EXTENSION OF THE USES OF ALABAMA FLAKE GRAPHITE

A Thesis Presented by

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CONTENTS.

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INTRODUCTION.

This thesis incorporates a discussion of an investigation made concerning the extension of the uses of Alabama flake graphite. Most of the present uses are discussed in brief. In addition to this, the results of experimental work on several phases of the uses and possible uses of graphite are taken up.

First: The first series of experiments made was to find the value of graphite-oil mixtures as a lubricant and the most advantageous way to prepare such mixtures; attention being paid to the flake size of the graphite and the quantity of graphite in the mixture.

Second: Tests were made to determine the possibility of preparing blocks of graphite dust and some binder which would be suited for such commercial uses as furnace linings, electrodes and armature brushes.

Third: An investigation was made to ascertain whether graphite dust is suited to use in boilers for the removal and prevention of a certain type of boiler scale.

GENERAL AND STATISTICAL.

Expanded by the increased needs of the world war, the graphite industry is now suffering from the effects of the after war reaction. Before this war the industry in America was one of the smaller mining activities. The mills and mines were in the most part owned by small companies between whom there was little or no cooperation. Before 1914 there were thirteen mills in Alabama, five in Pennsylvania, and three in New York State. These three states are the only ones in which graphite in any quantity has been produced.

At this time all American graphite was regarded as being of low-grade and unsuited for most commercial purposes. For crucible manufacture Ceylon graphite was considered essential.

For pencil manufacture graphite from Austria, Chosen, Madagascar, and Wales was used. Only these countries furnished the amorphous variety of graphite which is required in pencil manufacture. No workabled deposits of amorphous graphite have been discovered in the United States. However, there are some deposits of this kind in Mexico from which graphite has been used for pencil manufacture.

American graphite was limited to uses as a lubricant, as an ingredient of stove polishes and as a facing for foundry moulds. These uses did not require a very large amount of graphite and for this reason the industry in America had not developed.

Below are listed the yearly productions of graphite in the United States from 1907 until the beginning of the war. This material was produced in Pennsylvania, New York State, and Alabama. As will be seen the production averaged about five million pounds per year during this period.

Domestic Flake Graphite *

	Production in pounds	Value	Price per pound
1907	4,927,840	$171,149	$.0348
1908	2,288,000	132,840	.0580
1909	6,294,400	313,271	.0497
1910	5,590,592	295,733	.0530
1911	4,790,000	256,050	.0535
1912	3,543,000	187,689	.0523
1913	5,064,727	254,328	.0510
1914	5,220,539	285,368	.0545

Compared with the above the imports for the same period were;

Imports of Graphite, 1907-1914. *

	Imports in short tons	Value	Price per pound
1907	22,939	$1,777,389	$.0390
1908	11,456	762,367	.0364
1909	21,267	1,854,459	.0438
1910	25,235	1,872,592	.0369
1911	20,702	1,495,729	.0360
1912	25,643	1,709,337	.0335
1913	28,879	2,109,791	.0381
1914	22,002	1,398,261	.0315

The imported graphite, which came mostly from Ceylon, includes all grades and hence the price per pound appears no higher than that of domestic graphite. As will be seen from the above tables, the average yearly imports were about 40,000,000 pounds, while the average domestic production was only about 5,000,000 pounds. The domestic production during this period was only 11.1 per cent of the graphite used in the country, exports being practically none.

During this period the manufacture of artificial graphite was carried on on a rather large scale. This artificial product was used for lubri-

* Mineral Resources of the United States, 1908-1915)

cation purposes and for the manufacture of electrodes and brushes for electric motors and dynamos. Practically all of this artificial graphite was made in the electric furnace by the International Acheson Graphite Company of Niagara Falls.

With the coming of the world war the graphite industry took on a different aspect. During the first two years of the war, it was necessary to develop the natural graphite resources of America in order to meet the increasing needs, due to the increased manufacture of war materials sold to the Allies. During this time it was impossible to increase importations from Ceylon, due to the facts; First, that there were decreased shipping facilities and second, that most of the Ceylon material was taken by England and France for use in their own factories in the manufacture of crucibles for use in making high-grade steels. Hence the only course open was the development of the domestic graphite deposits.

With the entrance of the United States into the war, even greater developments took place in the domestic graphite industry. The annual production increased from 5,000,000 pounds before the war to 12,000,000 in 1918. This extra graphite was used mostly in the manufacture of war materials, The development of the domestic industry was more marked in the Alabama field than anywhere else. Here about 25 mills were constructed. Most of these mills added to the production in the record year of 1918, but some of them were just being put into operation at this time.

For the manufacture of crucibles during this period, mixtures of ceylon and domestic graphite were used. An order was issued by the War Minerals Relief Commission that 20 per cent domestic graphite must be mixed with Ceylon graphite for the manufacture of crucibles. Many experiments were made to determine whether domestic graphite was suitable for crucible manufacture and the proper method for its use. The general result of these experiments showed that high-grade domestic graphite was suited for use in crucible manufacture and that mixtures of such graphite with the Ceylon material produced crucibles as good as those made from the pure Ceylon product.

During this time there was every inducement for capital to be invested in domestic mines. The result of this is shown in the table below which gives the domestic production and the importations of graphite for the years 1915 to 1918.

Domestic Graphite Production, 1915-1918. *

	Production in pounds	Value	Price per pound.
1915	7,074,320	$417,273	$ .0590
1916	10,931,989	914,748	.0835
1917	10,584,080	1,094,398	.1065
1918	12,861,839	1,454,799	.1130

Imports of Graphite, 1915-1918 *

	Imports in short tons	Value	Price per pound
1915	23,075	$2,241,163	$ .0487
1916	32,060	6,933,371	.108
1917	42,060	8,964,988	.105
1918	19,498	3,092,475	.080

With the close of the war the domestic graphite industry went to pieces. There was no longer the need for such a large production of high-grade steel and hence the steel production decreased. Then too, the Ceylon and Madagascar markets opened up once more. Due to the war needs, the industry in Ceylon had been overdeveloped. Therefore, this country had great

* Mineral Resourdes of the United States, 1916-1919.

quantities of the best grade graphite which could be sold even cheaper than the domestic mills could produce it. Since the war there has been practically no market for the domestic article. Prices are so low that the domestic mills cannot operate with profit. All of those in the Alabama district are now standing idle. The price of domestic graphite dropped to about 2½ cents per pound in 1921 and in 1922 it is but little higher. Even then there is little market for domestic graphite at any price. The manufacturers prefer Ceylon graphite and since they can get it, they are using it. Most of the Alabama mills too were built during the war times, to meet the war needs and are so designed and situated that they cannot extract the graphite profitably when the price is so low.

Domestic Graphite Production, 1919-1920 *

	Production in pounds	Value	Price per pound
1919	8,086,191	$731,141	$ .0895
1920	9,636,360	576,444	.0600

Since 1920 the production and price have both decreased greatly, but no statistics are available for this period.

Imports of Graphite, 1919-1920 *

	Imports in short tons	Value	Price per pound
1919	26,626	$2,978,096	$ .0555
1920	21,095	1,711,312	.0405

One of the great wastes in the graphite industry is the production of graphite dust. This is composed of forty to seventy per cent graphite; the impurities consisting largely of clay, feldspar and quartz. This

* Mineral Resources of the United States, 1920-1921.

dust is sometimes used for facing foundry moulds, but only a small part of that produced is used. The greater part of it is entirely waste. At the best it never brings over about one-half cent to one cent per pound. There is apparently no means of preventing the formation of this product. The only solution of this part of the problem would be to find a use for it so that its sale could help defray the cost of operating the graphite mills.

At the present time, with thirty nine graphite mills standing idle in Alabama there is a rather large economic loss to the country and especially to the State of Alabama. These mills represent an investment of four million dollars (estimated), interest on which would be two hundred thousand dollars per annum. There is this much actual loss without even considering that the country is being deprived of this capital for use in other industries. There is no way of changing the capital to other industries, since the mills can be used for no other purpose. The machinery is all of such a type that it would hardly pay to dismantle the mills and salvage the machinery.

The only solution of the problem appears to be an increase in the demand for graphite. This increase might come by an increased demand for it for the present uses, or it might come as a result of the development of new uses for graphite.

This paper deals with the possibility of using graphite on a larger scale in some of its present minor uses, and with some possible new uses for flake graphite. The problems taken up include: The use of graphite dust as a remover of boiler scale; the use of flake graphite with oil as a lubricant with regard to the quantity of graphite used and the size of flake used, and with the preparation and possible uses of graphite moulded with various binders under high pressure and heat. The purification of graphite by the Trent Process of oil purification will be taken up. Work on this phase however was not original, but was simply carried out in order to obtain data concerning its use on Alabama material and to prepare material for use in the lubrication work.

HISTORICAL.

The estimated per cent of the total graphite consumed by the following industries, according to statistics published in the Mineral Resources of the United States, by the United States Geological Survey, is shown in the table below:

	1913	1918
Crucibles	55 per cent	45 per cent
Stove polish	15 " "	5-10 " "
Foundry facings	10 " "	25 " "
Pencils	5 " "	5 " " (Pencils and Paints together)
Paints	5 " "	
Lubricants	5 " "	10 " "
Other uses	5 " "	5-10 " "

This shows that far more graphite is used in crucible manufacture than for any other one purpose.

Materials for use in the manufacture of graphite crucibles, i.e., clay, graphite and sand, must be selected with the greatest of care with regard for their purity and suitability for the purpose. Even the best of refractory fireclays will stand up only a short time when they are subjected to the extreme conditions of crucible use. The addition of graphite to the mixture, however, greatly increases the life of the crucible. Such a crucible, made with the proper graphite content will stand up as long as enough graphite remains to carry the weight of the metal and to allow the crucible to be handled. In addition to its refractory qualities and its ability to prevent corrosion of the crucible, graphite is an excellent conductor of heat. Thus a graphite crucible is able to withstand sudden changes of temperature without danger to itself.

Since the use of graphite as a refractory is without the range of this paper, no detail discussion of this use will be made.

Other uses of graphite-clay refractories are as crucible covers, pouring nozzles, skimmers, dippers, phosphorizers, pyrometer shields and linings of certain portions of furnace walls to prevent scale clinging to it.

Pencils.

Since the sixteenth century pencils have been made from graphite. Flake graphite is not suited for this purpose since its marking qualities are not nearly so good as those of the amorphous variety.

Pencils are made by mixing amorphous graphite with clay and forcing the mixture through small holes at a high pressure to form small cylindrical strips. These strips are air dried and then encased in wood.

Most of the graphite for pencil use comes from Siberia, Mexico,Bavaria, or Bohemia.

Foundry Facings.

The term foundry facings applies to the thin skin that is used to give foundry moulds as a smooth finish and to make the casting peel easily from the mould.

Many materials are sometimes used for this purpose. Such materials include soapstone, talc, carborundum, and various forms of carbon. However, graphite dust is used more extensively for this purpose than any other material. This use affords the only outlet for graphite dust, which contains 40 per cent to 70 per cent graphite.

Since graphite possesses no adhesive properties it must be mixed with some binding material before being used as a foundry facing. Clay is usually used for this purpose. The proportioning of the graphite-clay mixture must be carefully done since too much clay would destroy the power of the graphite to permit peeling and too little clay would not hold the graphite in place.

For dry sand work the graphite dust is applied wet, being mixed with a solution of molasses or some other vegatable substance possessing binding qualities.

With regard to the grade of graphite best adapted for foundry facings, the best results are obtained by the use of high-grade flake. This material may be adulterated considerably and still be better than the poorer varieties of graphite. Soapstone, coke, anthracite and even bituminous coal are often ground up with the graphite to cheapen the mixture. The preparation of proper specifications, based upon reliable tests, is one of the urgent needs of the foundry.[1]

With the exception of crucible manufacture, foundry facings utilize more graphite than any other of its uses.

Dry Batteries.

Graphite is extensively used as an ingredient of the mixture in dry batteries. Here it gives conductivity to the manganese dioxide. Instead of graphite, the powdered carbon in a dry cell, consisting of approximately half the mixture, might consist of powdered coke, retort carbon, or ground carbon electrodes and rods. All of the above materials are cheaper than high-grade graphite, though of lower conductivity.

According to Burgess and Hambenchen[2] the following may be taken as representing the filling mixture in well-known types of dry cells;

Manganese dioxide - - - - - - - -	10 pounds
Carbon or graphite, or both - -	10 pounds
Sal ammoniac- - - - - - - - - - -,	2 pounds
Zinc chloride - - - - - - - - - - -	1 pound

1 R. Moldenke, Principles of Iron Founding, 1917, p 305.
2 Trans.Amer. Electrochem. Soc. Vol. XVI, 1909, p 99.

The above named writers consider that the "more recent improvement in dry cells is undoubtedly due largely to the liberal use of this highly conductive, though more costly, form of carbon."

Graphite in Electrotyping.

Finely powdered graphite is used in electrotyping for two purposes. First: The forms after being made up are covered with graphite and polished. This enables them to strip clean and clear from the wax mould. Second: The wax mould, after receiving the impression of the original is dusted with graphite and polished before immersion in the copper bath.

Amorphous, Ceylon and flake graphite may all be used for this purpose. It is imperative, however, that the graphite used be of the highest possible purity and of even quality.

W. Pfanhauser[1] gives the following extract with regard to the use of graphite in electrotyping:

"The use of graphite as a conducting coating for the forms was proposed by St. W.Wood, in 1873. Only the purest graphite is suitable, and several processes for cleaning graphite chemically for the above purpose have been patented. In consequence of its unctuous character, graphite adheres better to forms than the various metallic powders that have been suggested as substitutes, and forms polished with graphite have a smoother surface than those on which such powders are used.

"The graphite is shaken on the forms and rubbed on with a fine camel's hair brush, to which is given a mild rotating movement. A correctly grapitized surface should possess a lustrous black metallic appearance and care must be taken to leave no portion untouched by the brush as this results in

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1 Die Galvanoplastik, Monographien uher angewantde Elektrochemie, Vol. XI, 1904, p 25.

an imperfect deposition of the copper. A very soft brush is not essential, in fact a rather stiff bristle brush may be used for all except wax or gelatine moulds. It is advantageous, in the case of gutta percha forms, to breathe upon the surface before applying the graphite as this results in better adhesion.

"On wood or plaster moulds that are saturated with stearine it is best to apply a paste of graphite and water. This is allowed to dry and the superfluous graphite is then brushed off.

"Special machines for applying the graphite are used where large surfaces have to be covered, and these give quicker and more even results than hand work. These machines consist essentially of a rotating horizontal plate on which the form is laid and above which a wide brush moves with a rapid whirling movement. Large forms are coated in about 5 minutes with such a machine. Such a machine makes 300 revolutions and is fitted with a brush about 30 inches wide."

Graphite Paints.

Graphite is widely used as a pigment in paint which must withstand the corrosive action of sulphurous gases, acids, alkalies, etc. It may be used to special advantage as a protective covering for metal work which must come in contact with such corrosive gases.

Amorphous graphite, flake graphite and artificial graphite are all used in the manufacture of graphite paints.

The following remarks on the subject of graphite paints are taken from "The Chemistry and Technology of Paints," by M. Tock, second edition, page 101:

"The purer a paint pigment is as to its content of graphite, the poorer is the paint produced. If graphite be taken with a content of 80 to 90 per cent carbon and mixed with linseed oil, it forms a porous fluffy film, and the particles of graphite coagulate in the linseed oil and produce a very unsatisfactory covering. If graphite be diluted with a heavier base, its weakness then becomes its strength and a very good paint is formed. Many of the characteristic chemical and physical defects of red lead are largely reduced and frequently eliminated when it is mixed in the proper proportion with graphite, a high grade of graphite, when finely ground with linseed oil acting as a lubricant and sliding under the brush.

"Pure graphite paint as is well known will cover from 1,000 to 1,600 square feet to the gallon. Such a paint film is so exceedingly thin that, while it looks good to the eye in a short period decomposition more easily takes place beneath it than beneath many poorer paints. It is therefore essential to reduce graphite with a heavier base and to this end it has been found that a mixture of silica and graphite produces very good results but even this paint has the objection of having too much spreading power.

"A six year test of a linseed oil paint made with a neutral ferric oxide, containing in its composition 75 per cent ferric oxide and 20 per cent silica mixed with graphite containing 85 per cent graphite carbon, has proved itself to be as good a paint as can be desired for ordinary purposes. The pigment in a paint of this kind will withstand the chemical action of gases and fumes, but the oil vehicle is its weakest part."

Stove Polish.

Stove polish consists of a mixture of amorphous or flake graphite with a binder of clay, asphaltum or soap in the case of the solid polishes and with gasoline or water in the case of the liquid polishes.

The graphite is ground to a very fine powder and then mixed with the binder or liquid vehicle. In the case of the solid polishes the mixture is often baked to hardness. Often carbon black, prepared by condensing the products of combustion of natural gas, is added to the mixture to intensify the color.

Graphite for Boilers.

Graphite has often been advocated for use in boilers for the prevention and removal of boiler scale. However, no definite data is obtainable concerning the proper amount or the proper grade to use with regard to purity, size of flake, etc.

Boiler scale lowers the conductivity of the heating surfaces and also prevents the cooling action of the water on the tubes; and causes cracking and pitting. The action of graphite is supposed to be purely mechanical,the small particles working through the fissures in the scale and loosening it. On new metal graphite prevents scale by forming a greasy protective coating on which scale does not readily form.

"A very finely powdered graphite says the"British Clay Worker" placed in a boiler immediately after it has been cleaned circulates with the water and rubs against the steel to which it imparts a graphite polish on which scale does not readily form. When the initial quantity is regularly followed up by smaller ones, the graphite by mechanical motion gradually softens and disintegrates any old scale that may still be present and if any new scale thereafter forms, and it always will to some extent, it forms with that scale so that it may be easily be broken up and removed. Inferior grades can not with safety be allowed in steam boilers.* "

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* Journal of Industrial and Engineering Chemistry, Vol. X, p 395.

"An editorial contributor to Power, 36;430, remarks that there have been too many cases of the successful use of graphite for the prevention and removal of boiler scale, and the avoidance of pitting in boilers, to leave its usefulness for this purpose longer open to debate. There may be a difference in views as to how and why it accomplishes it, but in numerous cases the feeding of graphite into a boiler has not only prevented the formation of new scale but has removed large quantities of scale already formed. In some cases, however, graphite has been tried without success; this is undoubtedly due to the fact that graphite has its limitations; it is efficient in some cases and not in others. Such failure is also attributable to the kind of graphite used and its mode of application. The action of graphite in this case is certainly a mechanical one; the presence of graphite in scale destroys the adhesion of the particles; so that the scale either does not form or is easily broken up by the disturbances incidental to the ordinary operation of the boiler. It is essential that the right kind of graphite be employed. Graphite such as is used in foundries for facing moulds has been used with the result that considerable scale forming material is deliberately introduced into the boiler and not sufficient amorphous carbon is present to counteract its effect combined with the effect of the scale forming material already present. The graphite used must be as pure as can be obtained and must have lubricating properties.* "

Graphite as a Lubricant.

Graphite has long been in use as a lubricant in combination with heavy oils or greases. In this form it has served in the lubrication of gears and slow moving, heavy journals. Its lubricating action is due to

* Journal of Industrial and Engineering Chemistry, Vol. XIV, p 855.

its formation in thin flakes which have a remarkably low coefficient of friction. These flakes when placed with the oil between journals and bearings form a thin veneer and prevent the heavy pressure from squeezing out the oil. Other natural lubricants which have this same property are talc and mica. Neither of these, however, is suited to stand such severe conditions as graphite may easily stand.

In addition to its use with heavy oils, graphite is now often used as a lubricant in mixtures with light oils or water and in some cases in the pure form unmixed with any other materials.

It might be well to say that all lubricants do not perform their functions in the same manner. Although graphite is a lubricant it is not an oil. Graphite, however, may be used as a partial or complete substitute for oil.

The lubricative effect of oil is due to the formation of a film of oil of greater or lesser thickness, depending on the bearing pressure and the viscosity of the oil, between the moving parts. When lubrication is perfect this film is always thick enough to prevent actual contact of the moving parts. The oil fills all microscopic pores in the metal, as well as yielding to the inequalities and by a cushioning effect it prevents the high spots on the bearing from coming in contact with the journal. Oil does not permanently identify itself with the metal, but simply forms an intermediate film, parts of which are in motion. The oil nearest the bearing surfaces is practically at rest, while that closest to the journal takes the motion of the journal. Thus, there are particles between the two surfaces whose velocities vary between the limits of rest and the speed of the journal. There is a rubbing movement of these oil particles, one on another. The ease with which the particles of oil glide over each other determines the friction of the bearing. With a heavy viscous oil this motion takes place with difficulty. On the other hand, though a light oil forms a film which should call for very low friction, it is easily squeezed out of the bearing, especially by high pressures. Thus, it is essential that the oil be constantly renewed and this results in a wastage of oil.

In many respects the action of graphite is unlike that of oil. Instead of forming a lubricating film between the moving surfaces, it forms a thin veneer on each surface. It enters every crack, pit of other irregularity of the bearing or journal and the result is a perfectly smooth surface on the journal, which exactly fits in a similar surface on the bearing. Whether thick or thin, the character of this veneering is always the same. It is dense in structure, capable of withstanding enormous pressures without breaking and presenting a perfectly smooth surface. By the presence of graphite then the frictionless surfaces of these coats of veneering is substituted for the frictional contact of the metallic surfaces. Evidence shows that there is no movement between the graphite surfaces; that there is no train of individual particles, the presence of which could be considered the equivalent of an oil film. Probably such dust like particles occur but they are soon thrown out or reabsorbed in the veneering.This is in brief the action of graphite as a lubricant.

When used in combination with oils or greases, the action of the graphite is in every way similar to its action when used alone. In addition to this action the oil acts as a carrier transporting the graphite to places where the veneering is wearing off. There is also the lubricating action of the film of oil which holds up the ordinary portions of the bearing, leaving only the high spots to depend solely on the graphite surfaces as a lubricant. It is only when it has left its suspension in oil and become implanted as a veneering on the metal surface that the full effect of the graphite is realized.

Professor Goss, of Purdue University, made experiments on the lubricating action of graphite, with the following conclusions;*

"(a) The addition of graphite to oil results in a lower frictional resistance than would be obtained by the use of oil alone. The reason is to be found in the superficial finish which the graphite bestows on the rubbing surfaces.

"(b) When graphite is used with oil the amount of oil required for a given service is reduced. While this conclusion does not rest on proof supplied by the undersigned, its truth becomes apparent when it is remembered that the smoother rubbing surfaces, which result from the use of graphite, subject the oil film to less wear than it would otherwise receive; the more accurate form of the surfaces reduces the thickness of the oil film; and the reduced thickness of the film leads to smaller wastes of oil from the ends of the journal.

"(c) By the use of graphite a lighter or an inferior quality of oil may be employed for a given service. The reason for this is that when the service demanded of a lubricant is reduced, the quality of the material necessary to meet the requirements may be lowered.

"(d) By the use of graphite, water (under favorable conditions) may serve as a sufficient lubricant. It is entirely logical to assume that the preparation of the surface of a bearing may be so complete that not only limpid oil, but even water, may suffice for their lubrication.

"(e) A small amount of graphite only is required. By experiments it is shown that a mixture of sperm oil and graphite gave best results when only four per cent of the weight of the mixture was graphite. It is

* A Study in Graphite, Prof. W. F. Goss, 1902.

probable that any change in the quality of the oil may demand a change in the percentage of graphite, and it is probable that as the oil becomes lighter or of poorer quality, the percentage of graphite should be increased. But that the amount need never be relatively great is apparent when it is remembered that the purpose of the supply is merely to maintain against natural wear the graphite coating on the surfaces in contact.

"(f) The supply of too much graphite increases journal friction. The effect of too much graphite is to unduly thicken the liquid oil. In general, the more viscous an oil, the greater its coefficient of friction, and hence the results observed inevitably follow.

"(g) The wearing qualities of the graphite coating are such that the benefit to be derived from the use of graphite persists long after its use has ceased."

It has been claimed that amorphous and artificial graphite are purer and are more capable of suspension in oil, and that they give better results as lubricants than natural flake graphite. This matter has been considered by C. H. Bierbaum, in a paper read before the American Society of Mechanical Engineers." *

An abstract of the paper follows:

"From a purely mechanical viewpoint, the suspension of graphite in oil should be a relatively simple matter; unfortunately, however, when the particles are fine enough to defy the force of gravity, they are subject to another force known as the Browonian movement. Under the latter forces the graphite particles are subject to what approaches perpetual

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* Iron and Coal Trades Review, Jan. 1918, p 718.

motion; it is not a continued movement in one direction but a zigzag course, caused by the free electrons striking the particles of graphite. A particle on being struck starts with a jerky movement and continues moving until arrested by the fluid friction of the oil, provided it has not already been struck by another electron causing it to bound off in another direction. An observer who saw this facinating action for the first time expressed himself to the fact that all the particles seemed to be on a St. Vitus Dance. During these erratic movements the particles of graphite collide with each other, and as a result adhere; they in turn are struck by other particles and in this manner there is gradually built up a mass of adhering particles which is subject to the action of gravity and as a result settles out. It is obvious that the greater number of free electrons present in the oil, the more rapidly the coagulation and settling out should proceed and such is the case. It is fully borne out by experience that the addition of a free acid or salt greatly accelerates the precipitation; in fact any electrolyte present has this effect, such as the acid residue or its resultant neutralized salt remaining in the oil after refining, or the rancidity of the oil, all tending to increase the number of free electrons and the precipitation of the fine particles of graphite.

Various experiments have been resorted to in order to effect so-called permanent suspension of graphite in oil. The one most commonly made use of is that of coating the finely ground particles with a foreign substance and then effecting a high degree of dispersion of these coated particles throughout the oil. The coating material is usually a vegetable compound; if an oil it should be one insoluble in the mineral oils, as castor oil or it may be tannic acid or an allied tannin compound.

"The value of a so-called permanent suspension in oil is more fanciful than real, for the reason that in all such attempts the graphite is ground to such an extreme degree of fineness that this very fineness mitigates against its being useful. In a bearing properly constructed, lubricated and in operation, the bearing surfaces are completely separated by the oil film and the extremely fine particles of graphite simply float in the film, asserting no appreciable effect, either useful or otherwise.

"The time, however, when graphite can be of benefit and perform its only and supreme function is when the oil film between the bearing surfaces is destroyed and the graphite serves as a solid lubricant. The graphite is carried between the bearing surfaces by the oil and in the same manner, when this oil is destroyed by being squeezed out, the graphite particles are carried along with the oil from between the bearing surfaces until the film is reduced to a thickness corresponding to the dimensions of the largest particles of graphite which at this stage will be arrested and held between the surfaces. Upon the complete destruction of the film, these particles so held are crushed and embedded into the pores and grains of the surface and thus made to perform the functions of solid lubrication. It is evident that the smaller the particles are, the less will be the amount of graphite so intercepted between the bearing surfaces; therefore, a given amount of graphite is most efficient if it exists in particles of the largest possible size. The more nearly permanent a graphite suspension is, the more nearly does it approach the colloidal state and the more completely is it carried out from between the bearing surfaces when the oil is destroyed.

"This can be demonstrated in a most striking manner by taking a light colored lubricating oil, thoroughly mixing it with a definate amount of graphite and then placing it between two highly accurate glass surfaces and observing the amount of colour left after a definite pressure has been applied for a definite time, while maintaining a definite temperature.

"An amorphous natural graphite ground so that its largest particles did not exceed .0002 inches showed under the foregoing conditions an almost opaque surface, while a commercial graphite suspended in tannin and whose largest particles did not exceed 1/250,000 inches showed a substantially colourless surface. This is readily accounted for by the fact that the largest particle in one graphite contained 125,000 times the bulk of those in the other, a condition existing at the time the glass surfaces in each case had approached each other near enough to arrest the flow of the respective particles."

Tests made by Professor C. F. Mabery, of the Case School of Applied Science,* show that the use of .35 per cent of colloidal graphite with oil as a lubricant, decreased the coefficient of friction 30 per cent (approximately) and made possible the use of only one-eighth the usual quantity of oil.

Graphite Electrodes and Brushes.

Graphite electrodes and brushes are prepared by mixing graphite and coke or graphite, coke andcopper filings with tar and benzehe. The mixture is carbonized under high pressure and heat and the temperature is carried high enough to change the coke and carbonized tar into artificial graphite. Amorphous graphite or artificial graphite is usually preferable for this use.

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* Jour. Ind. & Eng. Chem. V 2, p 115, and Jour. Ind.Eng. Chem. V 5, p 722.

METHODS AND TESTS.

The experimental work carried out was divided into three parts. First: On the Use of graphite mixed with oil as a lubricant, with varying size of flake and quantity used; Second: On the action of graphite dust as an agent for the removal and prevention of boiler scale; and Third: The moulding of graphite dust with various binders into blocks for such uses as furnace linings, electrodes, armature brushes, etc. Separate discussions of these divisions will be taken up in order.

The Lubrication Tests.

The efficiency of graphite oil mixtures was tested on a Babcock oil testing machine. This machine (figure 1) consists of a revolving journal about which a bearing is placed free to revolve. A pendulum hangs from the bearing. By means of springs, any desired pressure of the bearing on the journal may be obtained.

The length of the journal was one and a half inches and the diameter was one and a third inches, giving a bearing area of 6.28 square inches. The journal was of steel and the bearing was of brass.

It will be seen from the illustration that the design of the machine is such that a belt on the pulley serves to drive the spindle and the experimental journal; also that the friction between the revolving journal and the brasses which bear on it,gives rise to forces which swing the pendulum from its vertical position. The extent of this deflection is obtained by the arc A, which is graduated to read the tangential effort on the bearing. If, for example, the friction is low, due to superior lubrication or otherwise, between the brasees and journal, the deflection of the pendulum is small, while if the lubrication is imperfect, the

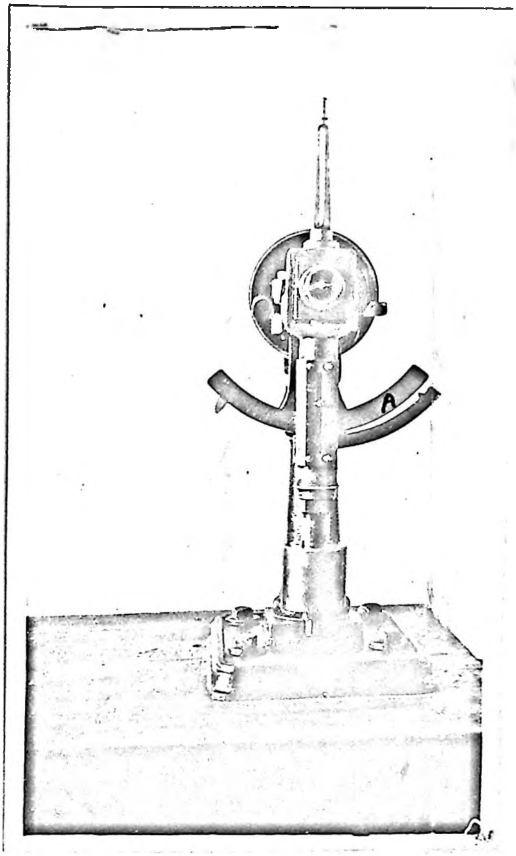


Figure 1
Babcock Oil Testing Machine
Used in Lubrication Tests

deflection of the pendulum at once becomes considerable.

When the lubricative properties of the mixture are exhausted, the friction increases greatly and the pendulum flies up to the horizontal where its motion is arrested by a stop.

The coefficient of friction between the journal and brasses is expressed by the formula: $C = 100 \times \frac{F}{P}$, in which

C = the coefficient of friction in per cent,

P = the average normal pressure between the journal and brasses in pounds.

F = the tangential effort at the circumference of the journal in pounds.

It will be noted that the upper brass always bears upon the journal with a greater pressure than the lower brass, the difference being equal to the weight of the pendulum. In all calculations it has been assumed that the normal pressure of the bearing on the journal is the average of the pressure on the upper and lower brasses. Thus:

Let W = weight of pendulum and bearing $8\frac{1}{2}$ pounds.

p = pressure exerted by the spring.

P = Average normal pressure between journal and bearing.

Then:

$$P = \frac{(p+W)+p}{2} = p + \frac{W}{2} = p + 4.25 \text{ pounds.}$$

The tangential effort (F) is equal to a constant for the machine times the sine of the angle of deflection. This constant is equal to

$$\frac{WaR - Wbr}{d}, \text{ where:}$$

Wa = the weight of that portion of the pendulum below the center of the journal.

W_b = the weight of that portion of the pendulum above the center of the journal.

P_1 = the distance of the center of gravity of the lower portion of the pendulum from the center of the journal.

r = the distance of the center of gravity of the upper portion of the pendulum from the center of the journal.

d = the diameter of the journal.

Since the machine was so calibrated that F was given as the scale reading, it was not necessary that it be computed.

The temperature of the bearing was determined by means of a thermometer placed in a hole in the bearing close to the journal.

Method of Conducting the Tests.

The tests were conducted in the following manner;

One-half c.c. of the mixture was fed into the bearing. The machine was then allowed to run until the lubricating properties of the mixture became exhausted and the pendulum rose to the horizontal position. During the tests the following factors were recorded;

The tangential effort;

The bearing pressure;

The speed of the journal in r.p.m.;

The temperature;

The life of the sample of lubricant.

Tests were first made to determine the effect of the size of the graphite flakes on its length of service as a lubricant and its ability to lower the coefficient of friction. Tests were made with several oils, which included light, medium and heavy oils.

Mixtures were made up containing a definite amount of oil and graphite. The quality of graphite, with respect to its purity was kept as near constant as possible in all these mixtures. However, with each oil, mixtures were made in which the graphite flakes used varied from -50 mesh to -250 mesh. All of the factors mentioned above were determined in the case of each mixture. Curves were plotted to show the effect of the size of the flakes of graphite on the lubricant.

After determining the effect of the flake size on the lubricating qualities of graphite-oil mixtures, the effect of the quantity of graphite was determined. With each oil used, mixtures were made up containing varying amounts of graphite, from .1 per cent up. The graphite used in this test was of a size that would pass through a 250 mesh screen. The above-mentioned factors were measured for each of these mixtures.

Boiler Saale Tests.

Graphite has often been recommended and used in boilers for the prevention and removal of boiler scale. The graphite used for this purpose has usually been of high grade. The present tests were made to determine whether low-grade Alabama graphite dust might be used for this purpose. Since the dust simply consists of particles of pure flake graphite mechanically mixed with a dust of clay, feldspar, mica and quartz, there is no apparent reason why it should not act in the same as pure graphite. The individual particles are themselves pure and apparently should act the same as if no impurities were present.

Tests were made by mixing graphite dust with the boiler feed water. Two boilers were used and the test lasted forty days in one case and forty-five days in the other. At the completion of each test the boilers were thoroughly examined to ascertain the effects of the treatment.

These tests were of necessity incomplete since it was impossible to obtain boilers containing every type of scale. Both boilers used in these trials contained scale that had come from the regular city water supply. An analysis of only one of the scales was made, since it was assumed that other would be approximately the same, the same water supply being used.

Test number one was run in a 125 B.H.P. boiler of the Tuscaloosa, Alabama, city water works department. This was a return tubularboiler of the Casey Hedges make. It was 72 inches in diameter and 16 feet long and contained four-inch tubes. The test lasted forty days. One quart of graphite dust was mixed with the feed water each day for the duration of the test.

Test number two was run in a 12.5 B.H.P upright fire tube boiler. One-half pint of graphite dust was added to the feed water each day for the period from March 15th to May 5th. The boiler was in operation six days per week.

Graphite Blocks.

The third phase of the work was the moulding of graphite with various binders into blocks. Should such blocks have sufficient strength, and a low enough electrical resistance they might be successfully employed as electrodes, armature brushes, or electric furnace linings. Graphite blocks are now used for such purposes, but those in use are made from amorphous or artificial graphite. No binder has yet been found which in combination with flake graphite will produce a satisfactory product.

In the present work these blocks were moulded in general from low-grade graphite dust. Should blocks made up of graphite dust prove satisfactory, this would open a new channel for the disposal of such dust.

Tests were made on all blocks moulded as to the crushing strength and the electrical resistance. The tests as to crushing strength were made with a standard 30,000 pound Olsen testing machine. Tests of the electrical resistance were measured by the usual Wheatstone bridge method.

The blocks were made by compressing the composition (graphite dust and binder) in a cylindrical steel mould. A pressure of about four tons per square inch was applied (by means of screws) to compress the mixture. This mould was encased in a tubular electric furnace of the resistance type and the mixture was heated to 1600°F and then allowed to cool. The pressure was maintained during heating by tightening the screws as the binder carbonized and the volume of the mixture decreased.

Blocks were first moulded from mixtures of graphite dust and Goulac (trade name for dried waste sulphite liquor from paper mills; American Gum Products Company). The mixtures varied from two per cent Goulac to eighteen per cent Goulac. These were not treated in the large mould which was used for the other mixtures, but were moulded in small cast-iron moulds in which the mixtures were compressed. These moulds were placed in a muffle furnace and heated to 1600°F and allowed to cool before the blocks were forced out by means of a screw.

Blocks were made with mixtures of hydrous magnesium silicate and graphite dust. Mixtures were employed containing seven per cent, fourteen per cent and twenty-one per cent of hydrous magnesium silicate. The gelatinous hydrous magnesium silicate was obtained by precipitation from dilute solutions of magnesium chloride and sodium silicate.

Blocks of graphite dust and refined coal tar were moulded. The mixture employed ranged from five per cent to thirty per cent tar.

Blocks of graphite dust and asphalt were moulded. The mixtures used here were from five per cent to twenty-five per cent asphalt.

Blocks of graphite dust and crude coal tar were made. Here the mixtures varied from five per cent to twenty per cent crude tar.

Blocks of refined coal tar and graphite dust refined by the Trent process with carbon tetrachloride were made. The mixtures used were ten per cent tar with ninety per cent graphite, and fifteen per cent tar with eighty-five per cent graphite. The object of using these mixtures containing purified graphite was to determine whether the weakness of the blocks was due to the structure and unctuousness of the graphite flakes or to the impurities in the dust.

Investigation of Trent Process as Applied to Alabama Graphite.

One of the phases of the work was a test of methods similar to the Trent process to determine their applicability to Alabama graphite. In this work the tests were made as follows;

Graphite was ground with water in the pebblemill until it was of a size grading from 100 mesh to 250 mesh. After grinding, the mixture of graphite and water was divided into small samples. Pine flotation oil was mixed with these samples and the mixtures were thoroughly agitated. Tests were made by adding the oil drop by drop to the mixture to find the quantity of oil required to agglomerate particles of graphite. and enable a separation from the gangue, to be made. After agglomerating the graphite, the gangue was separated by pouring off the water in which it was suspended through a wire screen. Graphite and oil in clusters such as it forms will not go through such a screen unless forced through by pressure. All the samples being tested were washed till the wash water appeared perfectly clear. The graphite and oil mixture was then placed in a dish and the oil was driven off by evaporation.

Analyses were made of all samples before and after treatment. The purified samples were screened and analyzed. Of course, there was no moisture or volatile matter in the treated samples, since the heat used for the evaporation of the oil also drove these off.

Size Tests of Graphite With Veedol Cup Grease.

Revolutions per minute, 2,400.

Size of graphite	Pure Oil		250 Mesh		200 Mesh	
Pressure in pounds per sq. in.	75	100	75	100	75	100
Service in square inches	76,400	30,200	189,200	111,200	165,600	103,000
Coefficient of friction in per cent	4.92	7.43	4.92	3.72	5.57	5.20
Temperature, degrees centigrade	225	235	260	300	270	290

Size of graphite	150 Mesh		100 Mesh		50 Mesh.	
Pressure in pounds per sq. in.	75	100	75	100	75	100
Service in square inches	115,000	64,000	85,400	37,700	79,900	33,700
Coefficient of friction in per cent	5.91	5.70	6.25	5.70	6.25	6.69
Temperature, degrees centigrade	250	250	235	235	230	230

Size Tests of Graphite with (Standard) No. 5 Cylinder Oil
Revolutions per minute, 2,400.

Size of graphite	Pure Oil		250 mesh		200 mesh.	
Pressure in pounds per sq. in.	75	100	75	100	75	100
Service in square inches	17,500	8,520	33,600	20,600	31,000	19,120
Coefficient of friction in per cent	6.25	5.95	5.91	5.45	5.91	5.45
Temperature, degrees centigrade	150	150	150	150	150	150

Size of graphite	150 Mesh		100 mesh		50 mesh	
Pressure in pounds per sq. in.	75	100	75	100	75	100
Service in square inches	25,060	16,600	22,600	14,000	20,100	11,560
Coefficient of friction in per cent	5.91	5.45	5.91	5.45	6.25	6.19
Temperature, degrees centigrade	150	150	150	150	150	150

Size Tests of Graphite with Light Engine Oil

Revolutions per minute, 2,400.

Size of graphite	Pure Oil		250 Mesh		200 Mesh	
Pressure in pounds per sq.in.	75	100	75	100	75	100
Service in square inches	30,200	13,080	73,480	24,100	63,200	23,100
Coefficient of friction in per cent	6.25	4.96	4.28	4.70	5.26	4.96
Temperature, degrees centigrade	125	125	200	125	150	190

Size of graphite	150 mesh		100 Mesh		50 Mesh	
Pressure in pounds per sq. in.	75	100	75	100	75	100
Service in square inches	41,000	19,080	36,700	17,080	33,200	15,080
Coefficient of friction in per cent	5.26	4.96	5.91	4.96	5.91	4.96
Temperature, degrees centigrade	180	190	200	200	200	200

Size Tests of Graphite with Renown Engine Oil

Revolutions per minute, 2,400.

Size of graphite	Pure Oil		250 Mesh		200 Mesh	
Pressure in pounds per sq. in.	75	100	75	100	75	100
Service in square inches	17,600	8,540	69,400	16,100	66,500	15,100
Coefficient of friction in per cent	4.92	5.70	3.95	4.96	3.95	4.96
Temperature, degrees centigrade	140	140	250	250	240	240

Size of graphite	150 Mesh		100 Mesh		50 Mesh	
Pressure in pounds per sq.in.	75	100	75	100	75	100
Service in square inches	59,300	12,600	48,800	11,600	29,200	10,550
Coefficient of friction in per cent	3.95	5.20	4.92	5.45	5.26	5.70
Temperature, degrees centigrade	240	240	200	200	150	150

Size Tests of Graphite with Atlantic Red Oil

Revolutions per minute, 2,400.

Size of graphite	Pure Oil		250 Mesh		200 Mesh	
Pressure in pounds per sq. in.	75	100	75	100	75	100
Service in square inches	26,600	10,050	80,800	20,070	72,100	17,600
Coefficient of friction in per cent	4.28	4.20	4.92	3.96	4.92	3.96
Temperature, degrees centigrade	160	160	250	250	160	150

Size of graphite	150 Mesh		100 Mesh		50 Mesh	
Pressure in pounds per sq. in	75	100	75	100	75	100
Service in square inches	36,800	13,600	29,250	12,100	27,250	11,580
Coefficient of friction in per cent	4.61	3.96	4.61	3.96	4.61	4.20
Temperature, degrees centigrade	160	155	160	160	160	160

Quantity Tests of Graphite with Renown Engine Oil.

Revolutions per minute, 2,400.
Pressure; 75 pounds per square inch.
250 Mesh 96.02 per cent graphite.

Per cent graphite,	0.0	0.1	0.2	0.4	0.6	0.8
Service in square inches	17,600	46,800	51,500	60,500	75,000	79,200
Coefficient of friction in per cent	4.92	4.61	4.28	3.95	3.95	3.95
Temperature, degrees centigrade	140	125	135	150	160	160

Per cent graphite	1.0	1.2	1.4	1.6	2.0	4.0
Service in square inches	86,250	87,100	87,800	88,300	88,700	89,000
Coefficient of friction in per cent	3.95	3.95	3.95	3.95	3.95	3.95
Temperature, degrees centigrade	160	160	160	160	160	160

Quantity Tests of Graphite with Light Engine Oil.

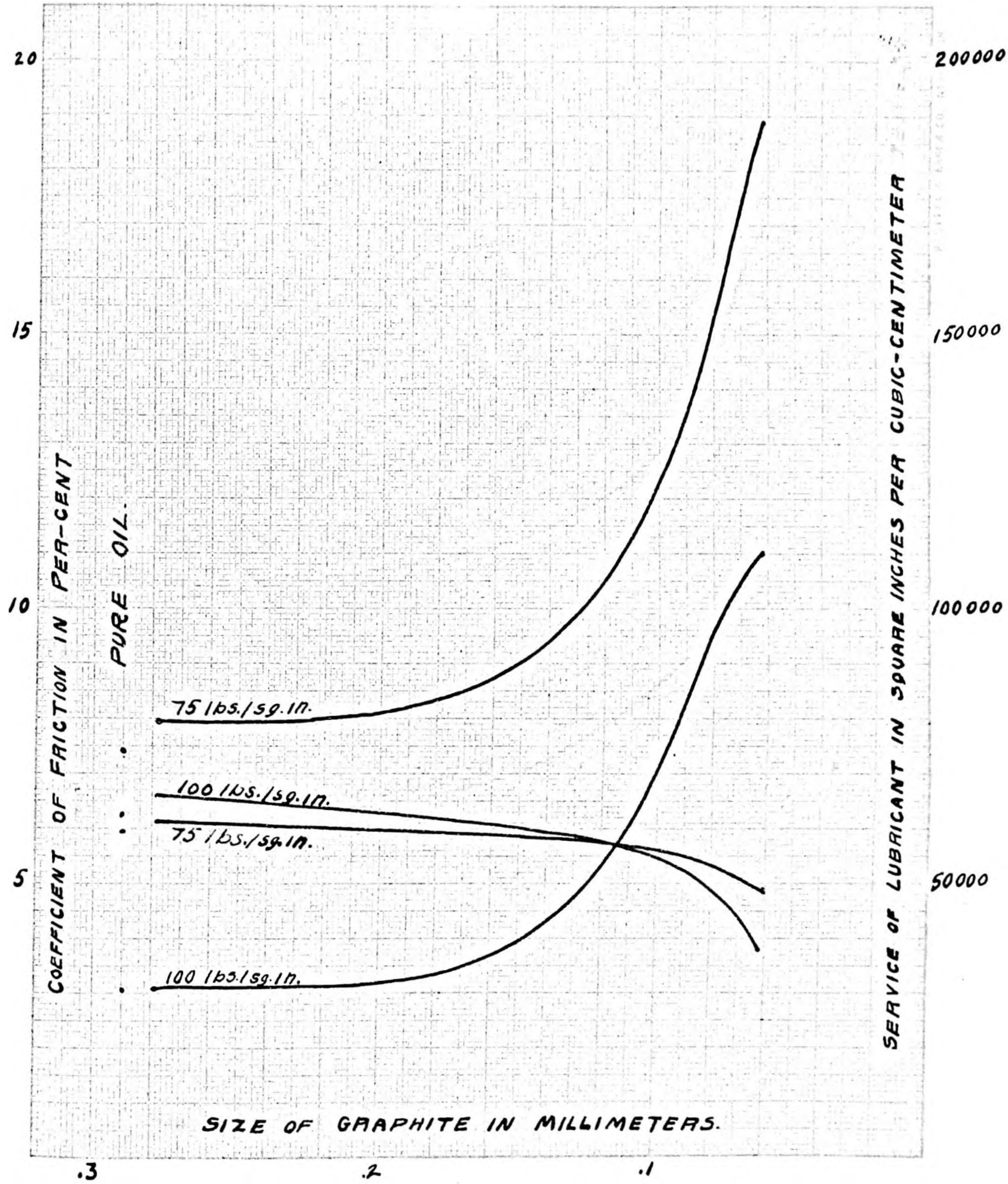
Revolutions per minute, 2,400
Pressure; 75 pounds per square inch.
250 mesh, 96.02 per cent graphite.

Per cent graphite	0.0	0.1	0.2	0.4	0.6	0.8	1.0	2.0
Service in square inches	30,200	44,800	49,800	58,500	68,500	77,200	77,500	80,400
Coefficient of friction in %	6.25	4.92	4.61	4.61	4.28	4.28	4.28	4.28
Temperature, °C	125	125	125	150	175	200	200	200

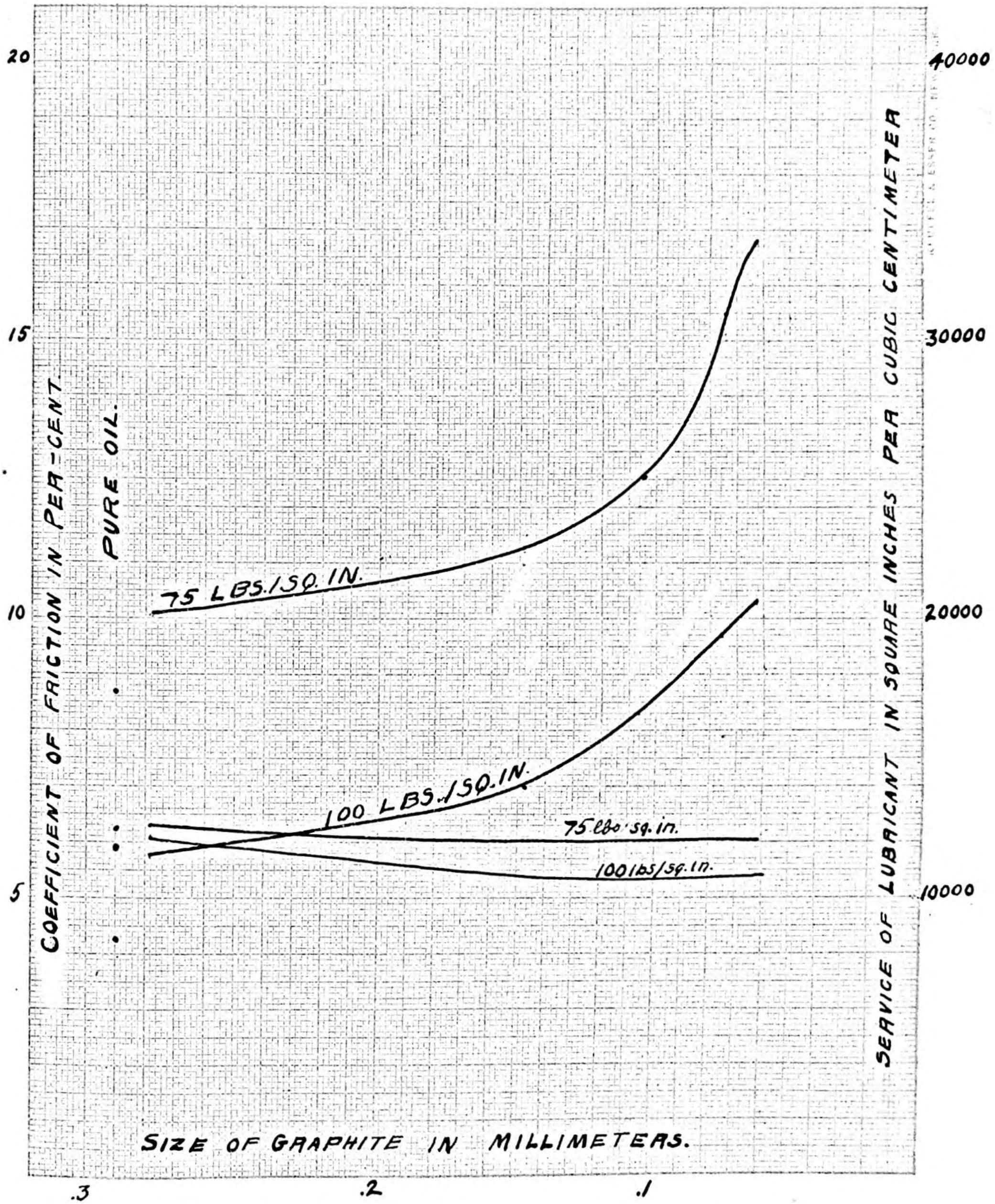
Quantity Tests of Graphite with (Standard) No. 5 Cylinder Oil.

Revolutions per minute, 2,400
Pressure; 75 pounds per square inch.
250 mesh, 96.02 per cent graphite.

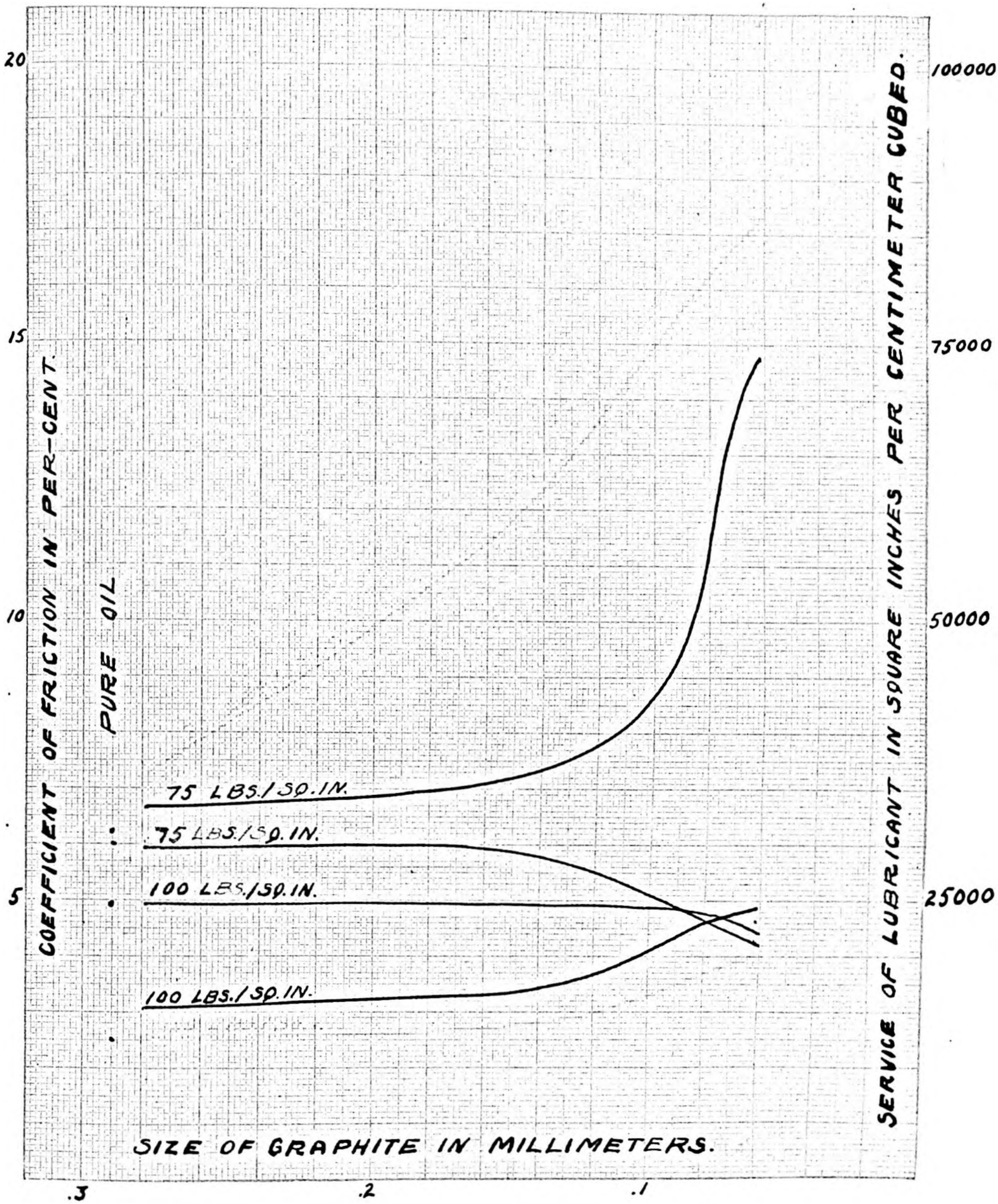
Per cent graphite	0.0	0.1	0.2	0.4	0.6	0.8	1.0	2.0
Service in square inches	17,500	21,200	23,200	28,800	32,300	35,200	38,000	38,600
Coefficient of friction in %	6.25	6.25	6.25	6.25	5.91	5.91	5.91	5.91
Temperature, °C	150	150	150	150	150	150	150	150



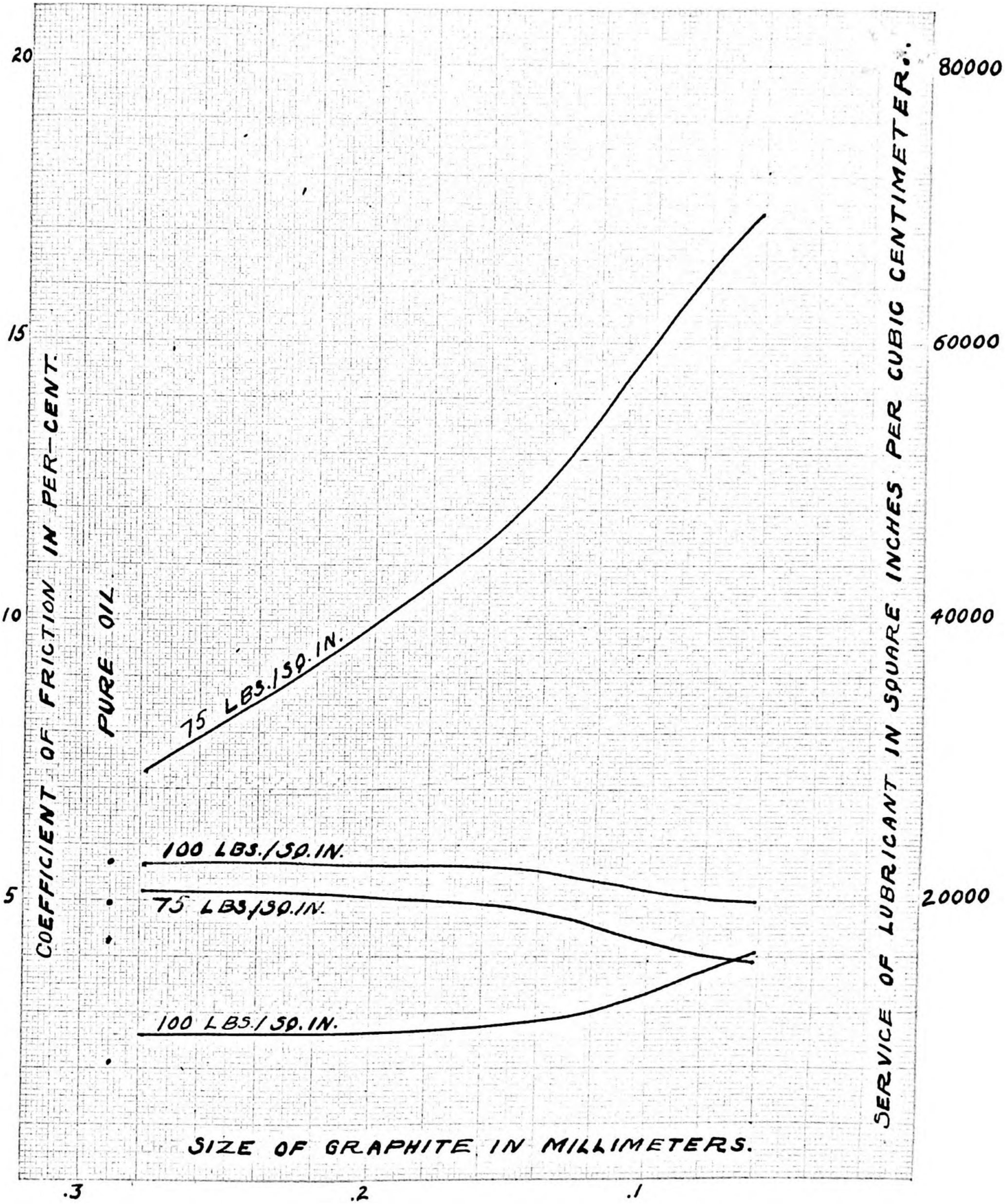
Curves for lubrication tests of graphite with Veedol Cup Grease
Coefficient of friction in red ink
Service of lubricant in black ink.



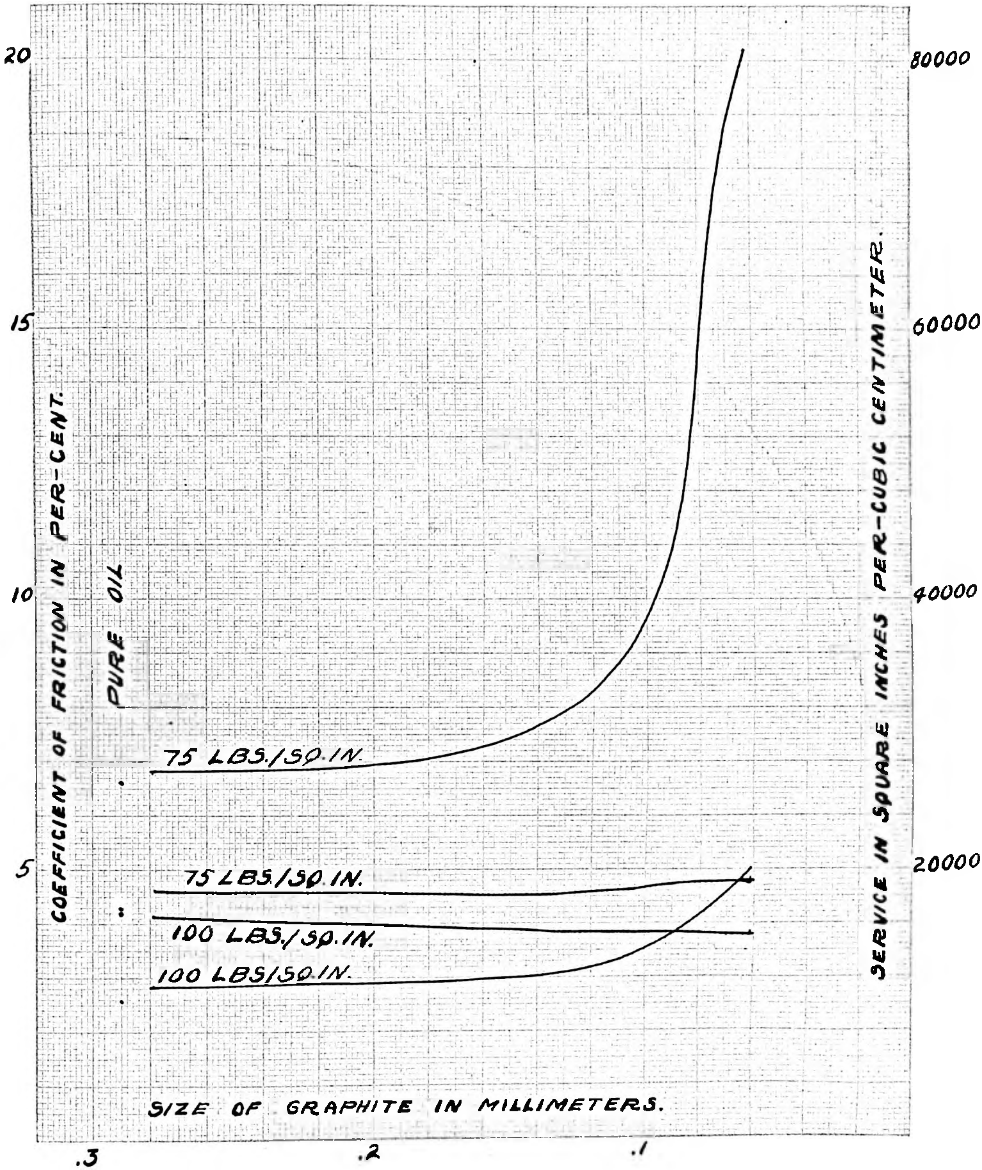
Curves for flake size tests of graphite with (Standard) no.5 cylinder oil.
Coefficient of friction in red ink.
Service of lubricant in black ink.



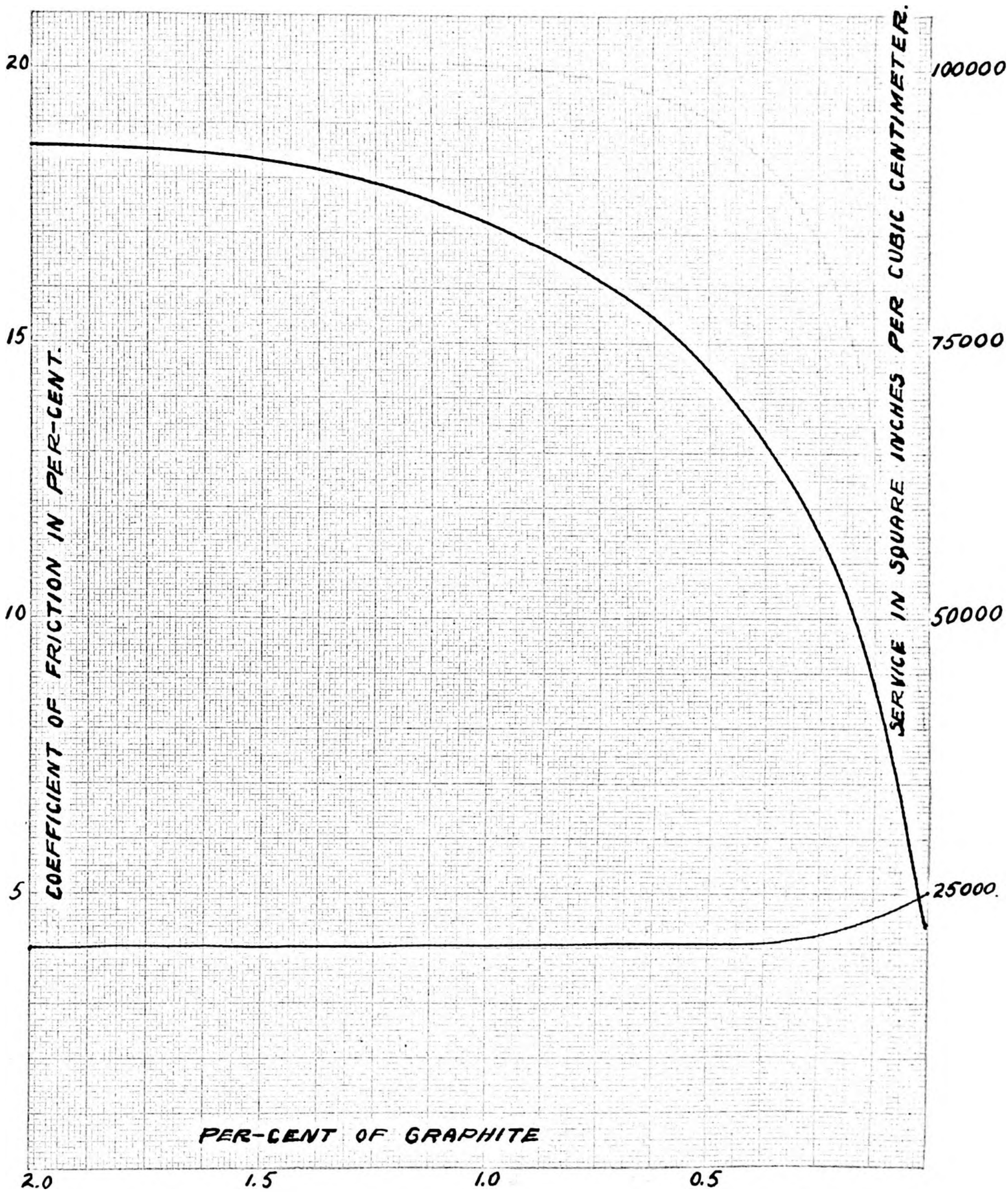
Curves for size tests of graphite with light engine oil
Coefficient of friction in red ink
Service of lubricant in black ink



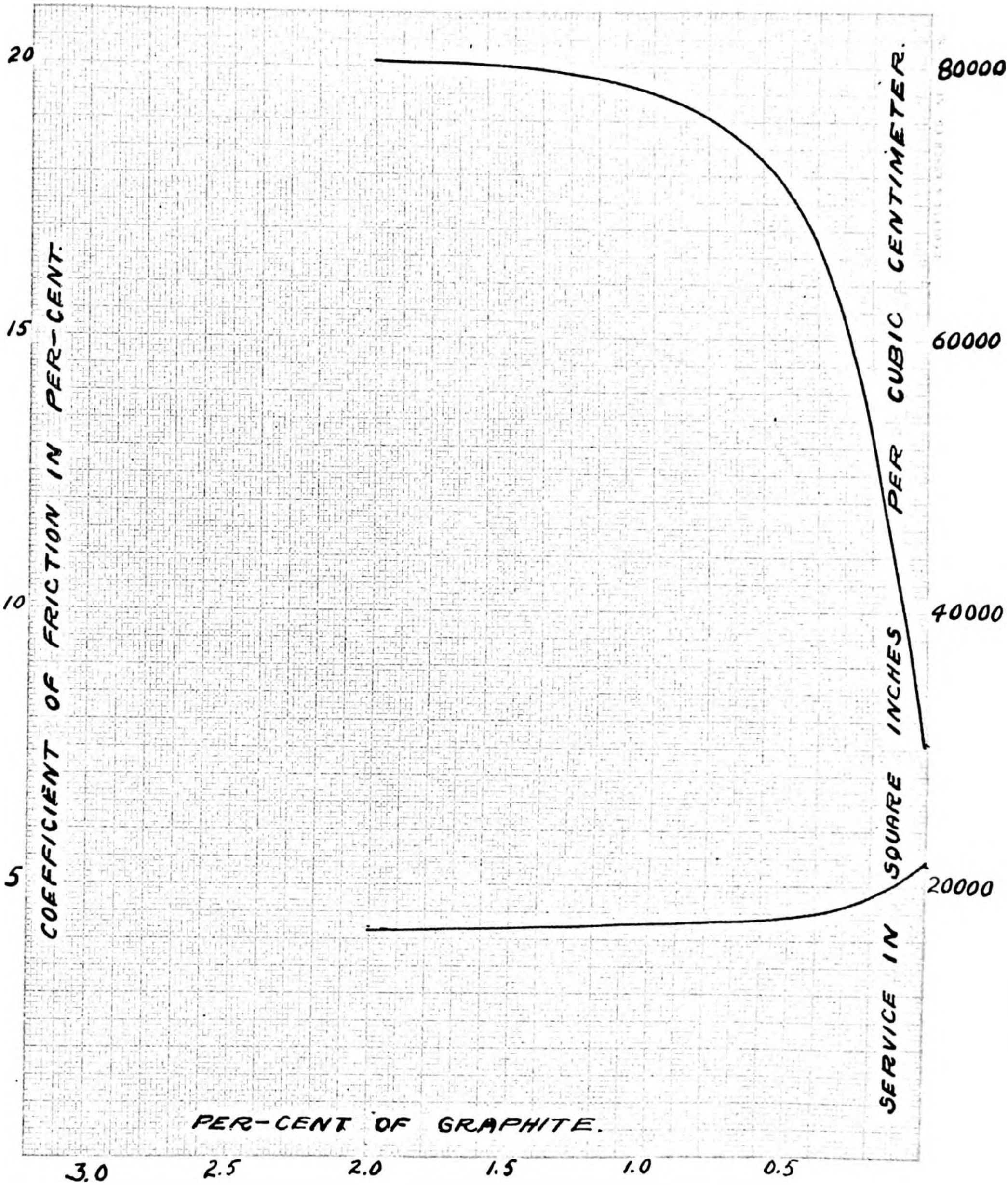
Curves for size tests of graphite with "Renown" engine oil
Coefficient of friction in red ink
Service of lubricant in black ink



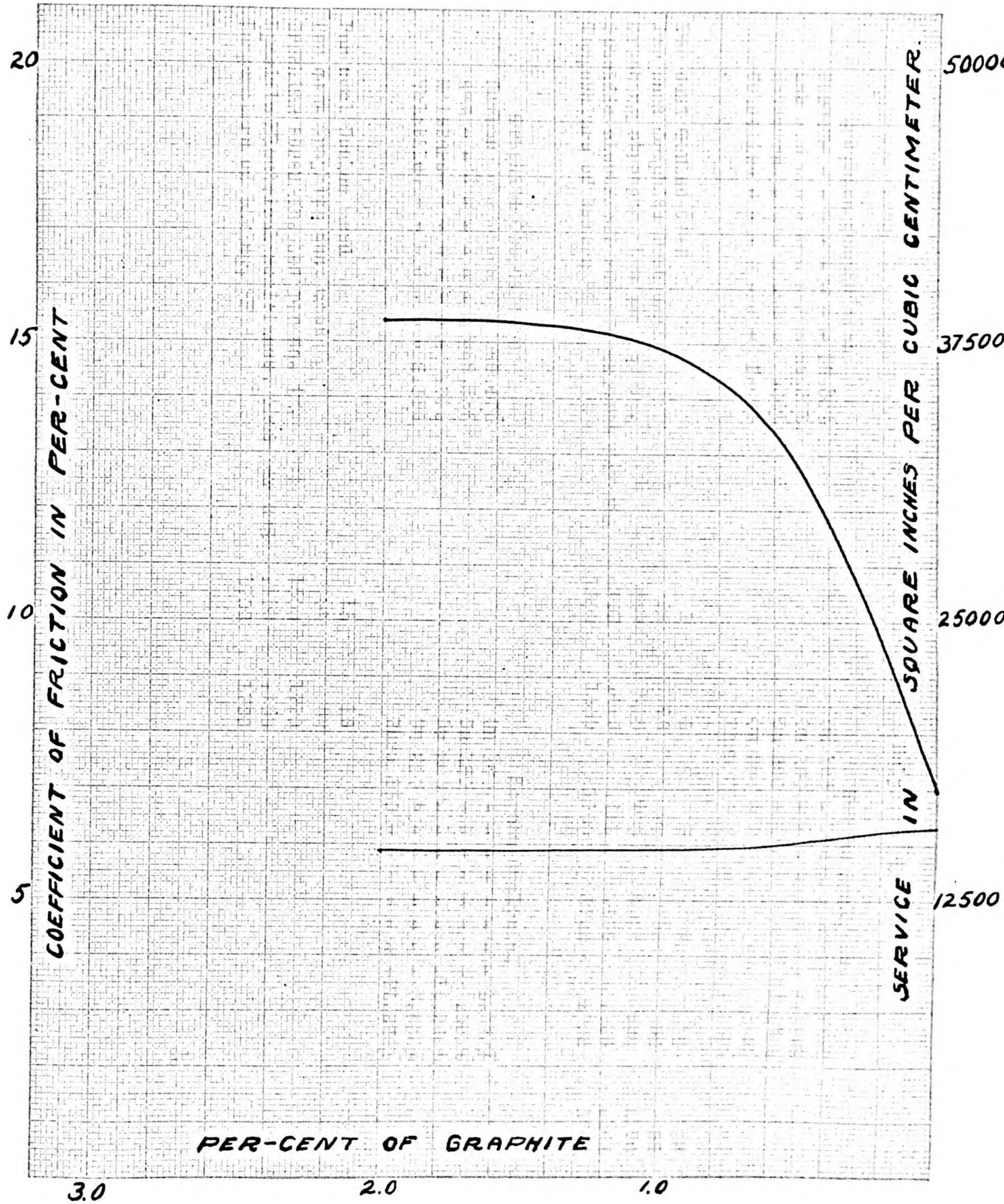
Curves for size tests of graphite with Atlantic Red Oil
Coefficient of friction in red ink
Service of lubricant in black ink



Curves for quantity tests of graphite with "Renown" engine oil
Coefficient of friction in red ink
Service of lubricant in black ink



Curves for quantity tests of graphite with light engine oil
Coefficient of friction in red ink
Service of lubricant in black ink



Curves for quantity tests of graphite with (Standard) no.5 cylinder oil
Coefficient of friction in red ink
Service of lubricant in black ink

PREPARATION AND TESTS OF GRAPHITE BLOCKS

Tests with Graphite and Dried Sulphite Liquor.

Graphite Composition	
Carbon- - - - - - - - - -	52.35%
Ash - - - - - - - - - - - -	44.55%
Moisture- - - - - - - - -	.66%
Volatile- - - - - - - - -	2.44%

Screen Analysis.	
On 100 - - - - - - - - -	2.785%
On 150 - - - - - - - - -	4.148%
On 200 * - - - - - - - -	68.850%
On 250 * - - - - - - - -	.815%
Thru 250 - - - - - - -	22.080%

Per cent Goulac used	2	4	6	8	10	12	14
Per cent Graphite Dust used	98	96	94	92	90	88	86
Crushing strength, lbs per sq. in.	359	725	970	1017	980	1170	1240
Specific electrical resistance, ohms per cm3	.363	.493	.411	.286	.123	.161	.146
Temperature of baking, °F	1200	1200	1200	1700	1700	1700	1700

Graphite Composition	
Carbon- - - - - - - - -	48.47%
Ash - - - - - - - - - - -	48.35%
Moisture- - - - - - - -	.85%
Volatile- - - - - - - - -	2.33%

Screen Analysis.	
On 100 - - - - - - - - -	1.171%
On 150 - - - - - - - - -	.081%
On 200 - - - - - - - - -	14.260%
On 250 * - - - - - - - -	3.832%
Thru 250 - - - - - - -	81.236%

Per cent Goulac used	16	18
Per cent Graphite dust used	84	82
Crushing strength, lbs per sq. in.	1500	1790
Specific Electrical resistance, ohms per cm3	.152	.156
Temperature of baking, °F	1700	1700

Tests with Graphite Dust and Hydrous Magnesium Silicate.
(Analysis given below*)

Per cent Hydrous magnesium silicate used	7	14	21
Per cent Graphite dust used	93	86	79
Crushing strength, lbs per sq. in.	.173	184	181
Specific electrical resistance, ohms per cm_3	.357	.380	.413
Temperature of baking, °F	1600	1600	1600

Tests with Blocks of Graphite Dust and Refined Coal Tar
(Analysis given below*)

Per cent tar used	5	10	15	20	25	30
Per cent graphite dust used	95	90	85	80	75	70
Crushing strength, lbs per sq. in.	1480	2130	2300	2240	2225	1282
Specific electrical resistance,ohms per cm_3	.225	.224	.245	.247	.244	.248
Temperature of baking, °F	1600	1600	1600	1600	1600	1600

Tests with Blocks of Graphite Dust and Crude Coal Tar.
(Analysis given below*)

Per cent of crude coal tar used	5	10	15	20
Per cent of Graphite dust used	95	90	85	80
Crushing strength, lbs per sq. in.	1650	1145	982	930
Specific electrical resistance,ohms per cm_3	.392	.345	.380	.275
Temperature of baking, °F	1600	1600	1600	1600

Analysis of Graphite Dust Used for Tests Shown Above.

Graphite Composition

Carbon- - - - - - - - -	48.47%
Ash - - - - - - - - - -	48.35%
Moisture- - - - - - - -	.85%
Volatile- - - - - - - -	2.33%

Screen Analysis.

On 100 - - - - - - - - -	.172%
On 150 - - - - - - - - -	.082%
On 200 - - - - - - - - -	14.626%
On 250 - - - - - - - - -	3.833%
Thru 250 - - - - - - - -	81.236%

Tests on Blocks of Refined Graphite Dust and Refined Coal Tar.

Graphite Composition	
Carbon	94.55%
Ash	5.45%

Screen Analysis.	
On 100	1.344%
on 150	1.640%
On 200	11.120%
On 250	.200%
Thru 250	85.520%

Per cent refined coal tar used	10	15
Per cent refined graphite dust used	90	85
Crushing strength, lbs per sq. in.	2635	800
Specific electrical resistance, ohms per cm_3	.985	.765
Temperature of baking, ^oF	1600	1600

Tests on Blocks of Graphite Dust and Asphalt.

Graphite Composition	
Carbon	48.47%
Ash	48.35%
Moisture	.85%
Volatile	2.33%

Screen Analysis.	
On 100	.172%
On 150	.082%
On 200	14.626%
On 250	3.833%
Thru 250	81.236%

Per cent asphalt used	5	10	15	20	25
Per cent graphite dust used	95	90	85	80	75
Crushing strength, lbs. per sq. in.	1427	1447	1575	1842	1270
Specific electrical resistance, ohms per cm_3	.277	.253	.227	.223	.224
Temperature of baking, ^oF	1600	1600	1600	1600	1600

TESTS ON THE EFFECTS OF GRAPHITE DUST IN THE REMOVAL OF BOILER SCALE.

Test No. 1.

This test was run in one of the boilers of the Tuscaloosa Water Works. This boiler was a 125 B.H.P Casey Hedges boiler. It was 72 inches by 16 inches and contained 62 four-inch tubes. The boiler was of the fire tube type, with horizontal flues and was covered with one-eighth to one-quarter inches of hard scale. One quart of graphite dust was added to the feed water of this boiler eash day for forty days.

At the end of the test period, an inspection showed that none of the scale had been removed by the graphite. However, the graphite did prevent the formation of any scale on two new tubes which had been placed in the boiler just before the test started.

Analysis of Scale. *
Dried at 105°C

Silica	38.40%	Sulphates	2.40%
Aluminum oxide	2.30%	Chlorine	trace
Ferric oxide	15.50%	Carbon dioxide	none
Calcium oxide	19.00%	Potassium oxide and sodium oxide	trace
Magnesium oxide	10.91%		
Loss on ignition	9.67%		

Test No. 2.

This test was run in a 12.5 B.H.P upright fire tube boiler at Morgantheaus Dying Works. One-half pint of graphite was added to the boiler feed water each day from March 15th to May 5th. The boiler was only fired six days per week. The result showed that none of the scale was removed.

Analysis for Graphite Used for Tests Above.

Graphite Composition

Carbon	48.47%
Ash	48.35%
Moisture	.85%
Volatile	2.33%

Screen Analysis.

On 100	.172%
On 150	.082%
On 200	14.626%
On 250	3.833%
Thru 250	81.236%

* Analyzed by H.F.Anders, analytical chemist,U.S.Bureau of Mines.

NOTES ON TRENT PROCESS.

Amount of Oil to Group Graphite.

To group 100 grams of graphite analyzing: Carbon, 90 %; Ash 10%.

Light pine oil 177 c.c.

Medium pine oil 164 c.c.

It was found that heavy pine oil could not be used for the purpose of purifying graphite since when it is added to the mixture of water and graphite it forms a sticky gummy mass which cannot be handled.

DISCUSSION OF RESULTS.

1. The Lubrication Tests.

(a) The Effect of the Flake Size; There are two factors which must be taken into consideration in determining the effect of the flake size of graphite on its properties as a lubricant. First, there is the effect of the flake size on the coefficient of friction and second the effect on the life of the lubricant. Each of these is important in its own way.

The coefficient of friction in a bearing determines the loss of power. Any agent which will diminsh friction is saving power. The discovery of a way to greatly reduce friction or to do away with it entirely would be the equivalent of discovering a new coal field or a new Niagara. It has been estimated that one-third to one-half of the power used in this country is wasted as friction. Business managers exert their best efforts to get all the possible power from the coal used in their industries, but very little thought is given to correct lubrication. Any lubricant is used, no consideration being made as to whether it will produce a very low or a rather high coefficient of friction.

The results of this series of experiments show that in general the addition of graphite to the oil lowers the coefficient of friction. The one case in which this did not happen, i.e., the test with Atlantic Red Oil, was probably incorrect due to impurities in the mixture.

In all cases except the one mentioned above, the addition of graphite lowered the coefficient of friction. The effect of the flake size is shown by the curves. These demonstrate that as the flake size of the graphite decreases, the coefficient of friction decreases. This decrease is more marked after the graphite flakes become small enough to pass a 200-mesh screen. Although it was not possible to make tests on particles graded below 250 mesh, it is possible that until some limit (unknown at present)* be reached, the use of smaller flakes would further decrease the coefficient of friction.

The second phase of the effect of the flake size on the qualities of graphite with oil as a lubricant is the effect on the length of time that a unit quantity of oil will last under a definite service. This factor determines the amount of oil that is to be used and thus it is one of the largest factors in the determination of the cost of lubrication.

In the present case this unit of oil is one cubic centimeter. The length of time that this quantity of oil will give lubrication to the testing machine is taken as the life of the oil. Of course, this is a special case and no definite statements can be made regarding the actual time that a fixed amount of oil would last under other conditions. The same ratios, however, with regard to its life when containing graphite of different flake sizes would probably hold true.

The journal of the machine used in this test had a bearing area of 6.28 square inches. Its motion was at the rate of 2,400 r.p.m. or 40 r.p.s. Thus, the life of the lubricant may be expressed as total surface covered by the lubricant. In the present case this surface covered is equal to forty times 6.28 square inches times the life of the oil in seconds. The curves of the life of the lubricant are drawn with respect to this total area acted on by the unit quantity of oil.

These tests showed that as the flake size of graphite decreases from 50 mesh to 200 mesh the life of the mixture increases. As the flake size

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* This limit is claimed to be the molecular size by the advocates of deflocculated artificial graphite.

approaches 200 mesh this increase becomes more marked.

As the flake size decreases from 200 mesh the life of the mixture still increases. However, at some point below 200 mesh there is a point of inflection in the curve and the life no longer increases with a positive acceleration as the flake sizes decrease. Although it still increases, it does so with a negative acceleration. This would lead to the view that there is some point, below the 250 mesh size, beyond which it would be useless to grind the graphite flakes. Just where this point is could not be determined, but judging from the general appearance of the curves it is probably around 400 mesh. It certainly is not so small as the molecular state of graphite, to which size deflocculated artificial graphite is reduced before being used as a lubricant.

(b) The Effect of the Quantity of Graphite: The second phase of the lubrication work was the determination of the proper amount of graphite to use with oil as a lubricant.

As before, the first factor in determining the qualities of a lubricant is the determination of its ability to lower the coefficient of friction. The curves show that as the amount of graphite added to the mixture is increased, the coefficiency of friction is lowered until a certain point is reached. After this, further additions of graphite have no effect. Any graphite added beyond this point is superfluous.

As shown by the curves this point varies slightly for different oils. Thus, less graphite is required to obtain the minimum coefficient of friction with a light oil than with a heavy oil. This per cent of graphite which gives a minimum coefficient of friction varies from four-tenths per cent with light gas engine oil to six-tenths per cent with a heavy cylinder oil. Five-tenths of one per cent graphite appears to be the most advantageous amount to use with a medium oil.

With regard to the influence of the amount of graphite on the life of the lubricant, it may be said that as more graphite is added the life of the lubricant increases. The proportional increase, however, decreases as more graphite is added. A point is soon reached (about one per cent graphite) beyond which further additions of graphite have very little effect on the life of the oil.

In the case of the light engine oil, the life of the pure oil was 17,600 square inches per cubic centimeter. The addition of one per cent graphite increased the life to 86,250 square inches per cubic centimeter, but the addition of only four per cent graphite only increased the life to 89,000 square inches per cubic centimeter.

The other tests show the same relative results.

2. Graphite Blocks.

Blocks moulded from mixtures of Goulac (dried sulphite liquor) and graphite did not have any favorable properties. The electrical resistance was extremely high never dropping below .123 ohms per cubic centimeter. The electrical resistance of pure carbon electrodes is about .014 ohms per cubic centimeter. Thus the resistance of these blocks is approximately ten times that of carbon. The blocks are low in mechanical strength, the crushing strength of the best sample (containing 18 per cent Goulac) being only 1790 pounds per square inch. With less Goulac the strength is much lower than this. The blocks are soft and are easily scratched and broken.

Blocks moulded from hydrous magnesium silicate have practically no mechanical strength, the best one being broken at 184 pounds per square inch. The electrical resistance is extremely high, never going below .367 ohms per cubic centimeter.

Blocks moulded from refined coal tar and graphite probably give more promise than those from any other mixture. Even here the electrical resistance is from ten to fifteen times that of pure carbon, and the mechanical strength does not go over 2,225 pounds per square inch, in the mixtures, where graphite dust is used. This mixture is one containing 25 per cent tar. A mixture of refined graphite dust and ten per cent tar had a crushing strength of 2,635 pounds per square inch, but its electrical resistance was extremely high, being .985 ohms per cubic centimeter.

Blocks made from crude coal tar and graphite dust give little promise. The crushing strength is low, never exceeding 1650 pounds per square inch, and the electrical resistance never drops below .275 ohms per cubic centimeter. This binder contains so much volatile matter that the shrinkage during carbonization is more than can well be compensated for by tightening of the mould.

Blocks from graphite dust and asphalt like those from the other mixtures are soft and of a relatively low mechanical strength. The electrical resistance is also too high.

In general it may be said that all blocks moulded from graphite dust and the binders used were of too low a strength and too high an electrical resistance to justify their manufacture and use. The figures on crushing strength are really deceptive and high, since the graphite flakes arrange themselves parallel to the pressure as they are being moulded and produce lines of weakness which do not show up in crushing tests, but which would at once become apparent in tensile strength or transverse strength tests.

3. The Boiler Tests.

The boiler tests gave negative results, so far as the removal of scale is concerned. Of course, this was a special case and these tests would apply only to scale with analyses similar to the one here shown.

However, the graphite dust did prevent the formation of any scale on new flues. The graphite coated the new tubes and all scale would slough off as formed. This indicates its usefulness so far as the prevention of boiler scale is concerned.

CONCLUSIONS.

Graphite as a Lubricant.

1. Purified flake graphite added to lubricating oil decreases the co-efficient of friction on the bearing and increases the length of service of a definite quantity of oil.

2. To obtain the best results, the graphite flakes should be such that they can pass a 250-mesh screen or even smaller.

3. The most advantageous quantity of graphite to use is about one per cent of the weight of the mixture.

Moulded Graphite Blocks.

Due to their high electrical resistance and their low mechanical strength, blocks of graphite dust can not be advantageously moulded for commercial purposes.

Boiler Tests.

While graphite dust may remove some boiler scale, it cannot be recommended as a positive remover of scale. However, on new metal surfaces it will prevent its formation.

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Respectfully submitted to the College of Engineering,

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