	Usual method of Tile Production		
RECENT	Alluvium Brick earth		H.M. S.M. W.C.	Single-lap	H.M. P.E. or S.E.	Moisture Content	HARDNESS
PLEISTOCENE	Glacial Clays	1					
PLIOCENE and MIOCENE		25					
OLIGOCENE and EOCENE	London Clay Reading Beds	60	W.C. H.M.	Plain	H.M. P.E.		
CRETACEOUS	Gault Weald Clay	120	W.C. W.C.S.P.	Plain	H.M. P.E.		
JURASSIC	Oxford Clay	145	S.D.P.				
TRIASSIC	Keuper Marl	170	W.C.	Plain	H.M. P.E.		
PERMIAN		210					
CARBONIFEROUS	Etruria Marl Coal measure shales and fireclays	280	S.P. S.D.P. S.P.	Plain	Roller bat		
DEVONIAN	Shales	325	S.P.				
SILURIAN	Shales	350	S.D.P.				
ORDOVICIAN	Shales	410					
CAMBRIAN		500					

Key:-

H.M. - Hand Made
S.M. - Soft mud
W.C. - Wire cut
S.P. - Stiff plastic
S.D.P. - Semi-dry pressed

P.E. - Tiles made by pug extrusion
S.E. - Tiles made by [illegible] extrusion

While this table refers to U.K. the relationship between age and hardness and moisture content are general as are their effects on the production technology used.

The old indurated rocks are hard and brittle, often won by blasting, and because of their massive nature positive winning equipment is necessary, usually face shovels. Heavy primary crushing equipment, jaw crushers or cubing rolls, is necessary to break the large lumps down. They may contain layers of massive sandstone and very hard impurities, siliceous, calcareous, or ferriferous bands and nodules. Ore minerals such as pyrites may be found or veins of quartz, felspar, gypsum or calcite. The clays of the Carboniferous period may contain variable amounts of carbon which give rise to difficulties in firing.

Except in the weathered zone where very plastic clays may be found, it is difficult to develop plasticity in the older clays which are generally prepared by dry grinding. In Great Britain this is true of all clays up to the Trias. Keuper Marl is usually prepared in a wet pan, Oxford Clay is dry ground for the important Fletton process, while Weald Clay may be either wet or dry ground. The more recent clays are all prepared in wet pans except in special cases.

The plastic clays are won by dragline or multibucket excavator. Kibbling rolls are sometimes used to reduce the size of the primary feed, but it is possible to have a preparation sequence which consists only of smooth rolls. Pebbles may have to be removed, and sand added as a diluent to the more plastic clays. The high moisture content and high plasticity may give rise to cracking during drying, but on the other hand some fine grained alluvial clays may be very siliceous and lack plasticity.

Although the nature of the raw material determines the technology to be used some processes are more flexible than others. The wirecut process provides the most flexibility. Dry ground hard shales or plastic clays prepared in a wet pan may be used as raw material and there is a whole spectrum of variants of the process between low output, low horsepower, unde-aired soft extrusion on the one hand and high output, high horsepower, de-aired stiff extrusion on the other. The process is suitable for common, facing and engineering bricks, both solid and perforated, for hollow blocks and for roofing tiles. The other processes are inherently more suitable for specific products, and while perforated or cellular bricks may be produced by the stiff plastic and semi-dry pressed processes, in general solid bricks are made.

The success of any process depends upon suitable raw material, but in brick manufacture it is essential to choose not only the type of product to match the market and the potential of the clay, but also to choose the appropriate machinery to treat that clay at every stage of the process from winning to firing.

2.4 Production control of raw materials

In a craft situation production control hardly exists since all products which are reasonably sound are sold and variations in quality are expected by the user and reflected in the price. There may, however, be some intuitive quality control of the raw material in the sense that the maker tends to choose those parts of the deposit which yield clays that provide him with the working properties he wants. By this he usually understands both manipulative properties which enhance output and appropriate ceramic properties which yield a sound product. In factory production on the other hand constant raw material is desirable and in modern, highly mechanised plants it is essential.

The purpose of production control of raw materials is to ensure a regular flow of clay with properties as nearly constant as it is possible to make them within the economic realities of the works. The process starts with selection in the pit to avoid or remove impurities. To reduce variation, the whole face may be taken in one cut as with a multi-bucket excavator or, less effectively, with a dragline. Face shovels may be used to mix heaps of different clays at the face or put set quantities of each into each truck load. Bulk blending of up to 50,000 tons of material in large storage heaps is common in U.S.A. Such a store provides a reserve against interruptions in the supply from the pit.

Weathering has traditionally been regarded as a means of improving clays. Certainly the harder clays and shales are broken down, especially under the action of frost, and some improvement in plasticity results. Rain tends to wash out some of the soluble salts, but more sulphate may be formed by the oxidation of pyrites. The impervious nature of clay prevents weathering effects from penetrating very far so that only the outer layers will receive the full benefit. However, each layer can be wetted as the heap is made and mixing takes place since the clays are laid down horizontally and re-won vertically. Weathering involves double handling and may add up to 2.75 man hours per ton.

The even more expensive process of souring pits or sump-houses is extensively used on the Continent of Europe. The clay is usually partially prepared by primary crushing or shredding at least, but often it goes through a wet pan and high speed rolls, and is then spread across a deep pit. When the pit is full, and after an interval which varies from days to months according to the views of management, the clay is rewon and undergoes further preparation before it is shaped. This souring process is claimed to even out the moisture distribution. Certainly each clay particle has the opportunity of becoming thoroughly wetted by the water slowly percolating through from its surface.

This process has been adapted in England to hard shales. Materials from six pits are brought to a central primary crushing plant where they pass through crushing rolls and are then laid down in a large sump-house. The material passing down the conveyor is automatically sampled from time to time and analyses carried out for carbon and sulphur. By this means variation in the raw materials is detected and adjustments made by altering the proportions of material from the various pits. The sump-house is in two halves so that while one half is being laid down the other is being re-won.

Some form of stockpiling is inevitable if control is to be achieved over the raw material. Equally some form of testing is necessary. The type of test to be carried out depends upon the critical property to be tested. In carboniferous shales this is usually carbon, and a simple loss on ignition test at 1000°C may be sufficient. Similarly where lime or soluble salts are the problem, analyses for carbonate and sulphate respectively will be done. Rarely is a full chemical analysis necessary or informative as a routine procedure.

Where plastic clays and sand are won together the residue on a 200 mesh sieve may be adequate to indicate changes in the proportion of the diluent. In other cases a complete particle size analysis may provide a useful control procedure.

Because the nature and proportion of the clay mineral present affect so markedly the properties of the raw material, a particularly useful test is IL/MA(2). This is the ratio of the Ignition Loss at 1000°C adjusted for loss due to carbon, carbonates and certain hydrates to the Moisture Adsorption of the clay in 24 hours under a relative humidity of 75% at a temperature of 25°C. The ratio is characteristic of the clay mineral and is 7 for well ordered kaolinites, 2-3 for disordered kaolinites, and about 1 for illites. The MA for pure clay minerals is known and the ratio of the MA of the sample to the MA of the clay mineral indicates the proportion of clay mineral present.

It is common experience that with some clays, while the general level of waste is satisfactory, on occasions it may rise to very high proportions. Changes have occurred in the composition of the clay and while this may not show up in chemical or mineralogical tests it can usually be detected by the Empirical Drying Test(3). In this discs of clay are subjected to known drying conditions, and as the conditions are varied the incidence of cracking is noted thus giving a ranking order of ease of drying of different clays. By this means seams which give the catastrophic cracking may be detected and eliminated.

Not all these tests will be done on all works, but as the production process becomes more mechanised and the consequences of breakdown, waste, or deterioration in the quality of the finished product more serious, so more attention must be paid to selection, blending, storage and the routine quality control testing of raw materials.

3. WINNING AND HAULAGE

3.1 Factors affecting the method of winning

The most important factors to be considered are:-

Nature of the deposit.

Depth to be worked.

Contour of the surface.

Output required.

Amount of blending and selection required.

Type of existing or proposed haulage system.

Capital available.

Maintenance facilities and supply of spares.

The nature and amount of overburden is important. It varies from loose sand to massive rocks and there is a limit to the depth which can be removed economically. The most economic method of removal is by tractors and scrapers on contract, cleaning sufficient for the next year's working in a short space of time. Hand-winning is not limited by the nature of the clay, but in mechanical systems the hardness, moisture content, and the distribution of unwanted materials are important.

In considering the depth to be worked attention has to be paid not only to the thickness of usable clay but also the area available and the cost of winning. Thus in thick deposits a single lift is often taken in the early years of the plant life and the lower depths are won by the more expensive method of benching at a later date. Deep faces can be won in a single lift by dragline or by blasting and loading from pit bottom. The depth of the water table affects the method of working, and although draglines and multibuckets operate under water this is not desirable since large variations in moisture content of the clay will result.

The contours of the surface determine the way in which the deposit will be developed. If possible it should be worked so that water drains away from the face since wet bottoms add to the cost of bottom working. Top working may be impracticable on steep slopes.

The equipment should always have excess capacity in order to ensure sufficient down-time for maintenance and to allow working time to clear slips and keep the pit tidy and efficient.

The amount of blending and selection required may be more than is economically feasible and some compromise may have to be reached. In thin seams intercalated with unwanted material stripping from the top by hand or by skimmer or horizontally-operated bucket excavator is the only practicable way. In thicker seams tractors and scrapers or bulldozers may be used to alternately win and discard but at least twelve inches of good material must be left to avoid contamination. The amount of blending required determines the number and kind of machines. Blending may be accomplished by winning the whole face roughly mixed, or by separate winning of different seams and mixing together in heaps. Alternatively each haulage wagon may be loaded with appropriate proportions of different materials. Several faces may be opened up to provide different materials for a blend and on large works a number of separate pits may be mixed together to minimise day to day variations.

The type of existing or proposed haulage system must marry with the winning and loading system. Thus the width of a face conveyor should be appropriate to the amount of material falling from the bucket of a multi-bucket excavator, and the tub, dumper or lorry should take an integer number of digger bucket loads. At low outputs or in seasonal yards where the making facilities are moved around as the clay is used up, a front end loader may be used to both dig and deliver into the preparation unit, but in general the most efficient utilisation of a digger is in digging not in moving to load or transport.

The capital available depends upon the national as well as the local economic situation. In developed countries labour is expensive and much effort is spent improving productivity by mechanisation. Based on recovering the investment in three years from the wages saved, it is now worth spending £3,000 to replace one man in Great Britain. While hand winning provides better selection and control of the raw material, it may take 2 man hours per ton against 0.2 man hours per ton for mechanical winning. A works producing only 50 tons per day would generate over £33,000 in saved labour over three years by mechanising. In developing countries it is capital which is scarce and labour plentiful so that hand winning or rudimentary machine winning may be expected to persist.

Maintenance facilities and supply of spares are assured in industrialised countries but this may not be so in developing areas especially where the machines are imported. An adequate supply of wearing parts must therefore be ordered with the machine and the stocks maintained. Since trained fitters may be scarce and the operators inexperienced, winning equipment should be simple, sturdy and easy to maintain.

3.2 Methods and equipment for winning

Plastic clays are readily won by hand; pneumatic shovels increase productivity. Hard materials may also be worked by hand when pneumatic picks assist. Often the face is benched in three foot steps working down from the top and throwing the material down until it forms a heap at the base. This method allows seams to be won separately and deep faces to be worked. Blasting may also be used for hard material or in deep quarries and the fallen material sorted, broken up and loaded by hand.

For plastic clays or friable shales multi-bucket excavators and shale planers produce a continuous supply of small chips of clay taken from the whole depth of face thus achieving good mixing. They can only be used, however, where there is no unwanted material in the mixture.

The multi-bucket excavator has a jib on which run two endless chains supporting a series of buckets with sharp leading edges which shave off the clay. The jib may be elevated or depressed up to 45^o to work from the base up or the top down. The strata should either be horizontal or run down the strike so that variation from one end of the face to the other is minimised, and since the machine runs on rails which are costly to move over, the face should be as long as practicable. A good solid base is essential for the rails so that there are advantages in working from the top of the pit which is easier to drain. Machines are available in a wide range of outputs from 5 yd^3/hour to 50yd^3/ hour.

In the shale planer the clay is dug by knives carried on an endless chain and either falls into buckets or onto a conveyor belt below. The machine operates with the jib nearly vertical rotating through an arc to make a circular cut in the face. The machine moves on tracks to make successive cuts and can be selective in winning a small part of the face so that it is less necessary to work near horizontal strata.

Fig. 1 Face shovels and draglines (Fig. 1)are the most extensively used excavators in the heavy clay industries. The configuration of rigid boom and arm in the face shovel allows pressure to be applied to the bucket in digging. This positive action allows the machine to deal with most materials. It is readily used for mixing and stockpiling clays, and the bucket can be used as a sledge hammer to break up big lumps. The configuration of the dragline allows the bucket to be thrown increasing the working radius. They are best worked from the top of the pit and provide some mixing of the seams as the bucket is dragged up the face. They are unsuitable for very hard materials.

Fig. 1 The third machine shown in Fig. 1 is the skimmer which has a fixed horizontal jib along which runs a bucket to take a shallow cut. It is useful for selective winning layer by layer but has a limited output.

Bulldozers are used for the removal of overburden but are less suitable for winning since unless they are fitted with special shovel blades, they can only load by puashing over the end of a ramp. Fitted with rippers they can be used to break up hard rock at the top of a face which can then be pushed down into the pit to weather and be rewon.

Tractors and scrapers are usually employed for a short time on contract to win large areas of relatively soft material. If the scraper operates over a slope extending the full height of usable clay a uniform mixture of the different seams may be obtained and pockets of impurities can be removed by hand. The machine wins and loads simultaneously and is best used to transport a year's supply of clay to a weathering heap close to the works whence it can be re-won by front end loader.

3.3 Methods of haulage

The important factors in deciding upon a method of haulage are:-

The type of raw material and method of winning.

Length of haul.

Output required.

Nature of the ground, gradients and pit bottom.

Capital and labour costs.

Haulage systems may be fixed or free ranging. Fixed systems transport material along fixed lines by continuous flow on conveyors or as unit loads in tub haulage or aerial ropeways. Free-ranging systems comprise units with their own motive power capable of travelling in any direction over a suitable surface. They include hand-barrows, animal transport, lorries, dumpers, bulldozers and tractors and scrapers.

In hand-winning tubs are usually hand-trammed from the different work places to a central turntable where the tubs are clipped onto the main haulage system. Tubs vary in size from 5 cwt to over 1 ton, but on level track are usually one half ton capacity or more. A down gradient should be provided if possible from the working face.

Hand-tramming was first replaced by horse-drawn tubs and then by a diesel or petrol locomotive as prime mover. When the layout is good, locos are economical for longer hauls (more than 220 yards) on level or nearly level surfaces.

Rope haulage includes single and continuous rope or chain haulage. Large tubs (1 yd^3) are usually bottom emptying or side tipping while smaller ones are overturned in a cage-tippler. Single rope systems operate intermittently by hauling in one tub or more on the end of a rope. The tubs return under gravity. The method can be used only over a straight course and is usually used over steep gradients, for example the gantry up into the works. A single captive tub has been used on almost vertical gradients from deep pits adjacent to the works.

In continuous haulage systems an overhead rope or chain may be used with the tubs fixed to it by V-notches and knocked clear by elevating the rope, or, especially on long hauls, the tubs may be held by friction chips to a rope beneath the axles and freed by knocking off manually or automatically. The system can operate long and short hauls over irregular ground following winding routes and can be made quite efficient on straight hauls where the labour costs are independent of distance. If the route is not reasonably straight, however, transfer points are necessary and each has to be manned.

Aerial ropeways have a high initial cost but low running cost making them suitable for long hauls and high outputs. The loading terminus is not easily moved so a secondary haulage system must be provided from the face, but this can be the aerial ropeway tubs themselves carried on rail trolleys.

Conveyors are expensive to instal but require no labour for running except clearing spillage and the considerable labour required to move the face conveyor forward periodically. The belts should be troughed and wide enough to take the fluctuations in load expected. Feeding arrangements should minimise damage due to hard abrasive materials; hoppers should be provided for even feeding from excavators.

Free ranging systems are mobile, flexible and can operate at relatively high speeds. They are readily extended to meet the increased haulage distance due to recession of the face or to increase output. Since unit loads are delivered intermittently hoppers and feeders are needed to receive them at the plant and may also be needed at the loading point.

In industrialised communities hand-barrows are not economic, but in developing countries porterage with baskets is extensively used. It is completely flexible and may be useful in some circumstances though pack and draft animals may provide a more efficient form of haulage.

Front-end loaders and traxcavators have a capacity up to about 1¼ yd^3. Although primarily loaders, they may be employed for transport over very short distances. Front-end loaders are fitted with pneumatic types and extensively used within the plant for feeding pans from stockpiles and from weathering heaps close to the works. Traxcavators have tracks and thus can operate under difficult bottom conditions in the pit.

While the provision of good roads extends the life of dumpers and permits higher operating speeds they can operate over wet or rough ground and over steep gradients. They are an economic and reliable means of transport increasingly used both in the pit and works. They are of sturdy construction suitable for direct loading by excavator and available in a wide range of sizes. The maximum economic haulage distance is about one mile for a six-cubic yard dumper, less for smaller sizes. Because of their fast turn round time the labour requirement is very low. For small outputs the digger operator may also drive the dumper. Large dumper trucks of the Euclid type are extensively used for clay haulage both in the pit and on main roads. The most economical haulage unit over long distances is, however, the conventional tipper lorry, but this requires a reasonable road surface on which to operate.

4. CLAY PREPARATION

Clay preparation is the essential sequence of processes needed to bring raw clay into a form suitable for the making process. Fine-grained clays, won in the plastic state, need very little grinding and tempering, and traditionally after the addition of water, only kneading by treading with humans or animals is carried out. With more difficult clays a combination of processes is required starting with sorting, blending and weathering; crushing and dry grinding and screening; tempering the mix by the addition of water and souring or ageing the moist dust or plastic clay; fine grinding of the plastic material in high speed rolls, steam tempering and even repugging and multiple de-airing. The variety of method indicates the range of properties of clay that have to be accommodated, but the object of each process is to minimise the original variations in the clay so that the product reaching the making machine has a uniform clay content, constant size-grading analysis and a constant and correct moisture content for the process used. The better and more uniform the quality of the product required, the greater must be the control exercised, either manually or automatically, over the various stages of the clay preparation. It is possible to make indifferent ware from adequately prepared clay; it is not possible to make good ware from inadequately prepared clay.

4.1 Storage of raw materials and primary treatment

Sufficient storage capacity should be provided to ensure constant feed to the plant. If there are likely to be extensive breakdowns in the pit or hold ups due to bad weather then bulk storage must be provided at the works. Otherwise it is sufficient to provide a buffer store to smooth out intermittent deliveries, and this may be no more than a large box feeder or hopper feeding the grinding plant.

Traditionally the costs of production fall into three roughly equal parts:- Winning, making and drying; firing; overheads. Actual cost exercises in U.K. have shown that winning and haulage may amount to 7% of the total, exceptionally up to 10%. A breakdown in the pit which leads to a stoppage of the making plant therefore means that one tenth of the production facilities is directly affecting one third. The importance of intermediate storage is apparent, and whether the works is large or small the continued supply of good clay is vital to effective production.

Primary crushers are used to break down hard clay lumps into approximately three inch cubes or less. This smaller material may be more readily fed and proportioned and higher efficiency is achieved in the secondary grinding process. Jaw crushers and gyratory crushers may be used for friable clays showing no tendency to pack between the jaws, and single roll crushers with an oscillating breaker plate and roll, toothed to suit the material, perform a similar function. Swing hammer mills break up the clay by impact. The most widely used crushers are double-roll. The rolls may be smooth but usually have bars, projections, corrugations, or teeth on their surface. Such rolls are frequently called "kibblers", "bar-kibblers" etc., but strictly speaking kibbling rolls have two sets of interspaced toothed rollers (Fig. 2). Rolls with projections used for breaking down slab-like lumps into small cubes are properly called "cubing rolls" (Fig. 3). Fig. 2 Fig. 3

Plastic clays may be cut up by corrugated rolls or shredded. The clay shredder produces pieces of clay 1/32 inch to ½ inch thick and is especially useful for blending different clays.

4.2 Dry grinding and screening

Dry grinding is normally used for clays up to about 12% moisture content. There are a variety of types of secondary grinders, including secondary hammer mills with a screen in the base to keep material above a certain size in the system; disintegrators, which are a form of high-speed, double-roller mill; and impact mills of various kinds, including attritors for very fine grinding used in conjunction with an air separator which, when hot air is used, give a dried classified product. The most important and widely used machine, however, is the dry pan.

Within the rotating pan are set two large diameter heavy rollers (mullers), which grind on renewable dead plates of wear-resisting metal. The rotation of the pan throws the crushed material towards the circumference thereby passing over an area of perforated grids. The diameter of the holes (typically ¼ inch) determines the size of particles leaving the pan while the oversize is fed back under the mullers by scrapers.

The output is determined by the speed of rotation of the pan and at high speeds (30 revs/min. or more) screening on the grids is less effective. This
Fig. 4 has led to inclined grids (Fig. 4) that slow the material down as it passes over and rim discharge pans. The latter have solid bottoms and a gap at the periphery adjustable to vary the fineness of grinding, often about ¼ inch, so that much oversize gets through and there is a high recirculating load, perhaps 50%.

In grinding and screening the efficiency of one process affects the other. F
Too much coarse material passed through worn grids in the pan overloads the screen, and ineffective screening results in fines being returned to the pan for unnecessary further grinding. The oversize from the screen is usually returned to the same pan though where there are several pans one may be reserved to grind all the oversize or it may be put through an impact mill or even rod- or ball-mill to produce a very fine product.

The most common size of screen in the heavy clay industry is British Standard No. 7 mesh (with an opening of 0.0949 inch or 2.4 mm). For stronger and finer textured products No. 14 mesh (0.0474 inch or 1.2 mm opening) may be used but rarely much finer. The simplest form of screen is a perforated steel plate. These need no maintenance beyond replacement when the holes wear and may be effective if the angle is properly adjusted, though there is a tendency for a proportion of fines to be carried along with the oversize.

Piano wire screens have high tensile steel wires stretched taut the length of the frame and set apart to give the opening required. There are no cross wires so oversized pieces can wedge the wires apart and allow coarse particles to pass through. The wires in any case eventually break so that frequent inspection is necessary. Wedge wire screens are more robust and profiled to allow a particle entering the space between two wires to fall clear.

Rotary screens consist of a rotating cylinder of wire mesh, often in different combinations of sizes, into one end of which clay is fed, the fines drop through and the oversize is discharged at the other end. It is a dusty and ineffective process with less than 25% of the screen area in use.

More and more mechanically or electrically vibrated screens are coming into use. The woven wire mesh provides a positive barrier to oversize particles, and electrical heating of the mesh prevents blinding by moist clays. They require no cleaning, only occasional inspection and replacement of the screen cloth when worn.

4.3 Plastic preparation and storage

Fig. 5 The most effective machine for plastic preparation is the wet pan (Fig. 5). It consists of a fixed gridded base around which the mullers rotate forcing the clay through the grids while the scrapers continually turn the material in towards the centre and hence achieve good mixing. An area of dead plates is usual at the point where the feed enters, and more dead plates may be provided if some true grinding is to be accomplished. The holes in the grids are typically 4 inches to 8 inches long and ¾ inch to 1 inch wide and the size is chosen to suit the degree of preparation required. Water is usually added at the wet pan and other additions may be made there, for example barium carbonate or body stain.

Fig. 6 A collecting dish (Fig. 6) beneath the wet pan provides some further mixing and enables the clay to be fed to a single point onto a conveyor. It is usual to follow a wet pan with a series of rolls to reduce the size of the coarse particles which inevitably pass through the grids. Where lime particles occur in the clay this is essential to minimise lime blowing. On old plants two or more pairs of medium speed rolls may be found with the gap between the rolls of each set smaller than the preceding one and the speed correspondingly faster to maintain the output. On modern plants one set of high speed differential rolls is usually sufficient. The rolls are set tight up. The speed of the faster roll is usually 130 to 250 rev/min and that of the slower 115 to 225 rev/min but some very high speed rolls (up to 1000 rpm) are now in use.

Just as hoppers are used to even out fluctuations in the feed of dry ground clay, so intermediate storage is useful for plastic clay. Indeed it is essential to maintain a constant rate of feed to the pug since otherwise the output will vary widely. On the continent of Europe souring towers or "Maukturm" are frequently used. These are large steel or concrete towers capable of holding 24 hours supply of clay. The material is fed in at the top and as it passes down the tower the weight of the superimposed material conditions the clay. Steam tempering is sometimes used at the top of the tower so that the material is stored hot and is still warm when delivered at the base. Discharge is by a sturdy worm feeder in the slowly rotating base.

Minor variations in feed may be overcome by a double shafted mixer before the pug, but a better means of hopperage is the circular screen feeder which has a perforated bottom section through which the material is extruded onto a rotating collecting disc and ploughed off to the pug. This performs an additional preparative function in extruding the spaghetti-like pieces of clay. A similar machine but without the perforated section is the rotary plastic feeder (Fig. 7). In both cases momentary fluctuations in the output of the wet pan cause the level of clay in the cylinder to rise or fall, but

Fig. 7

the output from the basal orifices is fixed and adjustable by means of gates.

Steam may also be added at a double shafted mixer before the pug. The purpose is partly to raise the moisture content to the desired value, but mainly to raise the temperature to about 80°C. This leads to improved extrusion characteristics with some clays and it can thus be regarded as a form of preparation. It is used extensively in France and Italy for hollow block production especially where the products pass immediately into a rapid dryer where they may be dried in two hours but more usually three to five hours. The products are often cracked, though this is not important in those countries where the blocks are to be hidden by rendering, but the chief disadvantage seems to be that, with certain clays at least, a lower strength is obtained in the fired product.

4.4 Blending of clays and additives

The blending of two or more plastic clays or clay with non-plastic diluents such as sand, grog or combustible matter is best carried out in
ig. 8 a proportioning box feeder. (Fig. 8). This consists of several separate compartments into which the different materials are placed and the proportions of each determined by the height of the orifice left at the bottom of the adjustable vertical gate between each compartment. The box feeder also functions as a hopper to provide an even primary feed for raw material received intermittently, or as a secondary feeder of partly prepared material to the pan etc.

Dry ground clay and diluents are stored in hoppers and blended by recombining the outputs of the hoppers onto a conveyor belt by means of synchronous feeders. Depending upon the degree of control required this feed may be by volume through a gate or by weight-proportioning devices. For small quantities of material volume proportioning is inadequate, and barium carbonate and body stains should be added by weight. Manganese dioxide is now supplied as a suspension in water which can be metered through a pump.

After blending the clays have to be thoroughly mixed, and while a wet pan with some dead plates provides the most effective mixing, the most widely Fig. 9 used mixer in the heavy clay industry is the double shafted mixer (Fig. 9). The shafts are contra rotating so that the knives cut and mix the clay and pass it forward. By choosing the length of the mixer and adjusting the pitch of the knives, or reversing some, the amount of mixing can be varied. Dry ground clay can be mixed and tempered by adding water at the entry end or by passing steam through pipes in the base of the trough.

Batch production is rare in modern brick and tile factories but may be used in some smaller works. A tempering pan, which is solid bottomed, is a most effective mixer since the components are put into the pan with water and the pan run for whatever period is considered necessary, when the mixed batch is shovelled out. An alternative is a pan mixer, designed for mixing concrete, which consists of a rotating pan with a set of knives rotating on an axis offset from the centre of the pan. This has a bottom opening discharge gate.

5. SHAPING

5.1 Hand making

This is the universal process changed in essence little in 4000 years. The clay is dug in shallow surface pits and may be kneaded and treaded with water and use immediately, left to sour for a few days, covered with mats and allowed to dry out to the right consistency, or even dug in the autumn and allowed to weather over the winter. The mould tables are set up near the pit and the bricks demoulded onto the ground to dry in the sun. In Europe the bricks are built several courses into hacks when part dry and such hacks are covered with a light roof as protection from rain. In the tropics, of course, no such protection is needed and the bricks may be used dry without firing. When the bricks are dry they are built into a clamp on an adjacent site, or perhaps fired in a simple kiln, for example a Bulls trench kiln. The customers collect the bricks in their own transport.

Such simple processing still exists not only in developing countries but also, though more rarely now, in developed ones. Larger works however win the clay year round mechanically, process it through a wet pan and deliver it as clots to the makers tables through a Lintott machine or an Aberson mixer. The process may be further mechanised so that all the maker does is to throw a prepared clot into an already machine sanded multiple mould.

In developing countries the hand-made process may be expected to remain the characteristic one for a network of small village workshops growing up wherever there is a need for a permanent building material.

5.2 Soft mud process

This process replaces the hand moulder by a machine, but that apart the method of clay preparation, drying and firing may be identical. The Berry machine (Fig. 10) extrudes clay into a multiple mould producing 4 or 6 bricks. ig. 10 The filled mould is pushed forward by the next empty one behind and the surplus clay struck off. The mould is jolted to loosen the bricks and then inverted over individual thin wooden pallets which enable each brick to be handled separately. The four mould Berry machine has a rated output of 1400 bricks per hour. Three machines make a viable and efficient works.

The Lancaster Autobrick Machine demoulds onto pallets and places them into dryer cars automatically, returning empty pallets to the machine. The Abersen and De Boer machines have outputs from 5000 to 15000 bricks per hour, and can also be completely automatic when used in conjunction with a pallet ascender and chamber dryers. Similar racks can be erected in the open air enabling large scale production to be carried out with natural drying. This is a process that might find favour in tropical developing countries.

5.3 Extrusion

Extrusion is the process of forcing plastic clay through a die to form a shaped column which is cut by wires spaced at intervals to give the desired size of product. This gives it its alternative name "wirecut". It is used to process a wide variety of clays of greatly different moisture contents to make all the products of the heavy clay industries, solid and perforated bricks, hollow blocks, roofing tiles, floor quarries, land drains and sewer pipes.

In its simplest form the material may be hand-won, put through a wet pan and extruder to produce bricks at 20 to 25% moisture content set onto a hot floor to dry. At the other extreme are the highly mechanised modern plants producing stiff-extruded de-aired bricks at 15% moisture content set directly on tunnel kiln cars. In between are a whole range of processes of different complexity but all employing an extrusion machine.

There are three forms of extruder, the stupid which is a piston extruder and hence essentially intermittent in operation; expression rolls; and, now the only important machine, the screw extruder usually referred to as an auger or pug. Modern de-airing pugs (Fig. 11) shred the clay in the first section and allow it to fall through a vacuum chamber which removes much of the air before consolidating it in the lower barrel. The machine shown has an output of 8-12000 bricks/hour and employs 100 h.p. on the mixer-pug-sealer and 150 h.p. on the main extrusion shaft, but up to 650 h.p. in all may be used on some machines to give outputs of 30,000 bricks/hour. The effect of de-airing is to increase the plasticity of the clay and to produce a denser green brick which gives a fired product of higher strength and lower water absorption than an unde-aired brick made from the same clay. Fig. 11

Many types of simple cutter are available for soft columns, but for stiff de-aired columns a very robust cutter is needed and the most successful is the reel cutter (Fig. 12). Adjustment of the cutter wires allows different thicknesses of bricks or lengths of hollow block to be cut, and various patterns of tiles are readily produced by specialist cutters like the Frey. Fig. 12

The surfaces of the column may be textured to produce attractive facing bricks. Soft columns may be rusticated by a wire or steel plate but stiff columns need the more positive action of wire brushes, rotating blades or texturing cylinders. Coloured sands and strains may be applied to the surface, also engobes or glazes.

Extrusion is the chief process for making perforated bricks, and apart from a few pressed in the U.S.A., it is the only process for hollow block production. A hollow block or perforated brick die has a bridge piece fixed at the back from which protrude metal tines on the end of which are cores Fig. 13 shaped to match the hole required (Fig. 13). All dies need to be balanced to produce an acceptable column, but hollow block dies need more adjustment than solid brick dies.

The extrusion process is of great importance. It spans the whole range of technological development. It is used to produce low-strength common bricks by labour intensive methods and high-strength facing bricks in the most modern works. It is not suitable for all clays and the characteristics of the material must be considered. Alluvial clays for example may not be plastic enough to form a good. column though making excellent soft mud bricks. Faults can arise in the process, laminations in the extruded column, drying difficulties and firing problems especially with dense de-aired bricks. Nevertheless in the development of industrialised brick-making from a craft society it must be given consideration.

5.4 Stiff-plastic process

Fig. 14 The stiff-plastic machine (Fig. 14) combines extrusion and pressing. It is suitable for hard clay and shales prepared by dry grinding. The screened dust is tempered in a mixer and fed into the top of a vertical pug which extrudes into clot moulds on a rotating table. The clots are ejected from the moulds and fed forward into a press which shapes the brick accurately and impresses a frog or indentation top and bottom. Escape holes are provided in the bottom die plate to allow excess clay to be removed. A repress is sometimes fitted more accurately to shape the bricks. Stiff plastic bricks thus have charateristically sharp arrises and are dense and strong.

The bricks are set direct in the kiln without a separate drying process and there is thus an immediate saving in labour over the traditional soft extrusion process. The double press shown has an output of 2400 bricks/hour so that one press and a Hoffmann kiln provide a works with the nicely balanced output of 100,000/week. This is a convenient size for a local brickworks and there are many in the colliery shale areas of Great Britain. Modern works, however, are much larger and the stiff-plastic process is steadily being replaced by stiff extrusion.

5.5 Semi-dry press process

In all other processes water is added to temper the clay for making and expenditure is required to dry it out again. In the semi-dry press process, clays are dry ground and pressed at moisture contents between 6 and 10%, though the largest brick industry in the world, the British Fletton industry, presses clay at 20% moisture content. This latter process is most efficient and produces inexpensive common bricks of excellent quality. The most usual press is the crank or eccentric. One double press produces 1200 bricks/hour. A repress may also be fitted. There is also a rotary table press which gives outputs up to 2000/hour but is more costly. The process as a whole is most economical though as with all press operation expert maintenance is essential.

5.6 Roofing tiles

Tiles are traditionally made by hand from clots. The mould varies according to the type of tile to be made but for plain tiles is a simple metal frame of tile thickness placed on a flat block on the makers bench. The sanded clot is thrown into the sanded mould so as to fill it completely and struck off level with the top of the metal. The frame and tile are slid off the bench onto a pallet and the frame removed. The tile is flat with two lugs which are subsequently bent up to form nibs and nail holes put in with a hollow punch. Plain tiles are "cambered" either by drying on cambered drying racks or by placing them face up in bungs of ten on a cambered "horse" and striking the top of the bung with a cambered plate.

The labour of making may be reduced by extruding bats about the size of the tile which are finished by hand in a mould. Plain tiles may also be extruded with a continuous nib and sold as such or special cutters used to shape the nibs, put in the nail holes and even profile the ends to bearer tails and other shapes. Stupids may be used for extruding pantiles and shaping them on special cutting tables attached.

Pantiles and interlocking tiles are made by pressing extruded bats in plaster moulds. The process has been made completely automatic with the shaped tiles removed from the mould by vacuum pads and placed on pallets moved automatically to chamber dryers. Even so the economics of clay roofing tile production are difficult and output has fallen markedly in the developed countries.

The roller-bat process is essentially a stiff plastic process for making bats for plain tiles. Moist clay dust is compressed in the gap between two wheels constrained at the sides by two flanges on the bottom wheel. The continuous ribbon of clay of tile thickness is oiled, cut up into tile sized pieces and repressed, either immediately or after souring for two or three days.

Roofing tiles require better clay preparation than bricks, indeed better clay. Perhaps the most promising form of production for developing countries is the Spanish tile which can be extruded as an oval cylinder scored at the sides to break into two tiles after firing. Continuous nib plain tile production equally needs little mechanical resources while the production of single-lap tiles from repressed bats would be expected to follow the establishment of the simpler forms of manufacture.

6. LABOUR REQUIREMENTS

Since the relationship between the cost of labour and the cost of machinery varies from country to country actual cost figures obtained in developed countries are not very helpful in considering procedures to be adopted in countries with surplus labour. Indeed direct cost comparisons cannot even be made between two developed countries for example Great Britain and U.S.A. because the cost of living and hence wage rates are markedly different. The cost of capital is similarly not constant and it is more useful to compare the labour content of operations as man-hours per 1000 bricks. As a guide the weight of 1000 British Standard bricks (215 x 102.5 x 65 mm) may be taken as 3 tons and the weight of raw clay to produce this as 4 tons so the figures may be readily transposed into man-hours per ton.

To provide labour figures which may be applicable to developing countries the data given have been extracted from surveys carried out in U.K. in 1947(6) and 1951 (7) and do not represent the best possible performance, although for very large outputs they approach it.

6.1 Winning and Haulage

Table 3 gives representative figures for labour for overburden removal.

Table 3

Labour used for removal of overburden

Works	Method of removal	Depth of overburden ft.	Tonnage removed per week	Man-hrs per ton of fired products	Man-hrs per ton of overburden
I	Dragline and dumper	6–20	175	0.2	0.2
II	blasting, excavator and 2 lorries	20	293	0.3	0.6
III	Blasting and hand loading	19–44	133	1.0	1.2
IV	Hand	1	17	0.4	1.6
V	Hand	1	15	0.5	2.7

The highest figures per ton of overburden are for seasonal works where to keep labour they are employed on this in winter. The most economic method where practicable is by tractors and scrapers on contract.

Hand-winning often involves multiple handling, as when a face is benched for example, and the winning cost alone may be 0.8 to 0.9 man-hours per ton without loading. Blasting, including drilling and setting charges, is about 0.15 man-hours per ton, and sorting, breaking up large pieces and loading by hand add up to another 0.75 man-hours per ton. In all hand winning and haulage will amount to about 2 man-hours per ton except under very easy conditions as in small craft shops with the making area near to the shallow surface pit when hand-winning and wheeling may be about 1 man-hour per ton. For small outputs of roofing tiles (80 tons/week) where a weathering curf has to be made and redug, the cost of hand-winning and haulage is 3 man-hours per ton.

Multi-bucket excavators have a very low labour cost, 0.02 to 0.5 man-hours /ton depending upon the output and layout of the pit. It might be expected that the level of output would markedly affect the labour content and it has been shown(6) that an exponential curve can be drawn for excavator operations so that at 100,000 bricks/week output the labour is about 0.3 man-hours per ton while at one million per week it has fallen to 0.05 man hours per ton. Since draglines operate from the top, no cleaning up of the pit bottom is required so that the labour for draglines is considered to be only two thirds that of face shovels.

The smallest size of face shovel has an output sufficient for 180,000 bricks per week. Two men are required, one driver and one cleaning up. At higher outputs better productivity is achieved as Table 4 shows.(8)

Table 4

Effect of output on labour requirements for winning with face shovels. (Adapted from Lacey & Green ,(8))

Output per week		No. of men	M.h./1000	M.h./ton Fired product
Thousands of bricks	Tons of clay (approx)			
200- 350	800-1400	3	0.6 -0.34	0.2 -0.11
350- 600	1400-2400	4	0.46-0.27	0.15-0.09
600- 850	2400-3400	5	0.33-0.24	0.11-0.08
850-1100	3400-4400	6	0.28-0.22	0.09-0.07
1100-1500	4400-6000	7	0.26-0.19	0.09-0.06
1500-2000	6000-8000	8	0.21-0.16	0.07-0.05

The system of haulage employed and the output effects the labour requirements. In free-ranging systems one driver is normally provided for each unit. In fixed systems the labour depends on the complexity of the system.

TABLE 5

Possible Variations in Labour for Haulage(9)

Type of Works	Weekly Output	Haulage System, and Labour Required							
		Simple		With Junction		Complex System		Hand Haul	
		Labour	M.h./ 1,000	Labour	M.h./ 1,000	Labour	M.h./ 1,000	Labour	m 1
Wirecut	96,000	1	0.5	2	1.0	5	2.5	-	
Wirecut	192,000	1	0.25	2	0.5	8	2.0	8	
Stiff plastic	86,500	1	0.56	2	1.12	4	2.24	-	
Stiff plastic	156,000	1	0.31	2	0.62	5	1.53	-	
Semi-dry-press	96,000	1	0.5	2	1.0	4	2.0	-	
Semi-dry-press	192,000	1	0.25	2	0.5	8	2.0	8	

Note: Man-hour figures are based on the then prevailing 48 hr. working week.

Hand tramming is very labour intensive, 0.25 man hours per ton has been recorded for distances up to 40 yards. This increases roughly proportionately with distance so that it may be trebled at 120 yards. Horse-tramming takes about 0.5 man hours per ton over a distance of 300 yards. The labour requirements for hand-barrowing are even higher 0.5 to 0.9 man hours per ton as the distance increases from 50 to 100 yards. Examples of specific systems of different kinds are given in Table 6.(9)

TABLE 6

Labour Associated with Specific Haulage Systems (9)

Type of Haulage System	No. of Examples Taken	Range of Weekly Outputs	Labour in Man-h./1,000	
			Range	Mean
Hand Tramming	1	146,000	-	0.30
Hand Tramming and Single Rope	9	39,000-158,000	0.50-2.73	1.30
Hand Tramming and Continuous Rope	4	154,000-300,000	0.25-0.93	0.68
Hand Tramming and Aerial Ropeway	1	255,000	-	2.10
Horse and Single Rope	1	84,000	-	0.60
Loco. and Single Rope	3	76,000-205,000	0.42-1.6	0.83
Single Rope and Continuous Rope	1	148,000	-	2.27
Loco. and Continuous Rope	2	592,000-6,467,000	0.27-0.36	0.32
Belt and Continuous Rope	1	69,000	-	1.06
Continuous Rope	12	85,000-3,872,000	0.23-1.29	0.55
Belt Conveyor	2	87,000-102,000	0.55-1.10	0.83
Lorry	1	132,000	-	0.21
Dumper	1	138,000	-	0.43

The minimum labour requirements for mechanised excavators and appropriate haulage are likely to be as shown in Table 7 for various weekly outputs of bricks.

TABLE 7

Minimum labour requirements for winning and haulage in M.h./1000 bricks. (Adapted from Macey & Green)(8)

	Output per week thousands			
	100	200	500	2000
Winning	1.0	0.5	0.3	0.2
Haulage	0.5	0.25	0.2	0.2

6.2 Clay preparation and shaping

The labour associated with clay preparation may be very small. On modern well laid out works there need be none, but one man is often allowed as a supervisor in case of difficulty and to be responsible for inspecting and adjusting the plant. Since the plant may well have an output of 300, - 600,000 /week, the labour could be as low as 0.07 man hours per thousand or less than 0.02 man hours per ton.

At the other extreme, hand-making and wheeling and hacking enables each man to produce about 1000 bricks per day so that the making charge alone is 8 man-hours per thousand. The preparative element is included in the winning and haulage which may be 4 man hours per thousand.

The soft mud process using the Berry machine is relatively labour intensive. One temperer is required and 4 men on the machine giving a total of 5 men for an output of 50,000/week, that is 4 man hours per thousand. Using a Lancaster machine with automatic demoulding and loading of pallets into dryer cars and the much higher output of 300,000/week, only 6 men are required for preparation and making to give 0.8 man hours per thousand. Fully automatic Abersen plants are lower still, perhaps only one quarter of this.

The extrusion process provides for a wide variety of preparative operations and the labour content depends upon the nature of the raw materials as well as on the output. Thus one man may be provided at the primary crusher to bar down difficult materials or remove lumps of unwanted stone. Similarly one or more men may be provided to sort material on a picking belt. One pan man is usually provided whether the pan is wet or dry, and in the latter case on old works a man would be provided to clean and inspect the screen. In the dry process too a temperer will be provided before the pug and two men on the extruder itself, one on the bow wire cutting off clots and pushing them up to the brick cutting wires where the second man trips the cutter and throws back ends. One man may also be employed cleaning up. One man for each thousand per hour output will be provided for taking off. This task was usually combined with wheeling away to the dryers so that one man would pick up, wheel and set down 500 bricks per hour. The total labour involved for 100,000/week might therefore be 11 men for the wet pan process and 13 for the dry pan variant giving respectively 4.4 man-hours per thousand and 5.2 man-hours per thousand for preparation and making.

With plastic clays containing no contaminant used for making hollow blocks the labour could readily be reduced to one pan man, two on the extruder and two men taking off for the same output of 100,000 brick-equivalents or about 0.7 man-hours per ton.

For nearly similar outputs the stiff plastic and semi-dry press processes are compared in Table 8. One double stiff plastic press is assumed and three semi-dry presses.

TABLE 8

Labour for Stiff Plastic Manufacture (100,000/wk) and Semi-dry press process (120,000/wk)

	Stiff Plastic		Semi-dry press	
	Men	m.h./1000	Men	m.h./1000
Dry pan	1	0.4	1	0.3
Screen and dust floor	1	0.4	2	0.7
Tempering	1	0.4	-	-
Taking off presses	2	0.8	3	1.0
Cleaning up & press relief	1	0.4	2	0.7
Totals	6	2.4	8	2.7

Although the semi-dry press process appears from this to be more expensive in labour than the stiff-plastic process, it can in fact be made very efficient at high outputs.

The manufacture of roofing tiles is complicated by the large variety of special shapes made. For simple standard shapes, however, a comparison is given in Table 9 between plain tiles and single lap tiles, hand made and extruded. The machine made output is 250 tons per week, the hand made 80 tons/week.

TABLE 9

Labour for the manufacture of roofing tiles.

Process	Plain tiles				Single-lap tiles			
	Hand-made 80 tons/wk		Extruded 250 tons/wk		Hand-made 80 tons/wk		Extruded bats pressed 250 tons/wk	
	Men	m.h. per ton	Men	m.h. per ton	Men	m.h. per ton	Men	m.h. per ton
Wet Pan	1	0.5	1	0.2	1	0.5	1	0.2
Clot production	1	0.5	1	0.2	1	0.5	1	0.2
Souring	1	0.5	-	-	1	0.5	-	-
Barrowing clots to makers	1	0.5	-	-	1	0.5	-	-
Making	-	-	4	0.6	-	-	8	1.3
Hand-moulding and setting in racks	10	5.0	-	-	16	8.0	-	-
Cambering and chequering	-	-	6	1.0	-	-	-	-
Totals*	14	7.0	12	1.9	20	10.0	10	1.6

If these man-hour figures are multiplied by three to provide an approximate equivalent of the man-hours required to produce 1000 bricks it is 4.8 man-hours per thousand equivalent for the best process, thus emphasising the labour intensive nature of roofing-tile making.

Footnote: * In all the tables the man-hours are correct for the totals; the addition of individual items does not necessarily agree in the last place of decimals.

7. CONCLUSIONS AND RECOMMENDATIONS

This paper has described the processes of winning and haulage and clay preparation and shaping and given examples of the plant which is available to carry out these functions. The labour requirements given were taken from U.K. experience but collected at a time, twenty years ago, when mechanisation was limited. Modern works have a total productive labour requirement of less than 2 man-hours per thousand and there are works producing for less than 1 man-hour per thousand. Such works have high capital charges, however, and running costs and especially maintenance costs are clearly more than on less mechanised plants. A high standard of operative is needed, and current thinking is moving towards the idea of three shift operation 365 days per year in which the shift supervisor is a qualified maintenance engineer and the shift workers also essentially supervisors. In this way each shift is responsible not only for the running of the plant but also for its repair and maintenance during that time.

The problems with which this workshop has to deal, however, are quite different. While there may be a place for highly mechanised plants in capital cities, the general problem is the establishment and operation of clay building materials manufacturing plants in African countries where normally there is plentiful cheap labour and mechanical plant can neither be afforded nor maintained on a large and wide-spread scale. In the change over from a craft industry to a semi-mechanised one it is the small output low horse power machine which is of most interest and it is pertinent to consider how the first stages of mechanisation can be achieved in winning and haulage, and clay preparation and shaping.

The size of unit is different. A craft operation is typically 5-10 tons per day, that is 10,000 to 20,000 bricks per week. The standard sized unit in the great 19th century growth of industrialised brickworks in England was 100,000 bricks per week or 50 to 60 tons per day. At 5 tons per day hand winning and haulage will remain, although hand barrowing might well be replaced by tipping carts drawn by animal power.

Although stratified deposits may be worked, the characteristic raw material in developing countries is likely to be soils and alluvial clays. Indeed since habitation often tends to be distributed along the river banks, mud may be a universally available raw material. For winning these recent horizontally disposed beds an agricultural tractor adapted to take a loading-shovel would provide the first stage of mechanisation. It is a simple, robust tool, requiring the minimum of maintenance and care in handling, and can act not only as a digger but also as a prime mover to tow a tipping truck.

Two men working together can win load and wheel for 100 yards, 10 tons of clay a day. The tractor with even a one-half cubic yard shovel will load and transport the same distance 50-100 tons per day. This requires a driver and access to a mechanic for maintenance and repairs so that taking running and maintenance costs into account, the minimum total running costs may be equivalent to the wages of four men. Since four men would win and barrow 20 tons per day the tractor loading-shovel becomes attractive at outputs greater than this.

Fig. 15

The craft works will employ hand-kneading as the means of preparation. A simple form of mechanisation for the larger outputs of around 50 tons per day is the "sludge pan" or tempering tub (Fig. 15)(5). This is a shallow pan with a vertical pug attached to the base. The centre shaft carries four arms that mix the clay and water in the pan and direct it in towards the centre. In the vertical pug knives attached to the same shaft cut and knead the clay and force it down to the discharge point at the base. The material is suitable for hand moulding or for extrusion of bricks, blocks, and tiles.

In order to improve the quality of the product some raw materials may require more preparation than this, and certainly it is important to eliminate all stones and to reduce the size of any large lumps of hard clay. For this a pan and rolls are needed. In general it is to be expected that the minimum preparation machinery will be installed to ensure an homogeneous mix.

The method of making is also important. Good bricks can be made by the soft mud process, and the Berry machine with an output of about 50,000 bricks per week is suitable for small scale mechanisation. The extrusion process is more versatile. It enables solid and perforated bricks, hollow blocks and roofing tiles to be made and thus may be most suitable for a small works to make all these products in turn to meet the local market. Although the stiff plastic and semi-dry press processes have the merit of not requiring a drying process, and hence they can easily be made non-seasonal, the high degree of maintenance required to keep presses operating effectively probably rules out these processes at first at least.

The development of an industrialised society from an agrarian one requires the concomitant development of infrastructure, - electric power, trained operatives and trained fitters and electricians. Complex plants to produce high quality products from appropriate raw materials may be built in major cities and information has been given on the potentiality of different items of plant for this purpose. Nevertheless the first stages of the industrialisation of brickmaking described here may be found more useful in developing a net work of small plants to make products of adequate quality available on a widespread basis.

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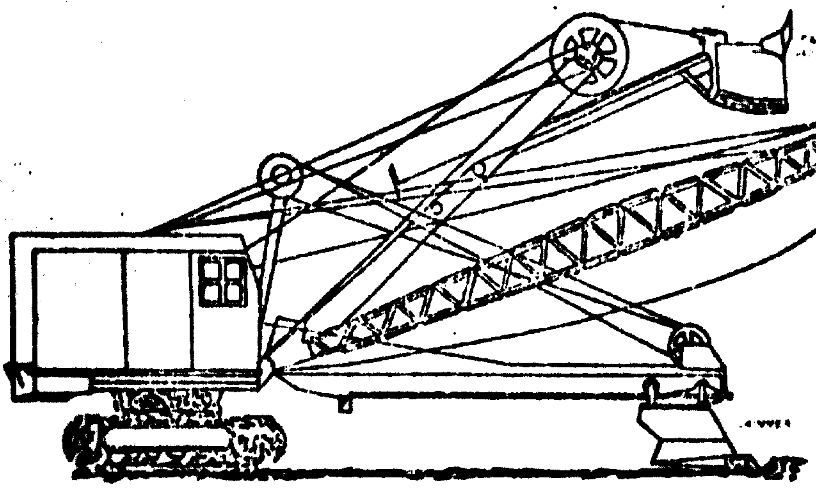


Figure 1 Composite drawing of some excavators [4]

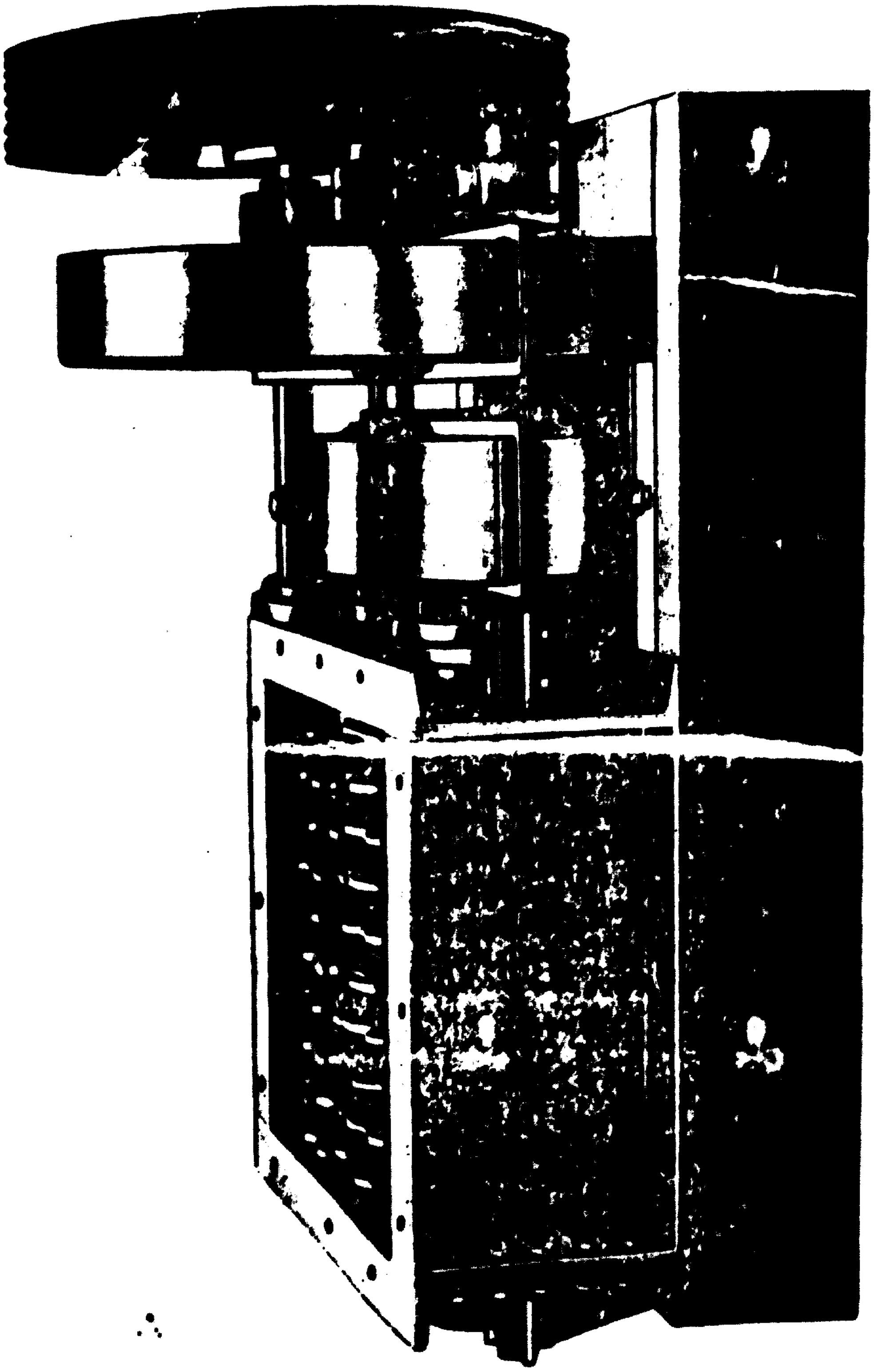
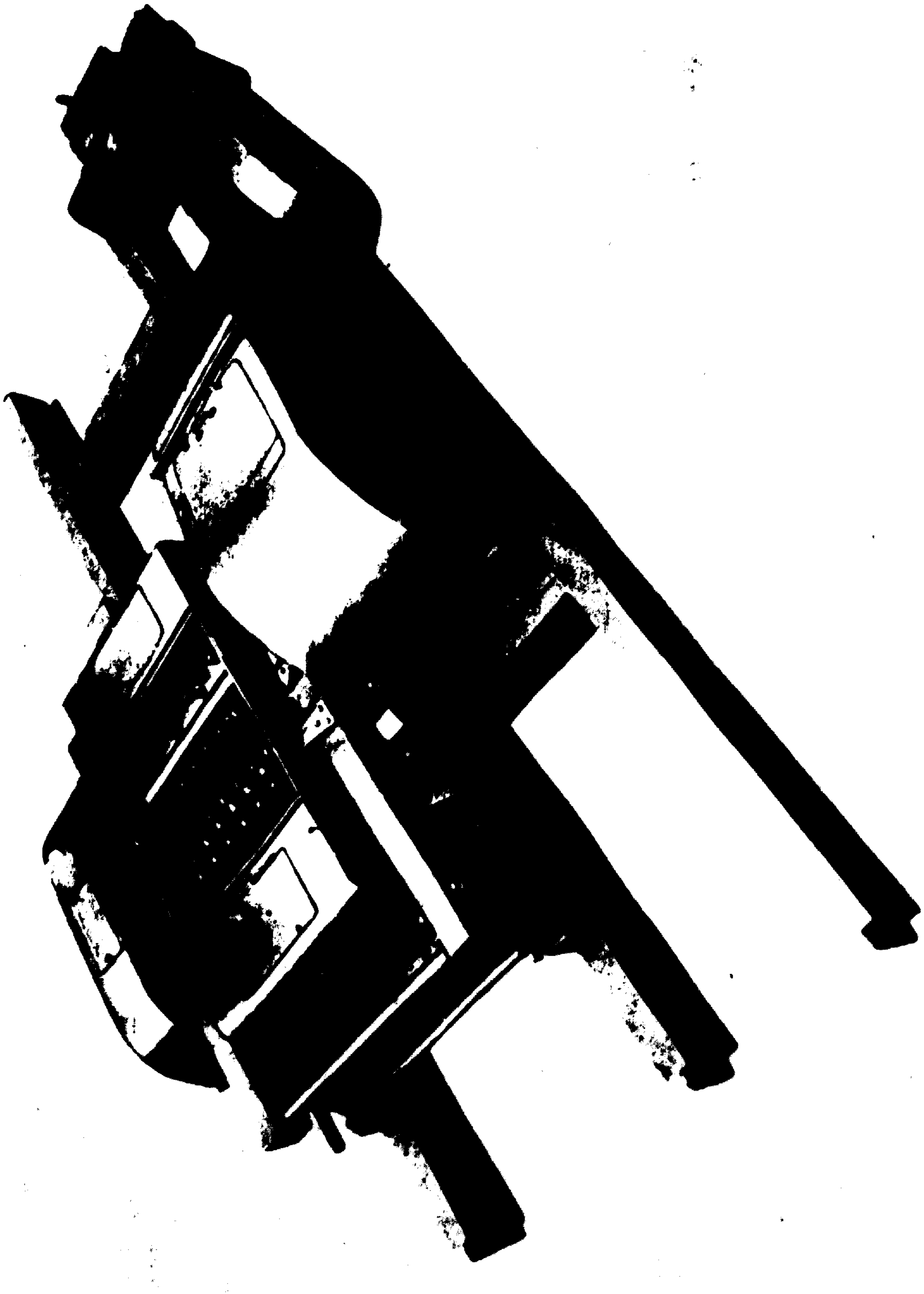


Fig. 2



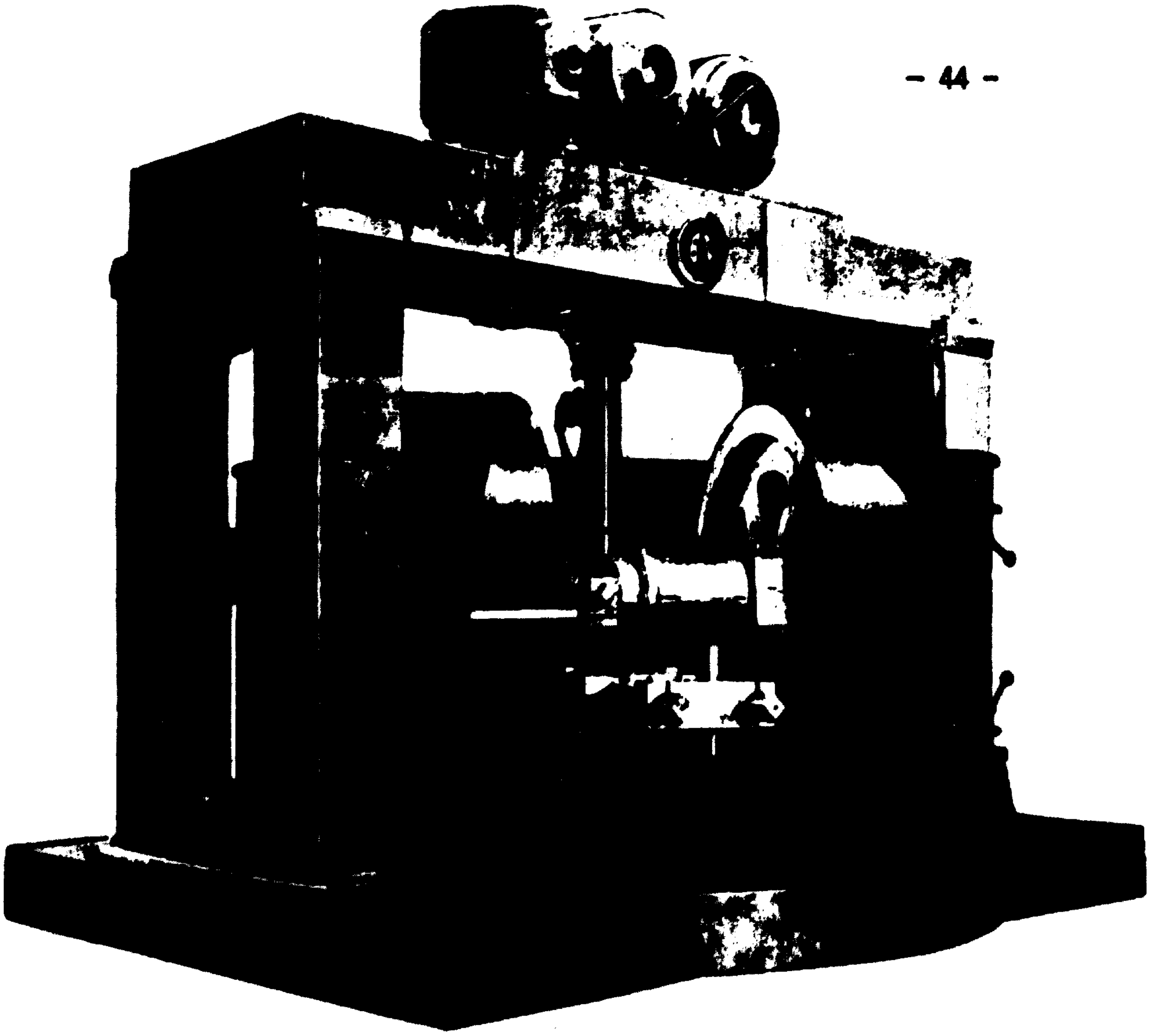


Fig. 5

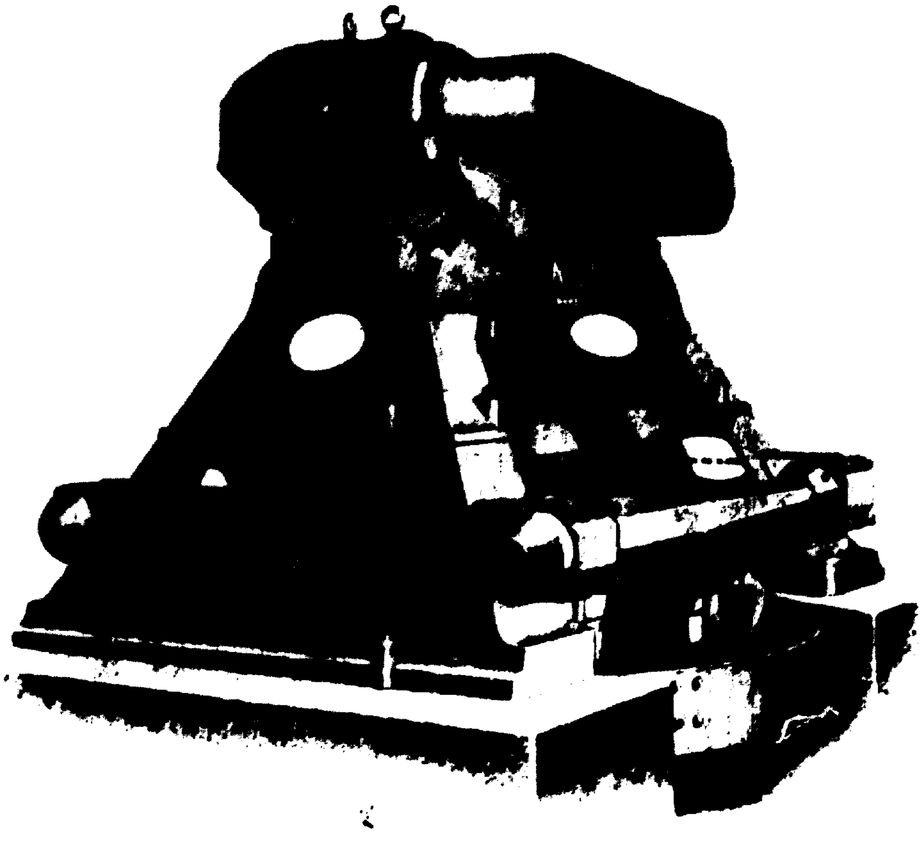


Fig. 4

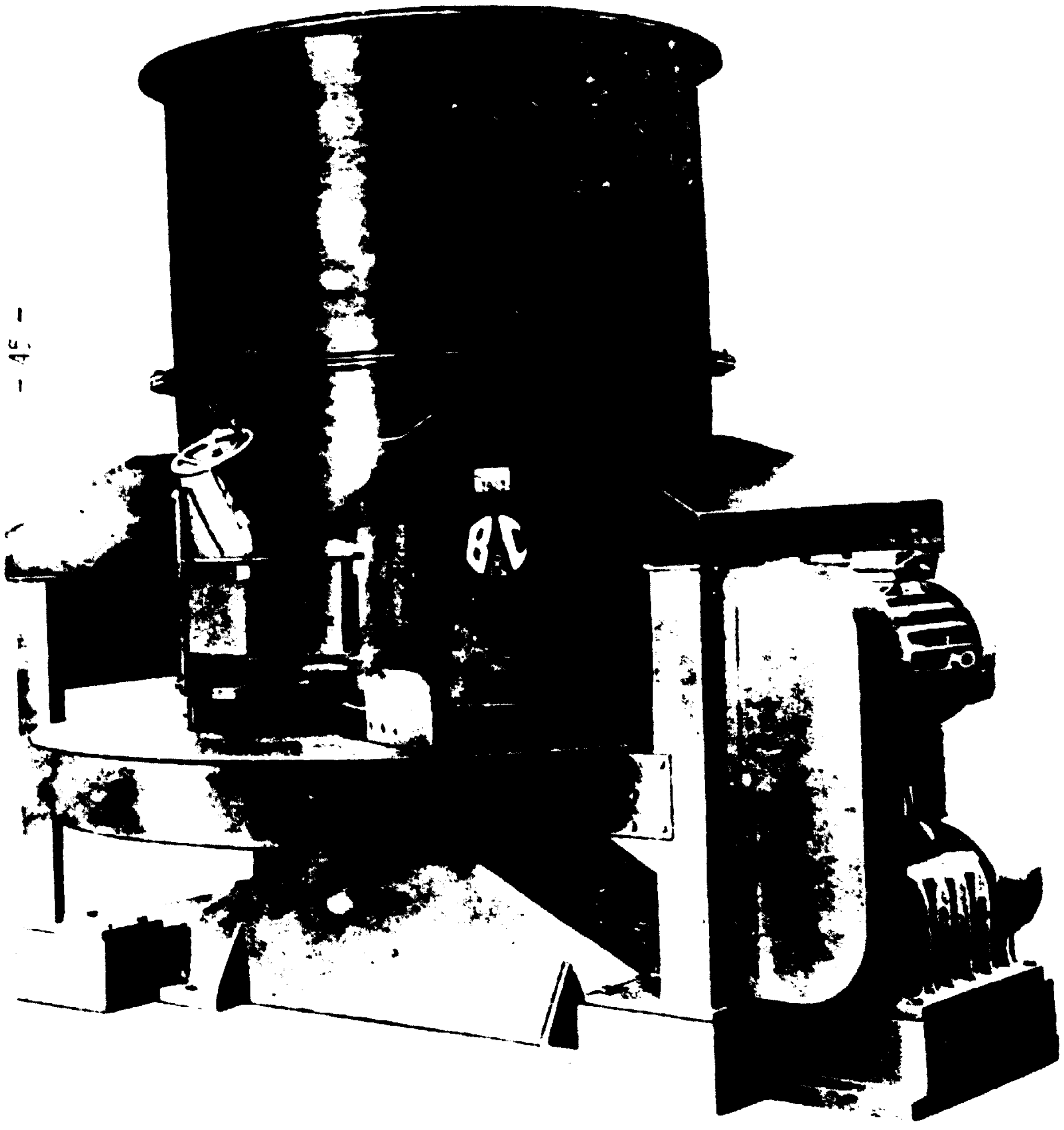


Fig. 7

Fig. 6

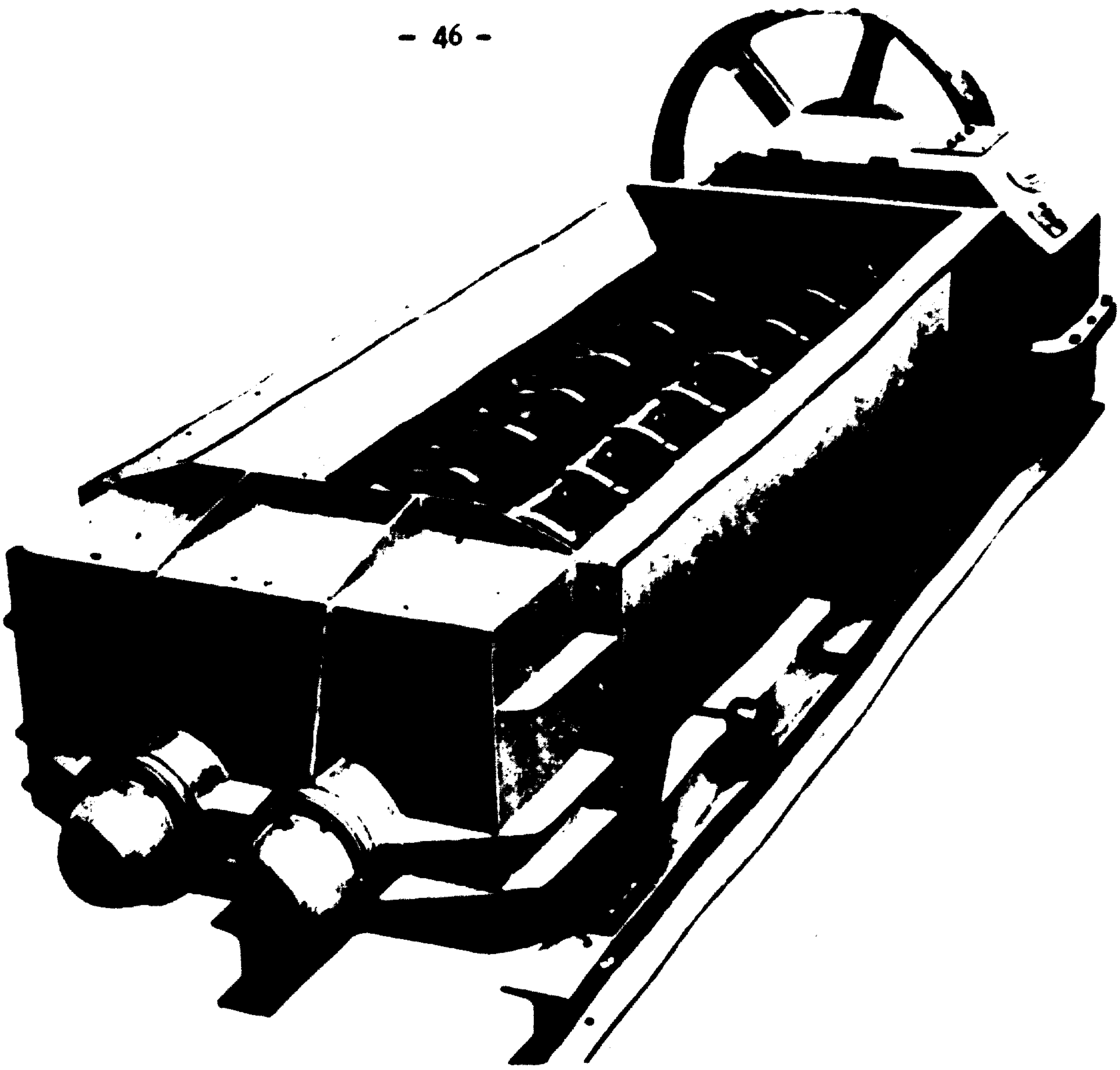


Fig. 9

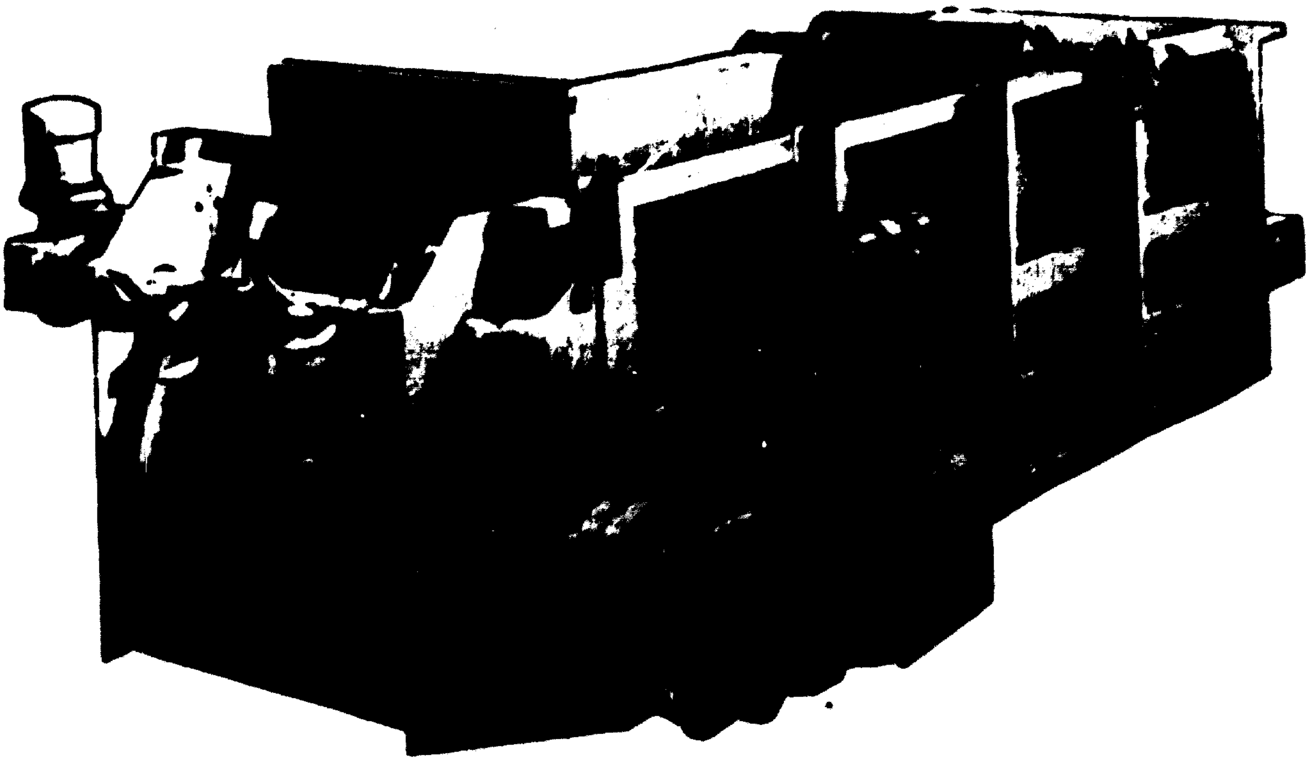


Fig. 8

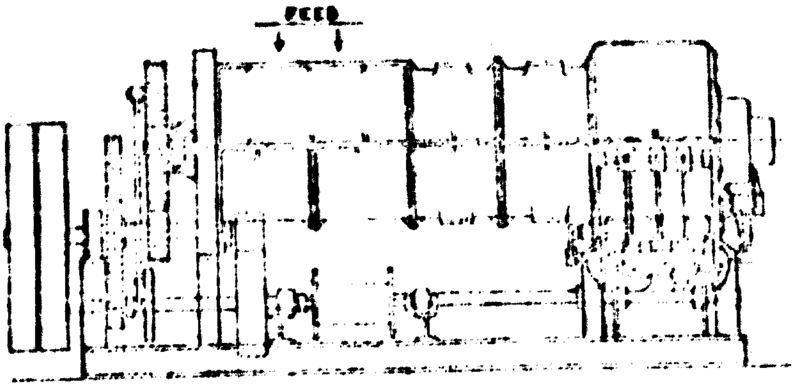


Figure 10 Berry machine [5]

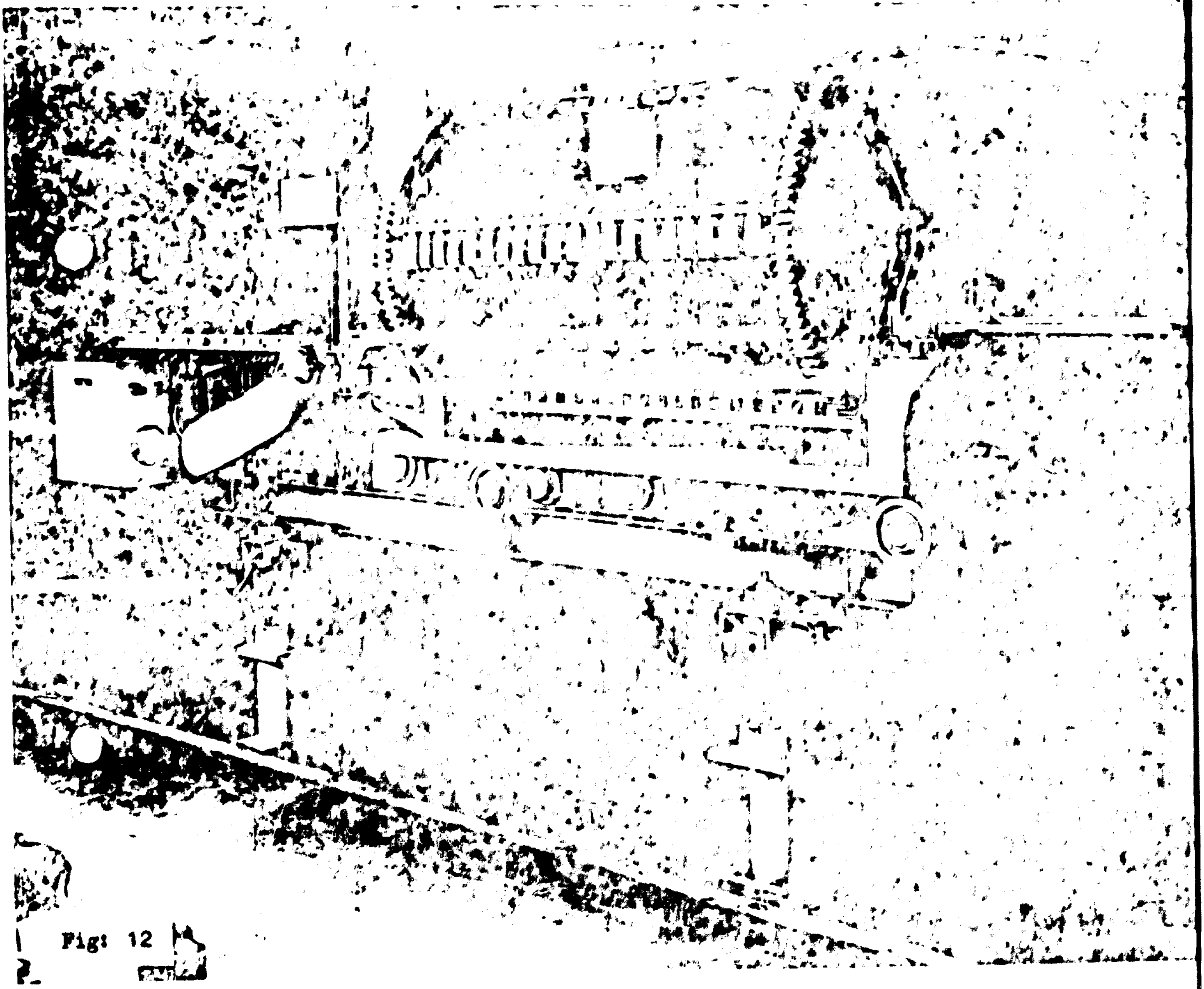


Fig: 12

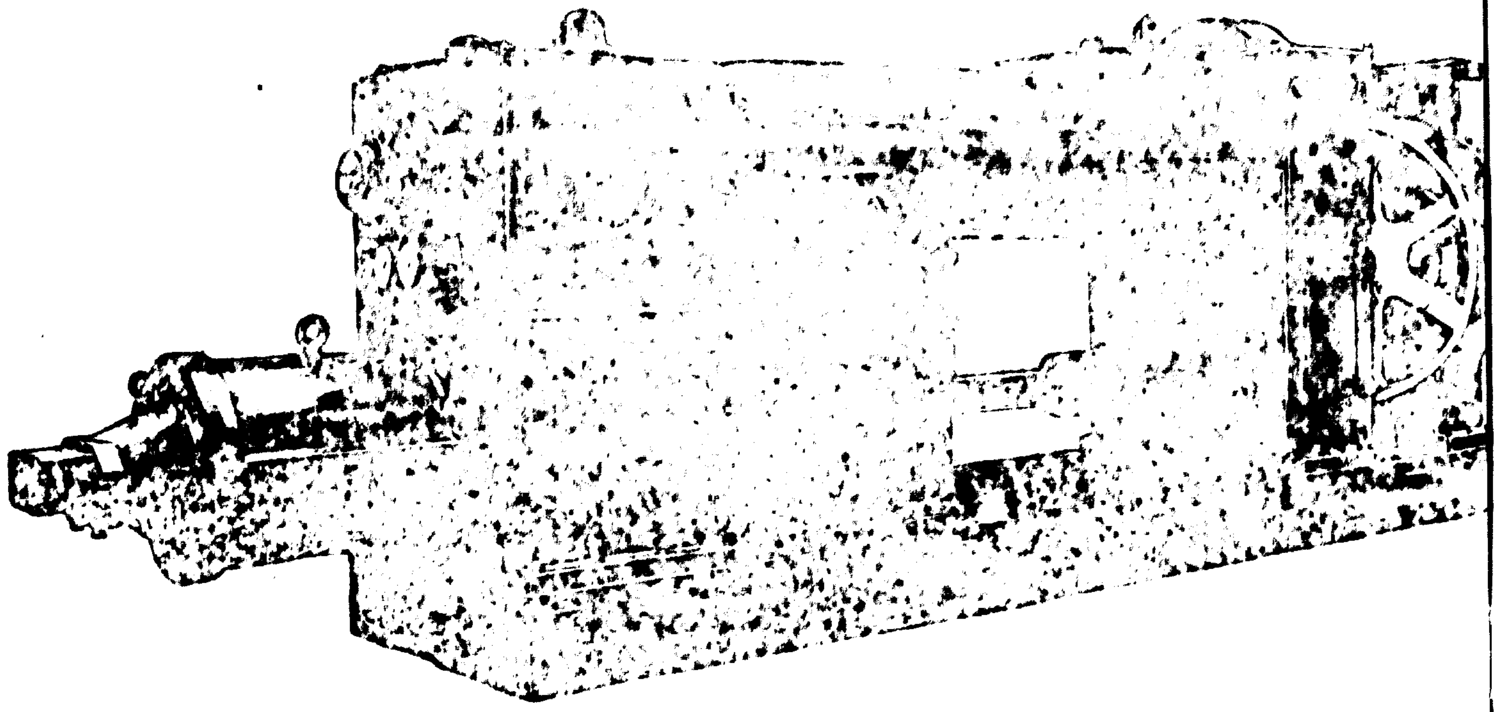


Fig. 11

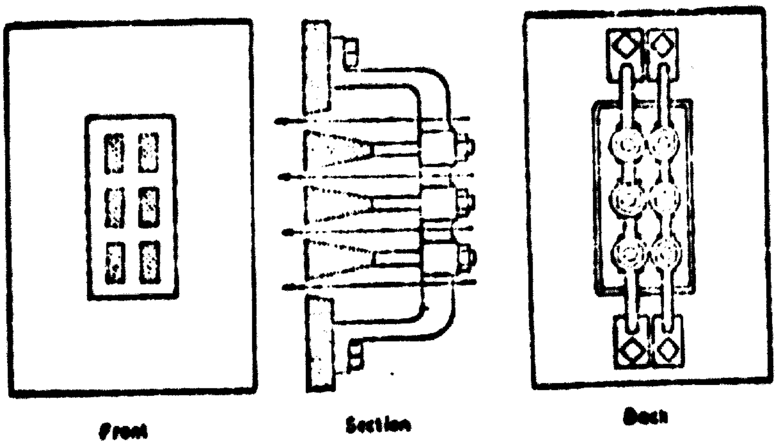


Figure 13 Hollow block die [4]

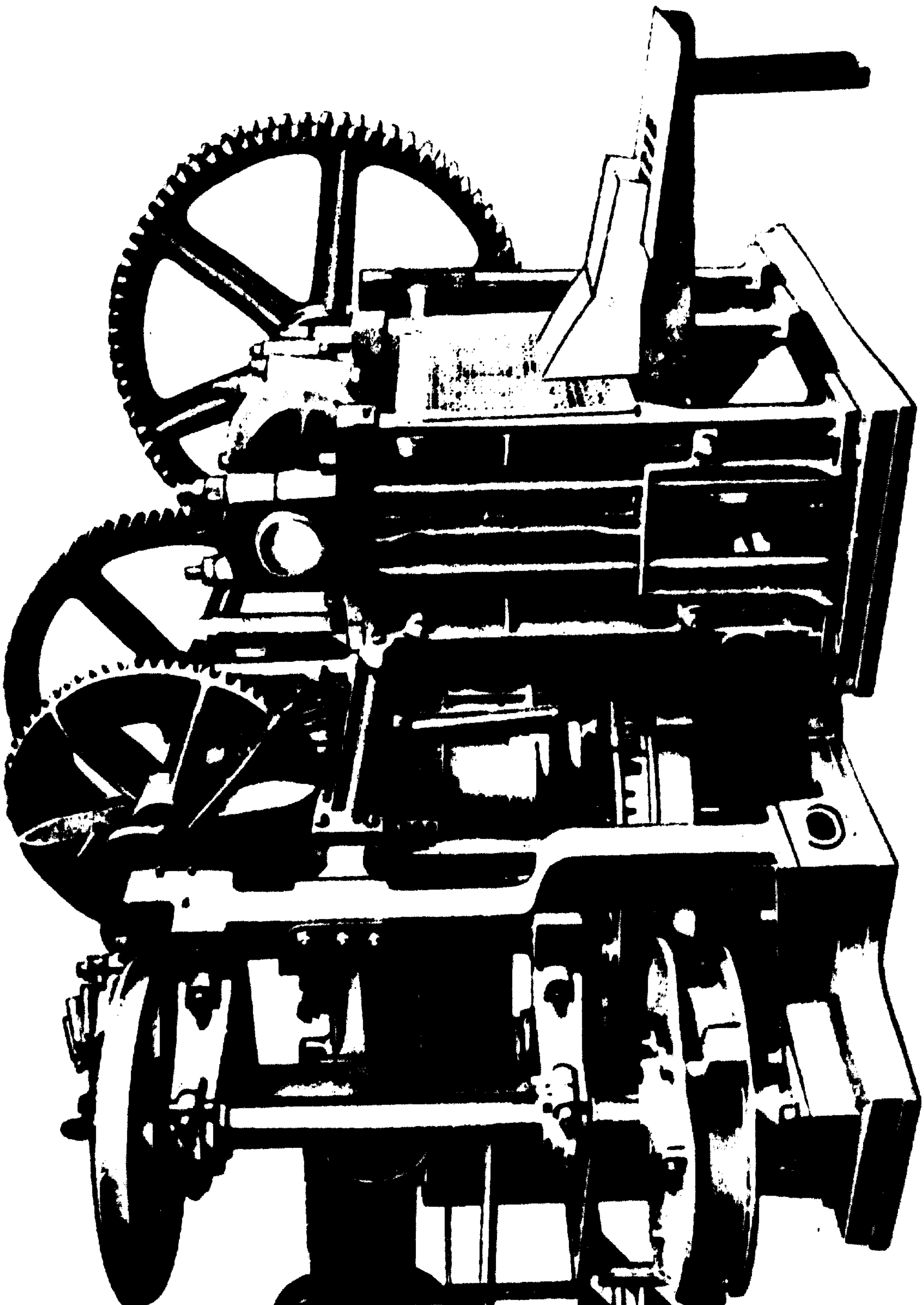


Fig. 14

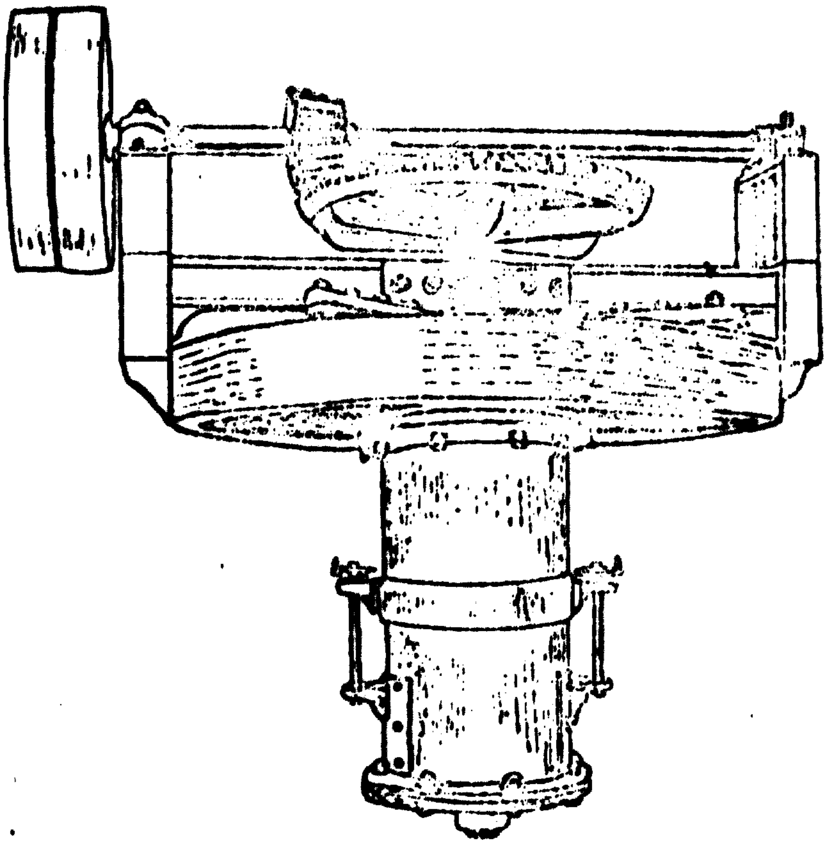
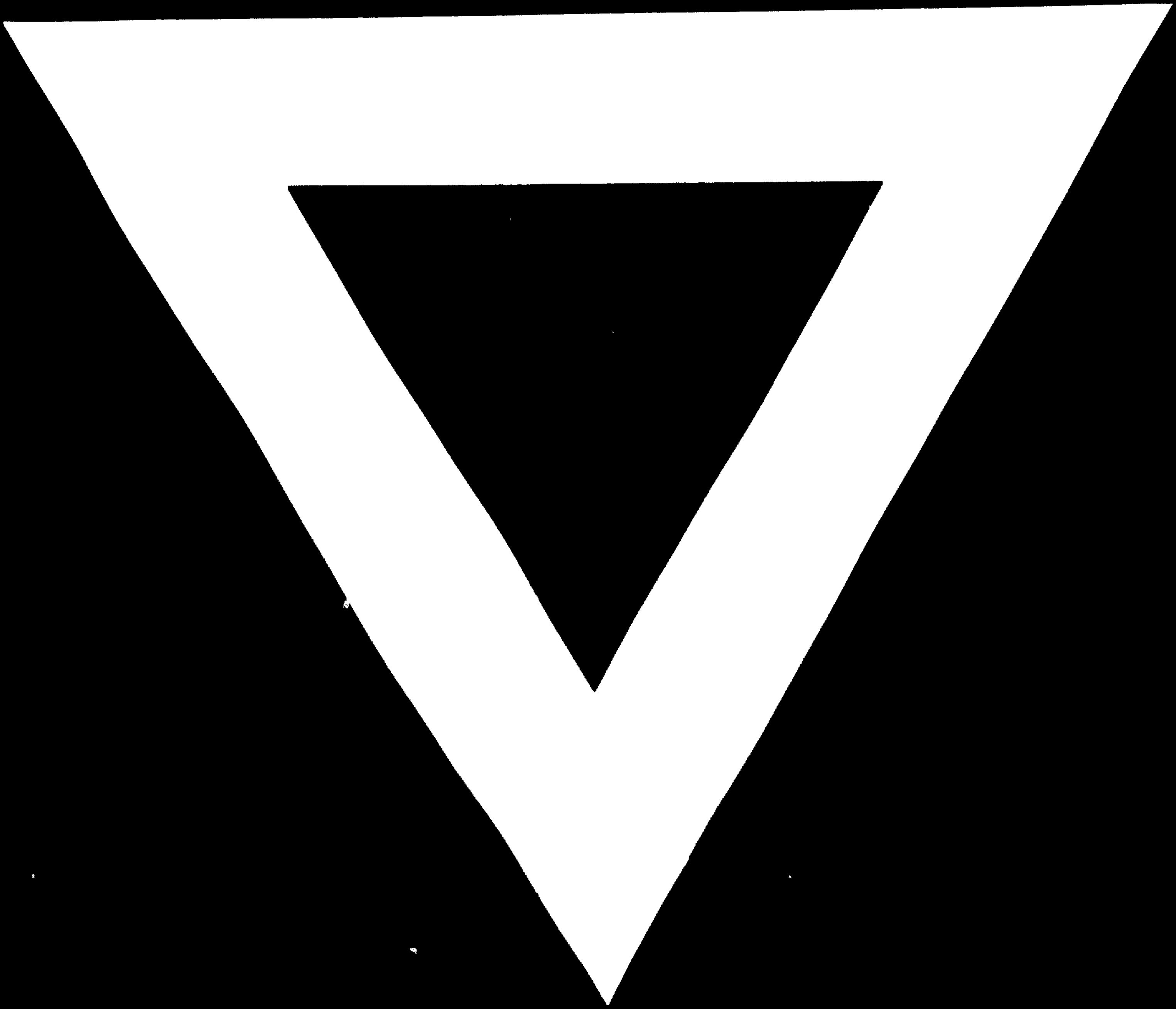


Figure 15 Sludge pan [5]



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