U. S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

RESEARCH PAPER RP798

Part of Journal of Research of the National Bureau of Standards, Volume 14, June 1935

PERFORMANCE OF A HOLLOW-WARE EXTRUSION MACHINE WITH DIFFERENT COMBINATIONS OF AUGERS, SPACERS, AND DIES

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ABSTRACT

A study was made of the effect of various combinations of augers, spacers, and dies on the performance of a union-type auger machine used in forming hollow clay tile. Measurements were made of the rate of extrusion per unit of time, per unit of power input, and per unit of power absorbed by the auger. Single-, double-, and triple-wing augers were used in combination with spacers 10, 15, and 20 inches in length, with dies 4, 5, and 6 inches in length, and die tapers of 0, 2, 3, 4, and 6 degrees. The effect of these variables on the density of the extruded clay was also noted.

Of the three augers, the single wing was the most efficient when used with a 10-inch spacer and a die not less than 4 inches in length.

Power consumption increased as the spacer or die length was increased, and also as the die taper was increased or decreased from 3 degrees. The rate of extrusion was highest with the 10-inch spacer and 3-degree tapered die. The density was not affected by changes in augers, spacers, or dies, but increased as the water content decreased.

CONTENTS

I. INTRODUCTION

This paper reports results of further studies at this Bureau in connection with machines for extruding clay columns. The results of earlier work, in which the effect upon performance caused by changes in design of augers, spacers, and dies for auger brick machines was considered, are given in a previous paper.[1] The following report deals specifically with the effect of the same factors upon the performance of auger machines used in the production of hollow tile,

[1] P. C. Grunwell, BS J. Research 1 1023 (1928) RP36.

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commonly known as "structural clay tile." The extrusion machine assembly and various measuring devices used in this investigation were designed and assembled by P. C. Grunwell.

In the formation of clay products by extruding continuous bars or columns of clay through dies, the resulting products may be classified as either "solid ware" or "hollow ware." After the clay enters the solid-ware die of the type used in the former investigation, resistance to flow results from friction between the clay and the die walls. To form the "cells" or "voids" in hollow ware the die is provided with cores which are suspended on rods from a cross bar or bridge, the latter being placed at some suitable distance back of the die entrance. This arrangement acts as a baffle in the path of the clay and causes a retardation of flow additional to that resulting from friction between the clay and die walls.

The additional load imposed by the presence of the bridge and cores in a hollow-ware die and the restriction to the flow of clay at or near the center of the column influence the performances of various combinations of augers, spacers, and dies in a manner somewhat different from those of the solid-ware die.

II. SCOPE OF THE INVESTIGATION

In this investigation the effect of the design of the dies, augers, and spacers upon performance was considered. The studies included determination of the water content and workable characteristics of the clay used for each test; changes in certain independent variables, namely, design of auger tips; distance of ingress of the die from the auger tip (hereinafter referred to as the length of spacer); length of die; and taper of die. Measurements were made also of extrusion rate of clay column; total electrical energy consumed by the assembly; amount of useful work done by the auger; and density of the extruded clay.

III. EQUIPMENT AND MATERIAL

1. EXTRUSION MACHINE

The auger machine used in the previous investigation was primarily designed for the production of brick and proved to be unsuitable for the extrusion of hollow ware because of its small capacity and light construction. It was consequently replaced by a "union"-type machine of greater capacity and power in which the pug mill and auger machine are combined instead of being built in separate units. This extrusion machine is shown in figure 1.

The pug mill was provided with a shaft which carried twenty knives with adjustable pitch and four kickers at the outlet end of the pugging chamber to force the clay downward into the auger barrel. The auger barrel carried a separate shaft provided with seven interchangeable half-wing augers and one interchangeable auger tip which propelled the clay through the auger barrel and forced it through the auger and die, B.

As the clay column emerged from the die it was cut into pieces and dropped into a small horizontal conveyor, C, which carried the clay to a housed inclined belt conveyor, D. The latter elevated the clay to a chute by means of which the clay was returned to the pug mill, thus forming a "closed circuit" of operation.

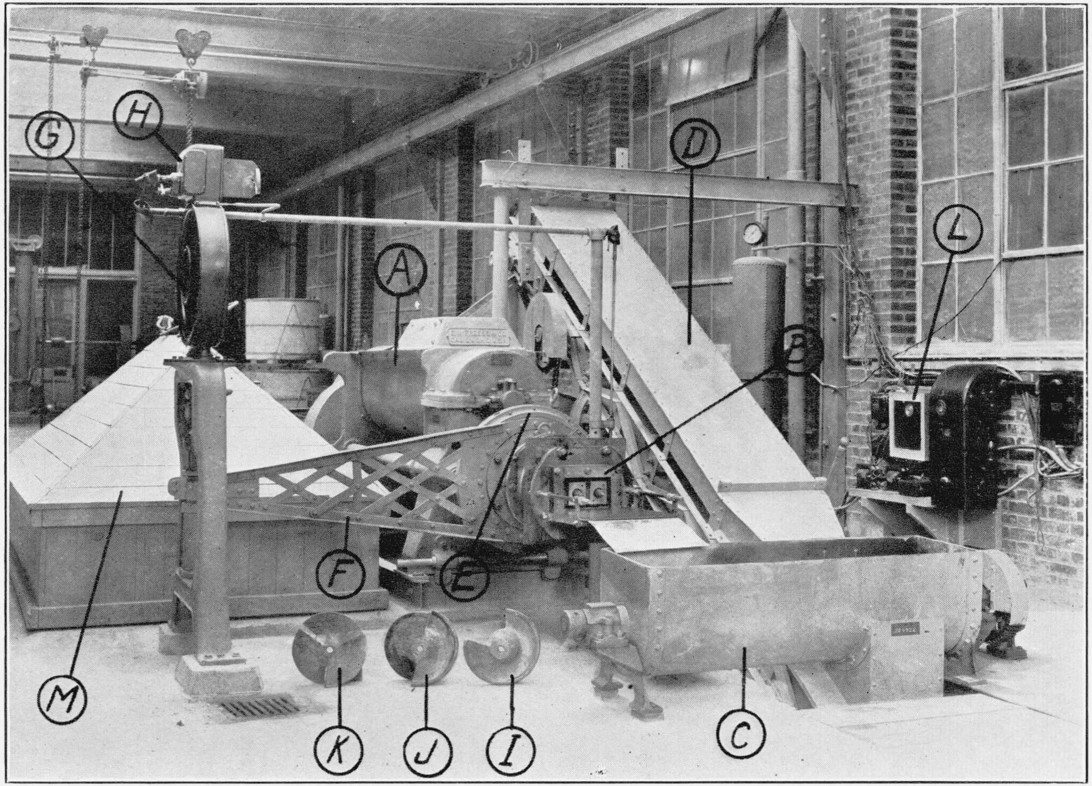

FIGURE 1.—*Extrusion machine assembly.*

The roller thrust bearing of the auger shaft and the ball-bearing joint (the latter at E, fig. 1) of the auger barrel used on the brick machine in the previous investigation were fitted to the new machine. The torsion-measuring apparatus consisting of the movable arm, F, attached to the ball-bearing joint, the dynamometer scale head, G, and the recording integrator, H, was placed in the same relative position as in the former investigation. These have been described in the previous publication.[2]

New interchangeable auger tips of single-, double-, and triple-wing design, 11⅞ inches in diameter (I, J, and K), were made to fit the barrel of the new machine. The pitches of these tips were 5¼, 11, and 9¾ inches, respectively.

Ten-, fifteen-, and twenty-inch interchangeable spacers, 12 inches in diameter, were used in the study of the effect of length of spacer upon die performance.

Figure 2 shows the details of a typical spacer and die assembly. The dies and cores were "built up" of 1-inch segments so that the die length or the core length could be changed either by inserting or removing one or more segments. For a study of the effect of die taper on machine performance, dies of 0-, 2-, 3-, 4-, and 6-degree taper were used. The taper was confined to the first 3 inches of the die ingress. Changes in die length were made by increasing or decreasing the length of straight issue. Thus, a 4-inch die had 3 inches of taper and a 1-inch issue, while a 6-inch die had 3 inches of taper and 3 inches of straight issue.

The bridge supporting the core posts and cores was attached to the inner wall of the spacer between the auger and die so that die changes could be made without disturbing the relative positions of the core and bridge.

A small "footage counter" or measuring device consisting of a wheel and revolution counter was attached to the egress end of the die to measure the length of clay column as it issued.

A 3-phase, 60-cycle, 220-volt, 680-rpm, 50-hp induction motor drove the auger machine through a chain drive and friction clutch.

The horizontal conveyor and the inclined conveyor returning the clay to the auger-machine pug mill were driven by a separate motor.

Measurements of the total power consumed by the auger machine assembly were made with the same integrating watt-hour meter used in the previous investigation. The amount of useful work performed by the auger was determined by means of the ball-bearing joint torsion measuring apparatus. No measurement was made of the power consumed by the independent 5-hp motor driving the return conveyors.

2. CLAY

The clay used for the tests was the same as that used in the previous investigation. It is a very fine grained plastic clay from eastern Maryland and was particularly constant in its working properties. Any significant changes in the working properties of the clay could be attributed to changes in its water content.

The clay was crushed in a dry pan to pass a no. 20 sieve and stored in bags. A batch of clay was prepared as needed by tempering the air-dried clay in a wet pan with sufficient water (about 26 percent)

[2] BS J. Research **1**, 1023 (1928) RP36.

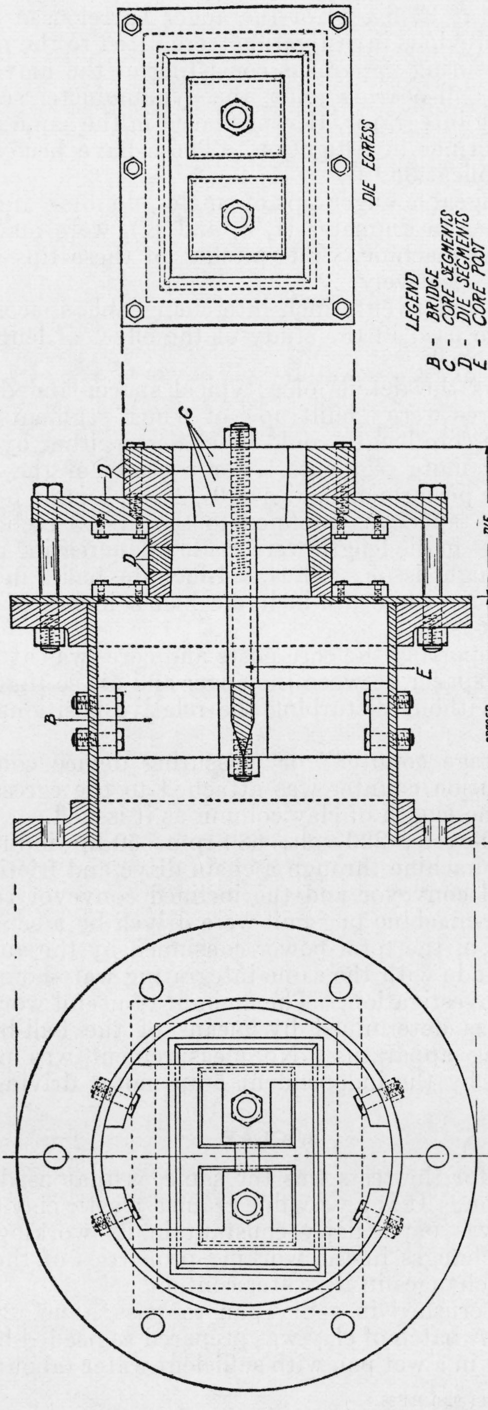

FIGURE 2.—*Detail of spacer and die assembly.*

to produce the desired plasticity. The tempered clay was stored in a "moist box" (M, fig. 1).

One clay batch was sufficient for a single complete test, and the same batch was used for successive tests until its moisture content had decreased to about 24 percent. This appeared to be the low limit for desirable working properties, and was generally reached after 12 to 14 extrusions had been made. The clay column was then cut into lengths, air-dried, and stored for future use.

IV. OPERATION

1. EXTRUSION

The pug mill to the auger machine was filled with tempered clay, and the assembly operated for a few minutes to insure sufficient clay in the machine and on the conveyor to deliver a constant supply to the pug mill, and to determine that the extruded column was of satisfactory quality. The column was considered satisfactory when straight, all walls and webs well filled, and the corners free from feather edging.

The assembly was then operated for a period of ten minutes and readings were taken simultaneously on the watt-hour meter, footage counter, and recording integrator. A unit length was cut from the clay column at the beginning and the end of the 10-minute test and weighed. From the data thus obtained the total power input, amount of power consumed by the auger, and the total weight of clay extruded were calculated.

2. FLOW PRESSURE, MOISTURE CONTENT, AND DENSITY

One sample of the clay was taken at the beginning of the test and another at the end for determining flow pressure and moisture content,[3] in order to correlate the results of succeeding tests with the workability of the tempered clay. Two sections of the clay column, 3½ inches long, were used for determining the density of the extruded clay, which was done by means of an overflow volumeter of the Schurecht type,[4] using kerosene as the liquid.

V. RESULTS

1. PERFORMANCE OF AUGERS

Each value given in the data tables was computed from the results of a series of 12 to 14 extrusion tests using one batch of clay repeatedly until the moisture content of the clay had dropped from about 26 percent to not less than 24 percent. As the clay became "stiffer", from decreased water content, the power consumption increased and, in general, the rate of extrusion increased. The data obtained in any one series of tests were averaged and these averages were taken as the numerical values for the particular combination of equipment used in that test.

Tables 1, 2, 3, and figures 3 and 4 show the relative performances of the single-, double-, and triple-wing auger tips. Each proved most efficient in combination with the 10-inch spacer and 4-inch

[3] These determinations were made in the same manner as described on p. 1034 of reference 1.
[4] H. G. Schurecht, J. Am. Ceram. Soc. **3**, 730 (1920).

die of 3-degree taper. With this combination the greatest rate of extrusion was obtained per minute, per hp-hr input, and also per hp-min consumed by the auger. Of the three augers the single

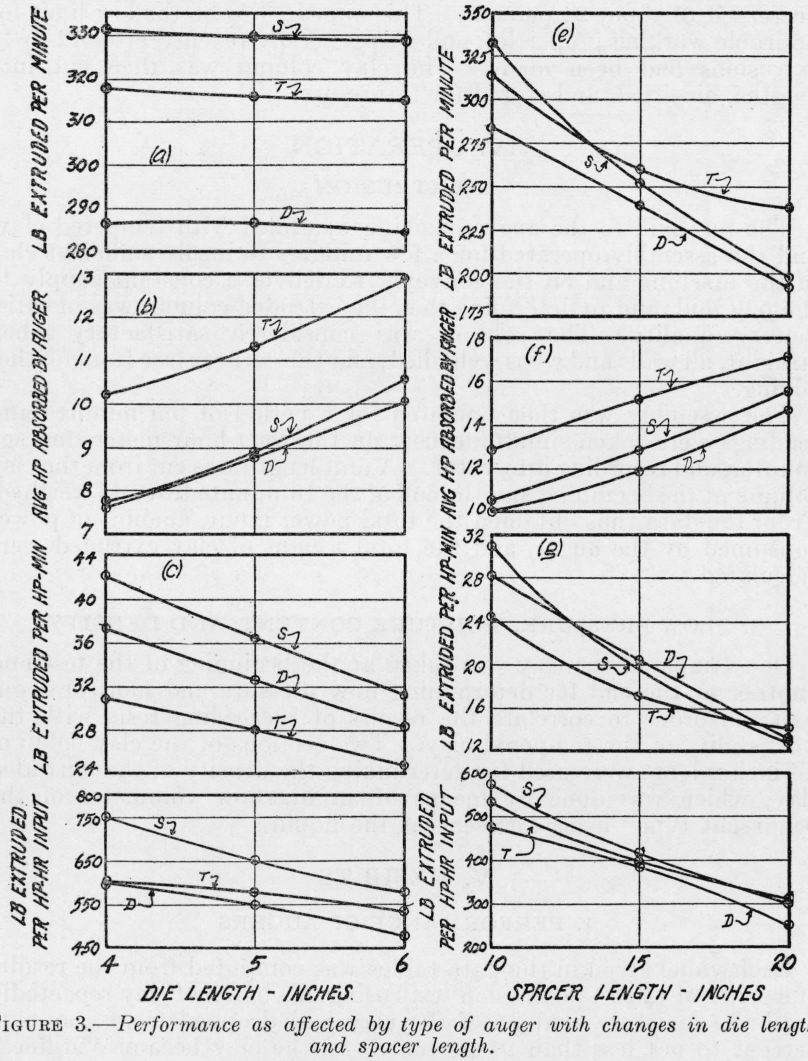

FIGURE 3.—*Performance as affected by type of auger with changes in die length and spacer length.*

S denotes single-wing auger
D denotes double-wing auger
T denotes triple-wing auger

wing was more efficient than the double or triple wing, and the latter more efficient than the double wing with respect to rate of extrusion and power consumption.

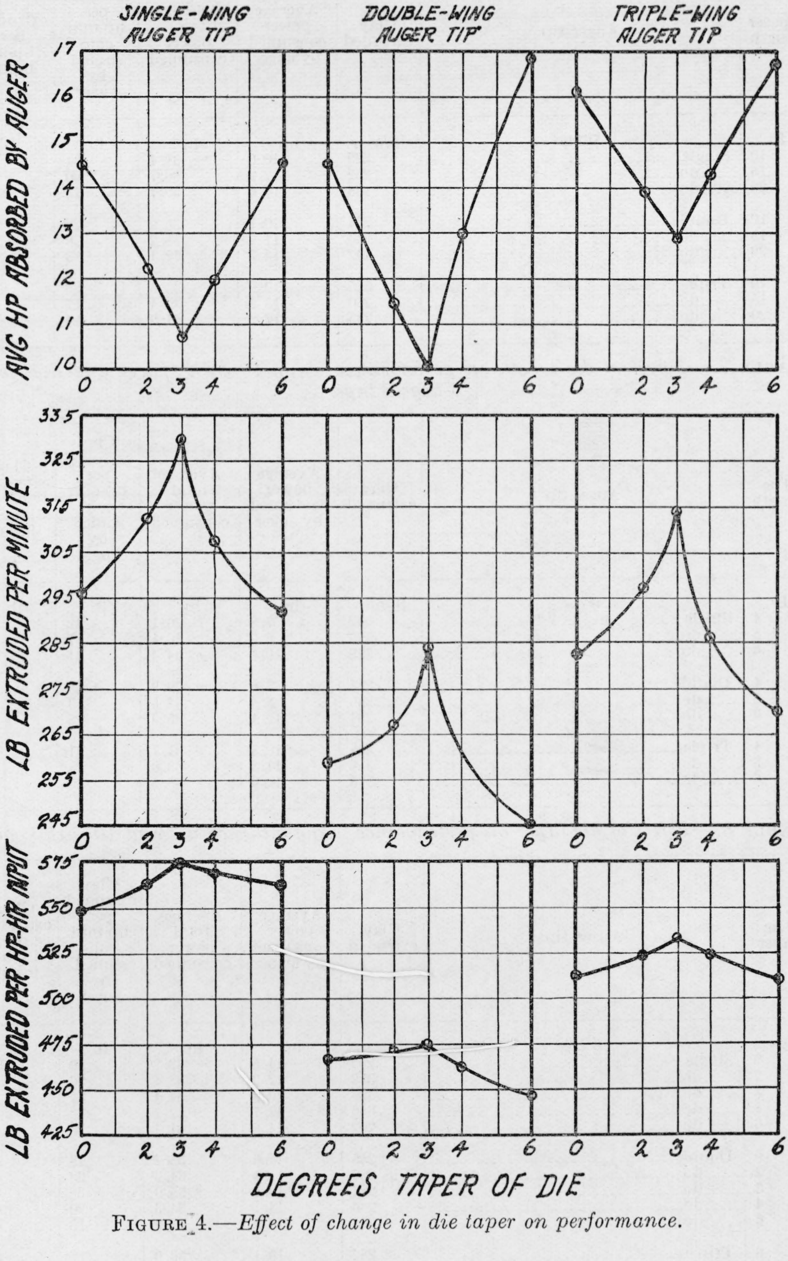

FIGURE 4.—*Effect of change in die taper on performance.*

TABLE 1.—*Effect of spacer length on performance, using 6-inch die with 3-degree taper*

Spacer length	Auger tip	Clay extruded	Average power consumed by auger	Average total power consumed	Clay extruded per hp-min consumed by auger	Clay extruded per hp-hr input
In.	*Wing*	lb/min	hp	hp	lb	lb
10	Single	329	10.6	34.4	31	575
15	do	252	12.9	36.7	20	412
20	do	198	15.6	39.7	13	298
10	Double	284	10.1	35.9	28	475
15	do	243	11.9	38.2	20	382
20	do	192	14.7	42.1	13	246
10	Triple	315	12.9	35.5	25	533
15	do	260	15.2	39.4	17	397
20	do	235	17.2	41.2	14	308

TABLE 2.—*Effect of die length on performance using 10-inch spacer and dies with 3-degree taper*

Die length	Auger tip	Clay extruded	Average power consumed by auger	Average total power consumed	Clay extruded per hp-min consumed by auger	Clay extruded per hp-hr input
In.	*Wing*	lb/min	hp	hp	lb	lb
4	Single	332	7.8	26.1	42	755
5	do	329	8.9	30.1	37	651
6	do	329	10.6	34.4	31	575
4	Double	287	7.6	29.9	38	599
5	do	286	8.8	31.5	33	547
6	do	284	10.1	35.9	28	475
4	Triple	318	10.3	31.7	31	603
5	do	316	11.3	33.0	28	573
6	do	315	12.9	35.5	25	533

TABLE 3.—*Effect of die taper on performance using a 6-inch die and 10-inch spacer*

Die taper	Auger tip	Clay extruded	Average power consumed by auger	Average total power consumed	Clay extruded per hp-min consumed by auger	Clay extruded per hp-hr input
Degrees	*Wing*	lb/min	hp	hp	lb	lb
0	Single	295	14.5	32.2	20	550
2	do	312	12.2	33.4	26	561
3	do	329	10.6	34.4	31	575
4	do	306	12.1	32.2	25	570
6	do	292	14.6	31.1	20	563
0	Double	258	14.6	33.2	18	467
2	do	266	11.4	34.0	23	470
3	do	284	10.1	35.9	28	475
4	do	260	13.1	34.3	20	461
6	do	245	16.8	33.2	15	447
0	Triple	282	16.1	33.0	18	513
2	do	297	13.9	34.0	21	524
3	do	315	12.9	35.5	25	533
4	do	287	14.3	32.8	20	524
6	do	269	16.8	31.6	16	510

Satisfactory clay columns were obtained when using the single-wing auger with dies 5 or 6 inches long, but some difficulty was encountered in extruding a satisfactory column when using the single-wing auger with a 4-inch die. In the latter case a zigzag motion, which was especially noticeable with soft tempered clay, was imparted to the clay column. The double- and triple-wing augers produced clay columns of good quality with all three die lengths.

2. EFFECT OF SPACER LENGTH ON PERFORMANCE

In table 1 and figure 3 (e, f, g, h) are shown the results of the tests made with the 10-, 15-, and 20-inch spacers with various combinations of augers and dies to determine the relative effect of change in spacer length on the performance of the machine.

It is seen that any increase in length of spacer through which the clay must be forced as it approaches the die results in increased power requirements, both power input (table 1) and power consumed by the auger (table 1 and fig. 3 (f)). The rate of extrusion increased 66 percent as the spacer length was decreased from 20 inches to 10 inches when the single-wing auger was used, increased 48 percent when using the double-wing auger, and increased 34 percent with the triple-wing auger.

3. EFFECT OF DIE LENGTH ON PERFORMANCE

Practical working limits of die length as determined were 4-inch minimum and 6-inch maximum. Dies less than 4 inches long produced a defective column due to zigzagging, except when the water content of the clay used in this study did not exceed approximately 24 percent. When a drier clay was used the quality of column was satisfactory, but the power required was excessive.

A satisfactory column was obtained with a 6-inch die under all variable conditions, while dies of greater length did not improve the quality of the product. Within these limits die length had very little effect upon the rate of extrusion, as may be seen from table 2 and figure 3 (a).

The effect upon power requirements, however, was very pronounced, the longer the die the greater the total power input (table 2) and the smaller the amount of clay extruded per unit of power consumed (table 2 and fig. 3 (d)). The auger required greater power as the die length increased (table 2 and fig. 3 (b)) in order to maintain a steady rate of extrusion. This resulted in a decreased rate of extrusion per horsepower-minute consumed by the auger, as shown in figure 3 (c).

4. EFFECT OF DIE TAPER ON PERFORMANCE

Taper is the most important factor in the design of the die. Table 3 and figure 4 show the effect of variation in taper on performance. The data indicate that a 3-degree taper offered minimum resistance to formation and issue of the clay column, and consequently the maximum rate of extrusion was obtained with minimum power at that taper.

In order to understand the effect of die design upon performance, the analysis can most advantageously be made through a study of the influence of any change in the die upon the amount of useful work done by the auger. The data of table 3 and figure 4 indicate that irrespective of whether the single-, double- or triple-wing auger was used, a die of 3-degree taper resulted in the maximum rate of extrusion per unit of time, per unit of power input, and per unit of power consumed by the auger. Also, it is seen that the die becomes less efficient as the taper is changed in either direction from 3 degrees. As the die taper is increased from 0 to 3 degrees, or decreased from 6 to 3 degrees, the total power input to the assembly increases. However, power input does not increase at the same rate as the increase in pounds of clay extruded per minute, and the maximum rate of extrusion per hp-hr input was obtained when a die with 3-degree taper was used.

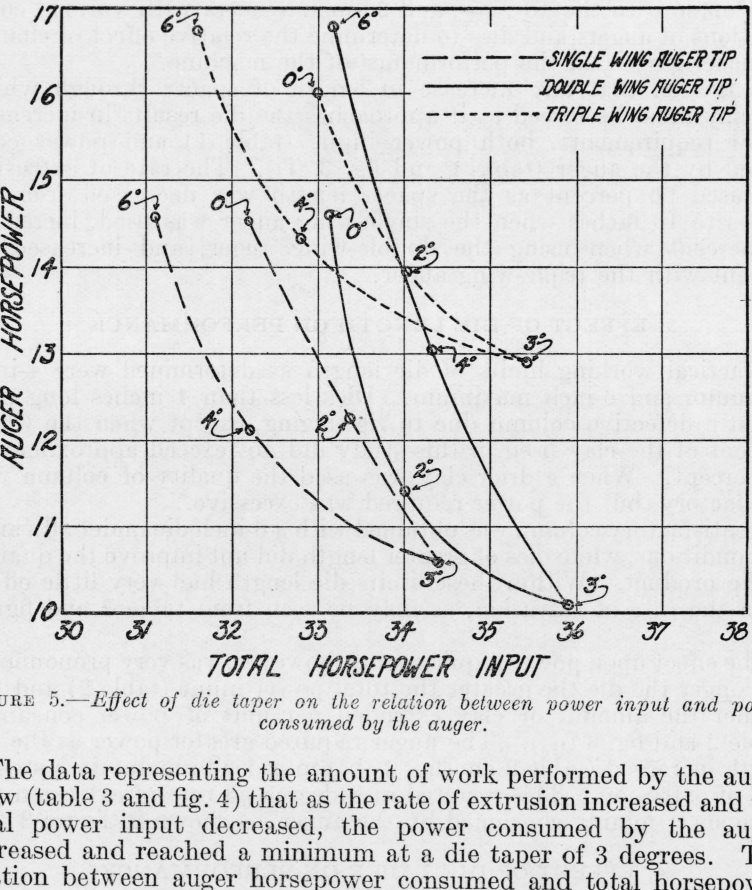

FIGURE 5.—*Effect of die taper on the relation between power input and power consumed by the auger.*

The data representing the amount of work performed by the auger show (table 3 and fig. 4) that as the rate of extrusion increased and the total power input decreased, the power consumed by the auger decreased and reached a minimum at a die taper of 3 degrees. The relation between auger horsepower consumed and total horsepower input as affected by the die taper is illustrated in figure 5, while the relation between auger horsepower, total horsepower input, and rate of extrusion as affected by die taper is shown in figure 4.

It is apparent that as the die taper approaches 3 degrees there is an increasing amount of energy being consumed by agencies other than the auger. As this condition changes, the pug-mill knives and kickers are required to do more work due to the increased rate of extrusion from the die requiring a greater rate of feed to the impeller blades and auge However, from table 3 and figure 4 it is seen that the additional power required by the pug mill is not sufficient to decrease the rate of extrusion per hp-hr input.

A very strict interpretation of the data would result in the conclusion that the 3-degree taper die is unquestionably the most efficient. However, several dies used produced good results and might well be used without seriously affecting the efficiency under conditions not conducive to using of a 3-degree die. A product of satisfactory quality is, after all, of paramount importance and there may be conditions which would require a die having a taper other than 3 degrees. Consequently, a more desirable interpretation would be to consider the data as indicating that there is some taper at which a die tends to be most efficient and that, within the limits of this investigation, that taper was 3 degrees.

Likewise the selection of any one auger as most efficient is hardly feasible, local conditions again being of great importance. The data here presented indicate that the single-wing auger is capable of producing better results should its use prove possible.

5. REPRODUCIBILITY OF RESULTS

Upon the conclusion of tests involving the different equipment combinations, an additional series of tests was made using a single-wing auger, 10-inch spacer, and a 6-inch die of 3-degree taper. The data from these tests were compared with data obtained in the previous tests in which the same combination of auger, spacer, and die had been used. The values for "pounds of clay extruded per minute" checked within 3.6 percent, for "power consumed by the auger" within 2.5 percent, and for "total power consumed" within 1.2 percent.

6. DENSITY OF EXTRUDED CLAY

Density determinations were made on samples from approximately 200 tests involving each different combination of equipment used throughout the investigation. In table 4 are given the results of determinations from twenty tests which are indicative of the trend of results in all of the tests.

TABLE 4.—*Density of clay extruded with various equipment combinations*

Water content of clay	Density	Auger tip	Spacer length	Die length	Die taper	Water content of clay	Density	Auger tip	Spacer length	Die length	Die taper
Percent	g/cm³	*Wing*	in.	in.	*Degrees*	*Percent*	g/cm³	*Wing*	in.	in.	*Degrees*
23.70	1.99	Triple	20	6	6	24.70	1.91	Triple	10	4	2
23.78	1.99	Double	10	6	0	24.71	1.91	Double	10	5	0
23.84	1.98	Single	20	6	0	24.78	1.91	Triple	15	4	2
24.02	1.98	Triple	10	6	2	24.80	1.91	Single	10	6	3
24.06	1.98	do	10	6	4	24.83	1.90	Triple	15	6	0
24.27	1.95	Single	10	6	0	24.96	1.90	Single	10	4	0
24.32	1.95	Double	10	6	2	25.35	1.88	Triple	10	4	2
24.49	1.94	Single	10	5	3	25.55	1.88	do	15	6	0
24.61	1.92	do	10	4	6	25.74	1.87	do	20	6	0
24.65	1.92	Double	10	4	3	25.80	1.86	Single	10	5	4

It is apparent that changes in die, auger, or spacer design do not materially affect the density of the clay column, but that water content does.

VI. SUMMARY AND CONCLUSIONS

A study was made of the effect of various combinations of augers, spacers, and dies on the performance of a union-type auger machine used in forming hollow clay tile.

Various combinations of equipment were used consisting of augers of single-, double-, and triple-wing types; 10-, 15-, and 20-inch spacers; dies 4, 5, and 6 inches long, and die tapers of 0, 2, 3, 4, and 6 degrees. Measurements were made of the rate of extrusion per unit of time, per unit of power input, and per unit of power absorbed by the auger. Density determinations of the clay column extruded were also made. From the data obtained the following conclusions seem justified:

1. The single-wing auger is most efficient with respect to rate of extrusion and power consumption, but cannot be used throughout as wide a range of variable conditions of spacers and dies as can the double- or triple-wing augers.

2. The greater the spacer length, the greater the power consumption and the lower the rate of extrusion.

3. Power consumption increases as the die length is increased. Within practical working limits changes in die length had no appreciable effect on rate of extrusion.

4. Maximum rate of extrusion per minute, per hp-hr input, and per hp-min consumed by the auger was obtained with a die of 3 degree taper.

5. Changes in die, auger, or spacer design do not materially affect the density of the extruded clay column, but water content does.

WASHINGTON, March 9, 1935.