Cacao Drying with a Bentall Rotary Dryer.

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A SUMMARY of the results from a series of eighteen trials conducted at the Lowlands Agricultural Experiment Station, Keravat, between September, 1961, and November, 1962.

Description of the Dryer.

Trials were carried out with an 8 ft. x 6 ft. rotary drum dryer having a final gear drive fitted to a central shaft and mounted on large bearings supported by heavy concrete piers as shown in Plates I and II. Hot air is supplied through ducts leading from the heat exchanger into both ends of a central core running through the drum. Electric power was used for the drum drive (3 h.p.) the blower fan for the oil burner (1 h.p.) and the main fan connected to the heat exchange unit (10 h.p.).

Obviously the generating plant requirement to supply power for these three motors is considerable and diesel power would in most cases be preferable.

A cast iron and steel boiler type heat exchange unit mounted over a firebrick lined square combustion chamber is used for indirectly heating the air forced through it by the main fan. This fan has a rated capacity of 3,500 cubic feet per minute but no figure is available for the static water gauge pressure against which this volume is delivered.

A simple burner fitted into one side of the combustion chamber is rated as being able to create a maximum temperature rise above ambient of 110 degrees F. in the air passing through the heat exchanger. This heated air passes initially into a single duct and then through two ducts leading off to each end of the drum from a T joint with the initial outlet. Thus, air is fed from each end into the hollow central core of the drum and thence out through a series of perforated tubes projecting into each compartment as shown in Plate I. Introduction of hot air into both ends of the drum in this way allows for more even distribution of this air through the bean mass in each compartment and hence more even drying. Normally, heat distribution in rotary dryers which have an inlet duct at one end only, is poor. This assumes, of course, a uniform distribution of outlet holes along the entire length of the central duct or core. Under these circumstances the tendency is for hot air to be blown to the far end of the central core and out into the drum. Consequently, drying is faster at one end of the drum than the other. This weakness can be corrected either by suitable arrangement of hole distribution, variation in hole size along the core or by blanking off holes in progressively greater numbers from one end of the core to the other.

The drying drum itself is divided into four compartments and is constructed so that all surfaces in contact with cacao beans are aluminium alloy. Each compartment is fitted with wooden baffles and the outer shell of the drum perforated with 3/16-inch holes. A final gear drive leading from a chain drive off the three h.p. electric motor gave a drum rotation speed of two r.p.m.

Installation of the Dryer.

During installation of the dryer several difficulties were encountered which could have been avoided by better planning. The major problem in putting the unit together was the heat exchange unit. This proved to be a relatively heavy piece of equipment, awkward to handle and unsatisfactory from a grower's viewpoint. Preferably the unit should be shipped in sections which can be easily handled and bolted together at installation.

Plans supplied with the dryer were inaccurate to the extent that no measurement was given for the thickness of the back concrete

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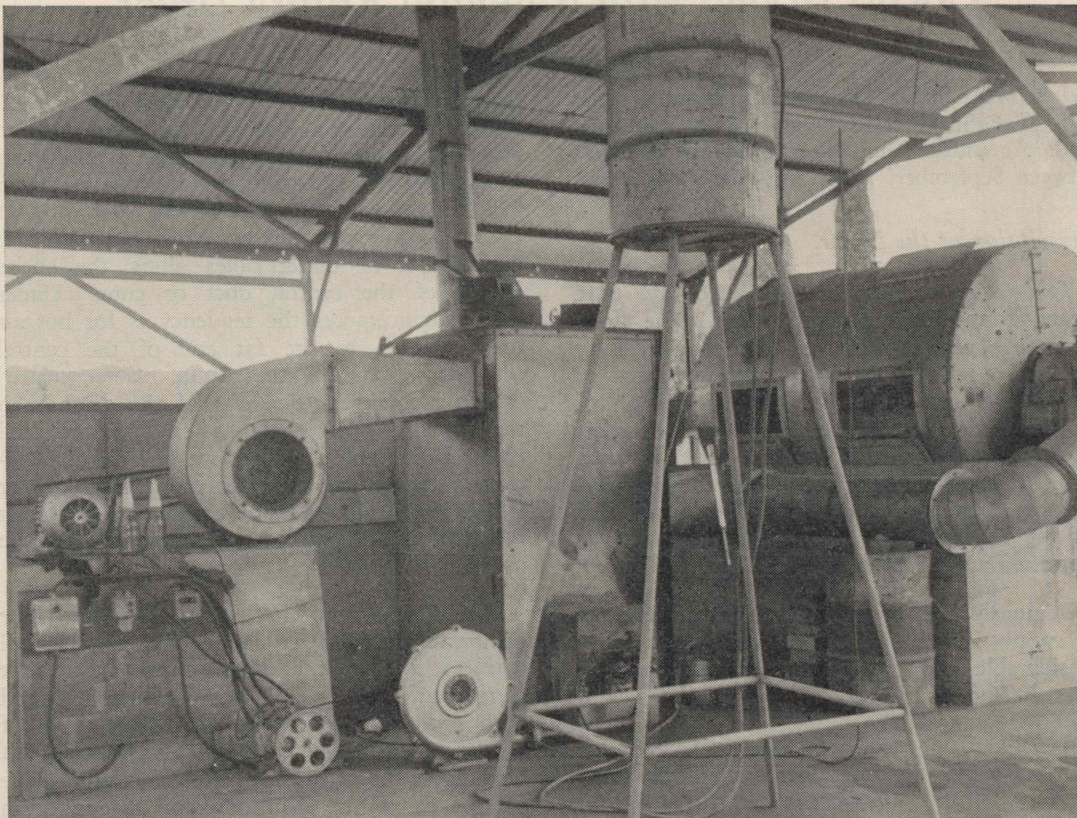

Plate I.—A general view of the dryer with fan and heat exchange unit.

wall running between the two main supporting pillars. Also, the clearance between this wall and the drum was insufficient and the distance between the two main concrete pillars incorrect. These foundations were in fact far too elaborate and heavy for an 8 ft. x 6 ft. dryer and it is very doubtful whether many growers would be interested in equipment requiring such extensive concrete work for supports. The requirement here is for sturdy, easily assembled, steel frames. Siting of the main blower fan on its concrete pillar was extremely poor, the whole unit being mounted over to one corner of the block. This resulted in one of the bolts, which had been set in the concrete to hold the base of the fan, breaking away because of its proximity to the edge. Again, the foundation was unnecessarily heavy and could have been easily replaced by a steel frame.

Drum components, particularly the outer shell, fitted together badly and the two elbow sections of the hot air ducting which fitted on to the central core of the drum had to be heated and hammered before fitting could be effected.

Finally, the unit lacks any braking mechanism to hold the drum in a given position during loading. A brake is essential to prevent the drum from moving out of position during loading operations.

Rotary Drying With Baffles Fitted.

As mentioned above, each of the four drum compartments was fitted with wooden baffles which, in effect, are long shelves running the full width of the drum and bolted to the dividing walls within it. Although the disadvantages of these baffles was anticipated, the first two trials (Trial 1 and Trial 2) were carried out with baffles left in the drum. For Trial 1, beans were first sun dried for two days before loading into the rotary dryer where drying was completed over a 48 hour period during which the burner operated for 16 hours only. Several interruptions to drying were made to allow migration of moisture from the centre of the beans to the shell without the continuation of drum rotation. However, at completion of drying approximately 50 per cent. of the beans were either shattered or else had worn or broken shells. The result of drying with baffles in the drum was much the same again in Trial 2. In this case beans had one day of sun-drying prior to loading into the dryer where drying was continued for a further 48 hours with burner operating for $12\frac{1}{2}$ hours. Drying was not carried to completion because of the high percentage of shattered beans and broken shells which had developed on the second day.

Results from the two trials illustrate again this weakness of rotary dryers which has been noted in previous work at Keravat. The stage at which the shell can be damaged occurs towards the end of drying when moisture content has been reduced down to about 10 per cent. and the shell has became fairly brittle. Two types of damage can occur. Firstly, the shell can be worn through by constant rubbing against other beans in the dryer drum. Secondly, the shell can be split or shattered as a result of beans being held by the baffle plates in such a way that as the drum rotates they crash against the sides of the drum each time they fall, instead of sliding gently around in the compartment.

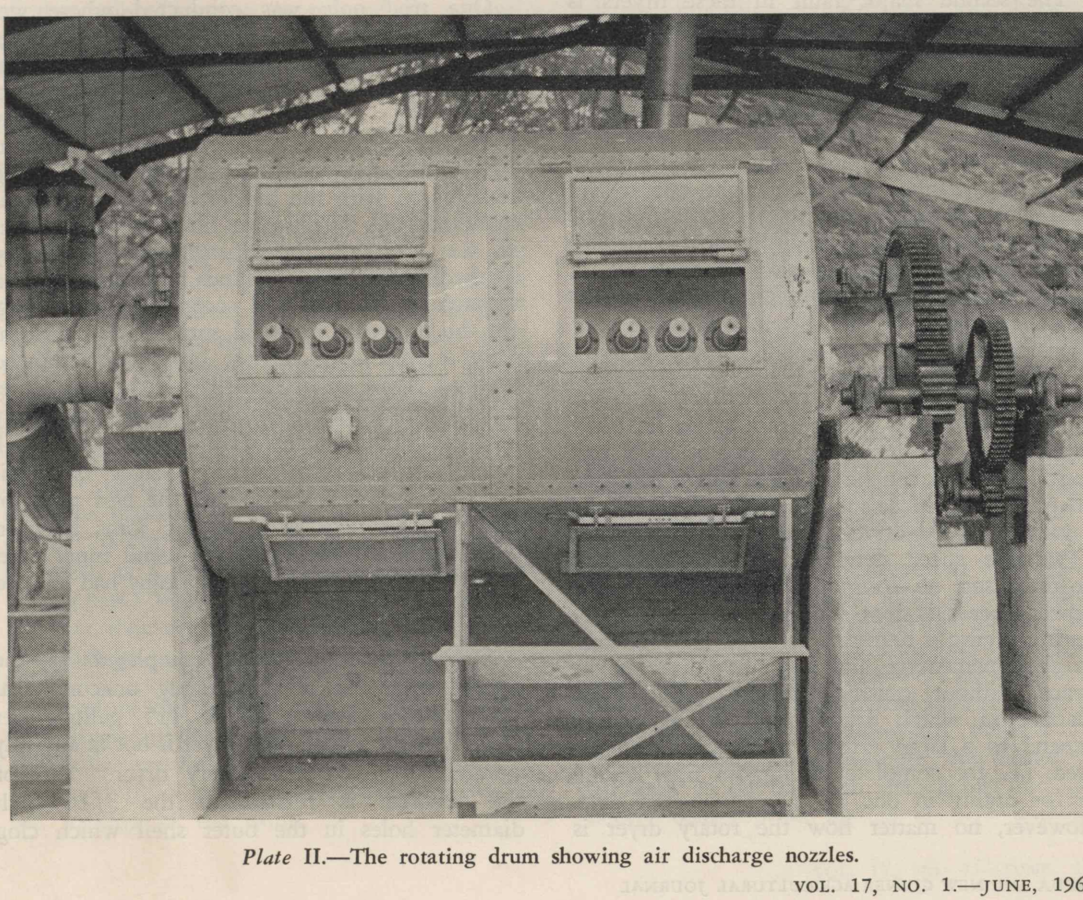

Plate II.—The rotating drum showing air discharge nozzles.

Both problems can be overcome and both are due to a combination of excessive drum speed and the presence of baffle plates in the drum compartments. Baffles are intended to break up the bean mass and prevent it rolling around and "balling". Their effect is, however, practically the opposite, particularly when beans are loaded direct from fermenting boxes. Under these conditions they tend to be held in one clogged mass between the baffles. Towards the end of drying, when the volume of the bean mass has been reduced by about 50 per cent. and each compartment is, therefore, only half full, the effect the baffles have is to hold back some of the beans as each compartment passes through the highest point of rotation until the angle is reached at which beans slide from the baffles and fall. This angle is such that beans falling from the baffle hit the outer shell of the drum and shatter or split.

The second major fault in these dryers is is the drum speed of two r.p.m. which is far too high to allow final drying of cacao beans without abrasion of the shell. The effect of a drum speed of two r.p.m. in combination with baffles, is devastating and causes a tremendous amount of damage—so much so that beans cannot be dried right out to six per cent. moisture and still command the ruling market price. A drum speed of two r.p.m. without baffles is also unacceptable as this, too, results in too much damage to the beans.

It is obvious, therefore, that two basic design requirements for rotary cacao dryers are the exclusion of baffles and a drum speed less than two r.p.m. The first requirement is easily met and the second can be realized by the addition of two or three sets of driving gears or else a variable speed drive. The reason for having a variable speed drive, or, alternatively, two or three sets of driving gears rather than one slower speed, is that variation in drum speed during drying is necessary to achieve a reduction in shell percentage and a good polish on the beans without causing damage. The exact manner in which drum speed is varied will depend to a large extent on how the dryer is used, i.e., for complete drying, for final drying or for drying in one, two, three or four days. However, no matter how the rotary dryer is used a drum speed of two r.p.m. is advantageous for the first five or six hours of drying and will do no harm. After this, drum speed will depend on method and time of drying and whether the compartment is fully loaded or part loaded (greater wear on the beans). Apart from these considerations a final drum speed of $\frac{1}{4}$ r.p.m. is advantageous as, at this speed, rotation can continue for as long as four days without causing damage to the beans. Obviously a variable speed drive covering the range of $\frac{1}{4}$ r.p.m. to two r.p.m. is the ideal. Alternatively, gearing the dryer to give speeds of 2, 1, $\frac{1}{2}$ and $\frac{1}{4}$ r.p.m. or 2, 1 and $\frac{1}{4}$ r.p.m. will suffice, using 2 r.p.m. initially, 1 or $\frac{1}{2}$ r.p.m. when beans become surface dry, and $\frac{1}{4}$ r.p.m. for final drying when the shell is brittle.

Complete Rotary Drying.

One trial only was conducted where wet fermented beans were loaded into the dryer direct from fermenting boxes. Clogging of the machine was anticipated and was in fact severe. The drum was loaded to full capacity with 130 cubic feet of fermented beans at 54.3 per cent. moisture content and drying commenced with the burner operating at maximum output. Within an hour or so all holes in the shell of the drum were completely blocked with mucilage and remained blocked throughout the first and second day of drying. On the third day, internal surfaces of the drum were scraped and cleaned. Inspection showed that all holes in the shell and hot air inlet tubes within the drum had been completely blocked. Inlet ducts were barely functional, being covered with a thick layer of semi-dry mucilage and beans. At the end walls of each compartment, and, at the joins between these walls and the outer shell and inner core, large masses of mucilage and beans had formed together and stuck.

Drying was eventually completed in the rotary dryer but at the highly uneconomical fuel consumption figure of 115 gallons per ton. Obviously then, this dryer is not in any way suitable as a complete rotary dryer. Part of the problem is related to the 3/16 inch diameter holes in the outer shell which clog so readily and rapidly. To some extent this can be avoided by the use of larger (5/16 or 3/8 inch) holes but even with these there is a tendency for clogging to occur. Also, with larger holes in the outer shell there is much less resistance in the system as a whole to the loss of hot air entering the drum under pressure through the central core and inlet ducts. This situation applies particularly towards the end of drying when perforations in the shell of the drum are free and the volume of beans within the drum has been reduced by about 50 per cent. Consequently air can escape rapidly through the outer shell without necessarily removing a great deal of moisture from the beans, and hence drying efficiency is reduced. One answer to this problem has been the utilization of "drawn" holes, 5/16 inch in diameter, in the drum shell. With this type of hole beans are held away from, and thus prevented from sliding over, the outer edge of the hole. Clogging is reduced to a level where it is no longer a major problem and wet fermented beans can be loaded direct from fermenting boxes and dried.

With One Day's Sun Drying.

Two trials were carried out in which fermented beans were dried initially for one day on a platform sun dryer and finished in the Bentall rotary dryer. These were Trial 3 and Trial 7, the results of which are summarized in Table 1. In both trials partial clogging occurred in the holes in the drum shell and also the inlet tubes although these tended to clear as drying continued. In Trial 3, after drying beans down to 6.4 per cent. moisture content it was found that approximately 20 per cent. of the beans were broken or worn as a result of excessive drum speed (two r.p.m.) with a fairly small load, despite the fact that drying was interrupted to avoid this damage.

Therefore the performance of the unit as a final dryer following one day's sun drying was not fully satisfactory although it would be improved by reduction of drum speed and by full loading of the drum.

With Two Day's Sun Drying.

Trials 5, 6, 9, 10 and 13-18 inclusive were all conducted with beans which had been dried for two days in the sun on a platform dryer and then loaded into the rotary dryer for completion of drying. Rotary drying was interrupted in all trials to avoid the excessive damage to the beans associated with high drum speed. As a consequence, fuel consumption figures for all trials are better than those which would have resulted from continuous rotary drying. Interruption to drying, whether with a rotary dryer or a platform dryer, allows migration of moisture from the centre of the bean to the outside during the period of interruption and, as this increases the availability of moisture at the start of the next drying phase drying is therefore more efficient. In addition, interruption to drying during the overnight period means that air at high relative humidity is not used for drying. The twelve hour period of greatest relative humidity at Keravat falls between 8.0 p.m. and 8.0 a.m. Therefore the air used for drying during the day has greater capacity to dry and drying is more efficient during this period.

Unfortunately the figures for fuel consumption against load for this series of trials are extremely variable, the variation being due to variation in fuel consumption per hour by the burner, variation in moisture content at the start of drying, and variation in load. Results are tabulated in Table 1 and graphically represented in Figure 1. For all trials up to Trial 12, fuel was supplied to the burner through a half-inch rubber hose leading from a 1,000-gallon overhead tank. Table 1 shows that when the burner was operating at maximum capacity (i.e., no smoke from the stack), fuel consumption per hour varied from 3.35 to 3.6 gallons per hour. In Trials 13-18 fuel was supplied to the burner from a 44-gallon drum fitted with a float valve to maintain a constant head of fuel. This was inserted into the pipeline system leading from the 1,000 gallon tank to the burner. The net result was a general increase in fuel consumption per hour with wide variation still evident. In Trials 17 and 18 for example, the burner was operated at full capacity throughout and gave hourly consumption figures of 3.59 and 3.94

Table 1.

Summary of Trials.

Trial Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Vol. wet beans (cu. ft.)	98	120	132	130	....	150	210	....	180	80	110	68	225	197	224	215	242	190
Per cent. moisture at end of fermentation	....	....	56.2	54.3	51.1	....	....	....	....	....	....	....	55.7	55.0	55.5	....	....	55.6
Initial sun drying (days)	2	1	1	Nil	2	2	1	....	2	2	2	2	2	2	2	2	2	2
Per cent. moisture after sun drying	....	....	41.3	54.3	36.6	44.9	41.5	....	....	....	....	....	37.1	40.0	39.3	41.0	42.0	38.6
Rotary drying system	Ib	Ib	Inb	I	I	I	I	....	I	I	C	C	I	I	I	I	I	I
Total time beans in dryer (hours)	48	$48\frac{1}{4}$	48	96	50	72	72	....	48	30	24	24	48	72	48	48	48	48
Total drying time (hours)	18	14	$25\frac{1}{2}$	$49\frac{1}{4}$	$33\frac{3}{4}$	$36\frac{1}{2}$	39	....	17	$19\frac{1}{2}$	12	14	$19\frac{1}{2}$	$22\frac{1}{2}$	$18\frac{3}{4}$	$18\frac{3}{4}$	$24\frac{3}{4}$	20
Burner operation (hours)	$16\frac{1}{4}$	$12\frac{1}{2}$	$23\frac{1}{2}$	42	$32\frac{1}{4}$	$36\frac{1}{2}$	39	....	17	$19\frac{1}{2}$	12	$13\frac{1}{2}$	15	20	$17\frac{1}{4}$	$17\frac{1}{4}$	$21\frac{3}{4}$	$16\frac{1}{2}$
Burner operating conditions	....	FC	FC	FC	T	T	T	....	FC	T	T	....	T	T	T	T	FC	FC
Maximum duct temperature (degrees F.)	....	152	157	180	152	136	164	....	204	131	133	....	162	151	157	159	150	150
Burner fuel consumption (gallons per hour)	....	3.5	3.4	3.6	2.8	2.2	2.5	....	3.35	2.3	2.5	3.85	3.87	3.75	3.1	4.35	3.59	3.94
Total fuel consumption (gallons)	....	43	80	151	90	79	96	....	57	45	30	52	58	75	53	75	78	65
Per cent. moisture at end of drying	....	FS	6.4	....	5.0	....	....	....	....	....	....	....	....	....	....	8.0	9.9	13.4
Weight of dry beans (lb.)	....	2,643	2,956	2,940	4,340	3,500	4,340	....	3,920	1,900	2,300	1,680	5,090	4,511	5,075	5,016	5,700	4,659
Fuel consumption (gall. per ton)	....	36.4	60.6	115	46.4	50.5	49.5	....	32.5	53.0	29.2	69.3	25.5	37.2	23.4	33.5	30.6	31.4
Broken beans (per cent.)	50	H	20	20	17	....	....	....	....	....	....	....	....	....	....	....	....	....
Wt. (lb.) dry beans/vol. (cu. ft.) wet beans	....	22.0	22.4	22.6	....	23.3	20.7	....	21.8	23.7	20.9	24.6	22.6	22.9	22.7	23.3	23.6	24.5

Key :—Ib............Interrupted with baffles. Inb............Interrupted no baffles. I............Interrupted.

C............Continuous. FS............Finished in sun. H............High percentage broken.

FC............Full capacity. T............Turned down.

NOTE.—Owing to fuel supply difficulties, Trial No. 8 was a failure.

gallons. However in Trial 16 during which the burner was at times turned down, average fuel consumption was 4.35 gallons per hour. A satisfactory explanation for these variations could not be found.

Performance of the dryer when loaded with beans which had received prior drying for two days in the sun was best in Trial 15 in which the drying of 5,075 pounds dry bean equivalent was completed at a cost of 23.4 gallons per ton. Maximum load in all trials was 5,700 pounds dry bean equivalent and the highest fuel consumption figure was recorded in Trial 10—53 gallons per ton for a load of 1,900 pounds dry bean equivalent.

Apart from the fact that final drying in the rotary dryer had to be intermittent to avoid the deleterious effects of a high drum speed, the unit was quite satisfactory as a final dryer.

Summary.

In a series of eighteen trials, the Bentall 8 ft. x 6 ft. rotary drum dryer, fitted with baffles and supplied with hot air from an oil fired heat exchange system, was tested at the Lowlands Agricultural Experiment Station, Keravat, for its suitability as a cacao dryer.

During installation of the unit it was found that the heat exchange system was too heavy and cumbersome for easy handling on a plantation and that the foundation required to support the drum bearings was too elaborate and too extensive. It was also found that there were errors in the plans.

Initial trials were carried out with baffles fitted in each of the four drum compartments. These clearly indicated the deleterious effect which baffles have on beans towards the end of drying and the extent to which beans can be worn or shattered. Further trials showed that although the unit was unsuitable as a complete rotary dryer, it could be used as a final dryer after one day of sun drying provided that it was fully loaded and drum speed was reduced. However, the most satisfactory performance was obtained when beans were used which had received an initial two days of sun drying on a platform dryer. Under these circumstances it proved capable of handling a load equivalent to approximately 2½ tons of dry beans and of drying this load for a cost of 25-30 gallons of fuel per ton.

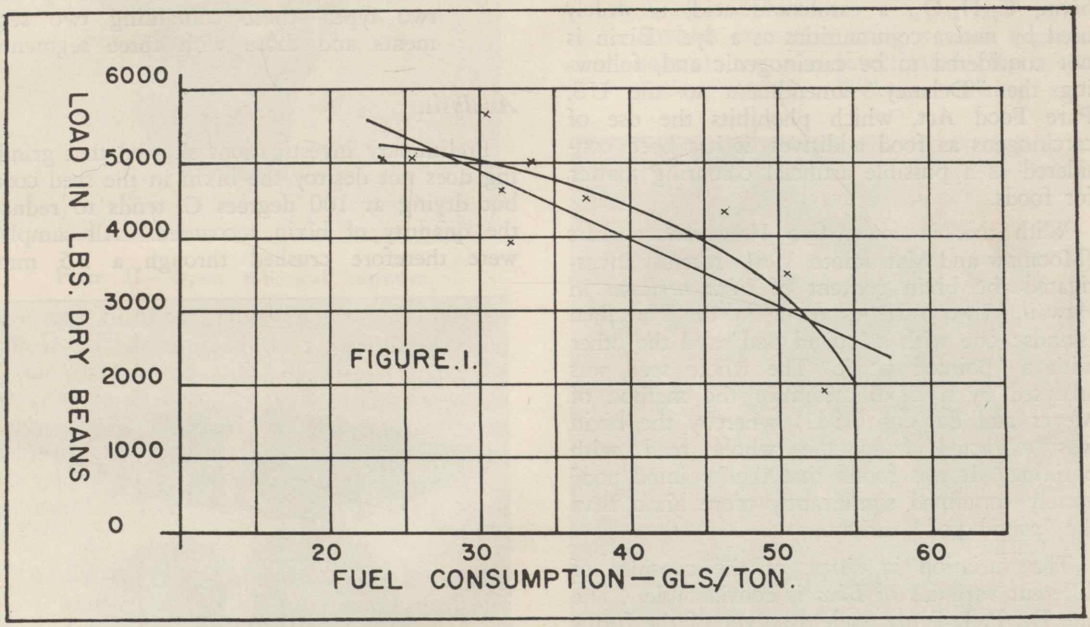

Figure I.—Graph showing relationship between load, expressed as weight in pounds of dry beans, and fuel consumption expressed in gallons per hour.